# PROSPECTS FOR SUSTAINABLE CROP PRODUCTION TECHNOLOGIES IN EAST TIMOR

A thesis presented in partial fulfilment of the requirements for the degree of *Doctor of Philosophy (PhD)* in Natural Resource Management

Institute of Natural Resources
**Massey University**
Palmerston North, New Zealand

**EDMUNDO DA SILVA SOARES VIEGAS**

**2007**

# TABLE OF CONTENTS

# LIST OF BOXES

# LIST OF TABLES

# LIST OF FIGURES

## Appendices

# ABBREVIATIONS

| | |
|---|---|
| ACF | Action Contre la Faim |
| ACIAR | Australian Centre for International Agricultural Research |
| ADB | Asian Development Bank |
| AFP | Air-filled porosity |
| AGSE | Agricultural Engineering Service |
| AMCAP | Ainaro and Manatuto Community Activation Project |
| ANU | Australian National University |
| AP | Agricultural population |
| AS | Aggregate stability |
| AusAID | Australian Agency for International Development |
| BD | Bulk density |
| BIMAS | Bimbingan Intensifikasi Massa |
| BPS | Biro Pusat Statistik |
| Buw | Barley unweeded |
| Bw | Barley weeded |
| C | Carbon |
| CC | Continuous cropping |
| $CH_4$ | Methane |
| $CO_2$ | Carbon dioxide |
| CNRT | Concelho Nacional da Resistencia Timorense |
| CPR | Crop-pasture rotation |
| CT | Conventional tillage |
| DA | District administration |
| DAP | Draft animal power |
| DD | Double disking |
| DIT | Dili Institute of Technology |
| ET | East Timor |
| ETADEP | Ema maTA Dalan ba Progresu |
| ETTA | East Timor Transitional Administration |
| FAO | Food and Agriculture Organization |
| FAO/RAP | FAO Regional Asia & Pacific |

| | |
|---|---|
| FAOSTAT | FAO Statistics |
| $F_c$ | Field capacity |
| GDP | Gross domestic product |
| GIS | Geographical information system |
| GLM | General linear model |
| GMD / $D_{gm}$ | Geometric mean diameter |
| GNP | Gross net product |
| GoTL | Government of Timor-Leste |
| HDI | Human Development Index |
| HT | High tension |
| ISO | International Students Office |
| KPa | Kilopascal |
| $K_s$ / $K_{sat}$ | Saturated hydraulic conductivity |
| $K_{unsat}$ | Unsaturated hydraulic conductivity |
| LT | Low tension |
| MAFP | Ministério de Agricultura, Florestas, e Pescas |
| MB | Mobile brigade |
| MPC | Mechanization Possibility Curve |
| MR | Moisture release |
| MT | Manual tillage |
| MWD / $D_{mw}$ | Mean weight diameter |
| N | Nitrogen |
| NGO | Non-governmental organization |
| $NO_2$ | Nitrous oxide |
| NT | No-tillage |
| NZ | New Zealand |
| NZAID | New Zealand Assistance for International Development |
| P | Phosphorus |
| PP | Permanent pasture |
| PASC | Pilot agricultural service centre |
| PR | Penetration resistance |
| PSD | Pore-size distribution |
| PUSLAWITA | Pusat Latihan Wirausaha Tani |

| | |
|---|---|
| Puw | Potato unweeded |
| Pw | Potato weeded |
| RAW | Readily available water |
| RDTL | República Democrática de Timor-Leste *(Democratic Republic of Timor-Leste)* |
| SAS | Statistical Analysis System |
| SOC | Soil organic carbon |
| SOM | Soil organic matter |
| SON | Soil organic nitrogen |
| SWCC | Soil water characteristic curve |
| TDR | Time domain reflectometry |
| TIDS | Timor Institute of Development Studies |
| TP | Total population |
| UNDP | United Nations Development Programme |
| UNEP | United Nations Environment Programme |
| UNICEF | United Nations Children's Fund |
| UNTL | Universidade Nacional de Timor-Leste |
| WB-JAM | World Bank Joint Assessment Mission |
| WC | Water content |
| WFP | World Food Program |
| WFP | Water-filled porosity |
| WSA | Water stable aggregates |
| WSSP | Water Supply and Sanitation Project |
| ZT | Zero tillage |

# Abstract

The prospects of sustainable crop production technologies in East Timor were discerned with relevant case studies and experimental data. An overview of the agricultural development in East Timor with particular emphasis on the traditional farming and cropping systems was presented complemented by the discussion on the aspects of agricultural mechanization and technological change and their socio-economic ramifications on food security. Empirical data from tillage trials, established both in East Timor and New Zealand, were gathered and discussed in the quest for a better understanding of tillage effects on soil structure and crop production environment.

The agro-climatic zones of East Timor provide a well-defined set of ecological boundaries upon which further collaborative research work can be developed. Given land resources as one of the major capital investments in agriculture development, the drive towards improvement and technical change in agriculture should be directed in a balanced combination, whenever appropriate, between technologies of *land-saving* (hybrid seeds, irrigation, and drainage) or *labour-saving* (mechanization, herbicides, varieties and cropping techniques) characteristics. Moreover, the justification for acquiring an improved technology for traditional farmers, to some extent, needs to conform to the features of their subsistence mode of farming. The emphasis in technology dissemination, therefore, will have to shift from communication to education.

Experimental results of this study on the effects of tillage, and no-tillage in particular as a form of conservation tillage, on the edaphic changes affecting cropping environment generally concur with the findings known in the literature. Organic carbon levels are generally restored with cropping in East Timor. In addition, soil bulk density and crop grain and biomass yield were not affected by tillage treatments. Soil compaction was significantly affected by tillage as shown by data from the Palmerston North experiment. Soil aggregate stability in the 0-10 cm topsoil was similar under all the tillage treatments. Manual tillage (MT) had the greatest number of soil aggregates on sieve after a 30-minute wet-sieving (68.3%)

followed by no-tillage (NT) (65.1), permanent pasture (PP) (62.6) and conventional tillage (CT) (56.5). Similarly, the top 0-10 cm soil under MT had significantly larger macroporosity (16.4%) than CT (9.23), NT (11.5), and PP (10.6). MT and CT significantly reduced the total C whereas N levels were significantly decreased by tillage (CT, MT and NT) compared to permanent pasture at the top 0-10 cm soil layer. Barley grain and biomass were unaffected by tillage whereas potato tuber yield and biomass were significantly less under no-tillage. Conventional tillage significantly increased water runoff but produced less leachate compared to no-till and permanent pasture. Total soil sediment loss was significantly lower under PP (95.8 kg/ha) and NT (132.9) compared to CT (3556.7) and MT (4652.2). pH of water runoff was significantly reduced under tillage treatments compared to that from permanent pasture whereas nitrogen losses were unaffected.

There are at least four major public policy components that will play vital roles in the development of sustainable crop production technologies in East Timor: (i) Agricultural research and development (ii) Agricultural extension (iii) International and regional networking (iv) Shift of policy focus. The policy approach needs to be decentralized and broad-based and conservation agriculture should be promoted as opposed to conventional production agriculture. Three major areas for the future research agenda include: (i) Integrated Farming Systems (ii) Soil tillage and erosion (iii) Applied science and technology. The last component may cover disciplines such as: food policy analysis, farm machinery selection and testing, soil testing and mapping, land evaluation and GIS, bio-energy technologies, improved local seed varieties, adaptive fodder crops for improved grazing and pasture management, appropriate agro-forestry and soil and water conservation technologies and cash crop initiatives.

## ACKNOWLEDGEMENTS

After a being long overdue, this thesis came to an end, and I must first and foremost praise Lord the Almighty for granting me the strength and perseverance to get through these long years of study. His blessings were also sent through many generous people without whom this study could not reach this far. My deepest gratitude goes to Prof. Peter Kemp for his invaluable contribution to this study as my Chief-Supervisor. His patience and guidance through the experimental and writing phases is very much appreciated. Despite being 'extra' student for him, it did not make me less extraordinary, on the contrary, I was, in times, given special time and priority. I thank Assoc. Prof. Alex Chu, my Co-supervisor, for being with me from the beginning until the end, and for his critical thinking which helped setting up the direction of this study, and for his trust and friendship. My thanks are also due to Dr. Ashraf Choudhary and family for their support and friendship, which counts back to my early years at Massey University. Dr. Choudhary helped with the talks with MFAT-NZ for the scholarship and later gave invaluable support during the first two years of my doctoral study.

There are a number of staff at Massey whom I like to thank for their help, support, encouragement, and assistance: Dr. Dave Scotter and Dr. Ian Yule for the fruitful discussions; Mark Osborne, Tom Todd, and Craig McGill for their help during my field experiments; Bob Toes, Ian Furkert, Ross Wallace, James Hanly, Glenys Wallace and Ann West for assisting me during the laboratory work. Mr. John Dando of Landcare Research helped me a lot with the analysis of soil physical properties, which I sincerely appreciate. The NZAID and the ISO of Massey University are tremendously supportive with the financial assistance and on other logistic matters during my stay in New Zealand. To them I owe a very deep debt of gratitude. I'm also thankful for the Helen E. Aikers scholarship received during the extended period of my study.

The cheerfulness and a joyful environment to study on campus count a lot, and I thank my international friends, too many to count individually, for providing me with plenty of these. I must pay special tribute to my friends at ETZA-NZ, Bhoj Bahadur Kshatri and Maya Kshatri, Zeferino Tilman and Duljira Sukboonyasatit, Tearoa and Josephath, and Helder and Magy da Costa for their countless help, particularly during the last months of my stay in New Zealand, prior to the completion of this thesis. Soccer has been an 'addiction' which I developed by accident, and to my soccer team-mates, kiwis, Pakistani, and international, I extend my sincere appreciation for their warm friendship.

I owe immense gratitude to many people in East Timor, my homeland, especially to HE Eng. Estanislau da Silva, Minister of MAFP; HE Mr. Francisco Benevides, Vice-Minister for Coffee and Forestry; Mr. César da Cruz, State Secretary for Region IV (formerly Permanent Secretary of MAFP); and Eng. Mário Nunes, National Director, Forestry Division and many other MAFP officers for their support and assistance during the East Timor fieldwork. I sincerely thank Mr. João Tilman for allowing me to set up experimental plots on his farmland and my cousin Mário Romualdo Soares who helped monitoring the experiments. The friendship and moral support from my colleagues in East Timor especially João Saldanha, Anacleto Ribeiro, Marcelino Magno, Francisco Guterres, and staff members of TIDS, and Estanislau Saldanha and João Cancio of DIT are gratefully appreciated. I am also deeply grateful for the love and constant prayers from my parents, my parents-in-law, and a multitude of relatives. Lastly, I devote my final words of appreciation to my wife Natália Viegas and our beautiful children Sheena, Shannon, Semantha, Egídio and Victor Dias Viegas for their caring love and sacrifice over many long years in New Zealand.

To the proud farmer of East Timor I dedicate this humble work.

# 1 GENERAL INTRODUCTION

## 1.1 INTRODUCTION

East Timor has emerged as the newest independent country in the world after centuries of political and socio-economic hardship under successive foreign colonial occupations. Moreover, East Timor has to bear a costly and inhumane period of severe destruction following the aftermath of the August 1999 pro-independence referendum. After a brief transitional period under the United Nations administration, and formally regaining its sovereignty as a nation state on 20 May 2002, it is now firmly driven towards achieving its reconstruction and development goals. The daunting tasks of having to start the development from scratch include improving food security, alleviating poverty and promoting the sound use of natural resources, for which the agriculture sector plays key fundamental roles (GoTL, 2006).

It is argued that many of the environmental problems of today's world are not the result of a 'bad' science but, rather, inadequate policies, institutions, and management systems. Therefore, a process of policy and institutional reforms is underway within the agriculture sector of East Timor with the aim of creating a small but effective bureaucracy in the public sector allowing a wider and full participation from the private sector and the agricultural community in view of attaining long-term sustainable agricultural development. This process has been complex and slow partly because of the big adjustments undertaken from a previously huge bureaucracy during Indonesian times and largely due to the inadequate information and supporting resources for policy planning and formulation (MAFP, 2004). Developing institutions at various levels that will foster a policy dialogue on issues related to food, agriculture and the environment is fundamental to identifying medium to long-term development strategies. It is also pivotal to setting up priorities for research and analysis on food, agriculture, and natural resource development policies that will help generate and share information regarding policy challenges and useful strategies for East Timor in its endeavours to secure food and nutrition for the whole population, improve people's living standards and preserve the natural resource base (MAFP, 2005).

This doctoral research project was designed to discuss the big three issues, namely food security, poverty reduction, and natural resource base protection through small and tangible ways with emphasis on the agricultural production sustainability. This is line with the linkages between Millennium Development Goals and poverty reduction such as (i) economic growth and rural development (ii) increasing basic social services and productive resources (iii) improving environmental regeneration (iv) human security, food security, increasing participation and empowerment (UNDP, 2006).

In a setting like the present East Timor, as in many other developing countries, these issues are closely interrelated in a fashion such that they may evolve into a cycle (poverty-hunger-environment degradation) almost impossible to break unless proper strategic policy measures are taken since the onset. To help inform such policies in East Timor, it is argued that the use of the major agricultural resource base which is the soil, by a specific farmer or household in a designated agro-ecosystem, has influential economic impacts to the household members and their living environment. Judicious and effective management of soil may have a major impact on soil productivity and erosion control, particularly in semi-arid regions like East Timor (Sandlund et al., 2001).

The experimental focus of this research was therefore limited to the manipulation of soil by different tillage systems and how that affects the structural properties of the soil under study and its ramifications on crop production. To put this into East Timorese perspective, manual tillage was compared to no-tillage and mechanical tillage using mouldboard plough, and with barley (*Hordeum vulgare* L.) and potato (*Solanum tuberosum* L.) (New Zealand site) and corn (*Zea mays* L.) and mung bean (*Vigna radiata* L.) (East Timor site) as the test crops. In addition, no fertilizers or chemical inputs were applied and efforts to eradicate weeds were kept minimal. In essence, as it is portrayed both in the experimental chapters as well as in the literature study chapters, the nature of the analysis is to contrast the human powered (traditional) farming system versus machine powered (modern) farming system; and the community tuber crop-based production system against the cereal production system. A summarized research setting is presented in Table 1.1 below.

## 1.2 BACKGROUND

Many countries worldwide today are facing the key issue of meeting the food and nutrition needs of their growing populations thus putting a tremendous pressure on the agricultural sector as the prime source of food production. On a global scale, agriculture has been very successful in meeting a growing demand for food production during the later half of the $20^{th}$ century. This has been due mainly to scientific advances and technological innovations, including the development of new plant varieties, the use of fertilizers and pesticides, and supported by extensive irrigation infrastructures (Gliessman, 1998, Zilberman et al., 1997).

This success however, was achieved at the expense of the overdrawing and the degradation of the natural agricultural resources - soil, water, and natural genetic diversity. So far, the global agricultural system is not environmentally benign and poses a long-term sustainability concern. Scientific agriculture and conventional farming embedded in modern agriculture today tend 'to drive ecology out of the input-output equation' (Pesek, 1994), and cannot continue to produce enough food for the global population over the long-term because it deteriorates the conditions that make agriculture possible (Gliessman, 1998). A report has just been recently released on a four-year global assessment on ecosystem change, coordinated by the United Nations Environment Programme (UNEP). The aim was at assessing the consequences of ecosystem change for human well-being and to establish the scientific basis for actions needed to enhance the conservation and sustainable use of ecosystems and their contributions to human well-being (Watson and Zakri, 2005). The main findings of this assessment were quite alarming as presented in Box 1.

**Box 1** **Four Main Findings of the Millennium Ecosystem Assessment 2005**

- Over the past 50 years, humans have changed ecosystems more rapidly and extensively than in any comparable period of time in human history, largely to meet rapidly growing demands for food, fresh water, timber, fibre and fuel. This has resulted in a substantial and largely irreversible loss in the diversity of life on Earth.
- The changes that have been made to ecosystems have contributed to substantial net gains in human well-being and economic development, but these gains have been achieved at growing costs in the form of the degradation of many ecosystem services, increased risks of nonlinear changes, and the exacerbation of poverty for some groups of people. These problems, unless addressed, will substantially diminish the benefits that future generations obtain from ecosystems.
- The degradation of ecosystem services could grow significantly worse during the first half of this century and is a barrier to achieving the Millennium Development Goals.
- The challenge of reversing the degradation of ecosystems while meeting increasing demands for their services can be partially met under some scenarios that the MA has considered but these involve significant changes in policies, institutions and practices that are not currently under way. Many options exist to conserve or enhance specific ecosystem services in ways that reduce negative tradeoffs or that provide positive synergies with other ecosystem services.

Source: Watson and Zakri (2005)

The issues are particularly delicate for developing countries of the tropics where a lot of pressure has been put on agricultural production to keep in pace with the population growth and this, in turn, has led to severe environmental degradation and ecosystem change (Lal, 2000). For these countries, a rapid agricultural development growth is constrained by various factors most notable among these include climatic conditions (Sanchez, 2000), lack or little use of inputs, poor technology transfer and pressure of population growth on land (Clarke and Bishop, 2002), and the use of marginal lands thus causing severe land degradation (Lal, 2000). Many countries in Asia, in their efforts to intensify and increase their food production, have introduced machinery and equipment which were neither tested locally, nor matched with the particular soils to be tilled. In addition, shortage of trained technicians and farmers in the use of equipment introduced has had its negative impact. The experiences of various countries testify to the problems with such inadequately planned transfer of technology. In many cases the targeted yields have not been maintained and serious land degradation has been caused (Salokhe and Ramalingam, 1998).

The task ahead is not only to increase food production but at the same time to ensure that the natural resource base, namely the soil, is properly managed so as to be able to sustain future generations. This major challenge cannot be successfully met without modernization of production technology supported by the development of appropriate socio-economic and research institutions and intensive education. However, there is the need for testing technology developed elsewhere under local conditions that will improve farming practices under the prevailing socio-economic situations. On the other hand, traditional farming systems have not changed much since the early 20th century (Lal, 1995).

Shifting cultivation and bush fallow rotation is widely used in the tropics. Shifting cultivation involves clearing and burning natural vegetation, cultivation of the cleared area for a season or two, then moving to a new plot while the old one regains its fertility under natural vegetation regrowth (Richards, 1985) Attempts to intensify the agricultural production in the tropics either by pursuing the traditional or modern methods of cultivation have caused wide concerns with regards to resource base deterioration. Lal (1995) identified general issues of agricultural sustainability in humid and arid/semi-arid tropics as follow:

1. High subsistence agricultural usage of the land,
2. Reduction in fallow period,
3. Soils of low fertility and low yields due to resource-based and no-input agriculture,
4. Soil degradation due to fertility depletion, accelerated erosion, structural deterioration and reduction in soil organic matter,
5. High risks of crop failure,
6. Water shortage and
7. Difficulties of mechanizing farm operations.

While these issues are generally relevant to East Timor, little attention has been drawn to identify and measure them adequately. Instead, successive political regimes have tried to modernize the agricultural sector without first establishing a firm ground of understanding based on the local knowledge of farming. Efforts were sought to replace or at least de-emphasize the traditional modes of farming instead of improving them. Despite great efforts at agricultural modernization during the last two decades of the Indonesian regime particularly, East Timor's agriculture of today remains predominantly subsistent, geared by farmers with small-sized holdings towards using traditional modes of farming within local kinship clans.

East Timor's subsistence agriculture is mainly characterized by a rice mono cropping in the lowland areas and a mixed cropping system in the uplands. Agricultural public policies during the last two regimes, namely Indonesia and the United Nations, were driven towards achieving food self-sufficiency with great emphasis on rice. The current government of the newly independent East Timor seems to be moving towards the same direction. However, as much has been said, East Timor is not an efficient rice producer (WB-JAM, 1999). Evidence has shown that while local rice produce is very much appreciated because of its organic brand, imported rice is available at the market with a far cheaper price. Thus, from a food security point of view, efforts should be diverted from maximizing the rice production to diversifying the food sector with other comparatively advantageous local food resources of cereal, legumes, and especially root crops (MAFP, 2005).

Due to the complexity involved and resources limitations, the experimental component of this PhD research project is based primarily on soil tillage for crop production and its results discussed within the broad context of agricultural mechanization development in East Timor. There are two contrasting situations where tillage could play a major role in sustaining a long-term crop and food production while preserving the natural resource base. The first situation is the upland mixed farming using traditional shifting cultivation, which implies clearing and burning of vegetation but the tillage and disturbance of soil are kept minimal. The other is the rice cropping system in the lowlands where the use of machinery is extensive and the mechanical treatment of soil is generally excessive following the conventional methods of cropping. An experimental design of appropriate mechanical means to achieve a sustainable yet energy efficient crop production forms the basis of this study.

The literature research component covers an in-depth literature study drawing research evidences and experiences from other countries particularly those with similar developmental and geographical characteristics. It covers three major topics namely traditional agriculture, agricultural/rural technology, and the importance of root crops in the food policy. The results will help support the policy design on agricultural mechanization and food policy for East Timor.

## 3.3 RATIONALE

1. The traditional farming system is an integrated part of East Timorese culture and in many ways reflects the local values, tradition, and knowledge. The system is stable and sustainable however it is inefficient and has low productivity.

2. Matching of the agricultural technologies integral to the respective ecosystem zones will enhance and provide sustained development of cropping systems and livelihood of farmers.

3. Root and tuber crops constitute a major diet component for a vast majority of East Timorese people particularly for the farming communities in the uplands. Their role therefore should not be less important than other staple foods in the formulation of the nation's food policy.

## 1.4 HYPOTHESIS

1. A sustainable long-term productivity cannot be achieved unless a proper policy framework for East Timor agricultural development is pursued.

2. The existing agriculture development policies may exert enormous pressure on marginal lands of the hill countries, especially if inappropriate set of crop production technologies are used.

3. The application of conservation principles will reverse the degradative trends of the current agricultural production systems.

## 1.5 OBJECTIVES

The main objective of this research is to assess the existing crop production systems in East Timor and offer prospective technological outcomes for long-term agricultural sustainability.

The specific objectives are:

1. To evaluate the existing cropping systems in East Timor, those using traditional modes of farming and mechanized systems in selected ecosystems.

2. To provide strategies for food security and sustainable crop production within a food policy approach in East Timor.

3. To investigate selected soil physico-chemical properties, crop yield, and biomass production performances under different soil tillage management.

## 1.6 ORGANIZATION OF THE THESIS

The rest of the thesis is structured as follows:

Chapter 2 – This chapter contains a general overview of the existing cropping systems in East Timor and updated figures of agricultural development indices. Special emphasis is given to the discussion of the prevailing traditional modes of farming in the uplands (shifting cultivation) as they are, under increased population pressure, largely viewed as environmentally destructive. Research evidence and experiences from other countries with traditional farming systems are presented with a literature synthesis on soil degradation and agricultural production sustainability.

Chapter 3 – This chapter presents views on agricultural mechanization/ technology development in a broad context with particular emphasis given to agricultural technology status in East Timor. Recent assessment results on agricultural machinery recovery program during the UN-Administration period and historic data during Portuguese and Indonesian regimes will be the base of analysis. A comparison study based on international and regional experiences complements this study. Conservation agriculture technologies will also be discussed and a preliminary agricultural mechanization scheme is proposed to the new government of the independent East Timor.

Chapter 4 – This chapter synthesizes the information gathered earlier in the previous two chapters and presents views on food policy scenarios relevant to East Timor's conditions. Two present situations worthy of attention are the lowland rice based cropping system and the upland maize/root crop based cropping system. In either case, the technology development needs to be devised through a proper strategy and policy plan, taking into consideration the socio-economic status of the majority of the population living in rural areas. A food policy approach is employed in order to achieve a better understanding of various dimensions of food security appropriate to East Timor.

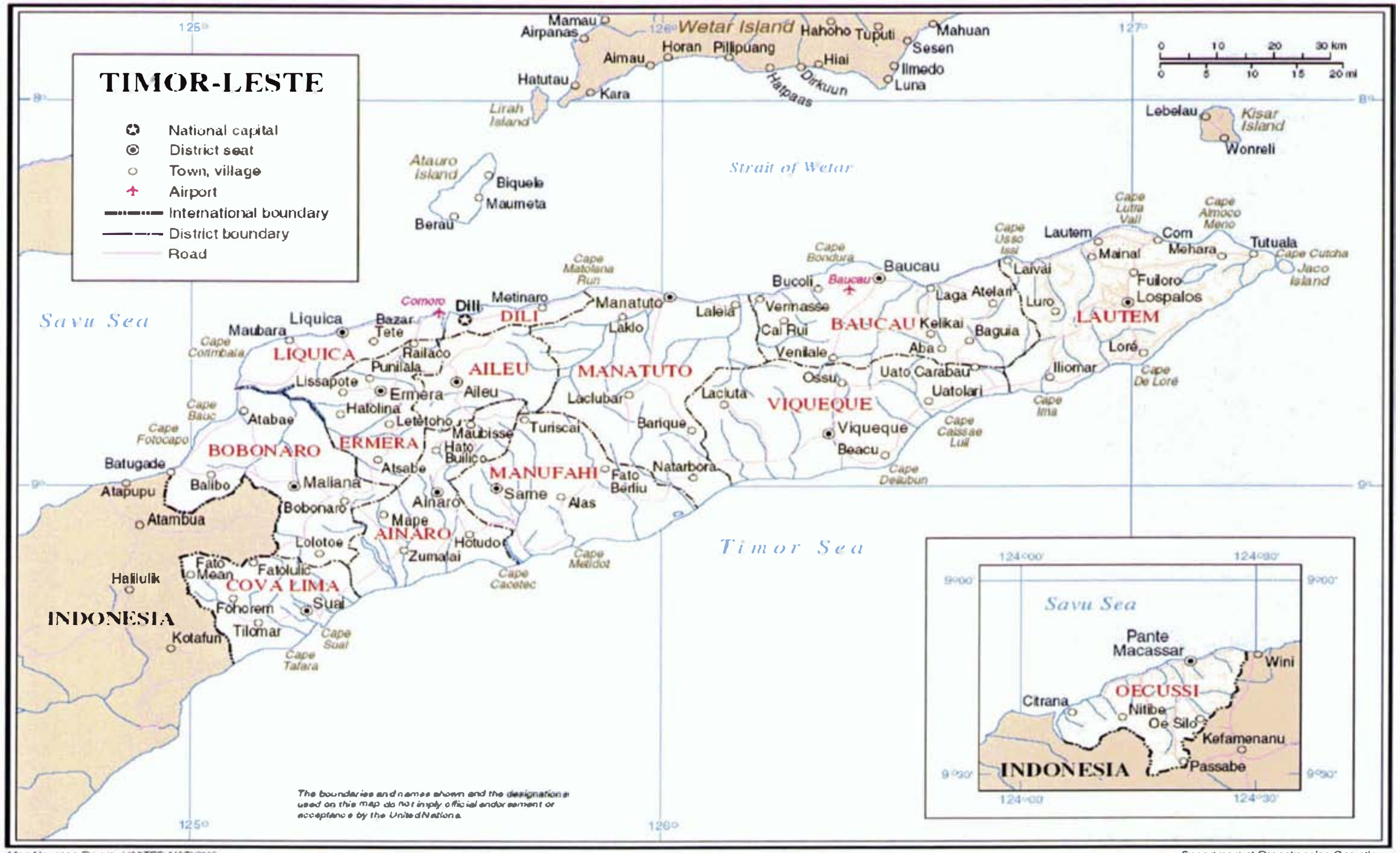
Chapter 5 – Experimental results, discussion and analysis, are presented in this chapter. As mentioned earlier, the focus is to assess the impacts of different tillage systems, namely manual tillage, no-till, and conventional tillage on selected soil physical and chemical characteristics and their implications on crop yield and biomass production. The crops chosen for testing were corn, mung beans, barley and potato. A major experiment was set up in Palmerston North New Zealand to compensate for the poor results from a small experiment attempted earlier in Dili, East Timor (Figure 1.1).

Chapter 6 – Simulated rainfall experimental results comparing the effects of different tillage practices on water runoff and leachate, sediment, and nutrient losses are presented in this chapter. The experiments were carried out in a laboratory at Massey University Campus, Palmerston North, New Zealand.

Chapter 7 – The final chapter presents a general discussion synthesizing the findings, from literature and experimental data, and draws out policy implications and areas for future research related to East Timor agricultural development.

Table 1.1 Summarized research setting

<table>
<tr><th>National agricultural related issues</th><th>Existing Systems / Features</th><th>Research Scope / Scope for Improvement</th><th>Proposed outcomes / recommendations</th></tr>
<tr><td>Poverty Alleviation</td><td rowspan="3"><ul><li>Shifting cultivation predominantly using slash-burn method</li><li>Rainfed upland mixed cropping (root & tuber, beans, maize, and rice)</li><li>Rice and maize cultivation in the lowland areas (rainfed and irrigated)</li><li>Low technology inputs and low crop and land productivity</li><li>Subsistent production</li></ul></td><td rowspan="3"><ul><li>Identifying key policy issues and research study areas (Chapter 1)</li><li>Defining the issues and consolidating the measures in the existing traditional agro-ecosystem setting (Chapter 2)</li><li>Specifying the first key discussion area: mechanization and rural technology advancement (Chapter 3)</li><li>Specifying the second key discussion area: root crop-based cropping systems (Chapter 4)</li><li>Implementing through experimenting: soil tillage and crop adaptation (Chapter 5)</li><li>Implementing through experimenting: tillage-induced erosion and non-point source pollution (Chapter 6)</li><li>Determining policy implications and future research needs (Chapter 7)</li></ul></td><td>Rural technology development based agriculture</td></tr>
<tr><td>Food Security</td><td>Root & Tuber Crop Based Cropping System and Food Policy Approach</td></tr>
<tr><td>Environmental Degradation</td><td>Selective conservative mechanization program with emphasis on conservation / minimum tillage</td></tr>
</table>




Map No. 4111 Rev. 6 UNITED NATIONS
January 2004

Department of Peacekeeping Operations
Cartographic Section

Figure 1.1 Map of East Timor

# REFERENCES


Clarke, L. J. & Bishop, C. (2002) Farm Power - Present and Future Availability in Developing Countries. *ASAE Annual International Meeting/CIGR World Congress, 30 July 2002.* Chicago.

Gliessman, S. R. (1998) *Agroecology: ecological process in sustainable agriculture.* Ann Arbor Press, Chelsea MI, USA.

GoTL (2006) Combating Poverty as a National Cause: Promoting Balanced Development and Poverty Reduction. Democratic Republic of Timor-Leste, Dili East Timor.

Lal, R. (1995) Tillage systems in the tropics: management options and sustainability implications. *FAO Soils Bulletin No. 71.* FAO.

Lal, R. (2000) Soil Management in the Developing Countries. *Soil Science,* **165,** 57-72.

MAFP (2004) Policy and Strategic Framework. República Democrática de Timor Leste, Ministry of Agriculture, Forestry and Fisheries, Dili, East Timor.

MAFP (2005) Preliminary Report on Donor's Agricultural and Rural Development Conference, 3-5 March 2005. Ministério da Agricultura, Florestas e Pescas, RDTL, Dili, East Timor.

Pesek, J. (1994) Historical perspective. *Sustainable Agriculture Systems* (eds J. L. Hatfield & D. L. Karlen), pp. 1-19. Lewis Publishers CRC Press, Inc., USA.

Richards, P. (1985) *Indigenous Agricultural Revolution.* Hutchinson Education, London.

Salokhe, V. M. & Ramalingam, N. (1998) Agricultural Mechanization in South and South East Asia. *International Conference of the Philippines Society of Agricultural Engineers, 21-24 April, 1998.* Los Baños, Philippines.

Sanchez, P. A. (2000) Linking climate change research with food security and poverty reduction in the tropics. *Agriculture, Ecosystems & Environment,* **82,** 371-383.

Sandlund, O. T., Bryceson, I., Carvalho, D. d., Rio, N., Silva, J. d. & Silva, M. I. (2001) Assessing Environmental Needs and Priorities in East Timor: Issues and Priorities. UNOPS and NINA-NIKU, Dili, East Timor.

UNDP (2006) Human Development Report 2006 Timor-Leste The Path out of Poverty: Integrated Rural Development. United Nations Development Programme, Dili East Timor.

Watson, R. T. & Zakri, A. H. (2005) Millennium Ecosystem Assessment Synthesis Report. The United Nations Environment Programme.

WB-JAM (1999) East Timor, Building a Nation, a Framework for Reconstruction and Development; Agriculture Background Paper. The World Bank Joint Assessment Mission.

Zilberman, D., Khanna, M. & Lipper, L. (1997) Economics of new technologies for sustainable agriculture. *The Australian Journal of Agricultural and Resource Economics,* **41,** 63-80.

# 2 DEVELOPING EAST TIMOR AGRICULTURE
## Sustainability Implications

## 2.1 INTRODUCTION

Agriculture is the backbone of East Timor's economy by providing the livelihood source for almost the entire rural and part of the urban populations, accounting for more than a fourth of GDP and generating a limited foreign exchange especially through coffee export. The agriculture sector therefore will inevitably be a major driving force to support a sound and sustainable development growth for the country in the future. However, given its subsistence nature, the challenges are enormous. The farmers produce for self-consumption, with basic inputs including unpaid family labour, small landholdings, basic tools, and rely mostly on rainwater (GoTL, 2003). Nevertheless, the government has embarked on a programme to design policies and strategies[1] at the macro-economic level to respond to these challenges with substantial support from the civil society and the international community (GoTL, 2006).

The National Development Plan with the visions for the year 2020 (Box 2) might look promising only in theory as the country is faced with multi-faceted constraints in all aspects of development, from poor physical infrastructure, limited human and financial resource capabilities, to inadequate law apparatus, not to mention unfavourable natural conditions for agricultural production in many parts of the country. The Ministry of Agriculture, Forestry, and Fisheries (MAFP in Portuguese acronym) is moving ahead with translating these visions into strategic action plans, especially as they are in a large part related to, or dependant on, this sector. As it is explicitly stated as well as inherently embedded in some of these visionary statements, the founding of an agricultural production system which is productive,

[1] See Planning Commission (2002), State of the Nation Report; GoTL (2003) Timor-Leste, Poverty in a New Nation: Analysis for Action; and GoTL (2004) Timor Leste: Millennium Development Goals Report.

sustainable and culturally appropriate will be of major importance. This chapter aims to provide insights on how this could be best achieved.

**Box 2**

**East Timor's vision for 2020**

- East Timor will be a democratic country with a vibrant traditional culture and sustainable environment;
- It will be a prosperous society with adequate food, shelter and clothing for all the people;
- People will be literate, knowledgeable and skilled. They will be healthy, and live a long, productive life. They will actively participate in economic, social and political development, promoting social equality and national unity;
- People will no longer be isolated, because there will be good roads, transport, electricity, and communications in the towns and villages, in all regions of the country;
- Production and employment will increase in all sectors – agriculture, fisheries and forestry;
- Living standards and services will improve for all East Timorese, and income will be fairly distributed;
- Prices will be stable, and food supplies secure, based on sound management and sustainable utilization of natural resources;
- The economy and finances of the state will be managed efficiently, transparently, and will be free from corruption; and
- The state will be based on the rule of law. Government, private sector, civil society and community leaders will be fully responsible to those by whom they were chosen or elected.

Source: Planning Commission (2002), National Development Plan

### 2.1.1 The Ministry of Agriculture, Forestry and Fisheries (MAFP)

As was mentioned earlier, the policy and institutional reforms are now underway especially in the public sector in various administrative levels. With a dramatically lower number of agents compared to the large staff membership under the Indonesian regime[2], MAFP is now carrying a heavy task to consolidate its plans and efforts to meet the increasing needs of the farming population. Box 3 presents the key policy objectives of MAFP.

Up to the present time, the government and MAFP in particular have benefited quite substantially from working in partnership with donor countries, international agencies and NGOs, and national development partners especially farmer groups. However, MAFP found it difficult dealing with the piecemeal nature of most donor and NGO

[2] MAFP currently employs about 235 staff, 41% of which are based at the national level, 17% in the capital, Dili, and 4 to 10 staff in each of the rest of the districts. During Indonesian times there were 700 agricultural extension workers at the village level alone (see MAFP, 2004).

projects and therefore decided to create a Coordination Secretariat partly to prevent overlapping and duplication of project activities. Official assessment indicates that there are a significant number of areas and communities uncovered or lightly served by the donor-funded projects. In addition, a large proportion of these projects will scale down their funding in the very immediate future (MAFP, 2004). This poses, apart from the already unevenly distributed donors' projects across the country and their consequent impact, a worrying situation where MFAP has to sustain its programs with a very limited budget and to cope with a wider area and community coverage.

Box 3

**MAFP' s Policy Objectives**

- Improve the level of food security of the rural population and to raise self-reliance
- Increase value-addition of agriculture, forestry and fisheries products by fostering output processing and marketing
- Active sustainable production and management of natural resources
- Contribute to the balance of trade by gaining revenue from commodity export and by substituting imports
- Increase income and employment in rural areas

Source: MAFP (2004), Policy and Strategic Framework

### 2.1.2 The Role of MAFP

From communications with MAFP officers and personal observation during several visits to East Timor along the course of this study, it is argued that the role of MAFP has been very limited to policy and strategy design, staff and institutional capacity building, information dissemination and the creation of basic infrastructures[3]. The latter include, but are not limited to, the ongoing reconstruction and maintenance efforts on numerous irrigation schemes, meteorological stations, and rural markets. Supported by the international development partners selected programs were also introduced targeting various sub-sectors in agriculture. These range from the

[3] Much of the information were collected while acting as a Facilitator for the MAFP Donor's Agriculture and Rural Development Meeting in Fuiloro, Lospalos, East Timor 3 – 5 March 2005.

provision of agricultural machinery and equipment, improved crop seeds, biological weed eradication, pilot projects on agro-forestry and protected areas, livestock breeding and vaccination to marine resource protection programs.

Selected agricultural schools in the country will also soon be under MAFP's supervision with the view to strengthen the knowledge capacity of the youth in practical agriculture carried out in parallel with other capacity building initiatives at the farming community levels. A research and extension division has also been set up to support the policy formulation and information dissemination components of the ministry's duty with the search and provision of empirically valid database[4]. The research component is, in the view of this study, the most critical aspect of any agricultural development scheme, especially in finding innovative ways to use the country's limited resources to support a dynamic yet sustainable agricultural development transformation.

## 2.2 AN OVERVIEW OF THE AGRICULTURAL SYSTEM

### 2.2.1 Land, people and agriculture

East Timor is a small (approx. 14,610 km$^2$) country with a population of 787,338 people based on the Suco (village) Survey in 2001[5]. Selected characteristics of the population are presented in Table 2.1 below.

Geographically, it has difficult characteristics to support a highly productive agriculture system with rugged, erosion-prone terrain and poor soils in large parts of the territory. Of the 1,460,938 hectares of land area, 35% are located at more than 500 m latitude, 44% are in the 100 – 500 m altitude range, and only 21% are lowlands under 100 m altitude (Keefer, 2000).

---

[4] MAFP has produced a website containing substantial information about the sector's main activities, providing especially a significant number of literature sources (see www.gov.east-timor.org/MAFF/)

[5] Provisional count of 2004 population indicates an increase to 924,642 people. For details see www.dne.mopf.gov.tp.

Table 2.1 Selected characteristics of East Timor's population

| Population | East Timor 2001 | East Timor 1999 | Indonesia | East Asia & Pacific | Low Income Countries |
|---|---|---|---|---|---|
| Population (*millions*) | 0.79 | 0.91 | 210 | 1,855 | 2,460 |
| Population density (*people per square km*) | 55 | 60 | 116 | 116 | 76 |
| Urban population *(% of total population)* | 24 | 11 | 41 | 35 | 32 |
| Population ages 0 - 14 *(% of total population)* | 49 | 41 | 31 | 27 | 37 |
| Population ages 15 – 64 *(% total population)* | 49 | 57 | 64 | 67 | 59 |
| Population ages 65 and older *(% of total population)* | 2 | 2 | 5 | 6 | 4 |
| Dependency ratio *(% of dependents to working age)* | 93 | 77 | 54 | 50 | 70 |
| Life expectancy at birth (*years*) | 57 | 56 | 66 | 69 | 59 |
| Female | 59 | 58 | 68 | 71 | 60 |
| Male | 56 | 54 | 64 | 67 | 58 |

Source: GoTL (2003), Timor Leste, Poverty in a New Nation: Analysis for Action

A mountainous spine transverses the territory from west to east (refer to the map in Appendix 2.1) resulting in two rainfall patterns in the northern and southern coasts of the divide as described in Table 2.2. Diverse microclimates occur with altitude such that rainfall intensity, wind velocity, and cloud generally increase with the increase in altitude while direct solar radiation and ambient temperature decrease. A general pattern of adaptive agricultural production can be observed as result of these microclimatic differences where rice is commonly cropped in warmer lowland areas, maize in the medium altitudes, and root crops are found at higher altitudes (World Bank, 2002, Keefer, 2000).

Permanently cropped land, such as house gardens and rice fields, is recognized by custom as individual property. Ownership of the vast majority of land, however, is determined by clan-inherited usufruct rights under traditional customary law. Traditional land rights are secured by the recognition of neighbouring community group members and the borders marked by natural objects such as river, mountain, and rocks or man-made erected wood or tree fences (Saldanha and Guterres, 2002). The initial right of indigenous people/clans can be passed on to their heirs. Those who are not members of the group that own the land only have rights over produce from the land and such a land ownership system fosters shifting cultivation which causes land fertility to decrease (Xavier, 2001).

Table 2.2 Agro-climatic zones in East Timor

| Zones | Features | Altitude (m) | Annual Rainfall (mm) | Months of Rain |
|---|---|---|---|---|
| *(i) Mono-modal rainfall pattern (NW monsoon)* | | | | |
| A | Northern Lowlands (coastal lands) - 147,045 ha = 10% | < 100 | < 1000 | 4 – 5 (Nov – March) |
| B | Northern Slopes (land in northern hills) - 336,627 ha = 23% | 100 – 500 | 1000 – 1500 | 5 – 6 (Oct – March) |
| C | Northern Highlands (hills and mountains in the north) - 290,553 ha = 20% | > 500 | > 1500 | 6 – 7 (Oct – April) |
| *(ii) Bi-modal rainfall pattern (NW monsoon & SE trades)* | | | | |
| D | Southern Highlands (hills and mountains in the south) - 215,021 ha = 15% | > 500 | > 2000 | 9 (Nov – April; May - July) |
| E | Southern Slopes (hill lands in the south) - 304,981 ha = 21% | 100 – 500 | 1500 – 2000 | 8 ( Nov – March; May – July) |
| F | Southern Lowlands (costal land in the south) - 166,700 ha = 11% | < 100 | Around 1000 | 7 – 8 (Nov – March; May – July) |

Source: (Keefer, 2000, Fox, 2001)

Saldanha and Guterres (2002), studying the relationship between customary land ownership and agricultural production in two sub-districts of East Timor, reported that the customary land ownership is insignificantly affected by the administrative regimes of Portugal, Indonesia, and the United Nations. In other words, the customary ownership has provided some sort of land tenure security over a period of centuries. However, they found no relationship between the security of land ownership under customary law and agricultural production, presumably due to the subsistence nature of the agricultural production and the unavailability of transactions within the customary land ownership system. A case study with a similar finding was reported by Saeed (1982) in Pakistan, investigating the reasons for the failing public policies designed to alleviate poverty. The study suggests that the absence of an economic force that should encourage land ownership by its cultivators is a key factor responsible for the poor economic condition of the working rural household that form the majority of the rural population.

In East Timorese context, land and environment are deeply rooted in the whole cultural setting where environment is regarded not only as the living area for a certain clan but more than that it is the place where the history of the existing lineage can be found, the site of ancestors' graveyards, the place of a *clan's* sacred altar and other cosmologically related affairs (Soares, 2001) (Figure 2.1). Culture, in Timorese perception according to Soares, is also the means to take care of the "environment", and the latter may not exist should culture not be respected. Both are interrelated and are the very means for human survival. It is probably similar to *Jhum,* a traditional farming practice considered as a way of life and culture for the tribal communities in parts of India and Bangladesh (Choudhury and Sundriyal, 2003).

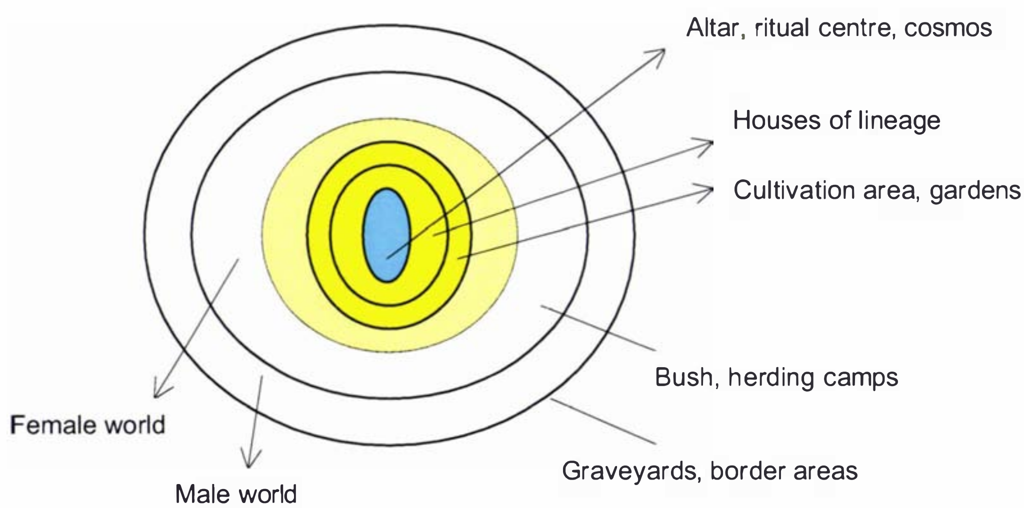



Figure 2.1 The East Timorese perception of land (Soares, 2001)

How the slash and burn practice generally employed for land clearing and subsistence farming prevails as a result of the shortage of labour and efforts, or the need, to "save time and energy" (Soares, 2001) is viewed within this cultural mindset is a matter of great debate. The view of traditional farming systems as generally sustainable but modern shifting cultivation practices being increasingly regarded as degradative to the environment has long and widely been studied (Altieri, 2002, Chidumayo, 1987, Alegre and Cassel, 1996, Brady, 1996, Arnason et al., 1982, Albers and Goldbach, 2000). This case study will be further explored later in this chapter.

### 2.2.2 Agricultural production systems

The main production systems are as follows:

*a. Upland mixed-crop cultivation*

This can be found predominantly everywhere in the uplands, generally hilly and sloped contours, with rainfall as the sole source of water. The main crops grown are cassava *(Manihot esculenta)*, sweet potato *(Ipomoea batatas)*, maize *(Zea mays* L.*)* and upland rice (*Oryza sativa)*, intercropped with vegetables and legumes such as squash *(Cucurbita)*, pumpkin *(Cucurbita spp.)*, mung beans *(Vigna radiata)*, red beans *(Vigna angularis)*, green peas *(P.sativum)*, etc.. The village survey carried out in 2001 reveals the coverage of root / tuber crops and maize crop production areas as shown in Appendices 2.2 and 2.3, respectively (GoTL, 2001). Fruit trees such as banana, citrus, papaya, mango, coconut and jackfruit are also commonly found in the gardens. All these types of vegetation are cropped surrounding the housing section which is commonly situated in an elevated area. In this case Figure 2.1 could best viewed as a downward looking contour of a mountain. Exception may be made to coffee growing areas such as Liquiça, Ermera, Aileu and Ainaro where coffee trees were planted and uncontrollably grown into aged and neglected plantations, resulting in vulnerability to disease (currently shade trees but also potentially coffee bushes) and low yields (Curnow, 2003, Old and Cristovão, 2003) and leaving very little room for intercropping with other commodity crops.

*b. Rice cultivation*

The bulk of the rice production comes from wetland rice mono-cropping in the valley terraces and in the alluvial soils and river basins in the lowlands. There are however, small scale rice production systems in the uplands as mentioned above. The rice production coverage area according to the village survey in 2001

(GoTL, 2001) is described in Appendix 2.4. Based on the reliability of water supply the following rice cropping systems can be observed:

(i) *Upland rice cultivation.* Unlike in wet cultivation where rice is broadcast or transplanted into puddled soil, upland rice is grown in dry soil conditions thus it is commonly known as dry-land paddy rice (*arroz sequeiro* in Portuguese and *padi gogo* in Indonesian language). It is part of a diversified cropping system for subsistence produced on a small scale in areas with abundant rainfall. Depending on the topography and contour relief down the areas surrounding the housing base the following types of variation can be found:

- *Paddy rice in terraces.* For water conservation and irrigation purposes these terraces are typically located on fortified slopes or gently undulating plains in areas with abundant rainfall where possibility exists for micro-catchments of rainfall water runoff. The embankments surrounding the plots help conserve the soil moisture over the cropping season which is limited to one crop per year and soil fertility is restored through fallowing for the rest of the year. In certain areas, grass and fodder plants are grown post-rice for animal grazing.

- *Rice cultivation along the stream / spring catchment areas.* Similar to the terraces mentioned above but with an extended period of water supply from the streams and mountain springs. It is common in areas with abundant and evenly distributed rainfall throughout the rainy season. The streams and springs, supported by a sufficiently recharged ground water-table, will continue to supply water flow for one or two months after the wet season. This provides scope for a better crop sequence or diversification as well as a prolonged used of land for productive cropping.

(ii) *Irrigated rice cultivation.* This is the main source of rice production in the country typically found on the flood plains of river basins in lowland areas. Traditional or technical irrigation schemes, channelling water from the seasonal or perennial river flows, provide water supply for this cropping system. Appendix 2.5 provides a visual presentation of areas covered by irrigation in East Timor based on the village survey in 2001 (GoTL, 2001). There are areas where the water supply is reliable to support more than one cropping season provided timely harvest, post-harvest and the subsequent land preparation activities are secured. A major constraint towards this aim is the lack of power input (man, animal, and machinery) to support intensive crop production. This is a major component, in terms of policy and resource allocation, in the current food crop division of MAFP as well as during the previous regimes. Basic infrastructure such as irrigation schemes, large scale mechanization, and the introduction of chemical inputs and a series of rice and cereal sufficiency driven policies were devoted to this division.

c. *Home gardens*. This type of agricultural production is perhaps the system most commonly practiced by every (farming) household, both in the uplands (upland mixed cropping described above) and the lowlands. A huge variety of rain-fed crops are grown simultaneously in the garden from staple food such as maize, cassava, and sweet potato, vegetables, and fruit crops as mentioned earlier for the upland mixed-cropping system. This system contributes largely to the root and tuber crops and maize production described earlier in Appendices 2.2 and 2.3. Some people with expert knowledge may also grow medicinal plants as well as spice crops in their backyard gardens while they also use specific spots in the area to raise domestic animals from poultry to pigs, goats, and cattle[6].

[6] It was widely campaigned during Indonesian times, duplicating efforts implemented elsewhere in Indonesia, to use the gardens as source for traditional medicine ('living pharmacies) and food production ('living kitchen') so as to ease the burden of having to purchase these products from the market.

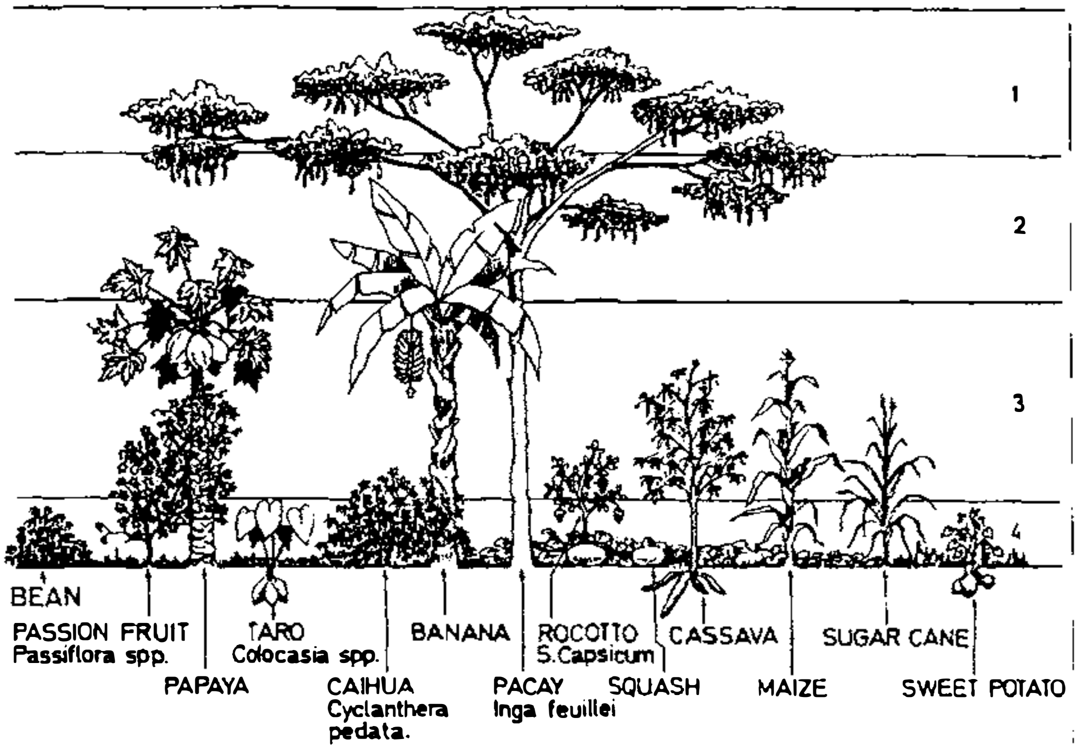



Figure 2.2 Ecological profile and production level of tropical home gardens (Ninez, 1987)

The home gardens are typically characterized by vegetation 'stories' or layers, imitating the tropical forest structure as described by Niñez (1987). The top 'storey' consists of tall trees forming a protective canopy against tropical sun and torrential rains. It supplies nourishment (mainly fruit), and adds to spontaneous soil regeneration (fallen leaves) while maintaining relatively constant moisture and temperature levels. A lower layer features staple and fruit production (e.g. *Musa* spp., mango, papaya and *Inga* spp. the most common in the tropics), followed by bush-level growth (e.g. cassava, maize, peppers, tomatoes, beans) in a third layer. In-ground and ground-covering species (roots and tubers and *Cucurbitacea)* form the last layer, while climbing species transverse the lower stories (Figure 2.2).

Home gardens possess a number of sustainability attributes, with regard not only to their ability to meet a number of farmers' needs without negatively affecting the resource base, and in many cases even improving it, but also to their potential to meet several economic, social, ecological and institutional conditions which contribute to their sustainability (Torquebiau, 1992).

The main attributes that have been identified as contributing to the sustainability of these systems are biophysical advantages such as efficient nutrient cycling offered by multi-species composition, conservation of bio-cultural diversity, product diversification as well as non-market values of products and services, and social and cultural values including the opportunity for gender equality in managing the systems (Kumar and Nair, 2004). A 3-year home garden study in Vietnam covering four different ecosystems concludes that richness and stability of home gardens make them important sites for in situ conservation within eco-zones, and great scope exists for the utilization of this information to improve nutritional and income-generating development projects (Trinh et al., 2003).

The crop production calendar for major staple foods in East Timor generally follows the pattern described in Figure 2.3.

d. *Tree crops cultivation.* Coffee plantations are typical for this kind of crop cultivation dominating the central and western upland areas of Ainaro, Aileu, Liquica, and Ermera[7]. Attempts have been made to expand this cultivation to commercially competitive crops such as cocoa, vanilla, and cloves. Coconut is another major tree commodity traditionally grown in plantation 'scale' in areas of eastern districts of Baucau and Viqueque. Copra, although not in a big scale, has long been an export commodity since Portuguese times. The coconut oil is currently at the initial phase of exportation as well. Large scale cultivation projects of tree and fruit crops were attempted during Indonesian administration covering a wide area of the territory with mixed results. These were specifically targeted at introducing new varieties of citrus, mango, banana, papaya, and other tropical and sub-tropical fruits. Cashew nut plantations were also introduced in the southern

[7] Coffee is the most important export commodity providing $4.8 million of the $6 million export earnings in 2002 (with the exception of oil and gas) and a significant source of seasonal employment (see MAFP, 2004). See also Piedade (2003) for an overview of the coffee industry.

areas with very little success, mainly due to minimal government control and security reasons.

| **CROPS** | N | D | J | F | M | A | M | J | J | A | S | O |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Lowland crops* | | | | | | | | | | | | |
| - Rice (1) | Planting | Planting | Planting | | Harvest | Harvest | Harvest | | | | | |
| - Rice (2) | Harvest | | | | | Planting | Planting | Planting | | | Harvest | Harvest |
| *Mid-altitude crops* | | | | | | | | | | | | |
| - Maize (1) | Planting | Planting | | | Harvest | Harvest | | | | | | |
| - Maize (2) | Harvest | | | | | | Planting | Planting | Planting | | Harvest | Harvest |
| *High Altitude (Root & Tuber Crops)* | | | | | | | | | | | | |
| - Cassava | Planting | Planting | Planting | Planting | | | | | | | Harvest | Harvest |
| - Cassava (previous year) | Harvest | Harvest | Harvest | Harvest | Harvest | Harvest | Harvest | Harvest | Harvest | Harvest | Harvest | |
| - Sweet Potato | Planting | Planting | Planting | | | Harvest | Harvest | Harvest | Harvest | Harvest | Harvest | |
| *Vegetables (intercropped)* | | | | | | | | | | | | |
| - Green pea, cow pea | | | | | Planting | Planting | | | | Harvest | Harvest | Harvest |
| - Peanut and beans | Planting | Planting | Planting | | Harvest | Harvest | Harvest | | | | | |

Planting: [dark green] Harvest: [yellow]

Figure 2.3 East Timor Crop Calendar

e. *Collection of forest products*. Forests provide not only timber for housing and firewood for cooking but they are also place for potential market products such as tamarind (*Tamarindus indica*) and candlenut (*Aleurites molucana*) as well as staple food crops such as sago, yams, wild beans, etc. In addition, sandalwood (*Santalum album*) has been for centuries providing a significant share in export revenues. There also non-timber forest products with potential for domestic and export markets such as honey, bamboo, and rattan. It also gives space for occasional grazing for domestic animals such as buffaloes and horses, but it is primarily the natural ecosystem for wild flora and fauna as essential components of the biodiversity[8]. It is argued that this very precious resource has undergone a significant degree of depletion over the years.

[8] East Timor is located in the "Wallace Zone" where the Indo-Malaysian and Australasian flora and fauna overlap, thus providing it with an area of great biological diversity (see MAFP, 2004). It is therefore vitally important that the forests should be properly managed to protect this valuable biodiversity.

f. *Livestock production*[9]. This is a sub-sector of the agriculture industry providing significant power source for farming, nutrient source for plants through livestock manure as well as protein source for the population. Water buffaloes are commonly used for *rencah* (a system of herding animals in flooded rice fields to puddle the soil in preparation for rice planting) apart from being used for gift exchanges during cultural encounters. Cattle also, like goats in providing meat and milk, are being trained in some parts of the country to plough the soil for plant cultivation. Until recently, horses are occasionally being used, apart for transportation purposes, to thresh the paddy rice post-harvest. Poultry (not in a commercial sense), the cheapest affordable protein source, can be found in almost every household in rural and peri-urban communities.

g. *Off-shore and inland fish production*[10]. Communities in coastal zones can afford the luxury of supplementing their diet with sea food products. However, despite living right close to the beach, East Timorese fishermen are not trained or well-equipped to explore the much more resourceful deep sea potentials. On the contrary, the production is mainly derived from a short catchment zone using traditional fishing gear aimed at meeting the immediate needs of the population. There are however on-going efforts through bilateral co-operations to take full advantage of the sea resources and to increase national domestic revenue. Despite promising, concerns are that this could result in an unbalanced share both in the production and in the revenue distribution given the currently low level of human scientific resources and skill ability in this area. Still in view of diversifying rather than maximizing production, efforts are also being placed at reviving the inland fish ponds once introduced during the Indonesian administration. Fresh water fish, naturally available in the lakes and rivers and through these fish ponds will inevitably enrich the already diversified food and nutrition sources of the farming communities.

---

[9] See MAFP (2004) for a summarized presentation of MAFP's policies and strategies for livestock development.

[10] More on fisheries development see MAFP (2004).

The agricultural production systems described above overlap one another or mutually co-exist as such that a single household may be involved in more than two production systems. The aim is to diversify production, balance seasonal requirements, and spread the risk of crop failure (MAFP, 2004). The operation of these systems however, has been severely disrupted due to the dislocation, resettlement, and migration of communities especially during Indonesian times and during the tragic transition towards independence (WB-JAM, 1999).

Overall, crop cultivation dominates the agriculture sector, with livestock, fisheries, and forestry contributing a much smaller role (GoTL, 2003). Although there is scope to increase food production by increasing the cultivation area, the low level of technology and inputs used currently, strongly favour an intensive approach based on enhanced and balanced use of fertilizers, higher yielding seed varieties and irrigation (MAFP, 2004). MAFP realizes that due to the growing economic needs of the population it is necessary that the focus of production strategies should move beyond commodity crops to cash crops with higher margins such as cashew nuts, mangos, spices, vanilla, pineapples, passion fruit, guavas, sandalwood and cut flowers. In addition, this should be followed by establishing small processing industries such as for producing roasted nuts, mango pulp, guava jam, and passion fruit concentrate (MAFP, 2004).

The discussion of the agricultural production systems will be deducted to more specific topics later in the next chapters. How these production systems evolve in a rural community setting where traditional knowledge is often ignored and alienated rather than transformed by modern scientific know-how through agricultural mechanization is discussed in Chapter 3. Another important aspect is how these production systems contribute to the food security of the country's population which will be the focus of discussion of Chapter 4. The whole analysis will be enlightened by the descriptive analysis in the next sections.

### 2.2.3 Perceived issues and problems

The people in East Timor live in different ecosystem types, facing varying natural and man-made conditions. Around the time of independence in 2002 and prior to the elections the local-level concerns were much more focused on the economy and basic human needs than on the political situation. A survey revealed that about 41 percent of East Timorese view infrastructure issues as urgent local needs, and 19 percent rate items such as water supply, roads, markets, communication and electricity as the top priority. One third of the electorate (33 percent) cites food security as one of the top two local problems, and almost all of those say it is the primary problem (The Asia Foundation, 2002)

Another survey carried out by Sandlund et al. (2001) in rural and urban areas of East Timor around that time also identified particular issues and problems some of which are discussed below:

*(i) Water quality and availability*

The availability of clean water for domestic and non-domestic use is a general problem found in the rural and urban areas. In most cases, people depend on surface water and water quality is normally particularly poor in the rainy season. Access to water is obviously more difficult in the dry season (Sandlund et al., 2001). This issue has been the focus of programs by many international agencies such as UNDP, CARE, and AusAID to mention just a few. Major water supply projects have been carried out by UNDP for district town water supply systems of Dili (2000-2004) and Liquiça, Manatuto, and Lospalos (2002-2003); for irrigation such as the rehabilitation of Lacló Irrigation Scheme (2002-2003); and rural water and sanitation services in Aileu and Baucau (2001-2003) (GoTL and UNDP, 2005). CARE Canada has also been involved in irrigation rehabilitation and soil conservation as well as rural community water and environmental health projects in East Timor. The latter project in particular was implemented in 2001-2004 focusing primarily on poor rural areas covering 23,808 people in 74 hamlets (www.care.ca). AusAID through Water Supply and Sanitation Project (WSSP) have helped re-establish the community based water supply and sanitation systems in rural districts and the provision of technical experts in Viqueque, Bobonaro, and Covalima from 2002-2005. The total beneficiaries on completion of this project are estimated at 66,000 people in 77 communities (www.ausaid.gov.au).

It is yet to be assessed how these projects have helped the communities to find solutions for their water supply and sanitation needs in the medium to long run. Of major concern is the operation and maintenance by the communities of the facilities already in place, the expansion of the projects to cover population needs in much remote areas, and the long term commitment from the funding agencies. Estimates in 2003 suggest that overall about 55 percent of the population has access to safe water. It is over 70 percent in urban areas, but only around 50 percent in highland and rural areas of the country (UNICEF, 2003).

A study by Cruz *et al.* (2005) in two sub-districts of Viqueque, a project area of AusAID/WSSP, reveals that water supply conditions at household level are relatively poor both in Uatucarbau and Viqueque. Only 34% and 44% of the population in Uatucarbau use enough water (≥30 liter/capita/day) during rainy season and dry season respectively. Similarly in Viqueque, only 25% of the respondents have enough water during rainy season while during dry season the number decreases to 24%. Comparatively, the level of external assistance in water supply to Viqueque (43%) is better than to Uatucarbau (33%). Due to its closer distance to Dili, Viqueque has a better position and received more water supply aid as compared to the remote sub-district of Uatucarbau.

*(ii) Agricultural production and market imperfections*

Many reported issues related to agricultural production are in fact legacy effects of the 1999 troubles. Many arable lands are left underutilised due to the lack of draught animals, crop seeds, and fertilizers, which are hardly affordable by local populations. In some areas, farmers prefer to be paid in cash rather than food implemented through WFP's "Food for Work" program so they could be able to invest in seeds, fertilisers and tools to increase their agricultural output and become economically self-sustained. In other parts, despite being primarily subsistent farmers, they are willing to produce more, but there is no market outlet for surplus production. Moreover, free provision and/or availability of cheap imported food especially rice consequently undermines local markets (Sandlund et al., 2001).

Meanwhile a government document reports a series of promising outcomes to boost the domestic production through multiplication of quality seeds. Through the AMCAP project of the UNDP it was able to pilot multiplication of seeds (rice, maize, soybean, mung bean) on 71 hectares in Manatuto yielding 186.5 tonnes of high quality seeds and in Natarbora (a resourceful agriculture area in the southern lowlands of Manatuto district) seed production increased by 400%. In addition, a large part of the hand tillers originally distributed to CNRT (the Timorese National Resistance Council) have been repaired and relocated to MAFP and three mechanical workshops with spare parts procurement founded by 2004 (GoTL and UNDP, 2005).

The sloping nature of the landscape also influences the economy of the upland communities. Market access is often limited because it costs too much to develop and maintain infrastructure where slopes are steep and topography undulates (Jackson and Scherr, 1995). Decreasing number of agriculture labourers due to urbanization, particularly to Dili and other district towns, is another major issue affecting agricultural production in rural areas. The impact of this migration is that the villages are drained of labour, thus reducing the capacity to plant and harvest leading to much of the land resources being underutilized (Sandlund et al., 2001). The search for job opportunities, leisure, and quick money is generally the cause for the rural youth to move into cities, and to quite often be left with despair when confronted with a very competitive labour market in the cities due to the 'openness' of the country brought about by globalization.

*(iii) Deforestation and land degradation*

Sandlung et al. (2001) reported the damage by torrential rains and flash floods identified in almost all the districts causing severe soil erosion and landslides in the uplands and disaster floods in the lowland areas. The study found some people in the community related this problem to the deforestation on the steep hillsides as the cause. Others, however, do not regard the removal of forest as a problem and seem reluctant to take preventive action to arrest soil erosion and other forms of soil degradation. The lack of market access in upland areas may also influence whether land users are inclined to practice land conservation and may constrain their ability to use the land sustainably (Jackson and Scherr, 1995).

The causes of erosion as a major source of soil degradation and ways to remedy the impacts on the social environment of East Timor have always been a long time concern. The issue was identified as a major problem since the time the Portuguese colonial regime began a seriously planned economic development of its then overseas province (Gonçalves, 1963). The problem persisted with little or no remediation towards the end of the regime. The agriculture development during the last two decades of the Portuguese rule (1953-1975) is well summarized by Reis (2000).

Government reports indicate some efforts being undertaken with regards to reforestation. The government has embarked on piloting upland farming techniques (based on the principles of soil and water conservation and agro-forestry) in 23 locations covering 16.9 hectares of farm land (GoTL and UNDP, 2005). The University of Hawaii (c.q. College of Tropical Agriculture and Human Resources) has also for some time been offering advice in this field (Friday, 2003, Friday, 2004). A literature synthesis on strategies and policies to address the issue of soil conservation compatible with East Timor's conditions can be found in Gusmão's (2003) study. Some of the soil and water conservation techniques are not new and have been introduced in the past by national NGO's such as PUSLAWITA and ETADEP in the hills of Dili and by other NGOs in other parts of the country[11]. A proposal on land reform in East Timor has been advanced in order to prevent further

[11] This information is drawn mainly from personal experience and active involvement in promoting social reforestation (among other activities) in the sub-district of Maubara - Liquiça while serving as an NGO worker under the Satya Wacana Christian University community development program (1991 – 1995).

land degradation including the redistribution of land and land titling for tenure security (UNDP, 2006).

Based on case materials Fujisaka (1994) found that farmer adoption of innovative conservation practices has been minimal at the community level. He argued that farmers do not adopt because they do not face the problem targeted by the innovation, farmer practice is equal to or better than the innovation, the innovation does not work, extension fails, the innovation costs too much, and 'social' factors.

These reasons may be of great relevance to the case of East Timor. Despite acknowledging the existence of some of the root causes of soil degradation, the extent to which the soil and the environment has been degraded is still largely unknown. It was generally argued in the past that research of this kind takes time and a large sum of financial resources the government cannot afford. Therefore, it was not uncommon to find statistical reports on certain socio-economic indicators largely available as opposed to the lack of environmental health studies or soil quality assessment reports (Viegas, 2002). It is therefore imperative that MAFP is allocated with sufficient funding to gradually improve its resources capability for research and development in this very important area.

Evidence from other countries and MAFP's own limited human resources, provide compelling reasons to suggest a requirement for more farmer participatory research (Poudel et al., 2000, Astatke et al., 2003, Sanginga et al., 2004, Fujisaka, 1989). It is also best to link science research with policy research where researchers are required to be: (i) concerned at many scales, from local to global; (ii) able to predict and allow for the influences of technical change; (iii) able to model biophysical processes and behavioural norms and responses in an integrated way (Hazell and Wood, 2000). The empirical facts drawn from these research programmes will better inform and provide the base upon which proper policies could be designed and appropriate measures taken towards achieving a sustainable land use and forest management.

### 2.2.4 Land use policies and productivity

Given the prevailing conditions on one hand and the developmental visions laid ahead as described earlier on the other, the tasks to fill the gap between these two ends pose enormous risks and challenges. Attempts to modernize East Timorese agriculture have been overwhelmingly great in the recent past but they failed to bring a decent transformation to the agricultural production practices in the country. It is argued that the efforts to stimulate more intensive farming systems in a particular region, and more broadly to alleviate rural poverty and improve food security, must be based on a solid understanding of rural land use and livelihood strategies, and the factors that drive them (Shriar, 2002).

Experiences in many parts of the world provide a large body of evidence on the arduous tasks of designing policies and strategies to reconcile the often conflicting aspects of a productive and sustainable agricultural production system (Shriar, 2001, Shriar, 2002, Saeed, 2000, Sanchez and Leakey, 1997, Pichon, 1996, Pichon et al., 2002). Many Asian countries while adopting land use policies to increase agricultural output have indeed created what is known as a green revolution resulting in increased food production. However, they have not created any lasting improvements in food security (Saeed, 2000). On the contrary, these policies have precipitated trends that point towards an impending decline in food production. As much as they represented a well-intentioned effort to improve food supply for indigenous use and agricultural output for export, these policies were implemented without intimately understanding the societal and ecological dynamics that precipitated a condition of shortage in the first place (Saeed, 2000).

In sub-Saharan Africa, the per capita food production continues to decrease even though this region compares favourably with other tropical regions in terms of climate and soil resources. Sanchez and Leaky (1997) attribute this to (i) the need for an enabling policy environment that favours smallholder rural development; (ii) the need to tackle soil fertility depletion as the fundamental biophysical constraint to food security and (iii) the need for more intensive and diverse land use, based on the domestication of indigenous trees to produce high value products while increasing agro-ecosystem resilience. It is assumed that this decrease is also due the lack of population control.

Frontier regions feature some distinct characteristics that have a profound influence on the strategies of farmers therein. These characteristics include an abundance of land but relatively limited labour, land tenure insecurity, poor market conditions and infrastructure, limited presence of research, extension and other agricultural services, and a low level of community and farmer organization (Shriar, 2002). In the Amazon frontier, Pichon's (1996) study seeks to increase understanding of the micro and macro-level forces that propel land-use decisions in the Amazon and offer insights about how farmers' land-use decisions may be altered to bring about forms of resource use that are consistent with the constraints and opportunities of the frontier environment. The analysis suggests that to be effective, any policy or technology-based effort on the part of governments or researchers to alter colonist land-use systems must begin to look systematically at the production systems of agricultural colonist populations already present in frontier environments. This knowledge is essential to understand the social and economic factors affecting present land use and choice of technology. It is also important for understanding factors influencing farmers' demand for more optimal systems of land use that are consistent with varying agro-ecological potentials, demographic situations, and the management capacity of the farmer.

A critical challenge for both forest conservation and human welfare is to induce a more rapid process of agricultural intensification, and thereby limit the degree to which it occurs out of desperation, caused by a scarcity of forest land on which to practice swidden or shifting cultivation for example. In addition to creating off-farm employment opportunities, a key objective should be to foster the conditions and develop the systems that will make it economically feasible and possible for farmers to intensify in ways that are agronomically and environmentally sustainable. This can help them limit pressure on remaining forest, both on and off their properties (Shriar, 2002).

Saeed (2000), translating the interaction between agricultural management policies and the agro-ecological system mechanisms into a system dynamics model, foresees a possible sharp decline in agricultural production across the board in the absence of sustainable agricultural technologies. Unfortunately, sustainable agricultural technologies, even when available, will not be put into practice as long as the technological and economic considerations governing agricultural policy remain divorced from environmental information concerning land resources and soil ecology. Short-term private gains in production will be sought at the cost of the decay of the common resource system that sustains agriculture. Thus, an institutional framework needs to be created, so that appropriate ecological information becomes a regular basis for the economic decisions leading to appropriate technological choices.

## 2.3 SHIFTING CULTIVATION WITH SLASH AND BURN

Shifting cultivation continues as the economic mainstay of upland communities in many developing countries worldwide (Rasul and Thapa, 2004, Dendi et al., 2005, Porro, 2005, Sommer et al., 2004). However, the conditions that historically underpinned the sustainability of rotations with long fallows have largely vanished (Sunderlin, 1997). The imperative to evolve more permanent forms of land use has been exacerbated by rapid population growth, gazettement of remnant wildlands into protected areas, and state policies to sedentarize agriculture and discourage the use of fallows and fire (Cairns and Garrity, 1999).

There are many compelling examples where shifting cultivators have successfully managed local resources to solve local problems. Technical approaches to stabilizing and improving productivity of shifting cultivation systems have not been notably successful (Cairns and Garrity, 1999, Greenland, 1975). Farmer rejection of researcher-driven solutions has led to greater recognition of farmer constraints (Fujisaka, 1994). This experience underlined the need for participatory, on-farm research approaches to identify solutions (Hazell and Wood, 2000, Astatke et al., 2003, Poudel et al., 2000, Sanginga et al., 2004). The challenge is to document and evaluate indigenous strategies for intensification of shifting cultivation through a process of research and development. This process involves identification of promising indigenous practices, characterization of the practices, validation of the utility of the practice for other communities, extrapolation to other locations, verification with key farmers, and wide-scale extension (Cairns and Garrity, 1999).

### 2.3.1 Understanding shifting cultivation

Shifting cultivation, also known as swidden cultivation or/and slash and burn by its method of land clearing, describes an act of removing all the vegetation in a certain area by slashing, drying and burning them in-situ for cropping purposes in rotation with a reasonably long fallow period. It involves three basic components (Kleinman et al., 1995): (i) conversion; (ii) cropping; (iii) fallow. During the conversion stage, slashing and burning serve to remove shading canopies, reduce pest competition, and help releasing nutrients from the stored biomass and make them available for the crops (Kleinman et al., 1995). Cropping practices vary depending on the needs, whether for subsistence or cash/budget cropping or both (Ninez, 1987). Fallow is a lengthy period after cropping designed to halt degradation and restore soil fertility (Kleinman et al., 1995) by replenishing soil organic matter, thereby improving soil structure and protecting the soil from erosion and excessive water run-off (Brady, 1996).

After hundreds of years as a sustainable form of land use, shifting cultivation has been maligned as inefficient and as a major cause of irreversible damage to tropical ecosystems (Albers and Goldbach, 2000). It is widely recognised however, that under certain demographic conditions, shifting cultivation is a sustainable system proven by its long history of adherence in many places around the world by local farming communities (Brady, 1996, Kleinman et al., 1995). Only when land use pressure increases due to increases in population densities and fallow periods are shortened (Cramb, 1993) or shifting cultivation is intensified (Arnason et al., 1982) does it run the risk of degrading the soil quality and productivity.

The intensification of land use by shifting Maya agriculturists in Belize, Central America, has led to a decline in soil fertility and crop yields. Examination of eleven nutrients in crop plants and soil, and changes in nutrient levels with the length of the cropping period indicated that phosphorus was the limiting factor for plant growth. Physical analyses of the soil and visual evidence suggested that erosion is a contributing factor to declining soil quality (Arnason et al., 1982). This is one of the most compelling reasons for a change from slash-and-burn to continuously cropped agricultural systems in heavily populated areas in the humid tropics (Alegre and Cassel, 1996). Public policies in Laos for example are set to eliminate slash and burn practiced by about 25% of the four million people (mainly of rice) on a third of the country's cropped area. Weeds, low and possibly declining soil fertility, intensification of the cropping cycle, rats (plus birds, wild pigs), and insects lowered rice yields or reduced system sustainability (Fujisaka, 1991).

As summarized by Sunderlin (1997) shifting cultivation practices become less sustainable as: (i) rotation of fallow plots is shortened or eliminated; (ii) tradition gives way to modernity; (iii) subsistence crops are replaced by cash crops; (iv) family capital is replaced by external funding; and (v) farms are close to urban areas. The increased population pressure is also another major factor that contributes to the decreased sustainability of shifting cultivation practices (Jarosz, 1993, Krautkraemer, 1994). Shifting cultivation effects if any do not however appear in isolation. As it is the case in Laos, the forest ecosystem has been degraded by a series of activities such as logging, burning, and rice mono-cropping. The potentials for environmental rehabilitation through natural succession appear to be minimal. Farmers cannot adopt high labour and cash cost innovations. It is recommended that an improved fallow is needed as an intermediate step prior to crop diversification, adoption of agroforestry technologies, and sedentary agriculture (Fujisaka, 1991). Well managed alternative systems to slash-and-burn can reduce soil structure deterioration, maintain soil fertility, and promote long-term productivity (Alegre and Cassel, 1996).

In East Malaysia, some villages are still highly dependent on shifting cultivation, while for others it is very much a spare-time activity. In the long term, the sustainability of all these farming systems will depend not only on internal adjustments by the farmers themselves, but on a whole range of developments in the economic environment, such as increased availability of non-farm employment and improvements in rural infrastructure (Cramb, 1993). The study reveals that shifting cultivation is only one component of a larger farming system and that farmers are well aware of the productivity and sustainability aspects of the whole system thus manage shifting cultivation as a means towards that end and not as an end itself.

In other cases, shifting cultivation is not just concerned with growing staple food for subsistence living but also with cash crops and tree commodities. In some parts of Indonesia, shifting cultivation is used to grow coffee and rubber (Chomitz and Griffiths, 1996). Their study concluded that tree crops rather than the subsistence – oriented shifting cultivation play a major role in deforestation. Another study in Indonesia, assessing the role of shifting cultivation in the loss of rainforests by Lawrence *et al.* (1998) found that the rate of primary forest conversion increased dramatically from 1990 to 1995. This however was due not to soil degradation or population growth but rather to changes in the socio-economic and political environment faced by shifting cultivators. Although the loss of primary forest is appreciable under shifting cultivation, the impact is less than that of the major alternative land-uses in the region: timber extraction and oil palm plantations. De Jong (1997) early suggested that swidden agricultural systems maintain an important degree of biodiversity, and that production of rubber, fruits, or timber in forests which are manipulated in various degrees is a viable option to the development of swidden agriculture. Such alternatives can increase local income, sustain compatible population densities, and sustain the Indonesian timber industry while preserving the country's biodiversity.

On a global scale, a study by Fearnside (2000) reveals that biomass burning and decomposition and soil carbon release from tropical forest conversion, shifting cultivation and secondary vegetation currently emit substantial amounts of greenhouse gases; these forests have the potential for large additional emissions.

An estimated $3.1x10^9$ t of biomass carbon is exposed to these forms of burning each year in tropical countries, of which $1.1x10^9$ t C is emitted through combustion and $49x10^6$ t C is converted to charcoal. Of the carbon converted to charcoal, $26–31x10^6$ t C would represent black carbon as defined by resistance to oxidation at 340° C. Carbon emitted annually through decomposition processes totals $2.1x10^9$ t C. The total gross emission (including burning and decomposition emissions both from aboveground and from belowground biomass and from the top meter of soil is $3.4x10^9$ t of carbon, of which $3.3x10^9$ t is in the form of CO2.

### 2.3.2 Crop and soil indicators

Results of baseline studies are useful tools to monitor and evaluate environmental conditions especially with regards to agricultural production systems. This is especially important when related to finding alternatives to slash and burn shifting cultivation covering a variety of agro-ecosystem conditions (Andriesse and Koopmans, 1984, Andriesse and Schelhaas, 1987b, Andriesse and Schelhaas, 1987a). By obtaining reliable data from a series of standardized monitoring studies conducted under different soil and climatic conditions, it may be possible to formulate statements applicable to bush-fallow systems generally (Andriesse and Schelhaas, 1987a).

*(i) The resulting effects of the burning and the ash*

A study on *Jhum* in Bangladesh shows that the ash from the burnt vegetation was found to add more available Ca, Mg, K, S, Fe, Mn, and Zn to the soil than was removed in runoff sediments, whereas soil C, N, P, and Cu contents decreased. X-ray diffraction, Mossbauer and infrared spectroscopy, and total chemical analysis of the clay fractions from selected soil samples in profiles from upper, middle, and lower parts of a slope in the Jhum catchment showed composition and properties of the fractions that were almost identical, irrespective of soil depth and site position (Abdul et al., 2004).

The study confirms the results of an earlier study in Sri Lanka and Thailand where successful burns resulted in a 20–25% decrease in organic carbon (approximately 55–58% organic matter), 5–10% decrease in CEC and <10% decrease in organic P. The top 25 cm was mainly affected. There were no significant changes in soil N, although N of the biomass was completely lost, probably from volatilization. In contrast, an incomplete burn in Sarawak resulted in a 20% increase in C and N, a 10% increase in CEC and a 4% increase in organic P. Incomplete burns, and consequently lower temperatures at the surface, may have the advantage of adding partly decomposed organic matter to the soil, thereby saving N. The disadvantage is the fewer bases will be added (Andriesse and Schelhaas, 1987b).

Similar findings were also reported from case studies examining nutrient dynamics for a hill rice-fallow system located on the eastern escarpment of Madagascar presented by Brand and Pfund (1998), in the Eastern Amazon by Holscher *et al.* (1997), and in the northern Zambia (Chidumayo, 1987). At representative slash-and-burn sites, the soil-pool of P and K increased from 100% beneath 5-year-old fallow vegetation to 166% and 126% at harvest, but Ca and Mg decreased. Comparisons between fallow and burnt fields showed that 95–98% of phytomass-fixed and 22–24% of soil-fixed C and N were lost by burning. Paddy at harvest only contained 1–7% of the nutrients in the burnt phytomass of the previous stand (Brand and Pfund, 1998). Repeated sampling on two 'slash and burn' plots, showed significant increases in pH, CEC, extractable K, Ca and Mg, but decreases in extractable Na and Al, C and N content in the plots from 7-year old fallow to the first-year cropping field (Holscher et al., 1997). In the chitemene shifting cultivation system (Northern Zambia) crops are grown in a small ash garden made by burning a pile of wood cleared from a larger area. The burning increased soil $NH_3$–N content by 40–50%, with a further increase of 15% after 262 mm of rainfall. In contrast, the soil in unburnt plots lost up to 30% $NH_3$–N. The content of other major nutrients, such as, P,K, Ca, Mg, and Na also increased in the top soil immediately after burning. The increase in soil $NH_3$–N after burning was attributed to the reduction in microbacterial activity. These soil nutrient changes appear essential in the production of finger millet in northern Zambia (Chidumayo, 1987).

Nutrient depletion is also a limiting factor in the sustainability of shifting cultivation systems in Eastern Madagascar. A study by Brand and Pfund (1998) showed that nutrients regenerated rapidly in the fallow vegetation, which after 1 year contained already 36–57% of the previous phytomass pool, whereas topsoil nutrient concentrations started to increase only after 3–5 years of fallow. The topsoil cation content increased during the early stages of shifting cultivation, but under long-term shifting cultivation, the soil nutrients fell to approximately 2/3 of the initial stock. The nutrient stock of the most degraded vegetation unit (grassland) was merely 1.1–6.5% of the nutrient stocks in the rainforest. The established nutrient balances showed, that the dynamics and the depletion depend greatly on the spatial and temporal scale of observation, on the topography of the sites and on the type of nutrients (Brand and Pfund, 1998).

A study in Côte d'Ivoire (Reuler and Janssen, 1993b, Reuler and Janssen, 1993a) investigating the influence of burning slashed vegetation on crop performance during three seasons at two sites, one with a 4-year-old (4-Y) secondary vegetation and the other with a 20-year-old (20-Y) vegetation suggested that at both sites, burning significantly decreased the number of weed seedlings. The lowest number of seedlings was found on the burnt plots of the 20-Y site. Ash production amounted to approximately 2.5 ton $ha^{-1}$ at both sites. Nutrient contents of ashes were also about equal at both sites. An exception was K content, being higher in ash from 4-year-old vegetation. They concluded that in the local shifting cultivation system, the combination of ash depletion and infestation of weeds are the main reasons for abandoning the fields.

Fertility improvement from the ash as a result of burning was most evident in the top 25 cm soil with considerable increases in available S (2–60%), available P (50–300%), Ca (10–100%), Mg (15–45%) and K (6–80%). Changes were most pronounced in the surface 5 cm but were still noticeable at 25 cm, and in cases even down to 75 cm. Increases in base content, with the exception of K, were quite substantial where much ash had concentrated due to piling up of felled vegetation. The burning of the piled vegetation had not only influenced local temperatures in the upper few centimetres, with a strong decreasing effect on organic matter and nitrogen content, but had also increased alkalinity, preventing crop growth at such sites. The practice of piling is therefore considered counterproductive. Leaching of K and S, in particular, and some Mg did occur in the Sri Lanka soil within 4 months of burning (Andriesse and Schelhaas, 1987b).

A laboratory study on soil burning in Sarawak (Malaysia) through a temperature range of 20–350°C suggests a decrease in cation exchange capacity and values for most exchangeable cations was observed whereas values for pH, electric conductivity, base saturation and available P increased. The burning resulted in a significant disappearance of organic matter and the subsequent release of nutrients stored therein. It is suggested that the microbiological changes from heating are probably of greater importance than the chemical ones, taking into account the normal rooting depth of annual crops of about 25 cm (Andriesse and Koopmans, 1984).

Key disadvantages to burning are losses due to volatilization of nitrogen and sulphur as well as smaller quantities of phosphorus and potassium. Those losses can be eliminated by preparing fields without the use of fire, offering the hope of more efficient nutrient cycling and improved sustainability. The effect of a shorter fallow in traditional slash-and-burn systems is widely known to reduce the system's productivity (Figure 2.4), a point confirmed by Kato *et al.* (1999). In the absence of burning, the reduced biomass had the opposite effect and increased rice yield and the subsequent cowpea and cassava yields, most likely due to a reduction in P immobilization.

*(ii) The effects on soil structure*

The dynamics of soil physical properties under slash-and-burn and some alternative systems were the subject of a study by Alegre and Cassel (1996) in Peru evaluating the effects of different land-clearing methods and post land-clearing management systems on soil physical properties such as: bulk density, soil water characteristic, infiltration rate, aggregate stability, and penetrometer cone resistance. Mechanical clearing reduced the infiltration rate from 420 mm $h^{-1}$ before clearing to 35 mm $h^{-1}$ for the straight blade and 95 mm $h^{-1}$ for the shear-blade bulldozing. Straight-blade clearing damaged soil structure the most as indicated by a decrease in the percentage of larger soil aggregates. The practice of planting on raised beds prevented foot compaction of soil near the plants; bulk density was 1.14 and 1.29 $gcm^{-1}$ for bedded and flat planted soil, respectively. They conclude that the greatest change in soil physical properties occurs during mechanical land clearing. Agro-forestry systems improved soil physical properties when cover crops and trees were included in the system.

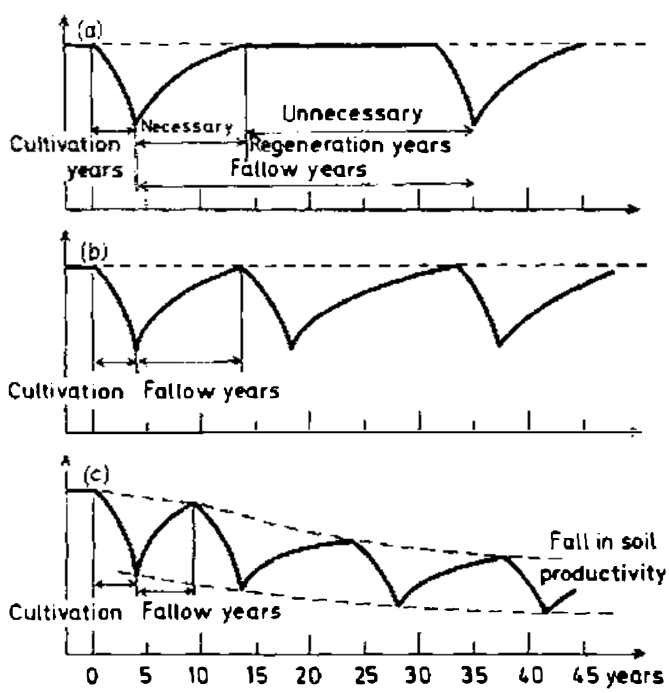



Figure 2.4 A theoretical presentation of the relationship between fallow period and productivity (Mertz, 2002)

In a different study with regards to grain production it was revealed that the greatest average relative grain-yields in descending order were produced by the following management systems: *slash / burn / flat-plant / fertilizer / lime* (94% average relative grain-yield) > *slash / burn / bedded / fertilizer / lime* (90%) > *shear-blade / burn / disk / bedded / fertilizer / lime* (88%) > *shear-blade / burn / disk / flat-plant / fertilizer /*

*lime* (86%) (Alegre et al., 1990). Of the various agro-forestry systems evaluated (multi-strata, peach palm production, shifting agriculture low input and high input continuous cropping) bulk density was lower after 4 years for the systems with trees or cover crops. Mean annual soil loss for alley cropping on sloping soils was 0.2 Mg $ha^{-1}$ $year^{-1}$ compared with 53 Mg $ha^{-1}$ $year^{-1}$ for two annual crops per year. The infiltration rate after 5 years of intensive grazing on five associations of legumes with grasses was reduced from 127 to 41 mm $h^{-1}$. Overgrazing caused severe soil compaction and reduced earthworm biomass (Alegre and Cassel, 1996).

A study in Brazil was aimed at evaluating the following systems: native forest (control), recently deforested (slash and burn); a two-year old crop of palm tree *(Bactris gasipaes)*; and a four-year old Brachiaria *(Brachiaria brizantha)* pasture (Araujo et al., 2004). Selected physical and chemical characteristics (granulometry, water-dispersed clay, soil bulk density, soil resistance to penetration, sediment parameters; chemical, exchangeable cations, available phosphorus, pH in water and in KCl, exchangeable aluminium, organic carbon, sulfuric acid digestion, equilibrium phosphorus, and humic substances) were compared. It was found that the soil under Brachiaria pasture presented the highest soil bulk density values in the A horizon, which suggests a tendency to compaction. The evaluated nutrients and organic carbon contents were low and concentrated in the top surface layer. Potassium showed a drastic decrease in the soil under Brachiaria pasture, probably due to losses by erosion, burning, and grazing. Among organic compounds, the humin fraction prevailed in all evaluated systems.

A 2-year study of soil composition and erosion comparing a *Jhum* cultivated catchment and a neighbouring non-burnt catchment showed additional loss by runoff of about 30 Mg $ha^{-1}$ (41.1 from the burnt site minus 11.5 from the non-burnt site) of upland soil, containing substantial amounts of plant nutrients, as a result of burning. The main loss occurred within 2 to 3 months after burning, but after 1 year, losses in the *Jhum* cultivated catchment were the same as in the non-burnt catchment. Furthermore, as almost half of the sediment was deposited in lower parts of the catchment, the net loss (export) was 15.5 Mg $ha^{-1}$, which corresponds to only 3 times the upper critical limit (about 5 t $ha^{-1}$ $yr^{-1}$) of sustainability, indicating that *Jhum* fallowed for more than 3 years may be sustainable (Abdul et al., 2004).

Similar to the *Jhum* system in Bangladesh, the growing rural population in the *chitemene* shifting cultivation region of northern Zambia has caused deforestation which has resulted in the reduction of (a) the length of the fallow period from 25 years to 12 years, (b) the per person woodland requirement of m 1.1 ha to 0.53 ha and (c) the frequency of clearing new chitemene gardens from yearly to once in two years. These responses to diminishing wood resources have artificially increased the population carrying capacity from 2.4 to 18.7 persons per $km^2$. This has enabled the survival of the chitemene shifting cultivation land use system in northern Zambia (Chidumayo, 1987).

### 2.3.3 Reconciling contrasting views

There has recently been a genuine shift to sustainable agricultural policies in the developing world particularly in the tropical countries, and East Timor is no exception (Anderson and Deutsch, 2001). It is particularly important considering the close association of traditional upland farming, the economic mainstay for upland communities in many countries in Southeast Asia, with resource-poor farmers, land degradation, soil and water losses, and increasing pest problems (Fujisaka, 1994, Cairns and Garrity, 1999).

A major focus of debate regarding the upland agriculture is on how to control shifting cultivation from depriving the people concerned from fulfilling minimum subsistence requirements as well as taking a toll of forest and land resources (Rasul and Thapa, 2003). The role of shifting cultivation in East Timor and elsewhere as a means to utilise spare resources to provide a considerable proportion of household food requirements and to act as a buffer, reducing the impact of perturbations in the economic environment (Cramb, 1993) may no longer be applicable. It is argued that nutrient depletion is an important limiting factor for agricultural sustainability in shifting cultivation systems (Brand and Pfund, 1998) and finding its alternatives however is not an easy task particularly considering the on-going conflicting evidence from empirical studies.

Official sources in East Timor appear to link soil degradation and forest cover depletion with the practice of shifting cultivation accompanied by slash and burn still commonly employed by peasant farmers particularly in the uplands (MAFP, 2004, Anderson and Deutsch, 2001). From the public policy point of view this matter has to be dealt with care to prevent poorly planned official schemes such as reforestation / agro-forestry projects during Indonesian administration being repeated. The issue of traditional farming and the shifting cultivation farmers has never been addressed sufficiently in the past. Research evidence from Indonesia, where it is still commonly believed that swidden agriculturists are responsible for about half of country's annual deforestation, shows that swidden agriculture has been stigmatized, rather than recognized for its potential for resource conservation. De Jong's (1997) study in West Kalimantan of Indonesia suggests that new forest management practices are part of and not superior to swidden agricultural practices.

On the other end of the spectrum, there is a large body of evidence suggesting that modern agriculture brought about by revolutionary technology waves has indeed increased the agricultural production quite substantially (Gliessman, 1998). However, empirical studies suggest that future increase beyond this level of production may not be possible without further jeopardizing the ecosystem resource base (Pesek, 1994). It cannot continue to produce enough food for the global population over the long term because it deteriorates the conditions that make agriculture possible (Gliessman, 1998).

It is therefore important that a new approach to natural resource management must be developed so that new management systems can be tailored and adapted in a site-specific way to highly variable and diverse farm conditions typical of resource-poor farmers (Altieri, 2002). This is especially relevant for public policies trying to address the problems faced by rural communities in the tropical uplands who have been practising shifting cultivation accompanied by slash and burn for centuries.

### 2.3.4 Finding solutions

Research and extension have offered farmers on-farm innovations — such as applying green-revolution technologies to shifting cultivation (Greenland, 1975), forms of agroforestry (Fujisaka, 1994, Kajembe et al., 2005), fire-free alternatives (Kato et al., 1999) or slash and mulch (Norgrove and Hauser, 2002) — intended to improve sustainability of upland agro-ecosystems. However based on experience, it is argued that the population growth and expansion of state control over common resources cannot help to control shifting cultivation as long as its structural causes are not addressed (Rasul and Thapa, 2003).

Their study suggests that an effective shifting cultivation control strategy would require: (1) granting land ownership rights to shifting cultivators, (2) linking shifting cultivation areas with local and regional market centres through infrastructure development, and (3) provision of necessary support services such as extension, credit and marketing (Rasul and Thapa, 2003). This is, in the view of the present study, highly relevant to the East Timorese conditions (UNDP, 2006). It will mark a milestone that will lead not only to improving traditional shifting cultivation practices but to a more gradual and sustainable agricultural change led by the farmers themselves, something that governments in the past failed to address.

## REFERENCES

Abdul, G., Koch, C. B. & Borggaard, O. K. (2004) Weathering intensity controlling sustainability of ultisols under shifting cultivation in the Chittagong Hill Tracts of Bangladesh. *Soil Science,* **169**.

Albers, H. J. & Goldbach, M. J. (2000) Irreversible ecosystem change, species competition, and shifting cultivation. *Resource and Energy Economics,* **22,** 261-280.

Alegre, J. C. & Cassel, D. K. (1996) Dynamics of soil physical properties under alternative systems to slash-and-burn. *Agriculture, Ecosystems & Environment,* **58,** 39-48.

Alegre, J. C., Cassel, D. K. & Bandy, D. E. (1990) Effects of land-clearing method and soil management on crop production in the Amazon. *Field Crops Research,* **24,** 131-141.

Altieri, M. A. (2002) Agroecology: the science of natural resource management for poor farmers in marginal environments. *Agriculture, Ecosystems & Environment,* **93,** 1-24.

Anderson, R. & Deutsch, C. (2001) Sustainable Development and the Environment in East Timor: Proceedings of the Conference on Sustainable Development in East Timor (25-31 January 2001). Timor Aid, Dili, East Timor.

Andriesse, J. P. & Koopmans, T. T. (1984) A monitoring study on nutrient cycles in soils used for shifting cultivation under various climatic conditions in tropical asia. I. The influence of simulated burning on form and availability of plant nutrients. *Agriculture, Ecosystems & Environment,* **12,** 1-16.

Andriesse, J. P. & Schelhaas, R. M. (1987a) A monitoring study of nutrient cycles in soils used for shifting cultivation under various climatic conditions in tropical Asia. II. Nutrient stores in biomass and soil--results of baseline studies. *Agriculture, Ecosystems & Environment,* **19,** 285-310.

Andriesse, J. P. & Schelhaas, R. M. (1987b) A monitoring study on nutrient cycles in soils used for shifting cultivation under various climatic conditions in tropical Asia. III. The effects of land clearing through burning on fertility level. *Agriculture, Ecosystems & Environment,* **19,** 311-332.

Araujo, E. A., Lani, J. L., Amaral, E. F. & Guerra, A. (2004) Land use and physical and chemical properties of a dystrophic yellow argisol in the Western Amazon Region. *Revista Brasileira de Ciencia do Solo,* **28**.

Arnason, T., Lambert, J. D. H., Gale, J., Cal, J. & Vernon, H. (1982) Decline of soil fertility due to intensification of land use by shifting agriculturists in Belize, Central America. *Agro-Ecosystems,* **8,** 27-37.

Astatke, A., Jabbar, M. & Tanner, D. (2003) Participatory conservation tillage research: an experience with minimum tillage on an Ethiopian highland Vertisol. *Agriculture, Ecosystems & Environment,* **95,** 401-415.

Brady, N. C. (1996) Alternatives to slash-and-burn: a global imperative. *Agriculture, Ecosystems & Environment,* **58,** 3-11.

Brand, J. & Pfund, J. L. (1998) Site-and watershed-level assessment of nutrient dynamics under shifting cultivation in eastern Madagascar. *Agriculture, Ecosystems & Environment,* **71,** 169-183.

Cairns, M. & Garrity, D. P. (1999) Improving shifting cultivation in Southeast Asia by building on indigenous fallow management strategies. *Agroforestry Systems,* **47,** 37-48.

Chidumayo, E. N. (1987) A shifting cultivation land use system under population pressure in Zambia. *Agroforestry Systems (Historical Archive),* **5,** 15-25.

Chomitz, K. M. & Griffiths, C. (1996) Deforestation, Shifting Cultivation and Tree Crops in Indonesia: nationwide patterns of smallholder agriculture at the forest frontier. *Research Project on Social and Environmental Consequences of Growth-Oriented Policies, Working Paper 4.* World Bank, Washington DC.

Choudhury, D. & Sundriyal, R. C. (2003) Factors contributing to the marginalization of shifting cultivation in north-east India: micro-scale issues. *Outlook on Agriculture,* **32,** 17-28(12).

Cramb, R. A. (1993) Shifting cultivation and sustainable agriculture in East Malaysia: A longitudinal case study. *Agricultural Systems,* **42,** 209-226.

Cruz, M. d., Viegas, E., Saldanha, J. M. & Correia, J. G. (2005) Water and Sanitation Coverage in East Timor: A Study on the Conditions of Uatocarbau and Viqueque Sub-districts. Program in Agriculture and Applied Technology - Timor Institute of Development Studies (TIDS), Dili - East Timor.

Curnow, R. (2003) Overview of the Coffee Sector in Timor Leste. Oxfam.

de Jong, W. (1997) Developing swidden agriculture and the threat of biodiversity loss. *Agriculture, Ecosystems & Environment,* **62,** 187-197.

Dendi, A., Shivakoti, G. P., Dale, R. & Ranamukhaarachchi, S. L. (2005) Evolution of the Minangkabau's Shifting Cultivation in the West Sumatera Highland of Indonesia and its Strategic Implications for Dynamic Farming Systems. *Land Degradation & Development,* **16,** 13–26.

Fearnside, P. M. (2000) Global Warming and Tropical Land-Use Change: Greenhouse Gas Emissions from Biomass Burning, Decomposition and Soils in Forest Conversion, Shifting Cultivation and Secondary Vegetation. *Climatic Change,* **46,** 115-158.

Fox, J. (2001) Diversity and Differential Development in East Timor: Potential Problems and Future Possibilities. *East Timor: Development Challenges for the World's Newest Nation* (eds H. Hill & J. Saldanha), pp. 155-174. Institute of Southeast Asian Studies, Singapore.

Friday, J. B. (2003) Agroforestry options for Timor-Leste. University of Hawaii, Manoa Hawaii.

Friday, J. B. (2004) Agroforestry opportunities for Timor-Leste: Forage Banks and Forage Gardens. University of Hawaii, Manoa Hawaii.

Fujisaka, S. (1989) A method for farmer-participatory research and technology transfer: upland soil conservation in the Philippines. *Experimental Agriculture,* **25,** 423-433.

Fujisaka, S. (1991) A diagnostic survey of shifting cultivation in northern Laos: targeting research to improve sustainability and productivity. *Agroforestry Systems (Historical Archive),* **13,** 95-109.

Fujisaka, S. (1994) Learning from six reasons why farmers do not adopt innovations intended to improve sustainability of upland agriculture. *Agricultural Systems,* **46,** 409-425.

Gliessman, S. R. (1998) *Agroecology: ecological process in sustainable agriculture.* Ann Arbor Press, Chelsea MI, USA.

Gonçalves, M. M. (1963) O Problema da Erosão em Timor. Missão de Estudos Agronómicos do Ultramar (MEAU), Lisboa.

GoTL (2001) The 2001 Survey of Sucos: Initial Analysis and Implications for Poverty Reduction. ETTA, ADB, World Bank and UNDP, Dili, East Timor.

GoTL (2003) Timor Leste, Poverty in a New Nation: Analysis for Action. Democratic Republic of Timor-Leste, Dili, East Timor.

GoTL (2006) Combating Poverty as a National Cause: Promoting Balanced Development and Poverty Reduction. Democratic Republic of Timor-Leste, Dili East Timor.

GoTL & UNDP (2005) Timor-Leste and UNDP Country Programme Review: Results Matrix 2005. The Government of Timor-Leste and United Nations Development Programme, Dili, East Timor.

Greenland, D. J. (1975) Bringing the Green Revolution to the Shifting Cultivator. *Science,* **190,** 841-844.

Gusmão, M. (2003) *Soil Conservation Strategies and Policies for East Timor*. Master's Thesis, University of Adelaide, Adelaide (abstract obtained through MAFF's Website).

Hazell, P. & Wood, S. (2000) From science to technology adoption: the role of policy research in improving natural resource management. *Agriculture, Ecosystems & Environment,* **82,** 385-393.

Holscher, D., Ludwig, B., Moller, R. F. & Folster, H. (1997) Dynamic of soil chemical parameters in shifting agriculture in the Eastern Amazon. *Agriculture, Ecosystems & Environment,* **66,** 153-163.

Jackson, L. A. & Scherr, S. (1995) Nondegrading Land Use Strategies for Tropical Hillsides. 2020 Brief 27, IFPRI.

Jarosz, L. (1993) Defining and explaining tropical deforestation: shifting cultivation and population growth in colonial Madagascar (1896-1940). *Economic Geography,* **69,** 366-379.

Kajembe, G. C., Julius, F., Nduwamungu, J., Mtakwa, P. W. & Nyange, D. A. (2005) Impact of Indigenous-Based Interventions on Land Conservation: A Case Study of a Soil Conservation and Agroforestry Project, Arumeru District, Tanzania. *Land Degradation & Development,* **16,** 311–325.

Kato, M. S. A., Kato, O. R., Denich, M. & Vlek, P. L. G. (1999) Fire-free alternatives to slash-and-burn for shifting cultivation in the eastern Amazon region: the role of fertilizers. *Field Crops Research,* **62,** 225-237.

Keefer, G. D. (2000) Report on Restoration of Meteorological Network - Timor Loro Sa'e. United Nations Transitional Administration in East Timor (UNTAET), Dili, East Timor.

Kleinman, P. J. A., Pimentel, D. & Bryant, R. B. (1995) The ecological sustainability of slash-and-burn agriculture. *Agriculture, Ecosystems & Environment,* **52,** 235-249.

Krautkraemer, J. A. (1994) Population growth, soil fertility, and agricultural intensification. *Journal of Development Economics,* **44,** 403-428.

Kumar, B. M. & Nair, P. K. R. (2004) The enigma of tropical homegardens. *Agroforestry Systems,* **61-62,** 135-152.

Lawrence, D., Peart, D. R. & Leighton, M. (1998) The impact of shifting cultivation on a rainforest landscape in West Kalimantan: spatial and temporal dynamics. *Landscape Ecology,* **13,** 135-148.

MAFP (2004) Policy and Strategic Framework. República Democrática de Timor Leste, Ministry of Agriculture, Forestry and Fisheries, Dili, East Timor.

Mertz, O. (2002) The relationship between length of fallow and crop yields in shifting cultivation: a rethinking. *Agroforestry Systems,* **55,** 149-159.

Ninez, V. (1987) Household gardens: Theoretical and policy considerations. *Agricultural Systems,* **23,** 167-186.

Norgrove, L. & Hauser, S. (2002) Yield of plantain grown under different tree densities and 'slash and mulch' versus 'slash and burn' management in an agrisilvicultural system in southern Cameroon. *Field Crops Research,* **78,** 185-195.

Old, K. M. & Cristovão, C. D. S. (2003) A rust epidemic of the coffee shade tree (Paraserianthes falcataria) in East Timor. *Agriculture: New Directions for a New Nation — East Timor (Timor-Leste)* (eds H. d. Costa, C. Piggin, C. J. d. Cruz & J. J. Fox), pp. 139-145. ACIAR Proceedings No. 113.

Pesek, J. (1994) Historical perspective. *Sustainable Agriculture Systems* (eds J. L. Hatfield & D. L. Karlen), pp. 1-19. Lewis Publishers CRC Press, Inc., USA.

Pichon, F., Marquette, C., Murphy, L. & Bilsborrow, R. (2002) Endogenous patterns and processes of settler land use and forest change in the Ecuadorian Amazon. *Deforestation and land use in the Amazon* (eds C. H. Wood & R. Porro), pp. 400. University Press of Florida, Florida.

Pichon, F. J. (1996) The forest conversion process: A discussion of the sustainability of predominant land uses associated with frontier expansion in the Amazon. *Agriculture and Human Values (Historical Archive),* **13,** 32-51.

Piedade, S. M. (2003) The Cooperativa Cafe Timor (CCT). *Agriculture: New Directions for a New Nation — East Timor (Timor-Leste)* (eds H. d. Costa, C. Piggin, C. J. d. Cruz & J. J. Fox), pp. 28-31. ACIAR Proceedings No. 113, Camberra.

Porro, R. (2005) Palms, Pastures, and Swidden Fields: The Ground Political Ecology of "Agro-Extractive / Shifting Cultivator Peasants" in Maranhão, Brazil. *Human Ecology,* **33,** 17 -56.

Poudel, D. D., Midmore, D. J. & West, L. T. (2000) Farmer participatory research to minimize soil erosion on steepland vegetable systems in the Philippines. *Agriculture, Ecosystems & Environment,* **79,** 113-127.

Rasul, G. & Thapa, G. B. (2003) Shifting cultivation in the mountains of South and Southeast Asia: Regional patterns and factors influencing the change. *Land Degradation & Development,* **14,** 495–508.

Rasul, G. & Thapa, G. B. (2004) Sustainability of ecological and conventional agricultural systems in Bangladesh: an assessment based on environmental, economic and social perspectives. *Agricultural Systems,* **79,** 327-351.

Reis, L. M. M. d. S. (2000) *Timor-Leste, 1953 – 1975: O desenvolvimento agrícola na última fase da colonização portuguesa.* Dissertação de Mestrado, Universidade Técnica de Lisboa, Lisboa.

Reuler, H. & Janssen, B. H. (1993a) Nutrient fluxes in the shifting cultivation system of south-west Côte d'Ivoire I. Dry matter production, nutrient contents and nutrient release after slash and burn for two fallow vegetations. *Plant and Soil (Historical Archive),* **154,** 169-177.

Reuler, H. & Janssen, B. H. (1993b) Nutrient fluxes in the shifting cultivation system of south-west Côte d'Ivoire II. Short-term and long-term effects of burning on yield and nutrient uptake of food crops. *Plant and Soil (Historical Archive),* **154,** 179-188.

Saeed, K. (1982) Public policy and rural poverty : A system dynamics analysis of a social change effort in Pakistan. *Technological Forecasting and Social Change,* **21,** 325-349.

Saeed, K. (2000) Agricultural Land Use and Food Security in Asia: Green Revolution and Beyond. Social Science and Policy Studies, Worcester Polytechnic Institute, Worcester, MA.

Saldanha, J. M. & Guterres, P. (2002) Customary property rights and agricultural production: A tale of two sub-districts in East Timor. Center for Economic Studies, East Timor Study Group, Dili, East Timor.

Sanchez, P. A. & Leakey, R. R. B. (1997) Land use transformation in Africa: three determinants for balancing food security with natural resource utilization. *European Journal of Agronomy,* **7,** 15-23.

Sandlund, O. T., Bryceson, I., Carvalho, D. d., Rio, N., Silva, J. d. & Silva, M. I. (2001) Assessing Environmental Needs and Priorities in East Timor: Issues and Priorities. UNOPS and NINA-NIKU, Dili, East Timor.

Sanginga, P. C., Best, R., Chitsike, C., Delve, R., Kaaria, S. & Kirkby, R. (2004) Linking smallholder farmers to markets in East Africa - empowering mountain communities to identify market opportunities and develop rural agroenterprises. *Mountain Research and Development,* **24**.

Shriar, A. J. (2001) The Dynamics of Agricultural Intensification and Resource Conservation in the Buffer Zone of the Maya Biosphere Reserve, Petan, Guatemala. *Human Ecology,* **29,** 27-48.

Shriar, A. J. (2002) Food security and land use deforestation in northern Guatemala. *Food Policy,* **27,** 395-414.

Soares, D. B. (2001) East Timor: perception of culture and environment. *Conference on Sustainable Development in East Timor, 25-31 January 2001* (eds R. Anderson & C. Deutsch). Dili, East Timor.

Sommer, R., Vlek, P. L. G., Deane de Abreu Sá, T., Vielhauer, K., de Fátima Rodrigues Coelho, R. & Fölster, H. (2004) Nutrient balance of shifting cultivation by burning or mulching in the Eastern Amazon – evidence for subsoil nutrient accumulation. *Nutrient Cycling in Agroecosystems,* **68,** 257-271(15).

Sunderlin, W. D. (1997) Shifting Cultivation and Deforestation in Indonesia: Steps Toward Overcoming Confusion in the Debate. Network Paper 21b; Rural Development Forestry Network; Overseas Development Institute, London UK.

The Asia Foundation (2002) Timor Loro Sa'e National Survey of Citizen Knowledge 2002. The Asia Foundation and NGO Forum National Timor Loro Sa'e, Dili, East Timor.

Torquebiau, E. (1992) Are tropical agroforestry home gardens sustainable? *Agriculture, Ecosystems & Environment,* **41,** 189-207.

Trinh, L. N., Watson, J. W., Hue, N. N., De, N. N., Minh, N. V., Chu, P., Sthapit, B. R. & Eyzaguirre, P. B. (2003) Agrobiodiversity conservation and development in Vietnamese home gardens. *Agriculture, Ecosystems & Environment,* **97,** 317-344.

UNDP (2006) Human Development Report 2006 Timor-Leste The Path out of Poverty: Integrated Rural Development. United Nations Development Programme, Dili East Timor.

UNICEF (2003) Multiple Indicator Cluster Survey (MICS - 2002). UNICEF, Report Prepared for the Government of Republica Democratica de Timor-Leste, Dili, East Timor.

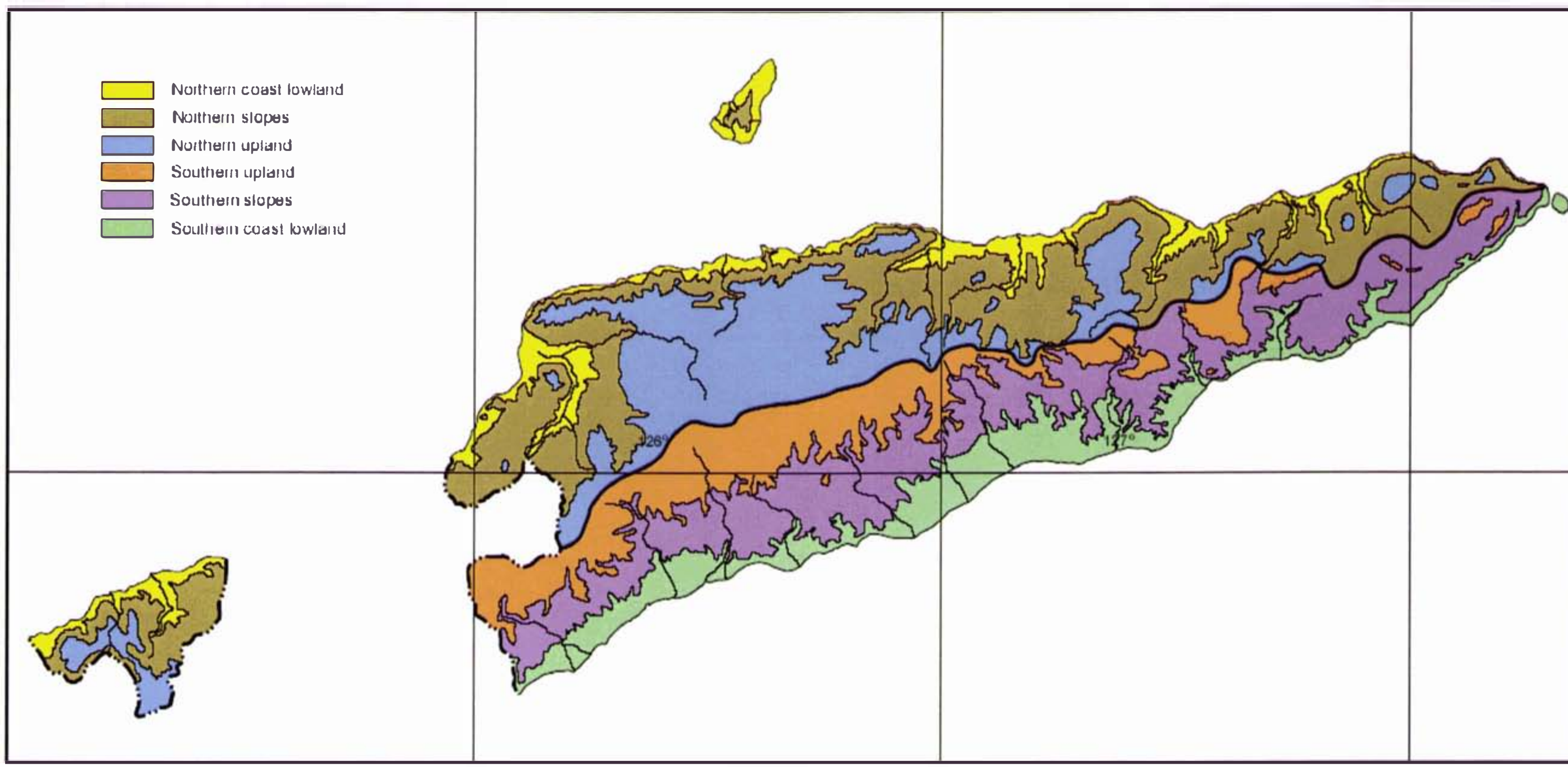
Viegas, E. (2002) Penelitian: Peranannya dalam Pembangunan Pertanian Berkelanjutan. *Suara Timor Lorosae (STL)*. Dili.

WB-JAM (1999) East Timor, Building a Nation, a Framework for Reconstruction and Development; Agriculture Background Paper. The World Bank Joint Assessment Mission.

World Bank (2002) East Timor: Policy Challenges for a New Nation, Country Economic Memorandum. The World Bank, Washington D.C. USA.

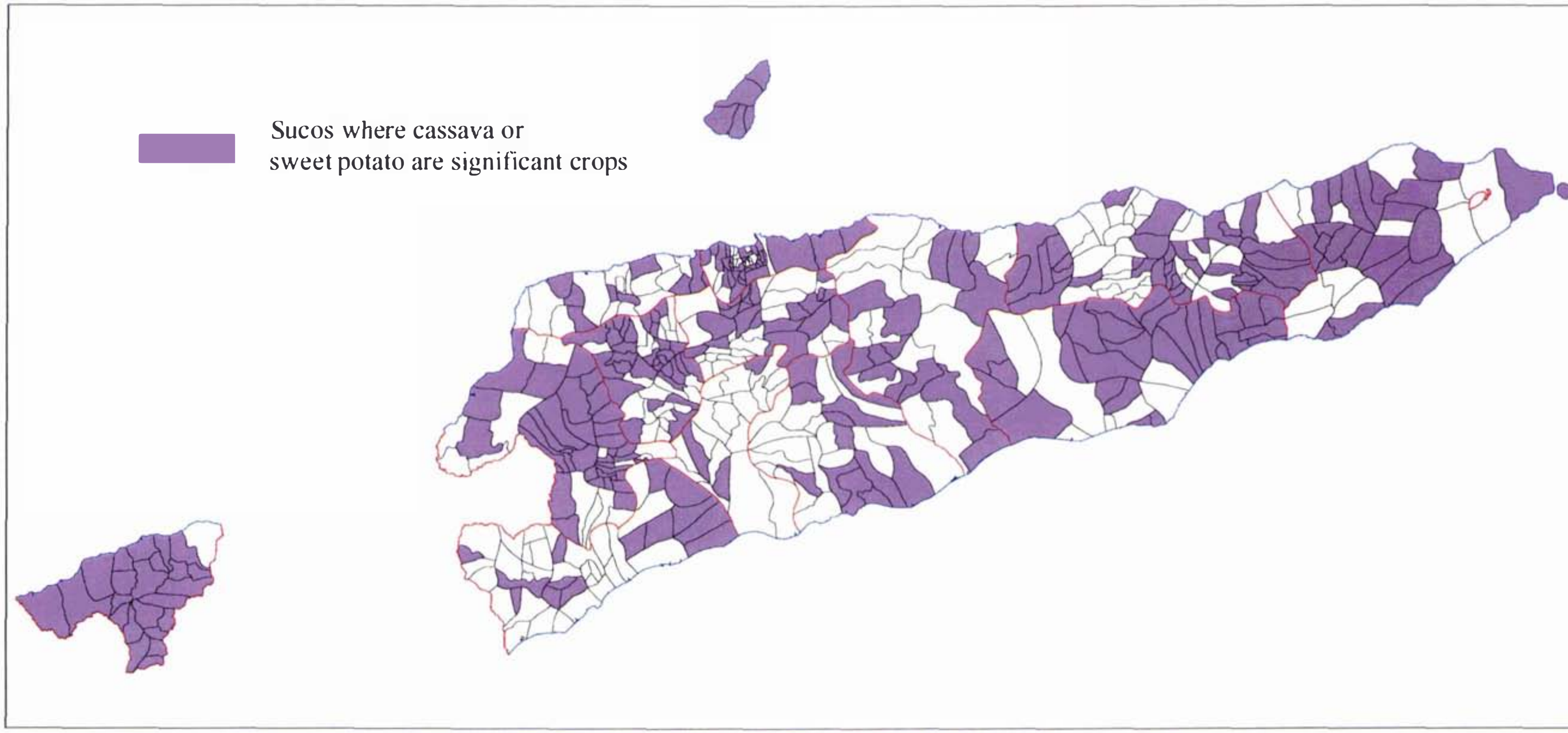
Xavier, P. (2001) Land rights and sustainable development in East Timor. *Conference on Sustainable Development in East Timor, 25-31 January 2001*. Dili, East Timor.

Appendix 2.1. Map of the agro-climatic zones of East Timor



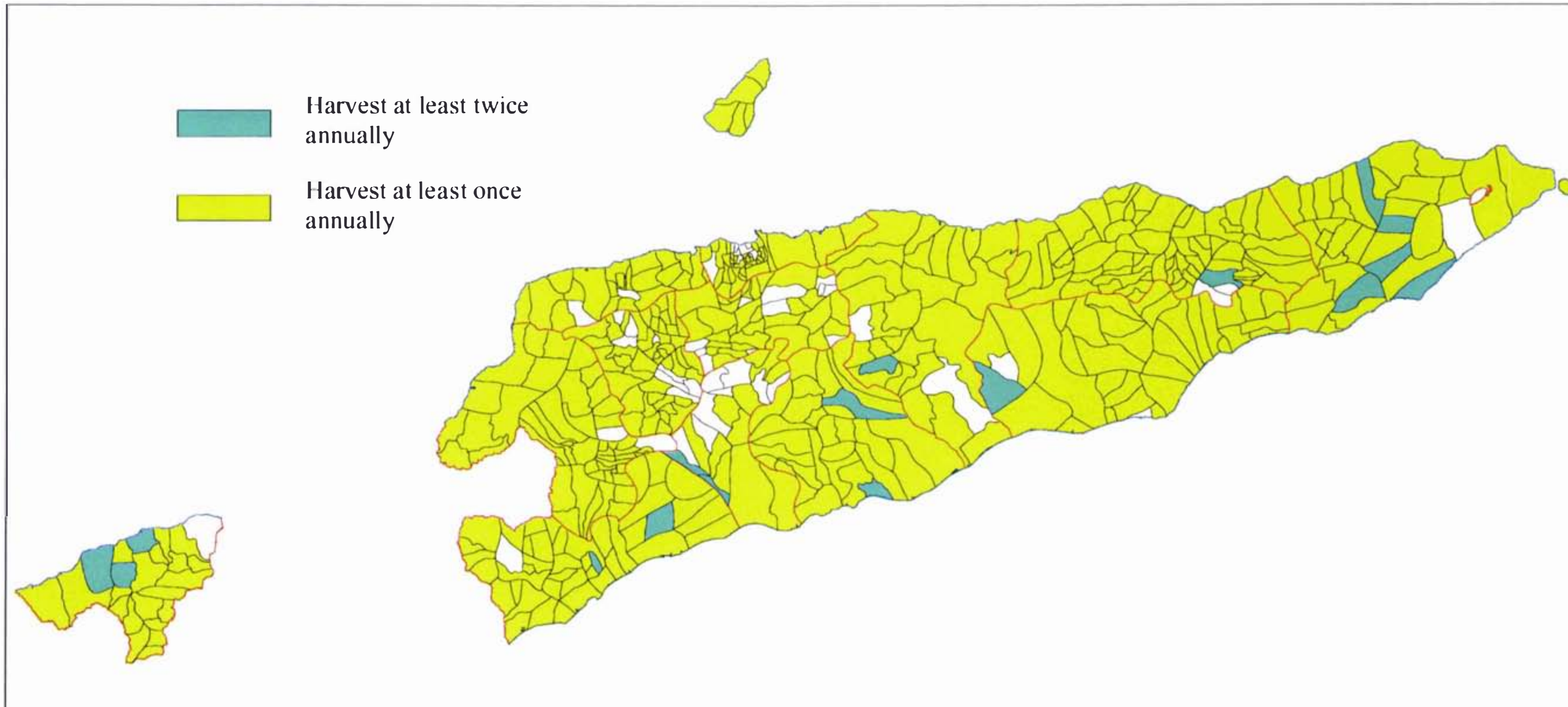

Source: Fox (2001)

Appendix 2.2. Map of sucos (villages) where tuber and root crops are among the three most significant crops (2001)



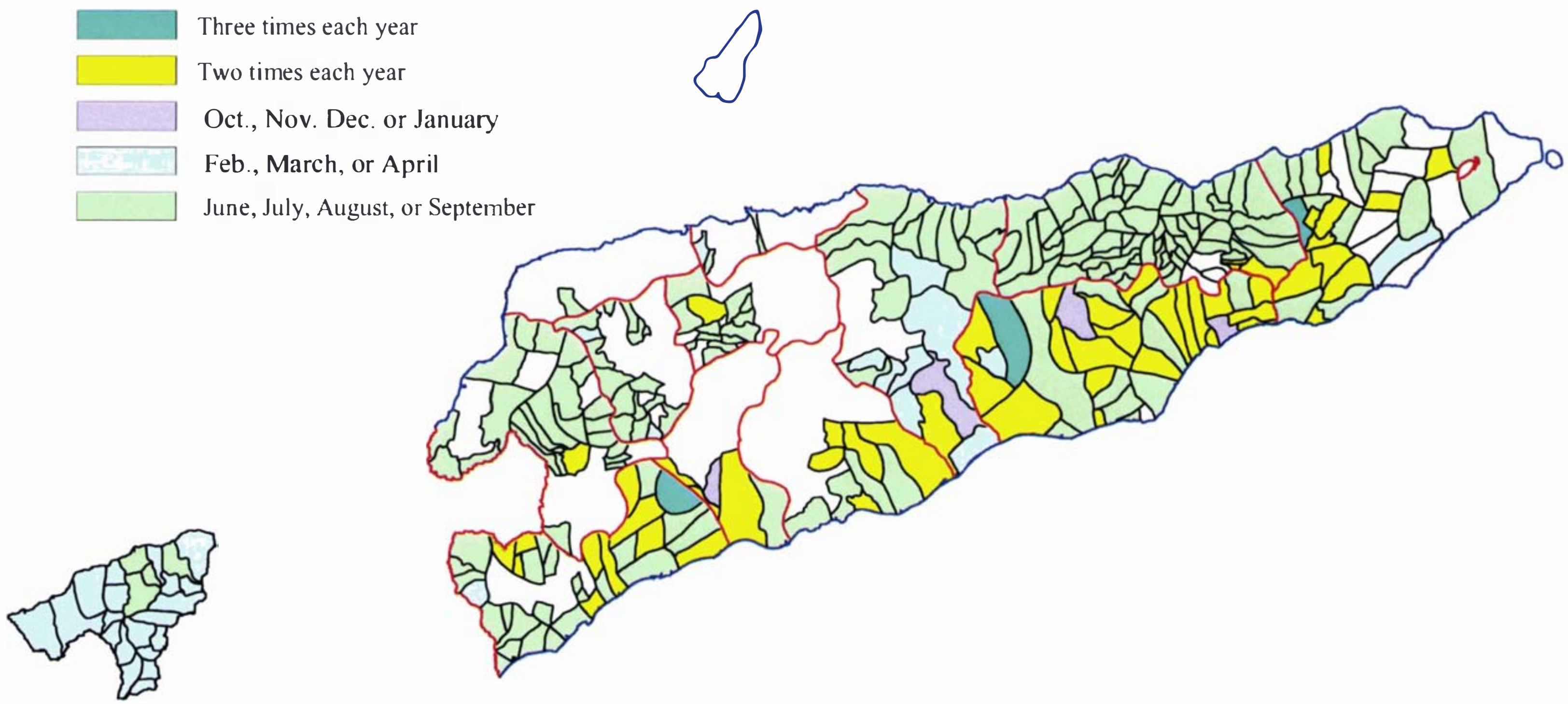

Source: GoTL (2001)

Appendix 2.3. Map of sucos (villages) where maize was reported as one of the three most significant crops (2001)



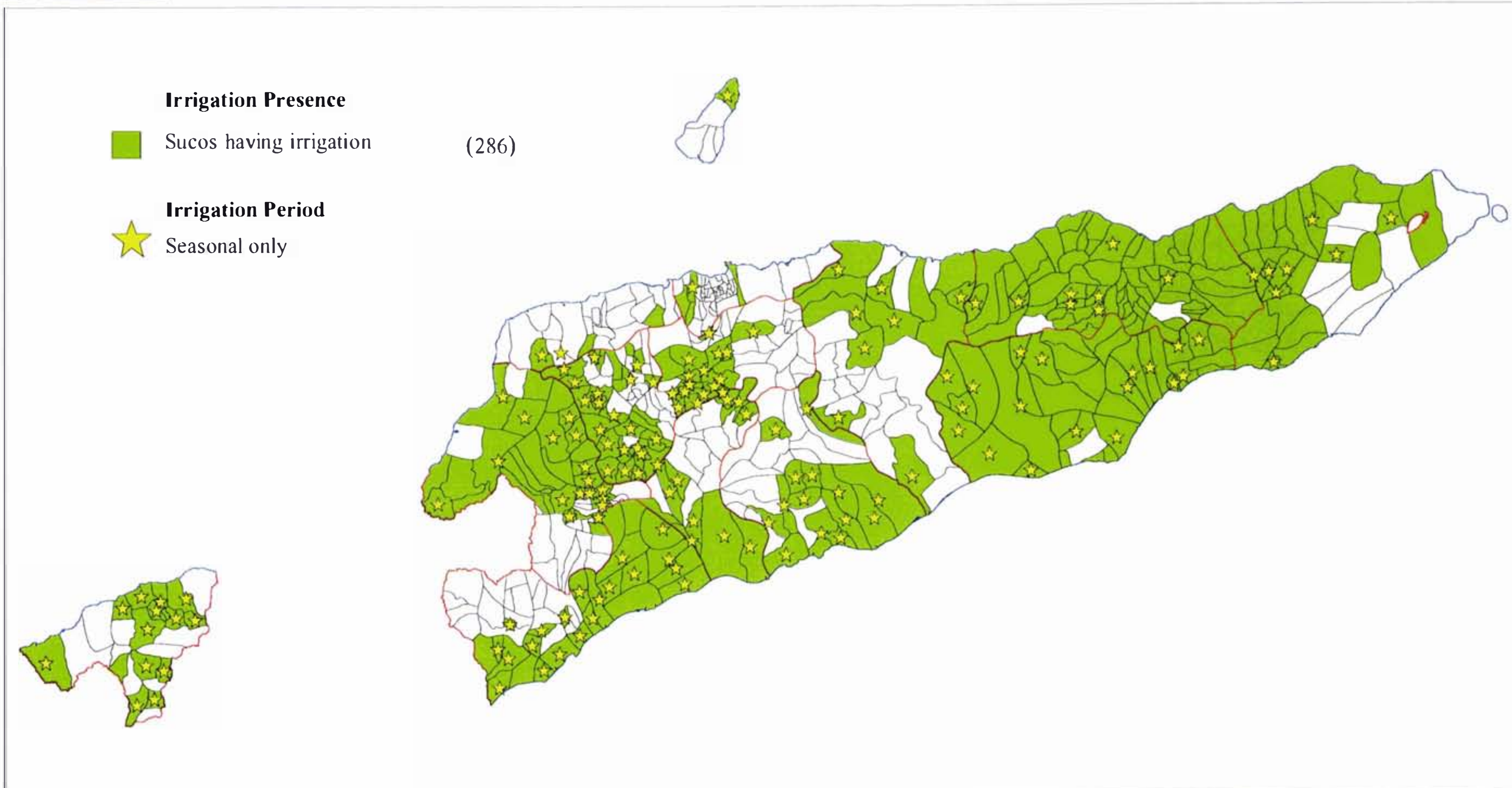

Source: GoTL (2001)

Appendix 2.4. Map of sucos (villages) where rice was reported as being one of the three most significant crops (2001)




Source: GoTL (2001)

Appendix 2.5. Map showing the presence and seasonality of irrigation (2001)




Source: GoTL (2001)

# 3 AGRICULTURAL MECHANIZATION Managing Techno-Cultural Change[1]

*The farmer who has access to and knows how to use what science knows about soils, plants, animals, and machines can produce an abundance of food though the land be poor (Schultz, 1964)*

## 3.1 INTRODUCTION

Agriculture is the mainstay of East Timor's economy, yet pursuing it, as an engine of growth and source of adequate food production will be, for a considerable period of time, hampered by a complexity of socio-economic, political, and techno-cultural constraints. Facing such conditions, and given that the vast majority of villages and population live from agriculture as the main source of food and income, the core objectives of development should be rural oriented. Survey data suggests that food and cash shortages are of major concern nationwide.[2] Cash shortage in particular will be a major constraint to introducing improvements in rural areas where the majority of the poor live.

At the national level, there is increasing willingness to adopt strategic agricultural development plans to address issues such as poverty alleviation, hunger and malnutrition. Inclusive in such plans is the necessity to pursue improved technologies, which enhance food security, while preserving the resource base. Farmers, extension workers and policy makers will be frequently required to make decisions on the level of technology that is suitable for individual farmers. This involves determining appropriate combinations of manual, animal and mechanical powered technologies that are technically suitable and meet economic and social development objectives.

---

[1] Earlier version of this chapter was published in: Agriculture: New Directions for a New Nation East Timor (Timor-Leste) (eds.) Da Costa, H., Piggin, C., Da Cruz, C.J., Fox, J.J., Proceedings of a Workshop 1–3 October 2002, Dili, East Timor, Organized by UNTL, RDTL, ANU, and ACIAR, pp. 32-44

[2] See details of village and household descriptive data in the Poverty Assessment Report, a work in partnership by the East Timor Transitional Administration (ETTA), the Asian Development Bank (ADB), Word Bank and UNDP (2001). Much of the data were also reported in East Timor: State of the Nation (Planning Comission, 2002)

## 3.2 HISTORICAL BACKGROUND

Many records have been documented about the colonial past, however very little is known about agricultural technology development, especially during the pre-1975 Portuguese administration.[3] The country's agricultural subsistence setting, as has been described earlier in Chapter 2, persists in spite of developmental efforts over many decades of successive regimes. After the plantation-based agriculture was established in the 1950s, the government embarked on creating the foundation infrastructures of a modern economy. The opening of new land for rice cultivation and improvement of irrigation systems in the major agricultural centers of Viqueque and Baucau in the 1960s marked the start of a new agricultural era. The introduction of tractors in substantial numbers and the establishment of several rural extension centers such as those in Natarbora, Betano and Loes occurred during this period. Apart from governmental efforts, missionary colleges such as Fatumaca, Fuiloro, and Maliana may have contributed to the introduction and promotion of agricultural machinery use.[4] New varieties of rice namely IR-5 and IR-8 were brought from the International Rice Research Institute in Los Baños Philippines and introduced and disseminated successfully. Interestingly, rice farmers in some parts of East Timor are still using variants of these early seeds. Another innovation introduced alongside with the seeds was the transplanting method of rice cultivation.

A similar path was followed during more than two decades of the Indonesian regime. The agricultural development thinking was mainly preoccupied with the problem of how to achieve food self-sufficiency through the adoption of 'green revolution' technologies such as large-scale machinery, hybrid seeds, chemical fertilizers and irrigation networks. Agricultural development priorities, as opposed to the

[3] Data on selected agricultural development indicators can be found at FAOSTAT (www.fao.org), covering a period from 1961 to 2000. See also Saldanha and Da Costa (1999) for an overview of development policies from Portuguese regime to the end of Indonesian rule. Of Portuguese era, an official data source of development indicators was the Speech Report of Governor Aldeia in 1973 cited by the authors.

[4] In terms of sustainability and reliability, the management of agricultural machinery in these missionary colleges provides a model of success. The Fuiloro School of Agriculture in Lautem and Fatumaca Technical School in Baucau for instance, apart from being educational institutions, have long been assisting local farmers with the provision of mechanical tools and equipment.

Portuguese era, were given to regions offering less security threats in the western part of the territory, namely Maliana and Suai.[5] Despite being referred to as a period of uncertain development (Saldanha and Da Costa, 1999), the last decade of the Indonesian era provided some measurable achievements. Data during this period are essentially useful for future potential assessments and policy design, especially in the area of agriculture and rural development.

All the developmental assets were severely damaged during the September 1999 tragedy. The transitional phase under the United Nations administration was in part aimed at recovering those assets and setting up necessary foundations for the new country's short-term and long-term development plans. There is a great deal of interest among the country's policy makers to adopt mechanization as a means to enhance agricultural productivity. Despite being potentially promising in theory, the success of such a plan depends on a large number of factors – largely site-specific and others being macro in nature. Consequently, the real cost of mechanization and its impacts have to be assessed over time. An approach that could make this task possible is to put in place realistic mechanization development policies and strategies right from the outset.

Table 3.1 presents a general picture of East Timor agriculture developed over the years, recorded from the last decade of Portuguese regime until the period of Indonesian administration. Figures are mainly estimates and should, therefore, be approached with caution. However, they may provide a rough indication, especially of the pre-1975 status of mechanical power and labour input. Since the introduction of the *Plano de Fomento* (Five-Year Development Plan)[6], the use of tractors has gradually increased. Not surprisingly, however, labour intensity was also on the rise,

---

[5] See Fox, J. (2001) Diversity and Differential Development in East Timor: Potential Problems and Future Possibilities. *East Timor: Development Challenges for the World's Newest Nation* (eds H. Hill & J. Saldanha), pp. 155-174. Institute of Southeast Asian Studies, Singapore. for an anthropological viewpoint on East Timor's agricultural development with especial emphasis on its stages of transformation.

[6] Plano de Fomento started in 1960 with development priorities given to vital sectors such as infrastructure (transportation and communication), agriculture, education and health. Introduction of new plants (cinnamon, cacao and other fruits) occurred during this period.

suggesting that the agricultural production has been predominantly labour-intensive (Gliessman, 1998).

Table 3.1: Selected agricultural development indicators of East Timor 1961 – 1999[1]

| Indicators | 1961 | 1965 | 1970 | 1974 | 1980 | 1985 | 1990 | 1995 | 1999 |
|---|---|---|---|---|---|---|---|---|---|
| Tractor in use | 7 | 8 | 98 | 110 | 114 | 115 | 115 | 115 | 115 |
| Tractor use intensity (ha/tractor) | 11429 | 10000 | 816 | 727 | 702 | 696 | 696 | 696 | 696 |
| Agricultural labour force (thousands) | 244 | 259 | 280 | 313 | 273 | 298 | 322 | 360 | 316 |
| Agricultural workers as a percentage of labour force (percent) | 86.8 | 86.3 | 85.9 | 85.5 | 84.8 | 84.4 | 83.6 | 82.8 | 82.3 |
| Agricultural labour intensity (worker/ha) | 3.05 | 3.23 | 3.5 | 3.9 | 3.5 | 3.6 | 3.95 | 4.5 | 4.1 |
| Cereal yield (kg/ha) | 1404 | 1197 | 1277 | 1500 | 1305 | 1492 | 1608 | 1954 | 1962 |
| Cereal import (thousand metric ton) | 0.8 | 1.9 | 2.4 | 2.5 | na | na | na | 39[2] | 50[2] |

1. Based on FAOSTAT database (www.fao.org). na: data not available.
2. Figures for rice only, from East Timor provincial statistics.

## 3.3 THE SCOPE OF AGRICULTURAL MECHANIZATION

Agricultural mechanization embraces the use of tools, implements and machines for farming and land development, production, harvesting, and on-farm processing. Within the historical and economic context, there are seven stages of evolution in agricultural mechanization (Rijk, 1989, Speedman, 1992):

1. Stationary power substitution, where mechanical power is substituted for human power used in stationary process,
2. Motive power substitution, stage where operation systems previously based on human power are replaced by mechanical power,

3. Human control substitution, where mechanization is emphasized on substituting operations previously controlled by human decision making,
4. Adjusting the cropping systems to the requirements of mechanization (cropping system adaptation),
5. Adjusting farming systems to the requirements of mechanization (farming system adaptation),
6. Adjusting plant physics to the requirements of mechanization (plant adaptation), and
7. Automation, where operations in agricultural production are fully automated.

The sequence of these stages is generally identifiable at the farm level.[7] In many developing countries including East Timor, stages I and II are clearly pronounced, and often adopted simultaneously. In other countries, stage III may be implemented on a few large state plantations while the majority of farmers have not yet adopted. Figure 3 1 shows the early mechanization development stages and all the possible mechanization technologies the farmer may select represented by the Mechanization Possibility Curve (MPC) (Rijk, 1989). The reasons for mechanization are mainly expressed in economic terms such as increase in labour productivity, increase in land productivity, and decrease in production costs. Therefore, the mechanization stages may be presented as the result of change in factor prices. The relative factor price for capital/labour in slope I indicates a cost minimizing process representing stage I (labour-intensive) while stages II and III require a greater capital-using process with a relative price change to L'K' and L"K" respectively (capital-intensive).

A jump from stage I to II and higher stages for many developing countries is not simple as it is governed by a number of factors and issues. Land and labour endowments, demand for off-farm labour, and demand for agricultural products are the major factors determining the rate and pattern of mechanization. Issues involved

[7] Another grouping of agricultural operations is based on the relative intensity of the use of power as compared to the use of human judgment namely *power intensive* (land preparation, threshing, milling, etc.) and *control intensive* (weeding, sifting, fruit harvesting, etc.). See Pingali et al (1987).

may range from choice of techniques, technology transfer and adoption, and type of technical changes to farming system evolution (Clarke, 2000, Clarke and Bishop, 2002). A comprehensive analysis will help identify the impacts of mechanization on land and labour productivity, employment, income distribution, and change in social and cultural values across different regions and agro-ecosystems within a country (Schultz, 1964). Public sector role will be pivotal in setting up the right direction based on a long-term vision for East Timor's mechanization program. International and regional experiences and studies conducted elsewhere may serve as useful references (Kaimowitz, 1993, Salokhe and Ramalingam, 1998).

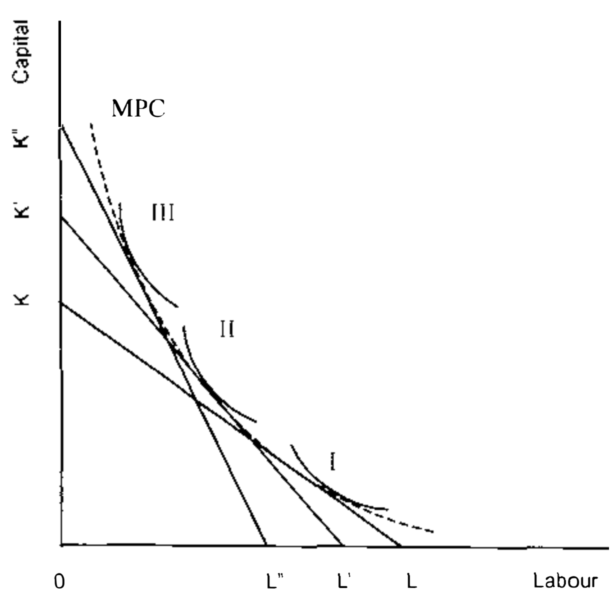



Figure 3.1 Mechanization Possibility Curve (MPC)
(Adapted from Rijk, , 1989)

Table 3.2 demonstrates a clear differentiation in mechanization stages among selected countries in Asia during the period of *green revolution* up to the most recent times. Figures for Japan, Taiwan, and South Korea suggest a higher degree of mechanization and larger degree of urbanization as indicated by the declining use of human power. Interestingly for Japan, the machine hours were also decreasing, which may suggest the preferential use of larger machines allowing rapid completion of work. A very low labour intensity also indicates a very advanced mechanization stage, where field operations are fully mechanized involving some degree of automation. Rice cropping in Taiwan is nearly 100% mechanized from planting to harvesting. For other countries, the increasing labour use was mainly induced by the adoption of labour-intensive modern rice varieties while the increasing machine hours were largely devoted to land preparation and threshing, particularly in the Philippines and Thailand (Duff and Kaiser, 1984).

A tremendous increase in the irrigated area in many Asian countries promoted by extensive irrigation schemes to increase cropping intensity has been one of the major reasons to acquire more power inputs. The number of tractors, as one of the major power sources and other farm machinery has been in an increased trend in all Asian countries (Salokhe and Ramalingam, 1998). Mechanization in most of these countries is associated with rice production as the main crop. A different scope and degree of mechanization may be promoted by countries having crops other than rice as the main crop like Pakistan (wheat), Sri Lanka (tea, spices), and Malaysia (rubber, oil palm). Apart from that varied geography characteristics also requires different types of machinery and equipment. These are part of soil and crop technical aspects related to mechanization that needs to be considered for a successful and sustainable mechanization program in East Timor.

## 3.4 MECHANIZATION TECHNOLOGIES

Both at academic and policy-making levels much of the controversy over agricultural mechanization has emerged from the fact that it is often considered only as the application of mechanical power technology, particularly tractors. There are, however, three main levels of mechanization technology needing consideration: hand-tool, draft animal, and mechanical power technologies[8] with varying degrees of

[8] See Clarke and Bishop (2002) for a detailed analysis of farm power present status and future projections for developing countries. Countries were categorized into six farm power typologies: predominantly manual; significant use of draft animal power (DAP); DAP predominant; significant use of tractors; tractors dominant; and fully tractorized.

sophistication within each level (Rijk, 1989), on the basis of capacity to do work, costs, and in some cases precision and effectiveness (Morris, 1985).

Table 3.2 Estimated inputs of human, animal and mechanical power, tractor use intensity and labour intensity for crop production in selected countries of Asia

| Country | Input (hours/ha) [a] | | | | | Tractor use intensity (ha/tractor) [c] | | Labour intensity (worker/ha) [c] | |
|---|---|---|---|---|---|---|---|---|---|
| | Category [b] | 1956 | 1970 | 1975 | 1978 | 1990 | 2000 | 1990 | 2000 |
| Japan | H<br>A<br>M | 1410<br>15<br>144 | 1178<br>2<br>185 | 815<br>-<br>179 | 694<br>-<br>148 | 2.4 | 2.4 | 0.89 | 0.57 |
| Taiwan [d] | H<br>A<br>M | 1088<br>122<br>40 | 985<br>103<br>56 | 778<br>51<br>84 | 601<br>36<br>98 | na | na | na | na |
| Korea | H<br>A<br>M | 1356<br>92<br>4 | 1284<br>101<br>8 | 1176<br>80<br>18 | 937<br>56<br>48 | 51.2 | 10 | 1.68 | 1.24 |
| Philippines | H<br>A<br>M | 504<br>200<br>42 | 552<br>136<br>45 | 640<br>136<br>45 | 640<br>136<br>45 | 923.4 | 873.9 | 1.11 | 1.23 |
| Thailand | H<br>A<br>M | 490<br>170<br>10 | 480<br>165<br>15 | 470<br>160<br>20 | 462<br>146<br>30 | 356.8 | 81.8 | 0.97 | 1.17 |
| India | H<br>A<br>M | 1218<br>230<br>120 | 958<br>247<br>na | 992<br>221<br>na | 1285<br>125<br>113 | 171.5 | 111.3 | 1.35 | 1.55 |
| Pakistan | H<br>A<br>M | 619<br>312<br>na | 637<br>308<br>na | 637<br>284<br>2 | 637<br>128<br>6 | 78.8 | 68.5 | 0.98 | 1.11 |
| Nepal | H<br>A<br>M | 1200<br>312<br>na | na<br>na<br>na | na<br>na<br>na | 1448<br>304<br>2 | 522.9 | 645.2 | 3.75 | 3.76 |

a. Figures estimated for rice production only. Source: Duff and Kaiser (1984)
b. Category: H=human; A=animal; M=mechanical
c. From FAOSTAT data (www.fao.org)
d. Tractor use intensity and labour intensity data not available (na) from FAOSTAT. Taiwan official source indicates that agricultural machines have gradually replaced labour input in farm production since the 1970s. For rice production, the labour input was only 255 hours per hectare in 1996, a 69 percent decrease in labour input compared to 1970 (www.coa.gov.tw/english/agricultural/)

### 3.4.1 Hand-powered tools

The predominant form of rural technology is based on manual labour, with the hand hoe as a basic ingredient. The main attributes of this system are that it represents a low-cost, low-energy, labour-using, family-oriented technology, which is closely attuned to traditional and subsistent farming methods such as shifting cultivation and intercropping, and is largely self-sufficient, drawn on locally made implements (Morris, 1985). Much of the agricultural production in the rural communities is emphasized on risk minimization intended for home consumption with only a small part passing through market channels.

Hand-powered tools are the most used technologies by East Timorese farmers. These tools cover a wide range of varieties from axe and machete for land clearing, hoe and steel digging sticks for seedbed preparation and tuber and root crop harvest, to sickle and knife for weeding and harvest. Other hand-powered tools include those for winnowing, rice polishing, maize grinding, candlenut, coconut and coffee processing, most of which can be easily found in any traditional household both in upland and lowland communities. Given the simplicity in the nature of many traditional implements, much scope exists for increasing productivity by improved hand tools and man-powered equipment.

A study by Clarke and Bishop (2002) revealed that humans are the most significant power source in Sub-Saharan Africa countries where 65% of the land is cultivated by human power. In Central and Western Africa, they account for an estimated 85% and 70% of harvested area respectively, while the land cultivated by humans is estimated at 40% in East Asia and 30% in South Asia.

### 3.4.2 Animal traction

Animal traction is often seen as an outdated and backward technology. Therefore, rapid agricultural development is often taken to imply the bypassing of the animal-traction stage and going directly from hand tools to the use of tractors and other purchased inputs such as fertilizers and pesticides. This is also the case in East Timor. Except for the *rencah* system using a group of water buffaloes to puddle the soil, horses for transport and rice threshing, there is little, if not negligible, evidence of the use of animal traction in combination with implements for land preparation and crop husbandry. Efforts were attempted during Indonesian times to introduce the *luku* system, a mouldboard-plough pulled by a single or a pair of oxen, for primary and secondary tillage. It involved the use of Bali cattle and was demonstrated primarily by Indonesian farmers who were relocated to several transmigration centers in East Timor. It lacked the dissemination effect probably due to technical reasons such as lack of animals and skills in animal husbandry, and lack of fodder. Also it may be due to the cultural aversion of local farmers to the use of animals for work. However, given the minimal adoption of modern technologies seen elsewhere, possible ways should be explored for the reintroduction of appropriate animal powered technologies.

Animal power is still widely used in China. Indian agriculture has been traditionally dependent on draft animal and human power as major sources of energy. During the 1960s several newly independent African countries, among them Tanzania, Zambia, Guinea, Ghana, and Côte d'Ivoire, adopted policies that were designed to leapfrog the animal traction stage by providing tractors and tractor-hire services at subsidized rates. Most of these attempts at rapid tractorization failed, and several countries subsequently reverted to encouragement of animal-draft power (Pingali et al., 1987). As mentioned earlier, in countries with advanced mechanization levels, the use of animal power has been gradually decreasing (Korea and Taiwan) and even totally displaced as is the case in Japan (refer to Table 3.2).

### 3.4.3 The introduction of tractors

Tractors were imperative to modernization in the view of many, including the policy makers in the past. During the last decade of Indonesian administration, through the agricultural intensification program (BIMAS), a huge number of tractors and implements were introduced annually.

Table 3.3 indicates the machinery status in 1997, an approximate figure to that of the pre-1999 crisis, and the situation in 2000, at a time when the machinery demand for land cultivation was at its peak. The inclusion of crop production does not necessarily imply a resulting effect from the use of tractors. In fact, the use of mechanization is not the sole factor contributing to increased yield. The concept of *net contribution effect* (increased crop production) and *substitution effect* (machinery substituting for labour) helps explain the relationship between the two (Ruthenberg, 1985), since it is difficult to view the specific economic benefits of mechanization technology in isolation. So the crop production in those years comes as a result of mechanization being applied in conjunction with other crop production technologies such as irrigation, improved seeds, the use of fertilizers and pesticides, labour and higher levels of management. Available data for 1997 on selected tools and equipment is given in Table 3.4.

According to Rijk (1989) a statistical correlation between the level of mechanization and yield does not necessarily indicate a causal relationship and may lead to the incorrect conclusion that mechanization increases production. In many cases the increased production induced by factors such as fertilizer application and good irrigation may result in higher net income, which in turn could stimulate mechanization investment. Research results also indicate that when adjustments are made for the level of fertilizer used, yield differences between mechanically and traditionally tilled fields become insignificant (Bernsten et al., 1984, Duff and Kaiser, 1984).

## 3.5 THE TRACTOR MOBILE BRIGADES (MBs)

The goodwill of policy makers in the recent past to adopt tractorization as a means to speed up the agricultural crop production was understandable, especially in a time when the need for food was paramount. The small-scale mechanization scheme suggested through the World Bank-led joint assessment mission in November 1999 came to be a big-scale one in realization,[9] which may not be easy to sustain over time.

Earlier assessments on the tractor brigades (MBs) suggested that farmers had little or no understanding of what was necessary for maintenance and that spare parts were difficult to obtain. At the policy-making level, requests emerged for the need of

[9] The distribution of hand-powered tools was part of the small-scale mechanization scheme. Parallel with this were the immediate projects of water buffaloes population recovery, reconstruction of meteorology stations, and the rehabilitation of major irrigation networks.

international expertise to assist with the planning and implementation of mechanization promotion programs (Wilson, 2000, Watahiki, 2000). Only one spare parts dealer exists in Dili and parts have to be imported, especially from Surabaya. Local manufacturers are non-existent even since the Indonesian period. Private sector repair and fabrication workshops are currently running in small-scale units. The Chinese Government has assigned a team of engineers and technicians from May – December 2002, to assess the latest condition of all the agricultural machinery and to train Timorese operators and mechanics in the repair and maintenance (Benevides, pers. comm. 2002).

Table 3.3 Number of tractors, paddy and maize production (ton), East Timor 1997-2000

| Districts | Number of tractors | | 1996/1997[c] | | 1999/2000[c] | |
|---|---|---|---|---|---|---|
| | 1997/98[a] | Aug 2000[b] | Paddy | Maize | Paddy | Maize |
| Aileu | 9 | 6 | 1,700 | 10,500 | 1,411 | 9,240 |
| Ainaro | 9 | 11 | 1,600 | 4,500 | 1,072 | 3,195 |
| Oecussi | 72 | 6 | 5,300 | 8,800 | 1,325 | 3,080 |
| Baucau | 42 | 37 | 12,000 | 14,000 | 9,720 | 13,300 |
| Bobonaro | 127 | 22 | 15,000 | 28,600 | 8,100 | 15,444 |
| Covalima | 14 | 17 | 5,000 | 16,000 | 3,600 | 12,160 |
| Dili | 6 | 7 | 200 | 2,000 | 172 | 1,900 |
| Ermera | 14 | 6 | 3,300 | 6,200 | 2,838 | 4,774 |
| Lautem | 24 | 7 | 3,200 | 7,700 | 2,880 | 7,392 |
| Liquica | 6 | 6 | 500 | 5,000 | 210 | 1,400 |
| Manatuto | 13 | 29 | 4,800 | 4,000 | 3,984 | 3,680 |
| Manufahi | 47 | 20 | 2,200 | 5,000 | 1,848 | 5,000 |
| Viqueque | 34 | 14 | 17,200 | 14,000 | 13,760 | 14,000 |
| TOTAL | 417 | 188 | 72,000 (43,200) | 126,300 | 50,920 (30,552) | 94,565 |

a. From Dinas Pertanian Tk. I records. Figures include the non-operational tractors. Figures for Oecussi, Baucau, Bobonaro, Manufahi and Viqueque consist mainly by hand-tillers.
b. Source: Wilson (2000).
c. Source: FAO/WFP Special Report (April 2000). 1996/97 figures were taken from BPS records. Figures in bracket are polished rice taken as 60% from unhusked paddy.

Since all the tractors are operating in the districts where there is little institutional support, the operation of these machines faces enormous difficulties. When machinery is stationed in remote parts of the country, it is very difficult to keep it properly fuelled, lubricated, and serviced. Not surprisingly, many machinery breakdowns do occur, and often these occurrences coincide with the time when the machines are under greatest stress especially during the peak cultivation season. Since the availability of spare parts and competent mechanics is extremely scarce, delays in getting the machines operational can be lengthy (Bernsten et al., 1984).

Table 3.4 Selected agricultural tools and equipment by district, 1997

| Districts | Pedal/power thresher | Sickle | Water pumps | Hand/power sprayer | Mist blower | Swing fog |
|---|---|---|---|---|---|---|
| Aileu | 4 | 95 | 2 | 102 | 15 | 0 |
| Ainaro | 4 | 0 | 0 | 61 | 2 | 5 |
| Ambeno | 49 | 0 | 2 | 37 | 2 | 20 |
| Baucau | 66 | 36 | 0 | 33 | 2 | 30 |
| Bobonaro | 12 | 0 | 4 | 216 | 5 | 25 |
| Kovalima | 54 | 0 | 6 | 48 | 0 | 20 |
| Dili | 0 | 0 | 7 | 16 | 1 | 110 |
| Ermera | 5 | 175 | 6 | 57 | 1 | 0 |
| Lautem | 4 | 0 | 0 | 79 | 7 | 0 |
| Liquica | 3 | 0 | 0 | 33 | 3 | 0 |
| Manatuto | 2 | 0 | 0 | 36 | 1 | 20 |
| Manufahi | 32 | 34 | 0 | 178 | 2 | 20 |
| Viqueque | 41 | 0 | 0 | 120 | 7 | 20 |
| Total | 276 | 340 | 27 | 1016 | 48 | 270 |

Source: East Timor Provincial Agriculture Department records

The MBs have been dissolved and the tractors and implements are now being held under the responsibility of the agricultural division of the District Administration (DA). Given the very limited public sector resources to manage the machinery fleet as mentioned above, Wilson (2000) identified 5 possible ways for long-term machinery management (and ownership).[10]

1. Incorporate the MBs within the Pilot Agricultural Service Centers (PASCs),
2. Transform the MBs to farmer-owned co-operatives,
3. Contract arrangement with locally-owned business companies with MBs' staff becoming shareholders,
4. Farmer group ownership through credit scheme,
5. Individual farmer ownership through credit scheme.

[10] Similar types of ownership were suggested earlier by Watahiki (JICA, 2000).

Currently MAFP has identified several problems needing immediate policy interventions such as[11]:

1. Large areas of potential arable lands left underutilized,
2. Lack or poor soil tillage resulting in late crop establishment which leads to low crop intensity and yield and frequent crop failures,
3. Limited access to tillage operation systems which can provide timely and affordable tillage services,
4. Farmers unable to afford the cost of medium to large size tractors.

A sound agricultural machinery management may help address these issues. Based on earlier assessments (Watahiki, 2000, Wilson, 2000) and short communications in Dili, there are three practical options[12] under which the current agricultural machinery can be properly managed:

1. Public management scheme
   a. ASC (Agricultural Service Centres), formerly PASC
   b. Agricultural Schools
2. Agricultural NGO's management scheme,
   a. Farmer group ownership through credit system
   b. Individual ownership through credit system
3. Private Companies' management scheme

These options are regarded as short-term possible and feasible immediate response with the existing managerial resources should the tractors are made available. However, they should be approached with caution. There are major efforts needed at setting up prior necessary conditions for each option to be materialized in a specific region, particularly for public ownership schemes which were proven less

[11] Source: various MAFP's recent documents.

[12] This is more to address the current needs to properly allocate the tractors and implement sets recently purchased by MAFP. Short communications were conducted with NGO's and ASC representatives to briefly gather their opinions and assess their commitments to own or manage agricultural machinery for educational and/or profit purposes for the rural community. The author argues that the whole scheme should be regarded as an on-going machinery management trial, which will be assessed over time.

successful in the past. Exceptional cases may exist outside these options where there are already individual farmers or groups of farmers capable of managing small tractors.

### 3.5.1 Public management

During a short introductory period, a subsidized tractor-hire service run by government agencies can be beneficial through a demonstration scheme. The demonstration effect, linked with extension efforts will help promote technology adoption leading to machinery ownership by farmers. In the long-run, ASC (agriculture service centre) or similar government-owned centres in the future are required to focus primarily on promoting and facilitating research (Viegas, 2002, Tripp, 2001). In this regard, research for the improvement of manual and animal powered technologies as described above deserve priority. Conservation tillage practices and technologies such as minimum and no-tillage using manual or animal draft to engine powered seed drills may as well be trialled in the long-run.

On a short-run however, public direct intervention is inevitable as was proven in the past, despite with very little success. Many shortcuts have contributed to largely a failure in technology adoption and dissemination at the community level. Evidence suggests that there were insufficient public resources as well as inadequate domestic and international network to promote a rapid agricultural recovery as well as to sustain its growth. Therefore, given the inexperience of ASC and public agricultural schools[13] in running and managing tractors for educational and business purposes, additional skill training and education packages are required. These could range from training on bookkeeping, finance, and operation and maintenance to setting up machinery workshops.[14] How these centres and schools will evolve in the

[13] ASC currently covers three centres namely Maliana, Viqueque, and Aileu while agricultural schools refer to the two schools in Natarbora and Bobonaro (short communication with Mr. Carlos Granadeiro of MAFP).

[14] ASC has experience in operating Rice Mill Units, trading of milled rice, animal feed and fertilizer. It also supports the rural economy by providing farmers with small credit with interest rate of 10% / annum (Based on a short communication with Mr. Adelino Rego of ASC on 18/1/06).

near future may have been foreseen and its measures established within MAFP's strategy and policy plans.

### 3.5.2 NGO's management

Farmers are used to working in (kinship) groups therefore, with proper assistance in developing managerial and entrepreneurial skills these groups could be transformed into potential and profitable co-operatives. On machinery management however, past experience has suggested that handing the tractors directly to individual farmers without proper assistance in operation and maintenance, is not a viable option. Besides, the capital cost of owning and managing agricultural machines and equipment is proven to be too high for small farmers. This is further exacerbated by the current uncertain climate in profitable agricultural business where the return of investment is very low.

However, there is opportunity for improvement, especially if it takes up initiatives which are based on sound applied research and experimentation results. The former, as mentioned earlier, will be much of government role to promote through centres such as ASC or the Research Division of MAFP. Of the latter, a lot can be learnt from the non-governmental organizations (NGOs), especially those engaging in rural community and agricultural development. Many of these NGOs have experienced a long and healthy relationship with local farming communities. Therefore, with mutually beneficial arrangements, these NGOs are in a better position to provide the tillage services.[15] In a very foreseeable future, providing there is timely service and assistance, either from the public sector or other private sector components, one individual or a group of farmers could certainly manage their own machinery in a sustainable fashion.

[15] HALARAE and ETADEP were the two prominent national NGOs working in agriculture and community development approached to discuss the management options offered by the MAFP. During an interview with Mr. Paulo Amaral, the Director of HALARAE on 18/1/06 he expressed great enthusiasm to accept the offer. Likewise, Mr. Gilman Santos, Director of ETADEP, in a short communication with the author on 19/1/06, offered his comments and a similar positive attitude to take up the role of managing the tractors for the benefit of the farmers. There are few other NGOs engaged in promoting sound agricultural and environmental practices such as HABURAS and HASATIL which could also be considered as government partners in this venture.

The nature of partnership between MAFP and the NGOs will be based on a contractual agreement where both parties will discuss and agree upon certain conditions and abide by certain rules. HALARAE and ETADEP are two national NGOs with reliable profiles and reputation that can offer potentially fruitful cooperation with MAFP in various aspects of community and rural development. Natarbora (Manatuto) and Welaluhu (Same) are potential agricultural areas of East Timor, where both HALARAE and ETADEP have already established solid partnership with local communities. Sare / Raimate have long been regarded as field office of ETADEP for many years. Table 3.5 presents some details of area and number of beneficiaries currently benefited from working in partnership with these two particular NGOs.

Table 3.5 Selected NGOs working in agriculture, target area and beneficiaries, 2006

| NGO | Location | Farm land (Ha) | | | Farmers' groups | Farmers |
|---|---|---|---|---|---|---|
| | | Irrigated | Dry land | Total | | |
| HALARAE[1] | Natarbora/ Manatuto | 169 | 204 | 373 | 7 | 80 |
| ETADEP[2] | Natarbora (Manatuto) and Welaluhu (Same) | 172 | | 172 | 11 | 130 |
| | Sare/Ermera | 121 | 81 | 222 | 32 | 544 |

1. Compiled by the author based on data from Mr. Paulo Amaral, the Director of Halarae. Halarae has experienced working on seed multiplication, a project funded by UNDP/UNOPS in Natarbora and plans to expand its scope to machinery management. The figures represent area, farmers, and farmers' groups identified as in need of tillage service.
2. Compiled from recent Etadep progress reports. These figures are the actual working area and number of farmers and farmers' groups serviced by 3 (three) units of Massey Ferguson tractors in each location, Natarbora/Welaluhu and Sare/Raimate. Farmland in Natarbora and Welaluhu are cropped with a variety of cropping systems with rice, maize, beans, vegetables, and other horticulture crops.

These factual conditions may provide valuable information for MAFP to start with the management of the current agricultural machinery fleet considering particularly the lessons underlying the experiences of the NGOs over many years of engagement at the grass-roots level. Expansion to wider land area and community coverage is permitted upon success, or similar schemes can be replicated in other potential agricultural areas such as Viqueque and Maliana. In the mean time, ASC and

Bobonaro agricultural school can set up pilot projects in these two districts, while Baucau, Lospalos, and Suai can be covered in a later stage. Areas where the tractors will be allocated to in each district can only be determined based on a specific survey. However, there is great scope for agricultural mechanization in the lowland ecological zones along the southern and northern coasts, providing road and farm infrastructure allow the entry and mobility of farm machinery.

### 3.5.3 Private companies

The entry of private contractors into the hire market will also be encouraged beyond the introductory period mentioned above. In the medium to long run, however, the involvement of the public sector will be limited, ideally, to policy making and creation of an environment conducive to private sector investments. This was proven to be difficult during the recent past, where local rice price for example, mainly from irrigated lowland rice production systems which involve a great deal of mechanical power for tillage, harrowing and puddling, has no competitive market advantage.

Different from the NGOs, these companies request some degree of profit in return to their professional service. Local experience suggests that the overall production cost is too high causing business in agricultural food crop production not attractive for investment.[16] Subsidies in fuel price and tax cut on imported machinery spare parts can provide incentives for greater involvement of business companies in agricultural production. Therefore, dependant on area size and crop commodities, these firms together with farmers and farmers' groups and with special subsidies from the government, can make attractive and lucrative deals out of rural agriculture. Past experiences of Dragon Service Co. suggest a great deal of work related to tractor operation and tillage services in areas of Manatuto, Baucau, Viqueque, and Liquica. Based on an interview with its management, the company is willing to negotiate the conditions of a management scheme for the agricultural machineries.

[16] An opinion shared by a representative from the Dragon Service Ltd. Delta Comoro. Formerly Rio de Oiro Ltd., it owns a quite reliable agricultural machinery pool and a mechanical workshop. It has previous experience in land clearing and seedbed preparation for low land rice production in Uatu-lari and Natarbora. Largely of FIAT type, its tractors and spare parts are mainly imported from

### 3.5.4 Analysis

Main problems confronted with the introduction of tractors revolve around issues such as: poor availability of spare parts; low realization of tractors utilization per season; poor skill of tractor operators and owners; low mobility associated with poor infrastructure; and technically inefficient machinery design with respect to the socio economic conditions of the farmers. Table 3.6 presents a calculated operational and maintenance cost of two type of tractors, recently purchased by MAFP, operating in favourable normal field conditions.

This is a baseline running cost for these two particular tractors and the real cost may increase depending on the actual field conditions and the type of work required. To what extent of area a tractor can cover is largely a function of factors such as field conditions, weather, soil types and operator's skill, and this may substantially affect the ability of the farmers to hire the tillage service. Again, based on the calculated baseline cost and related circumstances mentioned above, the rationale for charging a certain fee in a certain location may differ from place to place (Table 3.7). A charge of $50/ha is applied if a medium and large size tractor can provide service to an area of 200 and 300 hectares, respectively, to be able to recover its minimum running costs.

Additional fees may accrue due to transport and mobilization costs of the machinery if the farmlands are dispersedly located. Moreover, in relation to the recovery of the purchasing capital of the machineries, MAFP and its partners may need to carefully weigh the urban – rural dimensions of the localities. A set of strategic policy decisions must be made on whether to invest in poor communities living in fertile but isolated lands such as Natabora and Welaluhu or rather to further promote the already established growth-centered communities in parts of Baucau and Maliana for example.

---

northern Australia. The agricultural branch of the firm is currently engaged in horticulture and vegetable production in Loes (based on interview with Mr. Tonito Madeira on 19/1/06).

A rough estimation of the investment return, should the government undertake the management options described above through a revolving fund or credit scheme, is not entirely promising. From a farmer's perspective, the heavy burden is on the capital (ownership) and maintenance costs, even if it is shared collectively by a group of farmers, or even if the credit period is expanded to 10 years. However, the overall scheme can still go ahead with the assumption that the issues mentioned earlier in this section are tackled properly over the next 5 to 10 years. As with regards to the establishment of mechanical workshops, it is probably feasible to set up one attached to each 'Secretariado do Estado para a Corrdenação da Região' (State Secretariat for Region Coordination) I, II, III, and IV in Baucau, Manufahi, Ermera, and Maliana, respectively, with the central workshop located in Dili.

Table 3.6 Fixed and Variable cost for Kubota MX5000 and Kubota M9000 tractors (US$/year)

| Tractor / horsepower | Fixed Cost (i) | | | | | |
|---|---|---|---|---|---|---|
| | Depreciation | Interest | Maintenance | Housing | Tax & Insurance[1] | Total cost (i) |
| Kubota MX 5000 51 HP | 3798 | 1160.5 | 1055 | 105.5 | - | 6119 |
| Kubota M 9000 92 HP | 5310 | 1622.5 | 1475 | 147.5 | - | 8555 |
| | Variable cost (ii) | | | | | |
| | Fuel | Oil | Grease | Operator[2] | Tire[3] | Total cost (ii) |
| Kubota MX 5000 51 HP | 2856 | 57 | 34 | 402 | 600 | 4049 |
| Kubota M 9000 92 HP | 5152 | 103 | 62 | 402 | 600 | 6419 |
| Total Operational and maintenance Cost | | | | | | |
| Kubota MX 5000 (51 HP) | | | | | | 10168 |
| Kubota M 9000 (92 HP) | | | | | | 14974 |

Note:
1. Assumed no tax on personal property as well as no insurance scheme available.
2. Estimated at $10/hour for both operator + helper on an 8 hour/day work basis over 400 hours tractor work/year.
3. Maintenance cost for one tire (tear and wear) is estimated at $150/year. Prices for new front and rear tires for medium and large tractors are around $300 and $1200, respectively.

Table 3.7 Working area (ha) and estimated cost of tractor charge fee

| Tractor | Operational and maintenance cost ($/year) | Tractor fee | | | | | |
|---|---|---|---|---|---|---|---|
| | | $30/ha | $40/ha | $50/ha | $60/ha | $70/ha | $80/ha |
| Kubota MX 5000 (51 HP) | 10168 | 339 | 254 | 203 | 170 | 145 | 127 |
| Kubota M 9000 (92 HP) | 14974 | 499 | 374 | 299 | 250 | 214 | 187 |

## 3.6 RATIONAL TECHNOLOGY DEVELOPMENT

Experience in many countries indicates that land limitations are not necessarily a critical constraint to the growth of agricultural output. Australia, Japan, and New Zealand for example, have achieved relatively high crop productivity despite agricultural land and labour resource limitations (Table 3.8 and 3.9). Following the typology of Clarke and Bishop (2002) these countries fall into the category of fully tractor powered where agriculture is no longer the dominant sector. In countries such as Bangladesh, India, Nepal, Vietnam, and East Timor where GNP is low (Table 3.8) and there is an ample surplus of labour, land productivity through higher yields and cropping intensity is required, thus providing additional employment. Similarly, expansion, control and efficiency in irrigation are also ways to improve the productivity of agricultural land in the high man/land ratio economies of Asia.

Cereal and root crops/tubers data during the last five years of Indonesian administration in East Timor provide an interesting insight on the country's agricultural development. Rice, maize, cassava, and sweet potato are the four major staple crops for East Timor (see Chapter 2 for general overview of the traditional agriculture setting and Chapter 4 for selected food crop production data). By being staple crops, may already provide an incentive for farmers to produce more, mirrored by a significantly higher yield growth comparatively to some countries in Asia Pacific (Table 3.9). Other factors may have contributed to this growth, especially those derived from public policies during that time to stimulate production to meet self-sufficiency needs, including policies on mechanization. More on the importance of staple crops in food policy will be the subject of discussion in Chapter 4.

As was discussed earlier, high level of mechanization, however, does not necessarily imply higher crop productivity. Data from selected Asia Pacific countries indicates only a moderate relationship between the number of tractors/1000 ha and cereal productivity (r = 0.53). On the contrary, fertilizer consumption has a very strong relationship with cereal yield (r = 0.84). Similarly GNP per capita has a highly positive correlation (r = 0.86) with the investment in tractors (FAO/RAP, 1999).

Depending on their land and labour endowment, countries could rely on different technological strategies in agricultural growth. Japan, for example, emphasized yield-raising technology up to 1950's, while mechanization played only a minor role. Following this pattern, Korea and China also initially emphasized yield-increasing technology and later pursued mechanization. On the contrary, rather than yield increasing technology, the United States of America emphasized mechanical technology even before 1880. Unlike other Asian countries, Thailand has also rapidly expanded its agricultural area enhanced by mechanization, rather than pursuing yield-raising technology (Rijk, 1989).

Both strategies were employed in East Timor during the Indonesian era, part of a national policy to address the issue of food self-sufficiency as mentioned earlier. Yield raising technologies such as hybrid seeds were introduced but such technologies usually require inputs to achieve their potential. These additional inputs are often hardly affordable which consequently leaves the farmers with very little option but to revert to their local seeds.

A chosen strategy and its net effects of technological change on farm productivity, farmer's income, and societal welfare are highly dependent upon agricultural production systems. This is particularly challenging confronting subsistence-based communities in East Timor, which are by nature conservative and use methods and techniques that have withstood the trial of time.

Table 3.8 Total land area, percentage of agricultural area, total population (TP), percentage of agricultural population (AP), and GNP per capita of selected countries in the Asia Pacific Region 1998[1]

| Country | Total land area (1000 ha) | Agricultural land as percentage of total land area[3] (%) | Total population (TP) (1000) | Agricultural population (AP) as percentage of (TP) (%) | GNP per capita (US$) |
|---|---|---|---|---|---|
| Australia | 768230 | 6.9 | 18329 | 4.80 | 20090 |
| Bangladesh | 13017 | 63.3 | 122650 | 58.70 | 260 |
| **East Timor[2]** | **1461** | **43** | **882** | **70** | **348** |
| Fiji | 1827 | 15.6 | 786 | 41.50 | 2470 |
| India | 297319 | 57.1 | 966192 | 56.30 | 380 |
| Indonesia | 181157 | 17.1 | 203380 | 46.10 | 1080 |
| Iran | 162200 | 12 | 64628 | 28.70 | 2200 |
| Japan | 37652 | 11.4 | 126038 | 4.80 | 40960 |
| Korea | 9873 | 16.6 | 45731 | 10.50 | 10610 |
| Malaysia | 32855 | 23.1 | 20983 | 19.90 | 4370 |
| Nepal | 14300 | 20.8 | 22316 | 93.30 | 210 |
| New Zealand | 26799 | 12.2 | 3761 | 9.20 | 15720 |
| Pakistan | 77088 | 28 | 144047 | 52.20 | 480 |
| P. New Guinea | 45286 | 1.5 | 4499 | 78.50 | 1150 |
| Philippines | 29817 | 31.9 | 71430 | 41.20 | 1160 |
| Sri Lanka | 6463 | 29.2 | 18274 | 47.20 | 740 |
| Thailand | 51089 | 40 | 59736 | 51.20 | 2960 |
| Vietnam | 32549 | 22.1 | 76387 | 68.60 | 290 |

1. Source: FAO/RAP (1999).
2. Source East Timor in Figures 1997 (total land, agricultural land, TP, AP); GNP estimated as non-oil GDP.
3. Arable land and permanent crops land excluding permanent pasture, forests and woodland, and other land (RAP Publication 1999/34).

Table 3.9 Mean productivity and annual growth rates of cereals, tubers and root crops, fertilizer consumption and number of tractors in selected countries in Asia Pacific region[1]

| Countries | Cereal Yield 1998 (kg/ha) | Growth 1988-98 (%) | Tubers & root-crops yield 1998 (kg/ha) | Growth 1988-98 (%) | Fertilizer Consumption 1997 (kg plant nutrients/ha) | Tractors /1000 ha 1997 |
|---|---|---|---|---|---|---|
| Australia | 1952 | 1.8 | 30838 | 1.4 | 42.6 | 6.67 |
| Bangladesh | 2669 | 1.3 | 10960 | 1.1 | 130.1 | 0.66 |
| **East Timor[2]** | **2650** | **4.7** | **4245** | **8** | **na** | **0.66** |
| Fiji | 2089 | -0.8 | 10792 | 13.0 | 67.4 | 26.92 |
| India | 2207 | 2.2 | 17011 | 0.9 | 95.3 | 8.54 |
| Indonesia | 3789 | 0.6 | 11726 | 0.2 | 79.5 | 2.32 |
| Iran | 1921 | 4.8 | 19411 | 3.4 | 59.4 | 12.40 |
| Japan | 5849 | 1 | 26819 | 0.6 | 366 | 499.77 |
| Korea | 6631 | 1 | 20842 | 0.0 | 471.1 | 64.61 |
| Malaysia | 2957 | 0.9 | 9513 | -0.1 | 157.8 | 5.69 |
| Nepal | 1968 | 0.7 | 8092 | 1.6 | 36.7 | 1.66 |
| New Zealand | 5379 | 2.3 | 42679 | 4.7 | 210.7 | 24.75 |
| Pakistan | 2159 | 2.2 | 14164 | 2.5 | 123.1 | 14.90 |
| P. N. Guinea | 4170 | 7.7 | 5338 | -2.6 | 19.4 | 1.81 |
| Philippines | 2241 | 2.3 | 6669 | -0.3 | 85.1 | 1.23 |
| Sri Lanka | 3156 | 0.8 | 8174 | -0.8 | 111.7 | 3.54 |
| Thailand | 2466 | 1.8 | 14200 | -0.3 | 72.3 | 7.31 |
| Vietnam | 3838 | 3 | 7013 | -0.8 | 218.3 | 17.08 |

1. Source: FAO/RAP (1999).
2. Source: East Timor in Figures 1997; (i) cereal yield is the average of rice and maize yields only, annual growth from 1992-1997 (ii) tuber and root crops yield is the average of cassava and sweet potato yields only, with annual growth from 1992-1997 (iii) data on fertilizer consumption is not available, use is negligible if any.

## 3.7 MANAGING TECHNICAL CHANGE

One of the major capital investments in agriculture development is in the form of land. In the context of technical change, any form or patterns of agricultural technology can be grouped as *land-saving* (hybrid seeds, irrigation, fertilizers, and drainage) and *labour-saving* (mechanization, herbicides, varieties and cropping techniques) as shown in Figure 3.2. A technical change is land-saving if the labour/land ratio increases ($I_1$) while technical change is labour-saving if the labour/land ratio decreases ($I_2$). $I_0$ is the original situation and $I_n$ represents a neutral technical change.

This technical change, where the move from $I_1$ to $I_2$ occurs along an isoquant reflects the view mentioned earlier that mechanization substitutes for mechanical and animal power. The net contributor view on the other hand sees mechanization as engine of growth due to better tillage, more timely operations, and allowing more cropping intensities (more output from less inputs) and can be represented by a move from $I_1$ or $I_2$ towards $I_n$. Both views can happen at once.

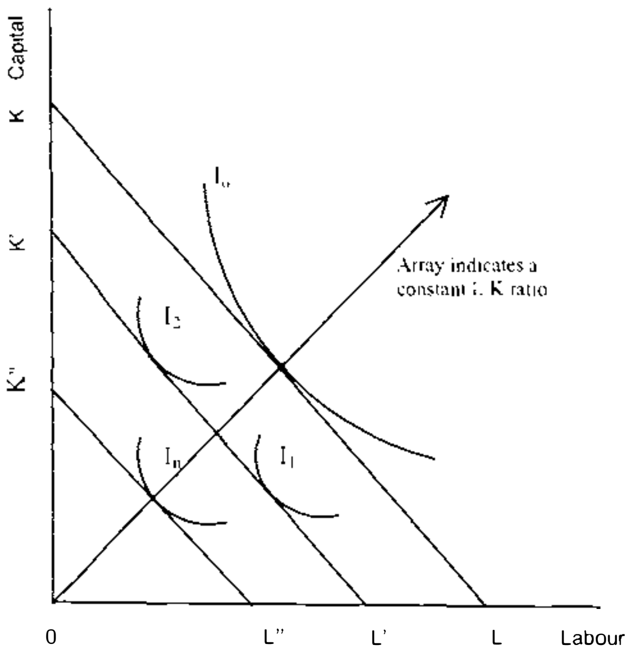



Figure 3.2 Capital-saving versus labour-saving technical change
(Adapted from Rijk, 1989)

When given the choices, farmers will weigh up the relative attributes of alternative approaches to technical change. Traditional farmers are efficient allocators of available resources according to their knowledge of technology (Schultz, 1964) and therefore tend to make rational decisions about new technology (French and Schmidt, 1985). According to Schultz (1964) every new technology represents a disequilibrium impulse which causes inefficient resource allocation. African experience suggests that the dominant theoretical perspective on technical change and innovation in small-scale agriculture (change under constrained maximization) is argued to be highly effective in identifying problems with small-scale agriculture

(Omamo and Lynam, 2003). Only through learning and experimentation will a new equilibrium be achieved. In fact, empirical evidence suggests that investment in human capital through education enhances early technology adoption and promotes greater productivity (De Souza Filho et al., 1999, Omamo and Lynam, 2003).

Based on contemporary research findings, French and Schmidt (1985) summarize four major components influencing technology acceptability and transfer as follows:

1. Technology compatibility with the biophysical and cultural environments,
2. The availability of resources that facilitate the adoption of technology,
3. The adequacy of technology to address the needs of the target population, and
4. The appropriateness of the transfer mechanism.

In order for a technology to be appropriate the first three components have to be met and channelled through a proper transfer process. The level, appropriate choice and subsequent proper use of mechanized agricultural inputs has a direct and significant effect on achievable levels of land productivity, labour productivity, the profitability of farming, and ultimately the quality of life of the farmers (Clarke, 2000).

Much of the technology-induced innovation proceeds along with the evolution in farming systems. In this context, it is relevant to mention four common sequential phases of farming system research (Clarke and Bishop, 2002, Clarke, 2000):

1. The examination of existing production systems with respects to constraints (appraisal);
2. The identification of potential improvements (experimentation);
3. The evaluation of promising product possibilities under local farmers' conditions (design); and
4. Extension to more farmers' fields (implementation).

For traditional farmers, therefore, the justification for acquiring an improved technology, to some extent, needs to conform to the features of their subsistence mode of farming. Following Morris (1985) some of its features relevant to technology change warrant important mention.

*1. Farm size and structure.*

Land characteristics such as topography, drainage, natural vegetation, and accessibility can limit mechanization feasibility. Land holdings are small for the majority of the population, with about 24% of households owning less than 0.5 ha, and a further 60% between 0.5 and 1.5 ha each (Planning Commission, 2002). Farm sizes, therefore, are generally small, and mechanization will make little headway, unless machines appropriate for smallholdings are available or substantial farm amalgamation takes place or through collective management of cooperatives.

Land tenure is quite a delicate matter in East Timor with a complexity of legal issues involved. Limited access to land ownership, or where land properties based on customary law is common, often means that farmers do not possess the collateral needed to qualify for medium-term machinery credit. Inheritance customs, combined with population pressure can lead to excessive fragmentation and dispersal of holdings. Land reform including the redistribution of land and issuing of land titles to secure land tenure is one of the solutions being proposed to the government (UNDP, 2006).

*2. Population, labour and gender.*

Family is usually the most reliable labour source. Excessive tractorization is usually associated with labour displacement in areas where labour is abundant. However the relative deterioration in access to basic social services in rural areas has forced a significant increase in rural-urban migration. Labour shortages during critical periods, such as weeding, can act as a constraint on overall productivity (MAFP, 2004).

GoTL (2003) argued that employment and creation of jobs are the core of improving living standards in East Timor. The public sector during Indonesian administration for example, employed 28,000 people, whereas the current payroll is only half that number. Therefore, creating an adequate number of formal and informal job opportunities to meet the needs of the country's youth is one of the key challenges for East Timor (GoTL, 2003).

Women play an important role in virtually all the agricultural production cycle. A survey in East Timor in 2003 indicated that of the women working in agriculture, only 1% receives cash income, as opposed to 25% working in non-agriculture. Even in the non-agriculture sector, only half the women (52%) worked throughout the year while the rest work part of the year (18%), or on an occasional basis (19%) (Ministry of Health, 2003). Observing the impact of technology on women, some researchers argue that, far from being beneficiaries, the role of women can deteriorate as a result of farm mechanization. Men are quicker to associate with machinery, leaving the unmechanized and most tedious jobs for women (Clarke and Bishop, 2002).

*3. Subsistence farming.*

Growth will have to start with agriculture, predominantly subsistent, which employs around three-quarters of the labour force. Most farmers are engaged in subsistence cultivation, employing family members on small plots of land with average holdings of around 1.2 hectares. Current productivity is low, output per worker is less than one-tenth of that in industry and services and, as a result, agriculture generates only one-fifth of GDP (UNDP, 2006).

There are two main groups of farming in East Timor namely the lowland rice and maize cultivation and upland mixed farming. The former is being gradually influenced by the use of tractorization in many production centers. The latter is still very much associated with bush-fallow and shifting cultivation. In both cases, the production is typified by low and unreliable yields, unimproved species, low use of fertilizer or animal fodder, and limited pest and disease measures[17].

*4. Low income and poverty*

One of the immediate concerns of development in East Timor is the rise of poverty across the country. About 41% of the people live below the poverty line of $0.55 per day and the percentage of those living in rural areas is even higher at 46% (World Bank, 2002). East Timor's low human development index (HDI) corresponds to a high level of poverty (UNDP, 2006).

---

[17] See Chapter 2 for a detailed overview of the traditional agriculture setting of East Timor.

A necessary condition for East Timor to alleviate this poverty level is to achieve sustained economic growth. About one-seventh of the population lives within 10% of the poverty line, suggesting that poverty is responsive to growth. However, the economy has experienced a roller coaster ride over the past five years (UNDP, 2006). The number of poor people is about 341,000 (43% of the total population). Of this, 15% live in urban areas and 85% of poverty occurs in rural areas. Consequently, poverty is mainly a rural phenomenon. Of the rural area poverty, lowland areas are home for about 47% poor while 38% live in the highlands (Planning Commission, 2002). Within this picture, it leaves little room for the introduction of any form of new technology, much of which remains expensive and inherently risky. Recent reports emphasized the urgent needs for an integral rural development aimed at empowering rural communities of East Timor to come out from the poverty-environment degradation cycle (GoTL, 2006, UNDP, 2006).

*5. Institutional support.*

Efforts to guide modern science and technology to solve poor people's food and nutrition problems are likely to be successful only if supported by appropriate policies and institutions (Pinstrup-Andersen, 2001, MAFP, 2004). Mechanization requires institutional support in the form of input supply, marketing, credit, extension and training, and adaptive research. Generally, the more capital-intensive and the less indigenous the technology, the greater are the demands for institutional support. In the long run, productivity growth is likely to come from three main sources: agricultural research, technology transfer systems (extension and education), and agricultural support facilities (Saeed, 1982, Kaimowitz, 1993, Mayer and Blaas, 2002). International research data suggests that investment in research and development raises agricultural value added sufficiently to give very satisfactory rates of return within the agricultural sector in both Africa (22%) and Asia (31%), but much less so in Latin America (10%) (Thirtle et al., 2003). For the Asia and Pacific (A-P) region, the investment in agriculture and agricultural research and technology development is low and declining - despite a very high rate of return on investment in A-P agricultural research (48 percent during 1958-98) (FAO/RAP, 2002).

## 3.8 MECHANIZATION POLICY

Given the role of mechanization in the process of getting agriculture moving, and its important social ramifications, mechanization policy becomes an important aspect of agricultural planning. International experience shows that agricultural mechanization strategy formulation has been initiated for a number of countries in partnership with the Agricultural Engineering Service (AGSE) of FAO (Clarke, 2000, Rijk, 1989). According to Clarke (2000) national governments are required to provide the basic conditions for a largely self-sustaining development of agricultural mechanization within a policy of minimum intervention.

It is particularly challenging for East Timor where its communities are by nature conservative and use only modest methods and techniques of farming. A selective mechanization is deemed necessary, as an attempt to remove smallholder power constraints, while avoiding the wasteful and undesirable effects of over-mechanization, particularly labour displacement (Morris, 1985, Schultz, 1964). This involves, by means of detailed farm management and agricultural engineering study, the identification of power peaks and the most appropriate, cost-effective way of dealing with them (Schultz, 1964).

At the present levels of productivity, it is debatable whether the average smallholder should give priority either to yield-increasing inputs such as improved seeds and fertilizers, or to mechanization. In practice the two are often inseparable. Public policies should be put in place, especially those most directly related to agriculture and rural technology development. Such policies should be carefully designed and tailored towards identifying and matching the existing ecological zones with appropriate technological innovations. An alternative view on learning, adaptation, and problem solving of science and technology proposed by Omano and Lynam (2003) is highly relevant.

The structure, management and funding of the MAFP's systems, as described earlier in Chapter 2, has become under internal scrutiny to meet the challenges of boosting agricultural productivity and national income. Given its limited size and emerging capacities, one efficient way to achieving these goals, is the need for the public sector to be decentralized and refocused on its strategic and regulatory functions. Thus, allowing the private sector to take over most of the program execution activities on a competitive and contractual demand-driven basis.

## 3.9 CONCLUDING REMARKS

Change is inevitable. The challenge is how to manage a gradual and evolutionary transformation with minimum social and cultural costs. Technical change for instance, cannot be viewed as the replacement of an entire set of traditional activities by a new set of modern activities. Certain tasks need to be modernized first, then others, until eventually the complete transition to modern farming is made. What is needed is a task-by-task analysis of the components of technology acceptability and transfer mentioned above.

From a policy point of view a 'selective approach' of mechanization is highly relevant to East Timor. It requires a careful assessment of mechanization needs, an appraisal of available technology, and the formulation of policy measures, which would encourage the development, and selection of an appropriate mechanization that supports the overall agricultural development objectives.

## REFERENCES


Amaral, Paulo (2006) (Director of HALARAE), Personal Communication.

Benevides, F. (2002) (Vice Minister of MAFP for Coffee and Forestry, formerly Director, Food Crop Division, MAFP, East Timor), Personal Communication.

Bernsten, R. H., Saefudin, Y., Maamun, Y., Igp, S., Hafsah, J., Siswosumarto, H., Siregar, M. & Sinaga, R. (1984) Consequences of the Mechanization of Land Preparation in Indonesia. South Sulawesi and Java. *Farm Power and Employment in Asia* (eds J. Farrington, F. Abeyratne & G. J. Gill), pp. 161-196. Agricultural Development Council, Bangkok.

Clarke, L. J. (2000) Strategies for Agriculture Mechanization Development, The Role Of Private Sector And The Government. AGSE, FAO, Rome, Italy.

Clarke, L. J. & Bishop, C. (2002) Farm Power - Present and Future Availability in Developing Countries. *ASAE Annual International Meeting/CIGR World Congress, 30 July 2002*. Chicago.

De Souza Filho, H. M., Young, T. & Burton, M. P. (1999) Factors Influencing the Adoption of Sustainable Agricultural Technologies: Evidence from the State of Espirito Santo, Brazil. *Technological Forecasting and Social Change,* **60,** 97-112.

Duff, B. & Kaiser, P. M. (1984) The Mechanization of Small Rice Farms in Asia. *Farm Power and Employment in Asia* (eds J. Farrington, F. Abeyratne & G. J. Gill), pp. 9-37. Agricultural Development Council, Bangkok.

FAO/RAP (1999) Selected Indicators of Food and Agricultural Development in Asia and the Pacific Region, 1988-1998. *FAO/Regional Office for Asia and the Pacific (RAP) Publication 1999/34*. Bangkok.

FAO/RAP (2002) Science and Technology for Sustainable Food Security, Nutritional Adequacy, and Poverty Alleviation in the Asia-Pacific Region. pp. 73. Food and Agriculture Organization of the United Nations, Regional Office for Asia and the Pacific, March 2002, Bangkok, Thailand.

Fox, J. (2001) Diversity and Differential Development in East Timor: Potential Problems and Future Possibilities. *East Timor: Development Challenges for the World's Newest Nation* (eds H. Hill & J. Saldanha), pp. 155-174. Institute of Southeast Asian Studies, Singapore.

French, E. C. & Schmidt, D. L. (1985) Appropriate Technology: An Important First Step in Sustainable Agriculture & Integrated Farming Systems. *1984 Conference Proceedings* (eds T. C. Edens, C. Fridgen & S. L. Battenfield), pp. 262-267. Michigan State University Press, East Lansing.

Gliessman, S. R. (1998) *Agroecology: ecological process in sustainable agriculture.* Ann Arbor Press, Chelsea MI, USA.

GoTL (2003) Timor Leste, Poverty in a New Nation: Analysis for Action. Democratic Republic of Timor-Leste, Dili, East Timor.

GoTL (2006) *Combating Poverty as a National Cause: Promoting Balanced Development and Poverty Reduction.*

Kaimowitz, D. (1993) The role of nongovernmental organizations in agricultural research and technology transfer in Latin America. *World Development,* **21,** 1139-1150.

MAFP (2004) Policy and Strategic Framework. República Democrática de Timor Leste, Ministry of Agriculture, Forestry and Fisheries, Dili, East Timor.

Mayer, S. & Blaas, W. (2002) Technology Transfer: An Opportunity for Small Open Economies. *The Journal of Technology Transfer,* **27,** 275-289.

Ministry of Health (2003) Timor-Leste 2003 Demographic and Health Survey (DHS): Key Findings. Ministry of Health, RDTL, Dili East Timor.

Morris, J. (1985) The economics of small farm mechanization. *Small Farm Mechanization for Developing Countries* (eds P. Crossley & J. Kilgour), pp. 171-184. John Wiley & Sons, New York.

Omamo, S. W. & Lynam, J. K. (2003) Agricultural science and technology policy in Africa. *Research Policy,* **32,** 1681-1694.

Pingali, P., Bigot, Y. & Binswanger, H. P. (1987) *Agricultural Mechanization and the Evolution of Farming Systems in Sub-Saharan Africa*. The John Hopkins University Press, Baltimore.

Pinstrup-Andersen, P. (2001) Appropriate Technology for Sustainable Food Security: Overview. *Appropriate Technology for Sustainable Food Security, FPRI 2020 Vision Focus 7 August 2001* (ed P. Pinstrup-Andersen), pp. 2-3. IFPRI, Washington, USA.

Planning Commission (2002) East Timor, State of the Nation Report April 2002. Dili.

Rijk, A. G. (1989) *Agricultural mechanization Policy and Strategy, The Case of Thailand*. Asian Productivity Organization, Tokyo.

Ruthenberg, H. (1985) *Innovation Policy for Small Farmers in the Tropics*. Clarendon Press, New York.

Saeed, K. (1982) Public policy and rural poverty : A system dynamics analysis of a social change effort in Pakistan. *Technological Forecasting and Social Change,* **21,** 325-349.

Saldanha, J. M. & Da Costa, H. (1999) Economic Viability of East Timor Revisited. *Working Paper 01*. ETSG, Dili, East Timor.

Salokhe, V. M. & Ramalingam, N. (1998) Agricultural Mechanization in South and South East Asia. *International Conference of the Philippines Society of Agricultural Engineers, 21-24 April, 1998*. Los Baños, Philippines.

Schultz, T. W. (1964) *Transforming Traditional Agriculture*. Yale University Press, New Haven and London.

Speedman, B. (1992) Changes in agriculture: challenges for education in agricultural engineering. *Proc. Agricultural Engineering and Rural Development Conference 2*. A Pergamon-CNPIEC Joint Publication, Beijing, China.

Thirtle, C., Lin, L. & Piesse, J. (2003) The Impact of Research-Led Agricultural Productivity Growth on Poverty Reduction in Africa, Asia and Latin America. *World Development,* **31,** 1959-1975.

Tripp, R. (2001) Agricultural Technology Policies for Rural Development. *Development Policy Review,* **19,** 479-489.

UNDP (2006) Human Development Report 2006 Timor-Leste The Path out of Poverty: Integrated Rural Development. United Nations Development Programme, Dili East Timor.

Viegas, E. (2002) Penelitian: Peranannya dalam Pembangunan Pertanian Berkelanjutan. *Suara Timor Lorosae (STL)*. Dili.

Watahiki, T. (2000) Present Situation and Mechanized Rice Cultivation in East Timor. JICA, Dili.

Wilson, P. (2000) Report of Technical Monitoring Mission, Immediate Recovery and Improvement of Agricultural Production. UNDP, Dili.

World Bank (2002) East Timor: Policy Challenges for a New Nation, Country Economic Memorandum. The World Bank, Washington D.C. USA.

www. coa.tw/english/ assessed in 2002

www. fao.org assessed in 2002

# 4 FOOD POLICY, AGRICULTURE AND ECONOMIC GROWTH[1]

## 4.1 INTRODUCTION

The economic system in East Timor that emerged from many years of Indonesian administration failed to develop an indigenous managerial capacity; promoted a culture of dependence on the government as the key provider of employment, direct transfers and subsidies; and built up an infrastructure which was very costly to maintain (MAFP, 2004, MAFP, 2005).

A small country like East Timor needs to develop economic policy guided by rationality and efficiency considerations. A rapid, broad-based and sustainable economic development is one sure means of employment creation, poverty alleviation, and improved living standards for all East Timorese. For the agricultural sector, this is in line with *"the development of an ecologically sustainable and profitable agricultural system leading towards economic self-sufficiency and competitiveness"*, as the mission statement that emerged from two major conferences on East Timor strategic development plan (CNRT, 1999, CNRT, 2000)[2]. For farming communities, this mission implies the provision of adequate, appropriate, and timely technology, services, and market access to increase their productivity and income.

For convenience, a broader discussion of macroeconomics is avoided[3]. The macroeconomic policies related to agriculture can be divided into two groups: those about which there is general agreement on the need of government intervention, and those about which disagreements still remain (Timmer, 1991). The former include agricultural research, large-scale infrastructure investment (including irrigation) and marketing infrastructure. And the latter, involve exchange rates, price

---

1 An earlier version of this chapter was presented as a paper at the 'Action Plan of the Ministry of Agriculture, Fisheries, and Forestry (MAFF) 2002-2003 Workshop', 8-9 July 2002, Dili, East Timor.

2 The National Council of Timorese Resistance (CNRT in Portuguese acronym) was the organizer of two major conferences in drafting a Sustainable Development Plan for East Timor prior to its independence. The first one was held in Melbourne Australia in 1999 and the second was in Tibar, Liquica, East Timor in 2000.

3 This topic has been dealt with quite extensively elsewhere (among others Hill and Saldanha, 2001; Tarrant, 1980; Timmer et al., 1983; and Timmer, 1998a).

interventions, land tenure, and agricultural extension. In other words, the former are mainly dealt with by budget policy, which has a direct impact on food, and agricultural policy through funding of projects, programs, and rural investments (Timmer, 1991).

This chapter aims at synthesizing relevant topics discussed earlier in previous chapters in a contextual food policy approach. A literature synthesis on food security and agricultural development is presented and some key agricultural development challenges in the future are pointed out. As argued by Timmer (1998a), there is no country in the world that has ever sustained the process of rapid economic growth without first solving the problem of food security. Putting in the context of East Timor, a special emphasis is placed on the importance of root and tuber crops in the popular diet and national economy.

## 4.2 AGRICULTURE AS THE ENGINE OF GROWTH[4]

Discussion in previous chapters has emphasized, quite extensively, the role of agriculture as the mainstay of East Timor's economy. However, to pursue agriculture as the engine of growth several conditions have to be met as outlined by Johnston and Mellor (1961). They offer five ways in which the agricultural sector can contribute to overall economic growth:

1. Meeting the food demands of a wealthier and growing urban population,
2. Increased exports as a means of earning foreign exchange,
3. Providing labour for the expanding sectors of the economy,
4. Providing capital for investment in the growing industrial sectors of the economy,
5. Increased cash incomes in the rural sector serve to increase demand for the products of the industrial sector.

The contribution of the agriculture sector into East Timor's real GDP for the years 1998, 1999 and 2000 was 24.5, 25.5 and 21.3%, respectively. Rural population working as labour in agriculture in the year 2000 was 75% of the total rural labour (Irawan, 2002). The agriculture sector, therefore, should be a priority in economic development of East Timor, as this will also help the non-agriculture sector. Apart from the Johnston and Mellor (1961) linkage mentioned above, there are two other sets of linkages between the agricultural sector and the non-agricultural sector that helps the growth of the agriculture sector (Saldanha and Da Costa, 1999).

(i) Lewis linkage: the agricultural sector provides the non-agricultural sector with labour and capital.

(ii) Timmer linkages: where the contribution of agricultural growth to productivity in the non-agriculture economy stems from several sources: greater efficiency in decision making as rural enterprises claim a larger share of output; higher productivity of industrial as urban bias is reduced; higher productivity as nutritional standards are improved; and link between agricultural profitability and household investments in rural human capital, which raise labour productivity while facilitating rural-urban migration.

Timmer (2000) also emphasizes the importance of recognizing that agriculture and the rural economy are greatly influenced by policies and outcomes in the rest of the economy. Of equally great importance are the non-market based inter-sectoral linkages through which agriculture contributes indirectly to economic growth. According to Block and Timmer (1994) these linkages arise from governmental learning by doing, increased economic stability, food security, and the relative efficiency of rural household decision-making. A study in Kenya indicates that agricultural productivity contributes significantly to non-agricultural productivity (Block and Timmer, 1994).

It is therefore very important that adequate resources in East Timor are channelled into the agriculture sector to serve as the engine of economic growth. Da Costa (1995) points out that specific objectives for East Timor's agriculture should be set primarily at increasing the level of nutrition of the people; improving the quality of agricultural commodities, livestock and fisheries for inter-district market; providing valuable agricultural products for inter-regional market, and improving the quality of commodity – coffee – for both national and overseas market[5]. Much has been said

[4] For detailed discussion on economic growth in East Timor see Saldanha, J. M. (2001) Economic Growth in East Timor. *Working Paper No. 09*. East Timor Study Group, Dili, East Timor.

[5] See Da Costa, H. (2001) Linkages between globalization, trade, investment and the environment. *Working Paper No. 07*. East Timor Study Group, Dili, East Timor. for the analysis of comparative

about poverty incidence in East Timor in previous chapters. Empowering the farmers to produce surplus food for sale is the first step on the ladder out of poverty (Hodges, 2005). And vice-versa, a study by Adelman and Berck (1990) suggests that poverty-reducing development strategies are the most food-securing strategies. Likewise, comprehensive food security and poverty alleviation must be the foremost priority of the science and technology agenda (FAO/RAP, 2002).

## 4.3 FOOD SECURITY

Based on past achievements, one could easily expect that a continued increase in food production would not really be a major problem for East Timor (World Bank, 2002, FAO/WFP, 2000). However, experiences in many countries indicate that despite their increased food production, there was still widespread malnutrition (FAO/RAP, 1999, FAO/RAP, 2002, Tarrant, 1980). Even little correlation is found between national food availabilities and food insecurity (Smith et al., 2000).

Literature also suggests that solution to food security is the pre-condition for a sustained and rapid economic growth (Timmer, 1998a). There are at least three major dimensions of food security: availability, accessibility, and utilization (Tweeten, 1997, Timmer, 2000).

1. AVAILABILITY of sufficient quantities of food of appropriate quality, supplied through domestic production or imports;

2. ACCESS by households and individuals to adequate resources to acquire appropriate foods for a nutritious diet; and,

3. UTILIZATION of food through adequate diet, water, sanitation, and healthcare.

Food policy, which encompasses a set of government efforts on food-related issues, should be put in place to be able to address such complex dimensions in a comprehensive manner (Timmer, 2000, Pinstrup-Andersen, 2000). With respect to food utilization in East Timor in particular, this study proposes incorporating as

advantages of East Timor's agriculture sector and its linkages with globalization, trade, investment and the environment.

much as possible into the domestic food policy the use of traditional food crops such as cassava, sweet potato and other root crops.

### 4.3.1 The importance of root crops

Given its importance in the national and popular diet, root and tuber crops could play an important role in feeding the growing population of East Timor. Apart from cultural considerations on the communities' familiarity with tuber and root crops, cereal production as shown by historical data suggests a continued cereal deficit over the years (Central Board of Statistics, 1997, FAO/WFP, 2000, FAO/WFP, 2003). While the urban populations consume rice as their main staple food, the rural communities still rely on maize, and root and tuber crops as their major food and nutrient sources. Despite the annual production increase of cereals, legumes, and root crops as presented in Table 4.1 and 4.2, the country is still heavily dependant on food importation and food aid to cover its national food deficit. The figures in these tables and earlier descriptions in Chapter 3 may demonstrate the significance of the root and tuber crops in relation to other major food crops.

A number of studies suggests that many of the developing world's poorest farmers and food insecure people are highly dependent on root and tuber crops as a contributing, if not the principal, source of food, nutrition, and cash income (Scott et al., 2000, FAO/WFP, 2000, FAO/WFP, 2003). Hence, an improved understanding of the production, utilization, trade, and estimated future economic importance of these crops has potentially far-reaching implications for investments in agricultural research at both the international and, more importantly, national levels (Scott et al., 2000).

Empirical energetic significance of root /tuber crops and their contribution in rural industries may be, among other factors, of great relevancy to East Timor. Evenson and De Boer (1978), analysing aggregate data on worldwide energy production and resource allocation in semi-subsistence food production system, emphasized the potential contribution of increased root and tuber crop productivity in food energetics. They conclude that, within their environmental range, the major tropical root and tuber crops are capable of superior energy yields over most other food crops both in monoculture and mixed cropping and therefore can be the dominant factor in raising energy output per unit area in either pure or mixed stands.(Evenson and De Boer, 1978). In Asia, root and tuber crops (cassava, sweet potato and potato) supply most of the starch used by industries, largely rural-based, where small firms coexist with large starch mills to provide intermediate processing despite diseconomies of scale (Fuglie, 2004).

Research on cassava and pulse in East Timor is increasing under the Seeds of Life Project with some promising results. Severely limiting soil iron and zinc concentrations to newly introduced cassava breeding lines were found in Baucau and Betano. Such micronutrient deficiencies are usually very easy and inexpensive to rectify. In spite of that, these lines significantly out-yielded the local cassava varieties (Howeler et al., 2003). Sweet potato and cassava developmental status and future prospects have been presented by Setyono et al. (1992).

Especially with regards to tillage[6], root and tuber crops are sensitive to soil compaction, inadequate aeration or poor drainage and therefore respond favorably to intensive tillage, followed by ridging or mounding (FAO/WFP, 1994, Howeler et al., 1993). However, large differences exist between crops, with potato, sweet potato and yam requiring more intensive cultivation than cassava and taro (Howeler et al., 1993). In order to reduce erosion as well as production costs, cassava should be grown with as little tillage as possible as long as high yield can be maintained. Contour ridging and mulching are other practices that not only tend to increase yields but also reduce erosion losses.

### 4.3.2 Food supply

Food availability highlights supply of food (from production, stocks and imports) at the national level and production and inventory at the farm level. There are no major problems facing the population in terms of food supply according to FAO/WFP assessment reports (FAO/WFP, 2000, FAO/WFP, 2003). The national requirements for major staple food have been estimated at 182,000 tons for 2003/4, while the domestic production only reached two thirds of the requirements (122,000 tons). The deficit was covered by importation and food aid (FAO/WFP, 2003).

[6] Tillage practices and their impacts on soil losses and crop and biomass yield will be the main focus of discussion in Chapter 5 and 6.

Table 4.1 East Timor major staple food crops: cropping area, production and yield 1992-1997

| Crop | Variable | Year | | | | | |
|---|---|---|---|---|---|---|---|
| | | ***1992*** | ***1993*** | ***1994*** | ***1995*** | ***1996*** | ***1997*** |
| Rice | Hectares | 18,897 | 19,860 | 21,740 | 18,084 | 21,202 | 21,711 |
| | Tonnes | 56,359 | 64,060 | 66,985 | 46,696 | 69,465 | 71,958 |
| | Tonnes/Ha | 2.98 | 3.23 | 3.08 | 2.58 | 3.28 | 3.31 |
| Maize | Hectares | 60,423 | 61,056 | 62,020 | 56,138 | 64,434 | 63,388 |
| | Tonnes | 94,354 | 104,424 | 115,680 | 103,039 | 122,493 | 126,321 |
| | Tonnes/Ha | 1.56 | 1.71 | 1.87 | 1.84 | 1.90 | 1.99 |
| Cassava | Hectares | 13,312 | 12,940 | 19,101 | 18,994 | 19,490 | 20,515 |
| | Tonnes | 51,568 | 69,910 | 74,318 | 75,642 | 78,125 | 85,287 |
| | Tonnes/Ha | 3,87 | 5,40 | 3,89 | 3,98 | 4,01 | 4,16 |
| Sweet potato | Hectares | 2,749 | 4,052 | 5,167 | 4,634 | 4,304 | 4,271 |
| | Tonnes | 10,433 | 19,114 | 18,026 | 18,246 | 17,111 | 17,648 |
| | Tonnes/Ha | 3.80 | 4.72 | 3.49 | 3.94 | 3.98 | 4.33 |

Source: Central Board of Statistics (1997)

Table 4.2 East Timor major legumes: cropping area, production and yield 1992-1997

| Crop | Variable | Year | | | | | |
|---|---|---|---|---|---|---|---|
| | | ***1992*** | ***1993*** | ***1994*** | ***1995*** | ***1996*** | ***1997*** |
| Mung beans | Hectares | 4,754 | 4,986 | 1,424 | 2,963 | 3,823 | 3,977 |
| | Tonnes | 3,926 | 4,238 | 1,199 | 2,496 | 3,688 | 4,079 |
| | Tonnes/Ha | 0.83 | 0.85 | 0.84 | 0.84 | 0.96 | 1.03 |
| Peanut | Hectares | 3,367 | 3,597 | 4,701 | 3,845 | 4,846 | 5,095 |
| | Tonnes | 2,929 | 3,201 | 4,513 | 3,811 | 5,124 | 5,500 |
| | Tonnes/Ha | 0.87 | 0.89 | 0.96 | 0.99 | 1.06 | 1.08 |
| Soybean | Hectares | 1,524 | 1,867 | 851 | 1,148 | 1,184 | 1,399 |
| | Tonnes | 1,230 | 1,587 | 809 | 915 | 1,381 | 1,686 |
| | Tonnes/Ha | 0.81 | 0.85 | 0.95 | 0.80 | 1.17 | 1.21 |

Source: Central Board of Statistics (1997)

### 4.3.3 Access to food sources

Food accessibility concerns the effective demand and purchasing power of consumers. It is obvious from the present situation that food security is primarily a function of buying power from earnings or transfers. Main development indices show that the majority of the population falls below the poverty line (GoTL, 2006, UNDP, 2006). Food self-sufficiency, as was the core objective of development of the food sector in East Timor during the past decade, should be de-emphasized allowing more focus on food security (MAFP, 2004).

The literature suggests that no matter how much food is produced it will have little effect on those who are unable to buy it (FAO/RAP, 1999, FAO/RAP, 2002, Tarrant, 1980). India for example, in the 1976, 1977, and 1978 had considerable stocks of grain after three successive good production years (Tarrant, 1980). Imports were reduced to zero and in certain special circumstances India began exporting grains. Despite this there was still widespread malnutrition and yet further improvements in production would have done little to remove this (Tarrant, 1980).

To combat hunger and poverty, it is worthwhile learning lessons from other countries and a quite useful lesson would be that of Indonesia. Indonesia used the agricultural sector and the rural economy to provide the foundation that permits the development strategy to pursue growth, stability, and equity simultaneously and to pursue them in a complementary rather than a competitive fashion (Timmer, 1998b). It implies structuring the development growth process from the very beginning to help solve the problem of poverty. From a broader view of development it inevitably means finding a strategy for raising the productivity of rural labour, and emphasizes the agricultural development of small farmers.

Projecting from the current situation, it is not unexpected that in the short-run food insecurity may prevail in many areas, affecting a large number of people. Currently, this lack of access to food is due to disruption of internal markets, poor roads, and limited means of transportation, as well as the loss of productive assets and income generating activities. At the microeconomic level, inadequate and irregular access to food limits labour productivity and reduces investment in human capital. At the macroeconomic level, periodic food crises undermine political and economic stability, reducing both the level and the efficacy of investment (Timmer, 1998a). An appropriate domestic food policy is expected to remove this food insecurity.

### 4.3.4 Food and nutrition

Ideally, food security means that all persons at all times utilize the food necessary for an active and healthy life (Tweeten, 1997). People may still experience food insecurity if food is available and accessible, but they fail to consume adequate nutrients. It is therefore, a matter of great concern that consideration be given to other vital food security components such as education, information systems, health, and nutrition.

From a nutritional point of view, however, the crucial variable may be food production, rather than agricultural production as a whole. In this regard, it is worthy of attention to include traditional food crops such as maize, cassava, sweet potato, and other root crops in the domestic food policy. Historically, policy makers and researchers have paid very little attention to root crops, as most of their efforts have been concentrated on cash crops or the more familiar grains. Root crops were regarded as food mainly for the poor, and have played a very minor role in the international trade (FAO/WFP, 1994). According to this source, very few people from tropical countries suffer from a simple protein deficiency. The most prevalent deficiency is protein-energy, in which an overall energy deficiency forces the metabolism to utilize the limited intake of protein as source of energy. This is an area in which root crops could play a more significant role as additional source of dietary energy and protein.

A short summary of nutritional values comparing selected foodstuffs is given below:

**Box 4. Nutritional comparison of rice, root/tuber, legumes and edible greens** (Bradbury and Holloway, 1988)

| | |
|---|---|
| **Energy** | rice (boiled) ~ *root crops* ~ legumes > edible greens |
| **Protein** | legumes > edible greens > rice (boiled) > *root crops* |
| **Minerals (Ca, Fe)** | legumes > edible greens ~ *root crops* > rice |
| **Vitamins** | edible greens > *root crops* ~ legumes > rice |

The contribution of root crops in the domestic diet may be insignificant for the time being, due to the low yields. However their genetic potential for producing increased yields is high and has not yet been fully exploited. In addition, some root crops are highly adaptable, producing reasonable yields from marginal lands with highly erratic rainfalls. This very fact has heightened the attention being paid to tuber crops in many countries in Africa e.g. Kenya and Zambia (FAO/WFP, 1994), Indonesia (Setyono et al., 1992) and the South Pacific (Bradbury and Holloway, 1988). In the case of East Timor, the misconception that root crops are a poor food source has long prevailed, partly because of the lack of appreciation of the number of people who depend on these root crops, and the number of lives that have been saved during the struggle for independence by root crops. Therefore, more attention should be given to the potential of root crops by researchers and policy makers in the future.

## 4.4 A FOOD POLICY APPROACH

Literature and evidence in many countries suggest that food security is inseparable with overcoming poverty. Because poverty is a function of the level and distribution of national income, food security cannot be separated from economic development. In essence, according to Tweeten (1997), food security embodies disciplines ranging from nutrition at the individual level, to family economics at the household level, to all-weather road construction and maintenance at the regional level, to the economic development policy at the national level, and to trade and aid at the international level. At the national level food security has two principal components: (i) broad-based, sustainable economic progress relying on the private sector under supportive public policies to raise most people out of poverty and food insecurity; and (ii) targeted food grants to those who lack resources and income or other means of food security.

Food policy encompasses the government collective efforts to influence the decision-making environment of food producers, food consumers, and food marketing agents (Timmer et al., 1983) in order to address the issues of food security mentioned above. The objectives of a national food policy in most societies, which are of great relevancy to East Timor, are:

1. Efficient growth in the food and agricultural sectors,
2. Improved income distribution, primarily through efficient employment creation,
3. Satisfactory nutritional status for the entire population through provision of a subsistence floor,
4. Adequate food security to ensure against bad harvests, natural disasters, or uncertain world food supplies and prices.

It is not within the scope of this paper to provide a food policy analysis, as it involves research and analysis on food policy components and objectives, and the identification of government initiatives to achieve these objectives. Rather, a general overview on food policy as part of economic development is provided. As has been mentioned earlier, food security, which embodies the above objectives, is an inherent part of economic development. And according to Timmer (1998a) the food and agricultural sector cannot grow rapidly and efficiently for prolonged periods of time unless a set of macroeconomic policies is in place whose main purpose is to stimulate the rest of the economy to grow rapidly and efficiently.

### 4.4.1 Research and extension

Agricultural research and extension in the future can have a very high economic payoff. It is worth trying to do in-country basic research, but the payoff is usually higher from applied research emphasizing the local adaptation of technologies from elsewhere (Thirtle et al., 2003, FAO/RAP, 2002). It is widely recognized that the major impetus behind technological change is research and development, while education and experience are critical to improving managerial capabilities to make efficient use of a given technology (Bravo-Ureta, 2002).

Extension has traditionally been considered a role of government. However, it is worthwhile to consider that the government may not be able to provide free extension services to all farmers during the post-transitory period. The government schemes may not be the most effective in providing services, and a more workable approach may be to pass the extension role to the private sector including NGO's (Nitta and Yoda, 1995, Fujisaka, 1994), in other words, through the privatisation of extension service (Bravo-Ureta, 2002).

### 4.4.2 Infrastructure

Road, bridge, seaport, airport, electricity, communication, and major irrigation facilities are among the basic infrastructure facilities the WB-JAM put forward as priorities in the reconstruction phase (WB-JAM, 1999). These facilities in the short and long run can be worthy public investments serving the private sector and food security. In addition, appropriate infrastructure makes private markets work well and raises national income. Sen (1989) suggests for a public distribution system geared to the needs of the vulnerable sections of the community can bring the essentials of livelihood within easy reach of people whose lives may remain otherwise relatively untouched by the progress of real national income.

### 4.4.3 Price interventions

Price interventions generally cover three main areas: agricultural input price policy, agricultural product policy, and agricultural finance policy. A common operational approach in the macroeconomic context is food price stabilization, which confers several benefits (Timmer, 1989). For food producers, it reduces the risk they face making productive investments. The reduced risk may help by promoting farmers' investments in new innovations and technologies leading to increased farm productivity. Consumers benefit from stable food prices because they do not have to incur the transaction costs from reallocating their budgets frequently, nor face the risk of a sudden and sharp deterioration in their real income.

### 4.4.4 Land tenure

The key issue in land tenure policy is how it can be used to improve both equity and efficiency. One way of increasing rural employment and agricultural production is through reallocation of the resources of production, especially land. Land reform including the redistribution of land and issuing of land titles to secure land tenure is one of the solutions being proposed to the government (UNDP, 2006). The land reform in Tawain (1949-53) is an example of successful land tenure promoting widespread technical change in Tawainese agriculture of today (Griffin, 1979). African experience suggests two viable ways to improve the food security status of the landless and the land-poor farmers. First, is to give them access to land, and secure their use rights by implementing a land redistribution policy. Second is to enable the landless to engage in viable non-farm employment opportunities (Tolossa, 2003).

## 4.5 CHALLENGES FOR THE FUTURE

### 4.5.1 Urbanization and production demand

In the future, a massive urbanization will be of major concern, needing especial attention. An increased need is foreseen for basic infrastructure, as well as urban-oriented food security policies (McCalla, 1998). With these changes will come the need for increased investment in 'the beyond the farm gate marketing system' to accommodate a very large increase in the demand for marketing services. According to McCalla (1998), at least five factors will contribute to the increase in this demand: (a) expanded use of purchased inputs in intensified farming systems; (b) a more than doubling of the volume of food moving from farms to towns and cities; (c) the income induced demand for perishable products (fruits, vegetables, and animal products); (d) increased demand, with rising incomes, for additional services (e.g., packaging, portion control, and location) to be incorporated into food; and (e) the possibility of expanded non-traditional exports to industrial countries.

### 4.5.2 Labour and mechanization

There are some problems and prospects of agricultural mechanization in the developing countries, some of which have been discussed earlier in Chapter 3 (Morris, 1985, El-Hossary, 2002). They are farm size and tenure, characteristics of tractor stock (ownership, condition and annual use), management and technical problems, institutional aspects of farm mechanization (extension service, research and training institutions, repair and maintenance network and local production of farm equipment). In addition, trends of agricultural mechanization in most technological advancing countries are energy saving in agricultural mechanization and research and development in the world of industry (El-Hossary, 2002).

Table 4.3 describes the composition of work force in East Timor. Both the rural and urban labour forces are estimated to be on the rise in the next 10 years. Many of the factors stimulating labour demand become, in the right circumstances, a stimulation for farm mechanization and hence lead to a reduction in labour demand (Tarrant, 1980). Where multiple cropping is possible, speed is of the essence in the preparation of the ground and the planting of each crop. Similarly, the harvest must be quickly accomplished to clear the ground for the next crop. Government fiscal policies may actively encourage mechanization. International aid from some donor countries to East Timor is channelled in the form of farm machinery, and this may encourage mechanization as well. Government-sponsored schemes for the provision of rural credit, especially as these generally favour larger farmers whose lands make suitable collateral for loans, may encourage the purchase of machinery at low real prices (MAFP, 2004).

Table 4.3 Composition of the work force in East Timor (thousands)

| **Indicator** | **2004** | **2007** | **2010** | **2015** |
|---|---|---|---|---|
| **Rural labour force** | 206.9 | 229.8 | 255.4 | 300.7 |
| - Subsistence farming | 139.7 | 152.9 | 165.0 | 177.2 |
| - Commercial activities | 67.2 | 76.8 | 90.4 | 123.5 |
| **Urban labour force** | 61.0 | 72.2 | 85.6 | 113.5 |
| - Public sector | 17.5 | 19.5 | 23.0 | 30.0 |
| - Private sector | 43.5 | 52.7 | 62.6 | 83.5 |
| **Unemployed** | 21.4 | 23.4 | 25.7 | 28.8 |
| **Total work force** | 289.3 | 325.4 | 366.7 | 443.0 |
| **Memo items:** | | | | |
| - Subsistence farming (%) | 48.3 | 47.0 | 45.0 | 40.0 |
| - Unemployed (%) | 7.4 | 7.2 | 7.0 | 6.5 |
| - Rural labour force | 77.2 | 76.1 | 74.9 | 72.6 |

Source: GoTL (2006)

The effect of farm mechanization is to create the need for a small, skilled labour force to use and maintain the equipment. However, farm sizes are generally small, and mechanization will make little headway unless either technology provides machines appropriate for smallholdings or substantial farm amalgamation takes place. But where conditions are less suitable (for example irrigated land is a smaller proportion of cultivated land) and provided government incentives are available to the farmer through cheap credit, and to manufacturing industry through tariff policies and subsidies, mechanization will displace substantial quantities of rural labour.

### 4.5.3 Productivity growth

Future productivity growth is likely to come from three main sources: agricultural research, technology transfer systems (extension and education), and agricultural support policies. Over the long-term, the challenge for researchers will be to continue to shift the production frontier upward (outward) through development of new technologies. The major source of upward movement will continue to be varietal improvement (Morris and Byerlee, 1998). In East Timor however, it is worthwhile to de-emphasize the introduction of the high yielding varieties (HYV's) seeds, allowing more focus on the improvement of local seeds. The encouragement of the use of these modern varieties in many countries to reduce their imports of food has been made possible so far only by subsidizing both inputs and outputs. One of the major inputs is fertilizer. And for a newborn country, subsidies for farming inputs and outputs could be very costly and therefore a careful analysis on selective subsidy policies is required (MAFP, 2004).

Decentralization in agricultural research will be required, leading to it being more strongly farmer-oriented, and more closely linked to the technology dissemination process. Greater farmer participation will be needed to adapt technologies to local circumstances, to improve the efficiency of technology transfer activities. Farmer organizations will increase in importance relative to individual farmers, because many new informational technologies will have to be managed at the district and village levels (Fujisaka, 1994, MAFP, 2005). The emphasis in technology dissemination will have to shift from communication to education. Instead of merely seeking to deliver specific messages to farmers, extension agents will have to concentrate on providing farmers with the knowledge and skills needed to better manage information-intensive technologies. Agricultural support policies also will have to change to accommodate the emerging information-based technologies from input subsidies to increased investment in public good aspects of technology development and dissemination (Kaimowitz, 1993, Saeed, 1982).

### 4.5.4 Agricultural sustainability

The agricultural system must be both sustainable and highly productive in the future if it is to feed the growing human population. For this twin challenge to be met, Poincelot (1986) recommended a new approach to agriculture and agricultural development that builds on resource-conserving aspects of traditional, local, and small-scale agriculture while at the same time drawing on modern ecological knowledge and methods. Traditional agriculture, despite its market limitations, can provide models and practices valuable in developing sustainable agriculture. The mainstream approach to modernizing agriculture on the other hand, apart from its successes promoted by scientific advances and technological innovations, has led to dependency on external inputs, e.g. seed, fertilizer, pesticides, machinery and fossil fuels (Gliessman, 1998).

In essence, agricultural practices tend to degrade the resource base and the challenge for modern agriculture is to minimize this degradation. East Timor, as a semi-arid region, has a different dimension as here one is dealing with low-input technology, and resource-poor farmers working in a highly unpredictable agroclimate and with a highly variable and low quality natural resource base. In this context, sustainable agriculture is largely a function of the socioeconomic conditions and is frequently controlled by these conditions. A great challenge for East Timor agriculture scientists in the future is to find alternative ways to increase agricultural productivity while preserving or even improving the agricultural resource base.

## 4.6 CONCLUSIONS

This chapter concludes by stressing the importance of solving the problem of food security if the process of a rapid economic growth is to be sustained. Three dimensions of food security, namely food availability, accessibility, and utilization have been briefly highlighted. Because food security concerns primarily the buying power of ordinary citizens, it is inseparable with poverty. Furthermore, poverty in turn, is a problem that can be solved only by profitable and equitable economic development. In this context, an appropriate domestic food policy may help reduce hunger and poverty. The incorporation of the traditional food crops into the domestic food policy is especially put forward into discussion.

Challenges in the future, both for the government and private sectors are undoubtedly enormous. Production demand in view of potential massive urbanization, productivity growth demand, debate of rural labour versus mechanization, and more importantly the urgent need for a sustainable agricultural strategy are among the main topics challenging East Timor agriculture in the future.

## REFERENCES

Adelman, I. & Berck, P. (1990) Food security policy in a stochastic world. *Journal of Development Economics,* **34,** 25-55.

Block, S. & Timmer, C. P. (1994) Agriculture and Economic Growth: Conceptual Issues and the Kenyan Experience. HIID Harvard University.

Bradbury, J. H. & Holloway, W. D. (1988) Chemistry of tropical root crops: significance for nutrition and agriculture in the Pacific. Australian Centre for International Agricultural Research, Camberra.

Bravo-Ureta, B. E. (2002) Research, extension, and information: key inputs in agricultural productivity growth. *Pakistan Development Review,* **41**.

Central Board of Statistics (1997) *East Timor in Figures 1997.* East Timor Province and Central Board of Statistics of East Timor Province, Dili East Timor.

CNRT (1999) Strategic Development Planning for East Timor Conference Report. *Strategic Development Planning for East Timor Conference, 5-9 April 1999.* Melbourne, Australia.

CNRT (2000) Reconstruction: Review of the Past and Perspective for the Future Conference Report. *Reconstruction: Review of the Past and Perspective for the Future Conference, 30 May - 2 June 2000.* Tibar, East Timor.

Da Costa, H. (1995) Social and Economic Problems of Agricultural Development in Semi Arid East Timor. *International Conference on Agricultural Development in Semi Arid Areas of East Nusa Tenggara, East Timor and Southeast Maluku 10-16 December 1995.* Kupang, East Nusa Tenggara.

Da Costa, H. (2001) Linkages between globalization, trade, investment and the environment. *Working Paper No. 07.* East Timor Study Group, Dili, East Timor.

El-Hossary, A. M. (2002) Planning and management in agricultural mechanization for developing countries. *Proceedings 8th International Congress on Mechanization and Energy in Agriculture, Kusadasi, Turkey, 15-17 October 2002.*

Evenson, J. P. & De Boer, A. J. (1978) Role of root and tuber crops in food production strategy for semi-subsistence agriculture. *Agricultural Systems,* **3,** 221-232.

FAO/RAP (1999) Poverty Alleviation and Food Security in Asia: Enhancing Forestry and Agroforestry Contributions. pp. 57. Food and Agriculture Organization of the United Nations, Regional Office for Asia and the Pacific, January 1999, Bangkok, Thailand.

FAO/RAP (2002) Science and Technology for Sustainable Food Security, Nutritional Adequacy, and Poverty Alleviation in the Asia-Pacific Region. pp. 73. Food and Agriculture Organization of the United Nations, Regional Office for Asia and the Pacific, March 2002, Bangkok, Thailand.

FAO/WFP (1994) Tropical root and tuber crops. *FAO Plant Production and Protection Paper 126.* FAO/WFP, Rome, Italy.

FAO/WFP (2000) Crop and Food Supply Assessment Mission To East Timor: Special Report, April 2000. (ed W. F. Program/FAO). WFP/FAO, Rome.

FAO/WFP (2003) Crop and Food Supply Assessment Mission to Timor-Leste, Special Report, 1 June 2003. Food and Agriculture Organization of the United Nations, World Food Programme, Rome.

Fuglie, K. O. (2004) Challenging Bennet's law: the new economics of starchy staples in Asia. *Food Policy,* **29,** 187-202.

Fujisaka, S. (1994) Learning from six reasons why farmers do not adopt innovations intended to improve sustainability of upland agriculture. *Agricultural Systems,* **46,** 409-425.

Gliessman, S. R. (1998) *Agroecology: ecological process in sustainable agriculture.* Ann Arbor Press, Chelsea MI, USA.

GoTL (2006) *Combating Poverty as a National Cause: Promoting Balanced Development and Poverty Reduction.*

Griffin, K. (1979) *The political economy of agrarian change: an essay on the green revolution.* Macmillan, London.

Hodges, J. (2005) Cheap food and feeding the world sustainably. *Livestock Production Science,* **92,** 1-16.

Howeler, R. H., Ezumah, H. C. & Midmore, D. J. (1993) Tillage systems for root and tuber crops in the tropics. *Soil and Tillage Research,* **27,** 211-240.

Howeler, R. H., Palmer, B., Hartojo, K. & Piggin, C. (2003) Evaluation of cassava and bean germplasm in East Timor. *Agriculture: New Directions for a New Nation East Timor (Timor-Leste)* (eds H. d. Costa, C. Piggin, C. J. d. Cruz & J. J. Fox), pp. 95-101.

Irawan, P. B. (2002) Human Development Indicators for East Timor. BPS-Statistic Indonesia and UNDP East Timor.

Johnston, B. & Mellor, J. (1961) The Role of Agriculture in Economic Development. *American Economic Review,* **51,** 566—93.

Kaimowitz, D. (1993) The role of nongovernmental organizations in agricultural research and technology transfer in Latin America. *World Development,* **21,** 1139-1150.

MAFP (2004) Policy and Strategic Framework. República Democrática de Timor Leste, Ministry of Agriculture, Forestry and Fisheries, Dili, East Timor.

MAFP (2005) Preliminary Report on Donor's Agricultural and Rural Development Conference, 3-5 March 2005. Ministério da Agricultura, Florestas e Pescas, RDTL, Dili, East Timor.

McCalla, A. F. (1998) Agriculture and Food Needs to 2025. *International Agricultural Development* (eds C. K. Eicher & J. M. Staatz), pp. 39-54. John Hopkins University Press, Baltimore Md.

Morris, J. (1985) The economics of small farm mechanization. *Small Farm Mechanization for Developing Countries* (eds P. Crossley & J. Kilgour), pp. 171-184. John Wiley & Sons, New York.

Morris, M. & Byerlee, D. (1998) Maintaining Productivity Gains in Post-Green Revolution Asian Agriculture. *International Agricultural Development* (eds C. K. Eicher & J. M. Staatz), pp. 458-473. John Hopkins University Press, Baltimore, Md.

Nitta, Y. & Yoda, S. (1995) Challenging the human crisis: "The trilemma". *Technological Forecasting and Social Change,* **49,** 175-194.

Pinstrup-Andersen, P. (2000) Food policy research for developing countries: emerging issues and unfinished business. *Food Policy,* **25,** 125–141.

Poincelot, R. P. (1986) *Toward a more sustainable agriculture.* Avi Publishing Company, Inc., Westport, Connecticut, USA.

Saeed, K. (1982) Public policy and rural poverty : A system dynamics analysis of a social change effort in Pakistan. *Technological Forecasting and Social Change,* **21,** 325-349.

Saldanha, J. M. (2001) Economic Growth in East Timor. *Working Paper No. 09*. East Timor Study Group, Dili, East Timor.

Saldanha, J. M. & Da Costa, H. (1999) Economic Viability of East Timor Revisited. *Working Paper 01*. ETSG, Dili, East Timor.

Scott, G. J., Rosegrant, M. W. & Ringler, C. (2000) Global projections for root and tuber crops to the year 2020. *Food Policy,* **25,** 561–597.

Sen, A. (1989) Food and Freedom. *World Development,* **17,** 769-781.

Setyono, A., Damardjati, D. S. & Malian, H. (1992) Sweetpotato and cassava development: Present status and future prospects in Indonesia. *Product Development for Roots and Tuber Crops* (eds G. I. Scott, S. Wiersema & F. P.I.), pp. 29-40. International Potato Center (CIP), Lima, Peru.

Smith, L. C., El Obeid, A. E. & Jensen, H. H. (2000) The geography and causes of food insecurity in developing countries. *Agricultural Economics,* **22,** 199-215.

Tarrant, J. (1980) *Food Policies*. John Wiley & Sons Ltd., New York.

Thirtle, C., Lin, L. & Piesse, J. (2003) The Impact of Research-Led Agricultural Productivity Growth on Poverty Reduction in Africa, Asia and Latin America. *World Development,* **31,** 1959-1975.

Timmer, C. P. (1989) Food price policy : The rationale for government intervention. *Food Policy,* **14,** 17-27.

Timmer, C. P. (1991) The role of the state in agricultural development. *Agriculture and the State: Growth, Employment, and Poverty in Developing Countries* (ed C. P. Timmer), pp. 1-28. Cornell University Press, Ithaca.

Timmer, C. P. (1998a) The Macroeconomics of Food and Agriculture. *International Agricultural Development* (eds C. K. Eicher & J. M. Staatz), pp. 187-211. John Hopkins University Press, Baltimore, Md.

Timmer, C. P. (1998b) The role of agriculture in Indonesia's development. *International Agricultural Development* (eds C. K. Eicher & J. M. Staatz), pp. 539-549. John Hopkins University Press, Baltimore, Md.

Timmer, C. P. (2000) The macro dimensions of food security: economic growth, equitable distribution, and food price stability. *Food Policy,* **25,** 283-295.

Timmer, C. P., Falcon, W. P. & Pearson, S. R. (1983) *Food Policy Analysis.* John Hopkins University Press, Baltimore Md.

Tolossa, D. (2003) Issues of land tenure and food security: the case of three communities of Munessa wereda, south-central Ethiopia. *Norwegian Journal of Geography,* **57,** 9-19.

Tweeten, L. G. (1997) Food security. *Promoting Third-World Development and Food Security* (eds L. G. Tweeten & D. G. McClelland), pp. 225-256. Praeger Publishers, Connecticut.

UNDP (2006) Human Development Report 2006 Timor-Leste The Path out of Poverty: Integrated Rural Development. United Nations Development Programme, Dili East Timor.

WB-JAM (1999) East Timor, Building a Nation, a Framework for Reconstruction and Development; Agriculture Background Paper. The World Bank Joint Assessment Mission.

World Bank (2002) East Timor: Policy Challenges for a New Nation, Country Economic Memorandum. The World Bank, Washington D.C. USA.

# 5 TILLAGE AND EDAPHIC CHANGES Impacts on crop and biomass production

## 5.1 INTRODUCTION

In recent decades, the possible adverse effects of conventional tillage on the agricultural resource base have become increasingly apparent. Greater attention is turned to techniques that require less disruption of the land itself, introducing new soil and water management techniques (Barkin, 2001) and other alternative management methods. Many of these alternatives have been based upon the principle of reducing the number and intensity of tillage operations, which are commonly known as conservation tillage practices (Gajri et al., 2002). The most obvious advantage of conservation tillage from an environmental viewpoint is its role in minimizing the risk of erosion. Surface residues protect soil structural conditions at the surface from the energies of raindrop impact and surface flow and the soil losses due to wind erosion. Aggregate breakdown, surface sealing and crusting, and clogging of worm holes or voids between structural units is reduced (Bradford and Huang, 1994).

Riley et al. (1994) suggested that many of the changes caused by conservation tillage practices are interrelated, and their consequences may be of greater or lesser importance, depending on the soil type and on the external constraints of the climate. These changes can be summarized as follows:

- Accumulation of available nutrients (phosphorus and potassium) and organic matter near the soil surface;
- Increased bulk density and penetration resistance in upper and central topsoil layers;
- Lower air-filled porosity and gaseous exchange and, sometimes, higher water-holding capacity;

- Lower surface infiltration rates, but in some cases, increased hydraulic conductivity between topsoil and subsoil; and
- Greater aggregate stability, greater earthworm activity, and more favourable conditions for promoting pore continuity.

Holland (2004) summarizes that conservation tillage can improve soil structure and stability thereby facilitating better drainage and water holding capacity that reduces the extremes of water logging and drought. These improvements to soil structure also reduce the risk of runoff and pollution of surface waters with sediment, pesticides and nutrients. In addition, by reducing the intensity of soil cultivation it lowers energy consumption and the emission of carbon dioxide, while carbon sequestration is raised though the increase in soil organic matter (SOM).

This chapter aims to present some empirical evidence based on field experiments on how different tillage systems exert different impacts on soil properties and crop performances. Of prime importance is to find out specific relationships between selected parameters under study and to contribute to a better understanding of soil – machine – crop interactions. Supported by research data from other sources, the discussion will help complement the topics discussed in the early chapters. With chapter 2, particularly on the issue of traditional shifting cultivation, this study helps to support policy design to avoid replacing the slash and burn, especially on the slopes, with intensive tillage-based cropping systems. Moreover, the use of manual tillage in this study may provide insights and confirm some research findings discussed in chapter 3 on mechanization. In addition, potato as a tuber crop is tested under various tillage management systems, which can also make relevant contributions to the discussion on food policy in chapter 4.

Due to a wide range of resource limitations, it was not possible to set up specific experiments or field surveys in East Timor to address the issues discussed in the respective chapters. This research therefore was limited only to study the impacts of soil tillage on selected soil physical and chemical properties to provide an assessment of soil structure suitability for crop production management. As part of the broader objectives stated earlier, the assessment was contextually employed into two contrasting environmental settings. The semi-arid environment of East

Timor with its generally traditional mode of farming was the first focal point (Experiment 1 - ET). However, due to the lack of supporting systems, and partly because of financial and time constraints, the establishment of a proper experimental station could not be realized in East Timor. Instead, only a small experiment was carried out in a local farmer's paddy rice field on the outskirts of Dili, the capital of East Timor. Due to the limitations cited above, this experiment was merely designed as a quick test of the research methodology to a specific environmental condition of East Timor. In anticipation of the minimal results from this fieldwork, and to complement these results with others from a different environmental background, another set of experiments was carried out at Massey University Campus in Palmerston North, New Zealand (Experiment 2 - NZ).

### 5.1.1 Scope and limitations

This study covers changes in selected soil physical and chemical properties that occur as a result of implementing different tillage systems. Their impacts on crop yield and biomass are also investigated.

It is acknowledged however, that the results obtained under New Zealand conditions are not transferable to East Timor's as such given the site-specific and crop-specific nature of an experiment of this kind. Contrasting soil and climatic conditions in these two countries strongly dictate each own specific characteristic for tillage and crop production research. Nevertheless the principles and lessons can be learnt and the results may contribute both ways, to East Timor and to New Zealand, in finding a better understanding of a traditional farming system and in seeking better ways to preserve soil and water resources for a sustainable agriculture.

### 5.1.2 Objectives

The specific objectives of this research were:

(i) To measure selected soil physical and chemical properties under different tillage systems i.e. no-tillage, manual tillage, mouldboard plough (ET) and permanent pasture (NZ) (as control treatment). The important soil properties considered in this research are soil penetration resistance, soil bulk density, soil water content, soil hydraulic conductivity, soil porosity, soil aggregate stability, and selected soil chemical properties such as soil pH, total C and N and Olsen P.

(ii) To measure and compare selected crop yield and total biomass of corn, mungbeans, potato, barley, and weeds under a semi-arid and temperate climate as affected by different tillage treatments.

(iii) To examine the relationship between soil physical and chemical characteristics and crop and biomass production mentioned above. The discussion is further focused on the extension of improvement of such soil properties and their impacts on crop and biomass resulted from the untilled plots relative to the conventionally cultivated plots.

## 5.2 LITERATURE REVIEW

### 5.2.1 Introduction

Tillage is a major input in agricultural production aiming at optimising crop production and conserving or improving production resources. It is traditionally carried out by the use of plough, an ancient tool for soil and seedbed preparation. Ploughing, despite its long history, is still among the least scientifically understood practices in terms of its impact on soil and environment quality and on the sustainable use of natural resources (Lal, 2004a). It is performed to bury the crop residues, incorporate fertilizers and amendments into the soil, kill weeds, obtain a good seedbed, modify the hydrothermal regime and aeration status, and improve root penetration (Gajri et al., 2002).

When used judiciously tillage can alleviate soil-related constraints to crop production such as compaction, crusting, low infiltration, poor drainage, unfavourable soil moisture and temperature regimes, disposal of undesirable biomass and wastes, and pest management (Lal, 1991). Intensive tillage on the other hand can lead to deterioration of soil structure, reduced infiltration, accelerated runoff and erosion, water pollution, leading to diminished friability and lower workability and degradation of soil and environment (Kay and Munkholm, 2004, Carter, 1994). The use of large-scale machinery favouring increased field size, accompanied by elimination of hedgerows and the sods to support draft animals, led to considerable erosion by wind and water in parts of the United States of America (Wolf and Snyder, 2003).

There is however no universal agreement on what constitutes efficient tillage as it is largely soil and crop-specific and governed by both biophysical and socio-economic factors (Hillel, 1980, Lal, 1995, Carter, 1994). Conventional tillage with annual mouldboard ploughing is still the most common practice in humid areas whereas reduced tillage has been extensively adopted in subhumid and semiarid areas with high erosion risks (Kay and Munkholm, 2004). Sprague (1986) noted that under certain soil and climatic conditions, intensive use of tillage has caused excessive soil degradation, inadequate control of weeds, undesirable soil moisture management coupled with time and energy inefficiency. These will lead to deterioration of soil physical, chemical, and biological quality over the long-run (Erkossa et al., 2006).

It is therefore imperative to find alternative means to improve production with the creation of a sound environment for crop growth which conserves and recharges soil and water resources. Conservation tillage is one of the means which may offer opportunities to attain these objectives. One of the main reasons for developing conservation tillage systems according to Steed et al. (1994) was the need to arrest various forms of soil degradation caused by the traditional tillage systems. The purpose of this review is to briefly describe and examine the differing principles and practices of conventional and conservation tillage, its environment impacts, and its effects on crop performance and soil properties.

### 5.2.2 Principles of tillage

Tillage can be described as a method of mechanically modifying structural units of soil for the purpose of improving plant and soil productivity (Smucker and Erickson, 1988) by creating conditions for gas, water, chemical, and heat movement in agricultural soils that provide an optimal habitat for crop growth (Leij et al., 2002). It is performed in a certain sequence/combination required to prepare soil, plant seeds, and control weeds (Gajri et al., 2002). Tillage using contemporary power and implement systems can excessively till and compact many soil types with few passes. In this case, tillage can drastically change and at the same time destabilize soil structure (Hadas, 1997).

Three primary aims are generally attributed to tillage: (i) control of weeds, (ii) incorporation of organic matter into the soil, and (iii) improvement of soil structure (Hillel, 1980, Cassel and Nelson, 1985). An auxiliary function of tillage, still insufficiently well understood which thus incurs a great deal of research worldwide, is the conservation of soil moisture involving rain infiltration, runoff, and evaporation (Castro Filho et al., 1991, Singh et al., 1993, Biamah et al., 1993, Aina et al., 1991, Freebairn et al., 1993, Unger and Cassel, 1991, Gicheru et al., 2004). Also, by burying the plant residues and loosening the soil surface, it enhances the surface energy and water exchange, permitting relatively rapid drying and warming in the spring (Robinson et al., 1994).

Since the soil is normally at field capacity after winter, the conventional system implies a major risk of soil compaction, and the new types of seed drills allow early sowing of spring cereals without harrowing (Arvidsson et al., 2000), which could be an important factor influencing crop yields (Robinson et al., 1994). The study by Arvidsson et al. (2000) revealed that early sowing made more than 30 days before conventional sowing increased yield by an average of 11%. It is also advantageous for traditional management systems where early planting is prohibited since crops are severely affected by water logging and fungal diseases (Erkossa et al., 2006).

1. Conventional tillage

Conventional agriculture has long been based on the practice of cultivating the soil completely, deeply, and regularly (Gliessman, 1998). A clean finely tilled paddock, clean fence rows and straight rows of crop were the stamp of a farmer who was both skilful and good (Coughenour and Chamala, 2000).

This cultivation practice, referred to here as conventional tillage, involves a combination of primary and secondary tillage operations normally performed in preparing seedbed for a given crop grown in a given geographical area (Mannering et al., 1987). Fawcett (1987) mentioned that the systems under conventional tillage are those which totally disturb the soil surface and bury residue from the previous crop. It is still used as the preferred tillage option for soils with internal drainage problems e.g. clay soils with poor structure or for pure sandy soils (Erkossa et al., 2006, Köller, 2003, Robinson et al., 1994). According to Köller (2003) the justification for this common practice varies from yield security, residue-free improved seed bed preparation, and (precision) drilling to weed control and burying weed seeds.

Traditionally, the mouldboard plough has been used worldwide as the *primary tillage* tool. Another common primary tillage tool is the disk plough, comprising a hardened steel round concave disk of 50 to 95 cm in diameter (McKyes, 1985). Chisel plough, subsoilers, and rotary ploughs also find use in many areas; they break and loosen the soil without inverting it (Hillel, 1980). *Secondary tillage*, performed after primary treatment, aims to improve seedbed levelness and structure, increase soil pulverization, conservation of moisture, destruction of weeds, chopping of crop residues and the like. Disk harrows, spike harrows, spring-tooth harrows, sweeps, drags, and cultipackers are among the common implements used to refine coarse soil conditions during secondary tillage (McKyes, 1985, Hillel, 1980).

Two contradicting effects generally occur in the soil during tillage, soil loosening as the effect from the tillage implements and soil compression by the tractor while it is pulling the implement. Following tillage, the soil structure tends to readjust back towards its original state as rainfall, the burrowing of worms, pressures exerted by roots, the cause of frost and wetting-and-drying combine to cause changes in the arrangement of the particles (Briggs and Courtney, 1985). When these readjustments are incomplete, repeated tillage may result in a progressive change in soil structure. In some cases this leads to long-term damage to the soil or to a state of unstable equilibrium (Lal, 2004a). In addition, farmers can be locked into a cycle of continuous plough tillage (Köller, 2003) or soils are more reliant on tillage practices to maintain physical conditions favourable to crop production and become "addicted" to tillage (Robinson et al., 1994). Köller further argued that based on contemporary research evidence, mouldboard plough can no longer be considered as the only basic implement for soil cultivation. And after typifying and symbolizing agriculture around the world for centuries, conventional tillage has been supplanted in many advanced agricultural economies by what has become known as conservation tillage and cropping agriculture (Coughenour and Chamala, 2000).

2. Conservation tillage

Recent trends in tillage research have been aimed at minimizing tillage operations and travel (both to reduce costs and to avoid soil compaction) while tailoring each operation to its specific zone and objective (Hillel, 1980). This approach, initially known as minimum tillage, underlies various tillage methods under the term of conservation tillage, a term named by the United States Soil Conservation Service in 1977 (Gajri et al., 2002). The emphasis is on leaving the soil surface covered with residue after planting rather than merely reducing the number of trips across the fields. Thus conservation tillage, according to the *Resource Conservation Glossary*, is "*any* tillage system that reduces loss of soil or water relative to conventional tillage; often a form of noninversion tillage that retains protective amounts of residue mulch on the surface" (Mannering and Fenster, 1983). More specifically, it is commonly defined as any tillage system that maintains at least 30% residue cover on the soil surface after planting to reduce water erosion or small grain residue equivalent on the surface during the critical erosion period to reduce wind erosion (Baker et al., 1996, Mannering et al., 1987, Köller, 2003).

Due to its broad definition, conservation tillage was further defined as an umbrella term used for tillage intensity ranging from zero-tillage (no-tillage) to other forms of non-inversion soil tillage practices that have the potential to increase (or at least maintain) crop yield, and reduce soil water runoff relative to conventional tillage (Baker et al., 1996, Köller, 2003). Within this range of definitions emerge several types of conservation tillage systems described by Mannering et al. (1987) such as: no-till or slot planting; ridge-till; strip-till; mulch-till; and reduced-till. Space will not permit a detailed elucidation of each of these conservation tillage practices. Rather, for convenience of discussion, conservation tillage is broadly divided into two categories (Willocks, 1984) as cited below:

1. No-tillage - where vegetation is controlled using an herbicide and the seed is direct drilled into the undisturbed seedbed using specialised drilling equipment. No-tillage is the most recognised category of conservation tillage.

2. Minimum-tillage - where vegetation is controlled using an herbicide, followed by a light cultivation or reduced cultivation prior to establishing the seed using conventional drilling equipment.

No-tillage farming is a relatively new concept made possible through the development of herbicides that can provide good weed control without using tillage (Baker et al., 1996). Where conditions suit, no-tillage is the ideal method of crop establishment in terms of minimal inputs and maximizing opportunities (Willocks, 1984). This has led to the rapidly growing interest in and adoption of no-tillage systems of crop production throughout the world. Research results from the tropics indicated the potential of no-till and conservation tillage methods for soil and water conservation (Lal, 2004a). In temperate agroecosystems, conservation tillage has enabled farmers, while conserving soil and water resources, to change cropping systems substantially, for example from crop-pasture rotation to continuous cropping (Coughenour and Chamala, 2000).

Despite its increasing coverage, it is not inappropriate to suggest that for considerations of any form of conservation tillage adoption, the interaction between soil type and climate is of prime importance. Conservation tillage practices developed in one location may not be suitable for another location, where conditions can differ greatly (Carter, 1994). Therefore, due to burgeoning constraints along the dimensions of soil, climatic, crop conditions, and institutional and policy divides, the functional knowledge of conservation tillage and cropping systems, although suffused by modern science, is specific to place (Coughenour and Chamala, 2000).

### 5.2.3 Tillage systems and the environment

1. Greenhouse gas emissions

Tillage causes certain physical and biological changes in the soil which influence the release of greenhouse gases, namely $CO_2$, $N_2O$, and $CH_4$, into the atmosphere (Ball et al., 1999, Gajri et al., 2002). Carbon dioxide ($CO_2$) is produced in the soil through the metabolism of plant roots, microflora, and fauna, and decomposition of organic material by micro-organisms (Al-Kaisi and Yin, 2005, Ball et al., 1999). Its emission is caused by oxidation/mineralization of soil organic matter through ploughing, low or unbalanced use of fertilizers, removal/burning of crop residues, and low or no rate of applications of biosolids including compost, green manure, and sludge (Lal, 2004b). The magnitude of $CO_2$ loss from the soil due to tillage practices is highly related to the frequency and intensity of soil disturbance caused by tillage (Al-Kaisi and Yin, 2005). Al-Kaisi and Yin concluded that soil $CO_2$ emission is generally lower with less intensive tillage alternatives relative to mouldboard plough, with the greatest differences occurring at the time immediately following tillage operations. An earlier study by Ball et al. (1999) confirms these $CO_2$ findings. There are, however, contradictory results documented by Baggs et al. (2003) who found larger $CO_2$ emissions in the zero till than in the conventional till treatments.

Generally, no-till systems are proved to promote C sequestration and could be an important land-use component for greenhouse gas mitigation (Diekow et al., 2005). A global data analysis study on carbon sequestration was presented by West and

Post (2002). They suggested that when assessing the potential for C sequestration in agricultural soils, it is particularly important to consider the crop rotation being used, in addition to tillage operations and inputs to production. A recent study in south-central Texas suggests that the use of no-tillage (NT) significantly improved soil aggregation and soil organic carbon (SOC) and soil organic nitrogen (SON) sequestration in surface but not subsurface soils (Wright and Hons, 2005b). Another study in North Dakota revealed that under no-tillage (NT), an estimated 233 kg C $ha^{-1}$ was sequestered each year in annual cropping system [spring wheat (SW) (*Triticum aestivum* L.)-winter wheat (WW)-sunflower (SF) (*Helianthus annuus* L.)], compared with 25 kg C $ha^{-1}$ with minimum tillage (MT) and a loss of 141 kg C $ha^{-1}$ with conventional tillage (CT) (Halvorson et al., 2002). This study confirmed the results of an earlier study in the Paraná State of Brazil (Sá et al., 2001), which suggested that no-tillage C sequestration potential for South Brazil was estimated as 9.37 Tg C $yr^{-1}$.

In a broad context, however, the contribution of agricultural operations to these emissions is fairly small. The clearing of native ecosystems for agricultural use in the tropics is argued to be the largest non-fossil fuel source of $CO_2$ input to the atmosphere (Vlek et al., 2004, Smil, 1994). A study in Norway confirmed that out of a total emission of $CO_2$ in 1998 of 41.4 million metric ton (MMT), agriculture contributed only 0.157 MMT, or <0.4% of the total emissions (Singh and Lal, 2005).

Methane ($CH_4$) is generated biologically from the decomposition of organic matter including biosolids and manure under anaerobic conditions, biomass burning, animal metabolism, and flooded rice fields (Chareonsilp et al., 2000, Lal, 2004b, Smil, 1994). Fertilizers and manures are the principal causes of $NO_2$ emissions (Lal, 2004b). The study by Singh and Lal (2005) revealed that, contrary to the $CO_2$ emission mentioned above, the methane and nitrous oxide ($N_2O$) gases emitted from agricultural activities contributed to 32.5% and 51.3% of their respective total emissions in Norway. Early results from the study of Ball et al. (1999) show that $CH_4$ oxidation rates may best be preserved by no-tillage. By contrast, a study in S.E. England (UK) found that emissions of $N_2O$ were two to seven times higher from fertilized zero tillage (ZT) treatments than from fertilized conventional tillage (CT) treatments (Baggs et al., 2003). These authors indicated that this could possibly result from the anaerobic conditions under the mulch with localized concentrations of mineralized C and inorganic fertilizer $NO_3^-$ which were conducive to denitrification.

2. Agrichemicals

The type of tillage used dictates the movement of soil and water through erosion, runoff and leaching and the transport of agrochemicals either bound to soil particles or in soluble form (Gajri et al., 2002, Holland, 2004). The increased use of fertilizer is recognized as a potential source of environmental pollution, specifically with respect to water quality (Lal, 1991). While conservation tillage practices may conserve energy as well as the soil, little is known of how these practices effect solute transport through the soil and reach the underlying ground water (Gish and Coffman, 1987). In contrast, plough-based tillage methods may enhance risks of soil erosion, increase rates of mineralization of soil organic matter, and accentuate emission of radioactive gases from soil related processes (Watts and Hall, 1996) as discussed earlier.

A study by Zhao et al. (2001), investigating the effects of tillage and nutrient source on water quality, revealed that sediment, total P, soluble P, and $NH^+_4$–N losses mainly occurred in surface runoff and the $NO^-_3$–N losses primarily occurred in subsurface tile drainage. Analyzing the combined surface and subsurface flow, the study further indicated that the mouldboard plough (MP) treatment resulted in nearly two times greater sediment loss than ridge tillage (RT) ($P < 0.01$). Ridge tillage with urea lost at least 11 times more $NH^+_4$–N than any other treatment ($P < 0.01$). Ridge tillage with manure also had the most total and soluble P losses of all treatments ($P < 0.01$). Zhao et al. (2001) concluded that tillage systems that do not incorporate surface residue and amendments appear to be more vulnerable to soluble nutrient losses mainly in surface runoff but also in subsurface drainage (due to macropore flow). On the other hand, tillage systems that thoroughly mix residue and amendments in surface soil appear to be more prone to sediment and sediment-associated nutrient (particulate P) losses via surface runoff. These results were later confirmed by Nissen and Wander (2003), studying the management and soil-quality effects on fertilizer-use efficiency and leaching. They reported that although total leached N was similar in all cropping systems under study, increased macropore flow in NT cores led to greater leaching of fertilizer N and less leaching of soil-derived N, as well as greater moisture stress and decreased plant N uptake.

Contrasting results, however, were found in a similar study by Jiao et al. (2004) where dissolved N and dissolved P loads were not affected by tillage and were similar following corn (*Zea mays* L.) in a continuous corn rotation and soybean [*Glycine max* (L.) Merr.)] in a soybean/corn rotation production. The study revealed that soils receiving inorganic fertilizer had a 70% greater nitrate ($NO_3$-N) load and 48% less dissolved reactive P than soils receiving organic fertilizer. This evidence suggests that fertilizing soils with a combination of inorganic and organic fertilizers might be a good way to reduce both $NO_3$-N and dissolved reactive P transport to water systems. The overall results suggest that the leaching of dissolved N and dissolved P compounds is influenced more by the type of fertilizer applied than tillage or cropping practices. Similarly, Zhu et al. (2003) reported that tillage had no effect on total leachate collected during the 6-yr experiment by either pan (228 mm $yr^{-1}$) or wick (558 mm $yr^{-1}$) lysimeters. The results of their study found that the flow-weighted $NO^-_3$–N concentrations and $NO^-_3$–N masses in leachate were not significantly different between tilled and NT, but increased with increasing N-rate (at 0, 100, and 200 kg N $ha^{-1}$, flow-weighted $NO^-_3$–N concentrations were 3.5, 8.2, and 23.9 mg $L^{-1}$ and $NO^-_3$–N masses were 17, 39, and 112 kg $ha^{-1}$ $yr^{-1}$, respectively). They concluded that under their experimental conditions, NT will not result in more $NO^-_3$ leaching than chisel-tillage over a multiyear period.

One thrust in research dealing with tillage systems is to define the best management practice for pesticide application which maintains a high level of chemical efficacy without accentuating non-point source pollution on non-target areas (Miller and Donahue, 1990). The success of no-tillage systems for example, depends on the successful use of herbicides (Stewart, 2004). Moreover, there is a tendency to use the more persistent types for better long-term weed control; these are more likely to be persistent long enough to move into waters (Miller and Donahue, 1990). A simulation work by Malone et al. (2003), looking at alachlor and atrazine transport through the undisturbed soil blocks using the Root Zone Water Quality Model (RZWQM), suggests that differences in soil properties other than macroporosity such as a lower soil matrix saturated hydraulic conductivity and porosity in subsurface soil (8–30 cm) can cause percolate to occur sooner through macropores on NT than on MP and cause higher herbicide concentrations in percolate on NT, even when the macropores at 30 cm (nmacro) do not differ between till and no-till.

Research evidence suggests that no-tillage or any other greatly reduced tillage systems require a higher level of management (Stewart, 2004). One of the main disadvantages of no-till is that, as with fertilizers, pesticides are more difficult to incorporate, thus they require different pest-control strategies and formulations (Baker et al., 1996). Crop rotation is one strategy that would reduce the amount of pesticides required and would be a logical consideration to help reduce environmental pollution from croplands (Miller and Donahue, 1990).

### 5.2.4 Tillage and cropping systems

1. Continuous, rotational cropping and pasture management

While conventional tillage is mostly associated with monoculture, planting crops in a designated sequence and rotation has found new parameters with no-tillage. With a no-tillage system, harvesting can be followed immediately by planting of the succeeding crop, thus reducing the time lag between crops (Coughenour and Chamala, 2000). Summer fallow (fallow) is still widely used on the North American Great Plains to replenish soil moisture between crops. A study was done by Campbell et al. (2005) to examine how fallowing affects soil organic carbon (SOC) in various agronomic and climate settings by reviewing long-term studies in the midwestern USA (five sites) and the Canadian prairies (17 sites). Another study, however, indicated that cropping systems in the Great Plains have gradually evolved over the past two decades from reliance on summer fallowing to continuous cropping under reduced or no-tillage (Schlegel et al., 2005). Machado and Freitas (2004), in a study on no-tillage in Brazil, concluded that no-tillage farming represents a radical change in agronomic practices in the country, by eliminating soil turnover, promoting agrobiodiversity through crop rotations, and keeping the soil surface covered with residue mulch, regarded as especially important under tropical and subtropical climates.

Recent experimental crop rotations aided by conservation tillage were attempted in the highlands of Ethiopia to tackle the issue of soil quality deterioration and consequent reduced productivity characterizing the Vertisols in the area (Erkossa et al., 2006). A similar study was carried out in the northwest region of Iran on conservation tillage and straw mulch management aimed at improving soil water storage efficiency and increasing the potential in dry climates to promote intensive winter wheat (*Triticum aestivum* L.) cropping (Hemmat and Eskandari, 2006). A recently published long-term experiment was conducted in the dryland semi-arid tropical Alfisols (Typic Haplustalf) in southern India under a sorghum (*Sorghum vulgare* (L))-castor bean (*Ricinus communis* (L)) rotation with the objective of selecting the appropriate land management treatments and to identify the key indicators of soil quality (Sharma et al., 2005).

A study conducted in the central Great Plains suggests that growing a legume cover crop in place of fallow in a winter wheat – fallow system can provide protection against erosion while adding N to the soil. However, water use by legumes may reduce subsequent wheat yield (Nielsen and Vigil, 2005). Legumes, with their adaptability to different rice-based cropping systems, offer opportunities to increase and sustain productivity and income of rice farmers. In the irrigated lowland areas, legumes (soybean, peanut and mungbean) are generally grown in rotation with rice (rice-rice-legume rotation) or (rice-legume-legume rotation) with two or more irrigations during the season (Adisarwanto et al., 1996). Rotation of rice-cowpea is also believed to be suitable for the humid tropic soils (Benites and Ofori, 1993). Recent study suggests that legumes, incorporated at 1-2 tons ha$^{-1}$ (alfalfa, buckwheat (*Fagopyrum esculentum*), rice by-products), can give weed reduction and increase rice yield by 70 and 20 %, respectively (Khanh et al., 2005). It was further postulated that legumes, and other allelopathic crops, can be useful as natural herbicides.

In lowland areas, the growing conditions required for rice are entirely different from those required for legumes. Rice is grown best under puddled and reduced conditions while legumes require unpuddled and oxidised conditions. The two conditions are associated with large differences in physical, chemical and biological properties of the soil (Adisarwanto et al., 1996). Mohanty et al. (2004) suggest that puddling only to the required level will deteriorate the soil physical conditions less as compared to more intense puddling. The unpuddled direct seeded rice maintained the soil in a better physical condition but the yield was significantly lower in relation to the puddled ones. Similar results concerning yield were reported by Kirchhof et al. (2000) where puddling had no significant effect on post-rice mungbean and peanut production but increasing puddling intensity tended to reduce soybean yield.

A study by Cass et al. (1994) indicated that a rotation of rice-soybean over a period of 21 years, deteriorated the soil structural quality, and thus it was unsustainable. Instead, they suggested that a rotation of rice and grass fallow would probably restore the soil structure to a favourable state. The inclusion of a green manure crop such as *Sesbania rostrata* berm in the rice-rice cropping system either during fallow and/or intercrop can be beneficial. The results of a study by Ramesh and Chandrasekaran (2004) revealed that there was a gradual build-up of SOC when *S. rostrata* was included and *in situ* incorporated at flowering stage as a basic means of improving soil quality in a rice-rice cropping system. A study in northeast Thailand revealed that annual applications of 1500 kg $ha^{-1}$ of leaf litter from different locally grown shrubs for five seasons resulted in increases in rainfed rice grain yield in 1997 of between 20 and 26% above the no-leaf litter control. The analysis for Eastern Australia, by contrast, indicated that after five wheat and two legume/fallow crops, negative N balances of up to −303 kg $ha^{-1}$ were calculated for the treatments where wheat stubble was not retained and bare fallow leys were used (Whitbread et al., 2003).

In the humid tropics, where soils are mainly acidic, rotation of acid-tolerant crops such as upland rice and cowpea under no-tillage practice was recommended by Benites and Ofori (1993). This was viewed as part of solution addressing the problems associated with shifting cultivation in transition to continuous cultivation. In the mountains of northern Vietnam, attempts were made to promote direct sowing upland rice in a dead mulch in the quest for alternatives to slash-and-burn systems, with promising preliminary results (Husson et al., 2001). A study in the western semi-arid zone of Mexico, looking at ways to increase the water availability for rainfed maize production, found the merits of direct seeding maize into residue mulch with an increase in infiltration rates of up to 10 times the traditional tillage.

The available water increased by 30% during the crop cycle (Scopel and Findeling, 2001). Zero-tillage practices are being introduced in South Asia within the rotational rice-wheat farming systems that dominate large areas of northern India, parts of Pakistan and Bangladesh, and the *terai* (lowland) in Nepal (Uphoff, 2004). The international rice-wheat system within the context of a sustainable agriculture emphasizing the prospects of no-tillage has been discussed at large by Lal et al. (2004).

New Zealand has quite a long experience in pasture production since its export income is heavily dependent on animal products. Efforts have been made in either renewal or renovation of the existing pasture lands. Surface reseeding of poor pastures on steep land by aerial methods and resowing of pastures into crop rotations on flatter land using cultivation have become common practice in temperate New Zealand (Choudhary and Baker, 1994). Traditionally, this has been achieved by using conventional means of tillage prior to grass seeding. In recent decades, however, direct drilling has gained many adherents due to its advantages. Allen (1981) and Baker et al. (1996), in their publications partly discussed the advantages of direct-drilling with regard to pasture renewal and renovation and provided some practical guidelines as well.

Two major attractions of direct-drilling related to pasture were that (i) the whole process of renewal is more rapid and streamlined and (ii) the consolidation of the surface is not affected, so that shortly after the new seeds have been sufficiently established, the old grass can be grazed (Allen, 1981). The New Zealand pattern of using a pasture-crop rotation on mixed cropping farms means that the renewal or restoration of pasture without cultivation is an integral part of the total low energy input system. The advent of glyphosate in particular has had a major impact on pasture renovation programs (Choudhary and Baker, 1994). Apart from that, a number of pasture seed drills commercially available such as 'Cross Slot'$^{TM}$ and 'Original Baker Boot'$^{TM}$, provide favourable soil microenvironments and are suitable for operations in contouring and trash-free pastureland (Choudhary and Baker, 1993). Attempts were also made to promote ecologically sound techniques such as triple disc drill and strip seeder drill. A study conducted by Lowther et al. (1996)

demonstrated the agronomic superiority of the strip seeder direct drill for pasture establishment.

Schipper and Sparling (2000) conducted a test in New Zealand covering a standard set of 16 primary indicators at 29 sites (0–10 cm depth) across nine soil great groups representing indigenous forest, plantation forest, pastures, and crops. The results revealed that pasture soils were less acidic (pH 5.3–6.9) than forest soils, but with more available P (5.5–43.0 µg $cm^{-3}$), higher total C (30.7–141.5 mg $cm^{-3}$), total N (2.7–9.0 mg $cm^{-3}$), and mineralizable N (68–175 µg $cm^{-3}$). The physical condition was similar to forest soils. Cropped soil on the other hand, had low total C (20–34 mg $cm^{-3}$), microbial C (160–956 µg $cm^{-3}$), respiration (0.29–1.33 µg C $cm^{-3}$ $h^{-1}$), and total available water (6.7–30.1% v/v), but high pH (5.8–7.2), Olsen P (11.2–199 µg $cm^{-3}$), and bulk density (0.96–1.3 g $cm^{-3}$). In an earlier study Sparling et al. (1992) reported that the re-establishment of pasture caused a more rapid recovery in microbial biomass C than total C, and increased the proportion of organic C comprised of microbial C. However, recovery of the total organic and microbial C pools and aggregate stability was very variable, and after 4 years of pasture none of the sites under study had re-established the levels found under permanent pasture. They concluded that the previous cropping history of these soils before being returned to pasture, rather than the organic or microbial C content, appeared to be of greater importance in controlling the aggregate stability characteristics.

An overseas study, investigating crop-pasture rotation (CPR) with NT reported that chiseling or paraploughing can alleviate plough-pans inherited by NT from previous CT; but higher soil strength at the soil surface under NT contributes to better forage utilization under grazing. Soil organic carbon (SOC) content in continuous cropping (CC) decreased with CT, and was maintained with NT only if grain was harvested. In CC systems with harvested forage, SOC decreased even with NT. CPR with NT maintained or increased the original SOC content. It was concluded that both CC and CPR were sustainable from the soil quality and productivity standpoints. However, compared with CC, CPR was a more economically and climatically buffered system due to higher diversity, and more environmentally sustainable since fuel and agrochemicals usage is reduced approximately 50% (Garcia-Prechac et al., 2004).

## 2. Crop yield performance

As far as crop yields are concerned, it is difficult to establish clear and major advantages of no-tillage, since the results to date have been variable over different soil types, seasonal conditions and types of management. Long-term trials undertaken in Western Australia concluded that conservation tillage, after some initial problems, performed well on the heavier soils but was less successful on light sandy soils. On average, conservation tillage practices outyielded conventional practice over an eight year period (Conacher and Conacher, 1986). The increased yields under no-tillage practices were also confirmed by other overseas studies (Dickson and Ritchie, 1996, Barber et al., 1996). Janson (1984), investigating intensive arable cropping in two different soil types under direct-drilling (DD) and conventional tillage (CT) in New Zealand concluded that reliability in crop yield under direct-drilling on light free-draining soils was easier to achieve. By contrast, on the heavy, slow-draining soils, despite the greater problems imposed by DD, the yield comparability with CT was achieved relatively quickly.

A study in north-western Turkey, examining the effects of three tillage systems on the properties of clay–loam soil (Eutric Vertisol) planted with winter wheat (*Triticum aestivum* L.) reported that increasing organic carbon (OC) and total N and decreasing bulk density (BD) and penetration resistance (PR) under reduced tillage (single disking / RT) increased grain yield to 4.6 t $ha^{-1}$, followed by mouldboard tillage (MT) and double disking (DD) at 4.4 and 4.2 t $ha^{-1}$, respectively, according to the 2-year mean (Ozpinar and Cay, 2006). A 3-year experiment was conducted under dryland conditions to determine the influence of conventional and conservation tillage systems on grain yield and yield components of a winter wheat cultivar on a clay loam soil (Vertic Calcixerepts) in the northwest region of Iran (Hemmat and Eskandari, 2006). The tillage treatments were conventional tillage (CT: mouldboard plow + disk), reduced tillage (RT: chisel plow + disk), minimum till (MT: sweep plow), and no-till ($NT_{ss}$ and $NT_{tr}$: with standing stubble and total residue, respectively), and the mean grain yield over three seasons was 1.0 t $ha^{-1}$ for CT, 1.3 t $ha^{-1}$ for RT, 1.1 t $ha^{-1}$ for MT, 1.2 t $ha^{-1}$ for $NT_{ss}$ and 1.4 t $ha^{-1}$ for $NT_{tr}$.

Contrasting yield results were found in other studies, which resulted from conservation tillage. Hughes et al. (1992) in a study on a 10-year maize/oats rotation in a fine silt loam soil found lower maize forage yields under reduced tillage as compared to fully tilled seedbeds. Two reduced tillage treatments (minimum tillage and no-tillage) gave depressed maize yields in 7 years out of 10. A major reason for this was likely to be differences in plant populations. Seedling establishment was often low and variable in no-tilled crops. The winter-grown oats showed no statistical differences among treatments. Reduced yields under no-tillage practices were also found by Acharya and Sharma (1994) in a study on maize/wheat rotation. Variable yield results were also reported by Lindwall et al. (1994) on continuous wheat, wheat-fallow, and wheat-barley-fallow rotations superimposed by conventional and no-tillage.

Research evidence suggests that tillage practices do not always have a direct impact on crop yield which is generally a result of interactions of a number of factors apart from tillage such as fertilizer and crop rotation. The study by Kelley and Sweeney (2005) in the eastern Great Plains demonstrated that tillage effects on grain yield were smaller than other treatment factors, averaging 3.23 t $ha^{-1}$ for RT and 3.06 t $ha^{-1}$ for NT. Plant N uptake responses indicated that grain yield differences were primarily related to greater immobilization of both fertilizer and soil N following grain sorghum, compared with soybean, and to better utilization of subsurface-knifed N than surface-broadcast N. The authors concluded that wheat yield potential was more strongly influenced by previous crop, fertilizer N rate, and N placement method than tillage system.

Another study in south-eastern Nebraska reported that corn and soybean produced less grain with greater summer temperatures while corn yield increased with less spring and more summer rainfall (Wilhelm and Wortmann, 2004). They further described that tillage and rotation practices affected corn grain yield; but only rotation affected soybean yield. It was concluded that the benefit of rotation for soybean grain yield did not vary with weather conditions. Seasonal temperature and rainfall patterns influenced the effects of tillage and rotation on corn yield. In contrast, for soybean, only the pattern of temperature influenced the effect of tillage on yield. Another study, investigating the agronomic performance of spring barley (*Hordeum vulgare* L.), sown into conventionally tilled (CT) seedbeds with double-disk drills or into standing stubble with several types of no-till (NT) drills (hoe, single disk, and notched coulter), reported that early season seed-zone temperatures were cooler under NT, but seed-zone water was slightly higher with CT. Low spike density consistently occurred in a wide row spacing (406 mm) NT drill treatment, and the highest overall yields were obtained with NT drills with rows spaced 255 mm or less (Schillinger et al., 1999). They concluded that no-till spring sowing into undisturbed standing stubble (2.4-5.2 t $ha^{-1}$) can produce grain yields equal to or exceeding those under CT and can provide environmental and potential soil quality benefits for low-precipitation dryland farming areas in the inland Pacific Northwest. A recent study concluded that long-term mean dry matter corn yields were not affected by tillage and residue practices during the course of this study; rather climatic-related differences seemed to have a greater influence on the variation in dry matter yields (Dam et al., 2005).

Despite the contradicting results cited above, it can be said that, usually, given adequate soil water, favourable precipitation, good drainage, reasonable soil fertility and good weed control, crop yields under conservation tillage can be equal to or higher than under conventional systems. Concerning sustainability, whilst yield and short-term economic differences between these tillage systems may not be all that great, this needs to be weighed against some obvious advantages, particularly in the more fragile or degraded agricultural areas.

3. Energy efficiency

Uri (1999) studied the relationship between energy use and the adoption of conservation tillage in the United States using cointegration techniques. The results showed that while the real price of crude oil, the proxy used for the price of energy, does not affect the rate of adoption of conservation tillage, it does impact the extent to which it is used over the period of 1963–1997. The policy implications are that the price of energy can be used to promote the adoption of conservation tillage through a fairly substantial increase in real energy price.

The results of a study in Canada showed that the total energy input per unit of land was lowest for the traditional fallow-wheat (F-W) rotation (3482 MJ $ha^{-1}$), intermediate (4470 MJ $ha^{-1}$) for N- and P-fertilized fallow-wheat-wheat (F-W-W) and highest for N- and P-fertilized continuous wheat (7100 MJ $Ha^{-1}$). Metabolizable energy output on the other hand, displayed similar response patterns as total energy input reflecting the higher total annual grain yields as cropping intensity increased. The energy output averaged 12639 MJ ha$^{-1}$ for F-W, 14641 MJ ha$^{-1}$ for F-W-W and 17764 MJ ha$^{-1}$ for continuous wheat. In contrast, the energy output to input ratios and the quantity of wheat produced unit$^{-1}$ of energy input decreased with cropping intensity. The average energy output to input ratio for F-W was 3.6, or 262 kg of wheat GJ$^{-1}$ of energy input, while those for F-W-W and continuous wheat were 3.3 and 2.6, or 240 and 191 kg of wheat GJ$^{-1}$ of energy input, respectively. It was concluded that rotations that included flax or cereal forage crops had the lowest energy efficiencies (Zentner et al., 1989).

In a recent study, Zentner et al. (2004) postulated that the use of conservation tillage management enhanced overall energy use efficiency for the mixed rotations, but not for the monoculture cereal rotation. They concluded that adopting diversified crop rotations, together with minimum and zero tillage management practices will enhance non-renewable energy use efficiency of annual grain production in this sub-humid region. Low-input systems in which tillage and/or herbicides were reduced but not eliminated were more efficient in converting energy into yield than high-input systems, provided that other inputs substituted for reduced inputs (e.g. mechanical inputs instead of chemical inputs) were used in moderation. Thus, most alternative methods of weed control (e.g. reduced herbicide and tillage inputs) are more energy efficient than conventional weed control practices (e.g. broadcast application of herbicides at recommended rates) (Clements et al., 1995).

Modern agricultural systems, despite being efficient in terms of human time and labour, are highly inefficient from an overall energetic point of view as five to ten times of fuel energy are required to produce a single unit food energy (Toky and Ramakrishnan, 1982). Comparing energy input : output ratio at a village ecosystem level in north-eastern India, Mishra and Ramakrishnan (1982) reported that the energetic efficiency (output : input ratio) of *jhum* in 5 ha of land worked out at 7:53 and that of valley cultivation on 2 ha of land at 40:14. In a different study Toky and Ramakrishnan (1982) concluded that *jhum* and valley agricultural systems are more efficient from the energy viewpoint, with higher output~input ratios compared with terrace cultivation, which is least efficient due to heavy fertiliser input requirements.

### 5.2.5 Tillage Effects on Selected Soil Properties

A large volume of information can be found in literature on the effects of tillage practices on soil properties under various soil types, cropping regimes and climatic conditions. Soil structure is dynamic and in almost all soils changes with time or rainfall after tillage. The structure may collapse progressively and surface crusts or seals may form especially on soils with low stability resulting from low contents of clay or organic matter. A crust is often a barrier to water infiltration and can be a cause of ponding and run-off (Dexter, 1997). Moreover, the specific effects of various tillage operations also vary. Thus, effects of changes in soil properties due to tillage must be interpreted differently for regions, localities within a region, and often for soils on a farm, when they differ appreciably in drainage, texture, depth, and topographic characteristics.

Well-developed soils have a good balance between voids and particles and have a high water storage capacity; accordingly, these types of soils offer the most favourable conditions for crop growth. They are also less susceptible to erosion. Tillage, in various practices, is primarily defined as the mechanical manipulation of the soil structure aimed at improving soil conditions affecting crop production (Hillel, 1980). Studies have indicated that soils which have long been continuously direct drilled are different to conventionally cultivated soils in a number of ways. A description of the main differences between soils under these two tillage systems has been made by McLaren and Cameron (1996 ). However, because of the many factors involved and the complexity of interactions encompassed, the tillage investigations must necessarily be long-term undertakings. In some situations, variability is such that a long run of experiments is necessary to determine a clear and consistent result.

Tillage and practices that change the organic matter content of soil are foremost amongst the many practices that influence soil structure (Kay and Munkholm, 2004). Some studies suggest tillage to have greater impact on soil properties and on crop yield than crop residue management (Bescansa et al., 2006). Nonetheless, the importance of the management and the maintenance of a stable soil structure under cropping regimes and tillage practices has been the subject of many studies. The results of some studies related to changes in selected soil physical and chemical properties are discussed. These include soil penetration resistance, soil compaction and density, soil aggregate stability, soil porosity and hydraulic properties, total C and N, Olsen P, and soil pH ($H_2O$). The discussion will also cover the effects of these soil properties on crop and biomass production.

1. Soil penetration resistance

There are several soil factors influencing penetration resistance. These, according to Bradford (1986), include matric potential (or water content), bulk density, soil compressibility, soil strength parameters, and soil structure. The changes in such soil compaction affecting properties induced by tillage systems are of the most concern of many studies.

Lampurlanés and Cantero-Martínez (2003), comparing soils under subsoil tillage (ST), minimum tillage (MT), and no-tillage (NT) cropped with barley (*Hordeum vulgare* L.) found larger penetration resistance under NT than in ST and MT. However, root length density profiles sometimes showed greater values for NT than for the other tillage systems, revealing a good soil condition for root growth under NT. The results confirm the findings of earlier studies by Braim et al. (1992) and Home *et al.* (1992). The former study concluded that within the topsoil (0-230 mm) of the direct drilled treatments, resistances to cone penetrometer were 7 - 9 times greater than those of the ploughed soils. While the latter study, investigating maize/oats rotation in a silt loam under full-tillage, minimum tillage, and zero-tillage found that penetration resistance was substantially lower in the full tillage compared to the other two treatments. Pasture plots gave the greater penetration resistance. Similar results were reported by recent studies (Fabrizzi et al., 2005, Govaerts et al., 2006, Katsvairo et al., 2002, Ozpinar and Cay, 2006).

Contrasting results, however, were found by Sidiras et al. (2001). The penetration resistance (PR) was measured together with other physical properties and root system performance at growth stages 5, 9 and 16 of the Feekes scale under winter barley. The results showed that in CT plots, PR was 1.75 MPa at growth stage 5, 1.87 MPa at growth stage 9 and 2.02 MPa at growth stage 16. In MT plots, the respective values for PR were 1.28, 1.70 and 1.94 MPa and in NT plots, which had the lowest PR, the values were 1.27, 1.52 and 1.70 MPa, respectively. Karamanos *et al.* (2004) also reported a significantly lower penetration resistance 2-3 months after sowing in the no-tilled plots after being initially higher.

2. Soil bulk density

*Bulk density*, $\rho_b$, the ratio of the mass of dry solids to the bulk volume of the soil, is not invariant for a given soil. It varies with structural condition of the soil, particularly that related to packing. For this reason it is often used as a measure of soil structure (Blake and Hartge, 1986). A review of the usefulness of relative bulk density values in studies of soil structure and compaction was presented by Hakansson and Lipiec (2000). Damage to soil physical structures under continuous tillage (ploughing and disking in particular), reduction of soil porosity, compaction and pulverisation by machines and stock, and cultivation of very wet to dry soils, all contribute to increases in bulk density (Conacher and Conacher, 1986). This consequently leads to the soil suffering effects such as increased resistance to mechanical cultivation, incurring greater wear and tear of parts and increased fuel consumption; impedance to root penetration; reduced water infiltration; increased waterlogging and surface water runoff, and accelerated erosion.

Numerous studies have so far investigated changes in soil properties affected by tillage practices, inclusively bulk density. A recent study in the Indian Himalayas' clay loam soil found the values of soil bulk density under zero-tillage (ZT) to be higher in 0–75 mm soil depth compared to soils under minimum tillage (MT) and conventional tillage (CT). At the depths below, however, the bulk density under ZT were either similar or lower than those of the other two treatments (Bhattacharyya et al., 2006). It was reported in another recent study that bulk density was affected by tillage practices, but only within the top 10 cm soil layer (Dam et al., 2005). The study concluded that both conventional tillage (CT) and reduced-tillage (RT) reduced bulk density relative to no-tillage (NT) over a period of 11 years. Similar results were reported by Bescansa et al. (2006). The study found the soil bulk density at 0 – 15 and 15 – 30 cm soil depth to be significantly higher under conservation tillage practices (no-tillage, no-tillage with stubble burning, and reduced chisel ploughing) than that under the mouldboard plough treatment (MT). An exception was found under the reduced tillage (RT) at the 0 – 15 cm soil where the BD value was similar with the one under MT.

Wet cultivation for rice cropping poses significant challenges with regards to soil compaction and its effects on the post-rice crop. According to McDonald et al. (2006), puddling, as a management scheme for rice, is typically considered advantageous for maximizing resource availability and yield. However, some experimental findings suggest a conflict between edaphic conditions created by this establishment technique and the performance of subsequent non-rice crops like wheat. Kukal and Aggarwal (2003) reported that increase in puddling intensity from medium to intensive, significantly increased bulk density from 1.63 to 1.67 Mg $m^{-3}$ in 16–18 cm and from 1.61 to 1.66 Mg $m^{-3}$ in 18–20 cm soil layers. In normal-puddled plots, the average bulk density of 14–20 cm soil layers was significantly higher (1.74 Mg $m^{-3}$) than that of shallow puddled plots (1.57 Mg $m^{-3}$) at the end of 3 years of study. Similar trends were observed in the case of soil penetration resistance. Despite favoured more soil wetness at harvest, higher intensity of puddling caused larger crack dimensions (length, width and depth) than unpuddled and low intensity puddled soils according to a study by Mohanty et al. (2004).

In a recent study by Ozpinar and Cay (2006), investigating the effects of tillage systems on the quality and crop productivity of a clay–loam soil in semi-arid north-western Turkey, bulk density (BD) was found significantly lower under rototilling with one disking (RT) at both 0–10 and 10–20 cm depths with 1.24 and 1.32 Mg $cm^{-3}$, respectively, when compared to MT (mouldboard plough followed by two diskings) treatment. At the 20–30 cm, however, MT provided the highest BD, at 1.49 Mg $cm^{-3}$. In the second year of the study, double disking (DD) had the lowest BD at all depths followed by RT and MT. Studies by Braim et al. (1992) and Unger (1996), contrastingly, found that bulk density was not significantly affected by tillage practices. These contradicting results may reflect the specificities of the circumstances and the nature of each study, primarily related to site characteristics, cropping regimes involved, and the timing and duration of the trials.

3. Soil compaction and density

Surface compaction may be created as a result of either traffic and/or treading when the soil is too wet or through the excessive use of tillage implements (Allen, 1981, Briggs and Courtney, 1985, Robinson et al., 1994) and could be reflected by the degree of penetration resistance and bulk density, two parameters largely used to assess compaction (Tarawally et al., 2004). Soil structural degradation by compaction alters soil pore architecture, and when the volume, dimension and configuration of soil pores are affected, mass and energy movement in the soil environment suffer the same fate (Lipiec and Hakansson, 2000). Soil compaction usually alters some basic soil properties such as pore volume, pore size distribution, macropore continuity, and soil strength. This, in turn, have a large influence on elongation of plant roots, and on storage and movement of water, air and heat in the soil (Hakansson and Voorhees, 1998).

Research data from Hungary showed that annual disking and plowing causes subsoil compaction at the depth of tillage within 3 years and that the compacted layer expanded both in surface and deeper layers after the 5th year. Soil quality deterioration by tillage-pans was improved by subsoiling and maintained by direct drilling and planting soil-loosening catch crops (Birkas et al., 2004). This confirms earlier studies cited by Allen (1981) which found that following ploughing to 25-30 cm subsequent wheel traffic caused very large recompaction effects through the depth of cultivation. In contrast, where direct drilling is adopted the soil rapidly builds up to an equilibrium level of reformation of aggregates and it then has a high enough strength to resist further compaction. However, Hakansson and Voorhees (1998) concluded from their research that compaction effects tend to accumulate and be more persistent under reduced tillage than in a system with ploughing. According to this source these conditions may still be adequate for clay soils due to improved continuity of macropore system. In contrast, for unloosened sandy soils the compaction effects usually accumulate with little natural alleviation. Consequently, compaction may prevent continuous use of reduced tillage or direct drilling, especially for sandy soils.

Repeated tillage at the same depth may result in the formation of a plow pan, a soil layer of increased bulk density and strength just below the tilth layer (Briggs and Courtney, 1985, Robinson et al., 1994). Consequences are that in wet periods plants may suffer from water logging in the root zone; and during dry periods the shallow depth of the roots may mean that they are unable to exploit water reserves deeper in the soil and may suffer from moisture deficiencies. In short, compaction of soils adversely affects crop performance by limiting the availability of soil oxygen, restricting root penetration, and reducing the ability of roots to take up water and nutrients (Robinson et al., 1994, Conacher and Conacher, 1986, Hakansson and Voorhees, 1998).

Compaction, as described above, alters many soil physical characteristics. However, despite the effected changes in physical properties, a recent study discovered that microbial measures were either unaffected by compaction or showed inconsistent increases (e.g., fungal hyphae, C use, total phospholipid ester-linked fatty acids (PLFA)) across sampling periods and soil types under study. It was found that soil strength values, ranging from 75 to 3800 kPa (no to severe compaction), were unrelated to either microbial respiration or biomass. The results show broad tolerance of microbial communities from contrasting soil textures to compaction, and indicate a poor link between physical and biological indices of soil health (Shestak and Busse, 2005).

In a recent literature review on the nature, causes and possible solutions to soil compaction in agriculture, Hamza and Anderson (2005) offered the following practical techniques: (a) reducing pressure on soil either by decreasing axle load and/or increasing the contact area of wheels and tracked vehicles with the soil; (b) working soil and allowing grazing at optimal soil moisture; (c) reducing the number of passes by farm machinery and the intensity and frequency of grazing; (d) confining traffic to certain areas of the field (controlled traffic); (e) increasing soil organic matter through retention of crop and pasture residues; (f) removing soil compaction by deep ripping in the presence of an aggregating agent; (g) crop rotations that include plants with deep, strong taproots; (h) maintenance of an appropriate base saturation ratio and complete nutrition to meet crop requirements to help the soil/crop system to resist harmful external stresses.

## 4. Soil aggregate stability

Soil structure can be characterized through measurable indicators such as aggregate stability, bulk density, and soil penetrability (Kemper and Rosenau, 1986, Hillel, 1998). Soil aggregation effects on soil physical and chemical properties of structured soils have been reviewed at length by Horn *et al.* (1994). Kemper and Rosenau (1986) defined aggregate as a group of primary particles that adhere to each other more strongly than to other surrounding soil particles. The stability of aggregates is measured as a function of whether the cohesive force between particles withstands the applied disruptive force. Most frequently, this concept is applied in relation to the destructive action of water (Hillel, 1998, Kay and Munkholm, 2004). This is probably the main reason for using the wet-sieving procedure to determine the water-stable aggregates (WSA) and mean weight diameter (MWD) of a given sample of soil as suggested by Yoder (1936) and Kemper and Rosenau (1986). A study in Londrina, state of Paraná, Brazil found significantly higher indices of MWD, geometric mean diameter (GMD), and aggregate stability (AS%) in soils under no-tillage than those under conventional tillage treatments (Castro Filho et al., 2002). A recent research by Primoradian *et al.* (2005), however, suggests the use of the non-linear fractal dimension $D_{nl}$ to be more appropriate to quantify the aggregate stability induced by tillage treatments compared with mean-weight diameter $D_{mw}$ and geometric mean diameter $D_{gm}$ of aggregates.

Apart from the disruptive force of water and wind causing erosion, the clearing of natural vegetation, loss of organic matter, repeated tillage, excessive working speeds, passage of heavy machinery and trampling by stock all contribute to a reduction in the number and size of stable aggregates in the soil (Conacher and Conacher, 1986). By any measure, however, the degree of aggregation is a time-variable property, as aggregates form, disintegrate, and re-form periodically (Hillel, 1998). In other words, Lal (1998) stated that agriculturally stable soils are dynamic and always change in response to management and weather. A recent study by Valmis et al. (2005) proposed a model to predict interril erosion which takes into account the aggregate instability index, $\beta$. The proposed equation to describe the interrill erosion rate ($R^2$=0.939,$P$<0.001) is as follow:

$E_i$=0.628 β $S_t^{1.3}$ $e^{0.0967 I_{30}}$ where $S_t$ represents the tangent of the slope angle, and $I_{30}$ represents the maximum rainfall intensity in 30 min. After validating the model with independent data, they concluded that the model predicted interrill erosion well ($R^2$=0.766, $P$<0.001).

Intensive cultivation can cause excessive breakdown of soil aggregates. An early study has shown the decrease in aggregate water stabilities after 10 years of continuous maize/oats rotation in a silt loam to be the greatest in the fully tilled plots as compared to the no-tilled plots (Horne et al., 1992). This is confirmed by recent studies indicating the prevalence of more stable aggregates in less mechanically disturbed soils prior to cultivation as it is the case under no-tillage or reduced tillage than in soils under conventional tillage practices (Zotarelli et al., 2005, Wright and Hons, 2005a, Valmis et al., 2005, Eynard et al., 2005). At two agricultural experiment sites (Passo Fundo and Londrina) in southern Brazil, Zotarelli et al. (2005) found that CT decreased the proportion of the largest macroaggregate class (>2000 μm) by approximately 10% in comparison with NT management, and there was a corresponding increase in the proportion of the 53- to 250 μm aggregate class. They also reported that the mean weight diameter (MWD) of the aggregates was on average 0.5 mm greater under NT compared with CT, and was also greater (approximately 0.2 mm) under more diverse rotations, which included a leguminous green-manure crop, in comparison with continuous wheat–soybean. The study by Castro Filho (2002), experimenting with two planting systems (conventional-tillage (CT) and no-tillage (NT), under three crop rotations (soybean/wheat/soybean (S/W/S), maize/wheat/maize (M/W/M) and soybean/wheat/maize (S/W/M)), found that no-tillage system had the best aggregation indices for the 0–20 cm layer due to the increase in the organic carbon content. The greatest quantities of organic carbon were found in the 2 mm aggregate size class. The study concluded that soil aggregate stability indices were not affected by the crop rotations.

A different study by Wright and Hons (2005a) reported that no-tillage increased the proportion of >2-mm and 250-μm to 2-mm macroaggregate fractions in soil compared with CT. At the 0-5 cm depth, NT increased SOC compared with CT by 158% in macroaggregate fractions but only 40% in <250 μm fractions. They further indicated that long-term impacts of NT included a greater proportion of macroaggregates and increased C and N sequestration, but impacts were dependent on crop species and varied with soil depth. A similar study confirmed that the loss of aggregate stability in cultivated soils was associated with organic C loss (Eynard et al., 2005). Their study suggests that most structural characteristics developed under tilled systems persisted after 6–16 years of no-till. At the sites studied by Zotarelli *et al.* (2005) the total organic C and N in the 0-5 cm depth interval, decreased in order native vegetation (NV) > NT > conventional tillage (CT). Similarly, in the study of Sasal *et al.* (2006) aggregates were 30% more stable in zero tillage (ZT) than under conventional ploughing (CP) in the top at 0.05 m due to a 21% increase in organic matter.

Franzluebbers and Arshad (1996) reported the distribution of water-stable aggregates (WSA) to be only secondarily affected by tillage. The primary effect was due to the clay content. Comparing two soils with different textures, this study also concluded that at a depth of 0 - 50 mm, macroaggregation (> 0.25 mm) was found significantly higher under no-tillage than under conventional tillage in coarse-textured soils, but similar, less or not significant in fine-textured soils. Similar results were also reported by Beare *et al.* (1994). This study found that at the 0 - 50 mm soil depth the total sand-free C and N were significantly higher in all WSA of no-tillage than of conventional tillage.

These studies, in general, confirm that no-tillage causes less damage to soil structure. Also, the greatest WSA found at the topsoil under NT is believed to be closely associated with more organic matter retained at this specific soil layer as compared to conventional tillage.

5. Soil porosity

Agricultural management affects pore-size distribution as well as pore continuity and tortuosity. Traffic reduces macroporosity and tillage mechanically breaks pore continuity and hinders biopore formation (Boersma and Kooistra, 1994). Pores are of different size, shape and continuity and these characteristics influence the infiltration, storage and drainage of water, the movement and distribution of gases, and the ease of penetration of soil by growing roots (Kay and VandenBygaart, 2002). Porosity is expressed as the ratio or percent of voids or pores to the total volume of soil, and in the case of most fertile mineral soils, it takes up about 50 percent of the volume (Wolf and Snyder, 2003 p. 84).

Effective porosity of the soil is largely determined by macropores (Ahuja et al., 1989) which is closely related to saturated hydraulic conductivity as it reflects the percentage of total pores that are open to infiltration during a rain event (Azooz et al., 1996). Effective porosity or macroporosity ($Ø_e$) is approximately equal to porosity minus volumetric soil water content at the field capacity (Aimrun et al., 2004). The volume fraction of total porosity with pores <7.5 $\mu$m in diameter are classified as effective pores for retaining plant available water. In contrast, the volume fractions of total porosity with pores >150 $\mu$m in diameter are effective pores for drainage of water freely with gravity (Azooz et al., 1996). A review by Kay and VandenBygaart (2002) indicates that the introduction of NT can result in the loss of porosity, most consistently evident after 15 years and is generally limited to depths of 5–20 cm. There is, however, some evidence that the porosity in the top 5 cm of the profile may be greater under NT. They also concluded that regardless of depth stratigraphy, morphology and time, there is generally an increase in pores 100–500 $\mu$m diameter when soils under CT were converted to NT or minimum tillage.

Research by Eynard at al. (2004), studying the effects of no-till, conventional-till (till), and grasslands (grass) on porosity and pore size distribution of two soils in eight locations in central South Dakota confirmed that soil porosity and very fine pore-size distribution were affected by management systems, most evidently in the surface horizons (0–0.30 m). Total pore space decreased in cultivated soils when compared with grasslands while no-tillage increased total soil porosity relative to tillage between the 0.05- and the 0.30-m depth below the surface. It was discovered that more very fine macropores (1- to 0.050-mm diam.) and, in particular, more tubular very fine macropores (indicating greater biological activity) were observed in grass than in cultivated soils, and more in no-till than in tilled soils. A similar study by Bhattacharyya et al. (2006) in the Indian Himalayas found that the average values of the volume fraction of total porosity with pores <7.5 $\mu$m in diameter (effective pores for retaining plant available water) were 0.557, 0.636 and 0.628 $m^3\ m^{-3}$ under conventional tillage (CT), minimum tillage (MT) and zero-tillage (ZT), respectively. In contrast, the average values of the volume fraction of total porosity with pores

>150 μm in diameter (pores draining freely with gravity) were 0.124, 0.096 and 0.095 $m^3 m^{-3}$, respectively under CT, MT and ZT.

Greater knowledge of intra-aggregate porosity modifications by tillage conveys new information for identifying additional hydrologic, ion retention, and aggregate stability responses to specific management practices (Park and Smucker, 2005). Overall, porosity is important because it influences: (i) the amount of air present in the soil, (ii) the rapidity with which spent air rich in $CO_2$ can be exchanged for air rich in $O_2$, (iii) the amount of water held by a soil, (iv) the rapidity with which water infiltrates a soil, and (v) how quickly excess water can be drained (Wolf and Snyder, 2003). The hydraulic aspects of porosity related to tillage are briefly discussed in the following section.

## 6. Soil hydraulic properties

Under agricultural land use, the properties of the macropore network are governed by the applied management and tillage system (Wahl et al., 2004). Tillage operations affect hydraulic conductivities in contrasting ways. Tillage, especially ploughing, creates macropores that cause saturated and near-saturated hydraulic conductivities to increase considerably, but also disrupts pore continuities that reduce hydraulic conductivities between plow layers and subsoils (Fuentes et al., 2004). Conservation tillage in particular, preserves soil water and this has been the main reason for its rapid dissemination in rainfed agriculture in semiarid climates (Bescansa et al., 2006). Because ploughing is minimized under conservation tillage there are more continuous macropores and other preferential paths reaching directly from the soil surface deep into the subsoil. Conventional tillage destroys the structure of the surface soils, mixing the plough layer and covering the macropore's connection to the surface. These macropores are capable of increasing the infiltration of water and dissolved chemicals (Andreini and Steenhuis, 1990, Green et al., 2003).

Infiltration into soils is strongly correlated with macroporosity. (Wahl et al., 2004). Chan and Mead (1989), assessing the effect of different tillage practices (i.e. conventional tillage and direct drilling) and pasture conditions on the infiltration and distribution of infiltrated rain water in an Australian Alfisol, reported that the highest density of macropores and the highest percentage of transmitting macropores were found in the permanent pasture. Conventional cultivation for 4 years, by contrast, completely disrupted this macropore structure, thus decreased the macroporosity. This, in turn, increased run-off by reducing channeling flow and changed the pathway of water movement resulting in increased leaching of the soil solution. Conversely, the study found that the macropore system was intact under direct drilling. Recently, Fuentes et al. (2004), in a similar study, reported that hydraulic conductivities in the natural prairie (NP) were about one order of magnitude larger than in the cultivated soils. In NT, saturated hydraulic conductivities in the top 5 cm of soils were significantly larger than in CT. No-till and CT soils had similar near-saturated hydraulic conductivities, indicating that even 27 yr of continuous NT could not restore the original hydraulic properties of the soil. Restoration of original hydraulic properties in cultivated former prairie soils may take considerably longer.

The study by Bescansa *et al.*(2006), at the end of 5 years of management on a clay loam calcic soil (*Calcic Haploxerept*) in semiarid northern Spain, comparing water retention under different tillage and mulching management, found that available water capacity (AWC) was greater with no-tillage (NT) than with reduced tillage (RT) and mouldboard plough (MT). Higher soil water content (SWC) under conservation tillage systems (NT, NT with stubble burning, and RT) than under MT was attributed mainly to greater AWC and to the mulching effect of crop residues. A study in the Indian Himalayas reported that saturated hydraulic conductivity values in all the studied soil depths were significantly greater under zero tillage (ZT) than those under conventional tillage (CT) (range from 300 to 344 mm $day^{-1}$). The observed $K_s$ values at 0–75 mm soil depth under ZT were significantly higher than those computed under CT at all the suction levels, except at −10, −100 and −400 kPa suction. Investigating the effects of crop rotations on hydraulic properties they stated that soybean-pea (S–P) rotation recorded significantly higher $K_s$ values than those under soybean-wheat (S–W) and soybean-lentil *(Lens culinaris)* (S–L) rotations up to −40 kPa suction. It was concluded that the interaction effects of tillage and crop rotations affecting the $K_s$ values were found significant at all the soil water suctions. Both S–L and S–P rotations resulted in better soil water retention and transmission properties under ZT (Bhattacharyya et al., 2006).

Saturated hydraulic conductivity ($K_s$) is an important soil physical property, especially for determining infiltration rate, irrigation practice, drainage design, runoff, groundwater recharge and in simulating leaching and other agricultural and hydrological processes (Aimrun et al., 2004). The research of Park and Smucker (2005) measured $K_s$ of multiple aggregate fractions from two soil types subjected to conventional tillage (CT), no tillage (NT), and native forest (NF). They found that long-term CT reduced intraaggregate porosities and $K_s$ within macroaggregates, of the same size fraction, from both the Hoytville silty clay loam and Wooster silt loam soil types. Values for $K_s$ of NF aggregates, 5.0 x $10^{-5}$ cm $s^{-1}$, were reduced 50-fold by long-term CT treatments of the Hoytville series. The $K_s$ values through Wooster aggregates from NF, 16.0 x $10^{-5}$ cm $s^{-1}$, were reduced 80-fold by long-term CT treatments. The $K_s$ values through NF and NT aggregates were positively correlated with their intraaggregate porosities ($R^2$ = 0.84 for NF and $R^2$ = 0.45 for NT at $P <$ 0.005) (Park and Smucker, 2005).

Chan and Mead (1989), studying water movement and macroporosity using a rainfall simulator under different tillage practices, found an evident decrease in macropore density and continuity under conventional cultivation. Similarly, Lal and Vandoren (1990) also reported higher cumulative infiltration and infiltration rate under no-tillage treatment than mouldboard plough and chisel plough treatments. Later, Benjamin (1993) also found that no-tillage had a better impact on hydraulic conductivity. Many researchers have reported that saturated hydraulic conductivity ($K_s$) and unsaturated hydraulic conductivity ($K_{unsat}$) were significantly and positively affected by zero-tillage (ZT) owing to either greater continuity of pores (Benjamin, 1993) or to water flow through a very few large pores (Allmaras et al., 1982) or more depth (Ehlers, 1977). The inconsistent results of soil physical and hydraulic properties under different tillage systems may be related to the transitory nature of soil structure after tillage, site history, initial and final water content, the time of sampling and the extent of soil disturbances (Azooz and Arshad, 1996).

The soil water retention function defines the relationship between water content and soil matric potential, and is an important hydraulic property necessary to study water flow and chemical movement in unsaturated soils (Wang et al., 2005). Soil-water retention function is generally described in the form soil-water characteristic curve

(SWCC). Tarawally et al. (2004) used SWCC to calculate pore size distribution and classify them into three pore size categories on the basis of their hydraulic functioning: >50 μm ($f_{>50\,\mu m}$), 50–0.5 μm ($f_{50-0.5\,\mu m}$) and <0.5 μm ($f_{<0.5\,\mu m}$). The greatest compaction levels were attained in the Fs (water content at saturation) and Fc (field capacity) soil water treatments, and a significant contribution to compaction was attributed to the existing soil water states under which the soil compaction was accomplished. For certain soils however, the differential water capacity defined as $d\theta/dh$ is higher from field data than from laboratory data in the range of low soil-water matric potentials (Pachepsky et al., 2001).

Suction properties constitute a key element for the functional representation of unsaturated flow conditions ($K_{unsat}$). These are usually shown by the water characteristic curve, which gives the relationship between volumetric water content (theta ($\theta$)) and matric suction (psi ($\psi$)). The water characteristic curve used in this study follows the closed-equation first forwarded by van Genuchten (1980) as follows:

$$\theta(\psi) = \theta_r \cdot \frac{\theta_s - \theta_r}{[1 - (\alpha\psi)^n]^m}$$

Where $\theta$ is the volumetric water content, $\psi$ is the matric potential, and $\theta_r$ and $\theta_s$ are the residual and saturated volumetric water contents, respectively. The $\alpha$, $m$, and $n$ are fitting parameters, which control a portion of the S-shape soil shrinkage curve.

The results of the studies mentioned above will be elaborated while digesting the findings of this research later in this chapter. In addition, the discussion will be complemented by a separate study on soil and nutrient loss through runoff and leaching under a simulated rainfall, presented in the next chapter. In short, it can be suggested that these infiltration and hydraulic conductivity studies show that although no-till soils may have high bulk densities and penetration resistance, they seem to have enhanced water conductivities enhancing water conservation and plant growth.

## 7. Soil organic matter and chemical properties

Miller and Donahue (1990) described the importance of soil organic matter (SOM) emphasizing its close relationships with the other soil parameters previously discussed as a "very important and active portion of the soil. It is the nitrogen reservoir; it furnishes large portions of the soil phosphorus and sulphur; it protects soils against erosion; it supplies the cementing substances for desirable aggregation formation; and it loosens up the soil to provide better aeration and water movement". A review on soil structure degradation with special reference to organic matter depletion and tillage was thoroughly presented by Kay and Munkholm (2004). Earlier publication by Kay and VandenBygaart (2002) discussed the depth stratification of porosity and organic matter due to conservation tillage.

Total soil organic matter concentration is a critical edaphic factor in dryland agroecosystem productivity which is partly controlled by crop biomass input via residues and roots. For smallholder farmers in fragile lands, multiple benefits could accrue as a result of management practices to re-establish soil carbon content lost because of land use changes or management practices that are not sustainable (Tieszen et al., 2004). Under rainfed conditions, reduced soil organic matter can decrease the effective utilization of limited precipitation by decreasing infiltration and hydraulic conductivity and increasing runoff and erosion (Shukla and Lal, 2005).

Wolf and Snyder (2003 ) stated that one of the surest ways to increase SOM is by means of conservation tillage through the combined effects of (i) lower amount of soil $O_2$ which slows down the decomposition of organic matter by microbial activity thus allowing SOM to accumulate, (ii) large proportion of residue on the soil surface, which reduces the amount of OM in close contact with soil microorganisms that can quickly decompose it, (iii) the greater amount of surface residue generally reduces erosion which is responsible for considerable SOM losses through water run-off. In general, agricultural practices for the purpose of increasing SOC must either increase organic matter inputs to the soil, decrease decomposition of soil organic matter (SOM) and oxidation of SOC, or a combination thereof (West and Post, 2002).

In a study on pasture and maize cropping following pasture conversion at four different soils in Manawatu, New Zealand, Sparling *et al.* (1992) found a marked decline in both organic C and microbial C under continuous cultivation following conversion from pasture. Another study by Aslam (1998) found greater amounts of microbial biomass C, N, and P in the no-tilled plots than conventionally tilled plots. Significant differences were found mainly at the 0 - 50 mm soil surface. The study, which spanned two cropping seasons with continuous conventional tillage, resulted in a significant decline in soil biological status and organic matter. A similar influence on soil biological status was found between no-tillage treatment and the adjacent permanent pasture control treatment. Similar results were reported by studies from other parts of New Zealand (Beare et al., 1994, Haynes, 1999, Haynes, 2000) and from overseas (Campbell et al., 1996, Diekow et al., 2005). Recent studies in the humid subtropical regions indicate that long-term no-till legume-based cropping systems and N fertilisation improved soil C and N stocks of previously cultivated land to the original stocks of native grassland (Diekow et al., 2005). Generally their findings suggested that with increasing time under pasture, soil organic content increased. By contrast, intensive cultivation mainly caused organic carbon decline partly due to enhanced decomposition of the existing organic matter by tillage.

The benefits of conservation tillage appear to increase with time, evidently as the increase in soil organic matter (SOM) reduces erosion and improves soil structure (Wolf and Snyder, 2003 p. 228). A study by Koch and Stockfisch (2006) indicates that after 7–9 years of conservation tillage, SOC and soil nitrogen (SN) were concentrated in the top 10 cm layer of the soil which can undergo a substantial loss by one ploughing operation. The study revealed that at the 0–30 cm soil depth, losses of 0.26 kg $m^{-2}$ SOC and 0.046 kg $m^{-2}$ SN occurred within 1–6 months after ploughing, accounting for 4 and 7% of the total initial masses, respectively. After 1.5–2.5 years after ploughing, losses from the 0–45 cm depth accounted for 6% and 10% of the initial total mass of SOC and SN, respectively. An earlier study by Rhoton (2000) reported similar results. Within 4 yr, no-till (NT) resulted in statistically significant ($P \leq 0.05$) differences compared to conventional tillage (CT). The surface 2.5 cm of the NT treatments had higher levels of SOM, exchangeable Ca, and extractable P, Mn, and Zn, but lower extractable K, Fe, and Cu and there were no noticeable tillage effects on exchangeable Mg and pH. Rhoton concluded that the differences in soil properties between tillage treatments were essentially independent of crop and were controlled by relative amounts of SOM and clay, and the extent to which these properties change with time. The study reiterated that NT practices can improve several fertility and erodibility-related properties of this soil within 4 yr, and enhance its sustainability.

The studies described above generally suggest an improvement in soil quality thus ensuring agricultural sustainability through the SOM enhancing practices of conservation tillage management.

### 5.2.6 Concluding remarks

Numerous studies suggest soil tillage plays an important role in agricultural sustainability. It influences crop yields through its effects on soil properties that regulate nutrient and water supply, competition with pests, and co-restrictive biophysical and socio-economic constraints. Appropriate tillage methods differ among soils, crops, and climatic regions, and the choice depends on a range of interacting factors. Tillage, or lack of tillage as is the case for the no-tillage agricultural production systems, in combination with the application of agrichemicals, is the one farming variable that most directly impacts our environment. It can greatly alter the soil physical, chemical, and biological properties leading to changes in crop productivity and the quality of the environment (Dick, 1997).

The literature also reveals the prevalence of soil degradation in many agricultural production and agroecology systems. To avert further degradation, the soil productivity balance must be shifted from degrading processes to conserving processes, and more urgently, in the fragile eco-regions and marginal lands of the tropics. Conservation tillage is one of the soil conserving practices recognised world-wide. However, it is also recognised that there is no single tillage system that can be widely used for diverse soil and climatic conditions.

The ultimate goal of this review is to stimulate research interest and discussion on the impact of tillage on the environment quality. The issue of environment and especially soil quality is as paramount to advanced and soil rich countries as to developing countries with fragile tropical land such as East Timor. While research work and supporting resources are generally largely available in the former category of countries that is not the case for the latter. Due to limited capital and human resources in developing countries, government-funded research projects are too often single disciplined studies using a top-down approach with inadequate farmer involvement.

For the two countries most related to this present study, and especially to East Timor, it is recommended, following Willcocks and Twomlow (1993) for southern Africa's case, that tillage research and development should give increased attention to: (i) understanding farmer constraints to reliable rainfed crop production systems and identifying existing and potential technology supply systems available to local farmers through a multidisciplinary approach; (ii) creating interim systems that are sustainable with existing resources and selective external information and technological input; (iii) establishing long-term tillage and agricultural production systems that conserve energy (labour and draught power), water and soil resources.

# 5.3 RESEARCH METHODOLOGIES

## 5.3.1 EXPERIMENT 1

### 5.3.1.1 Experimental Site

The first experiment was in a farmer's field in an outlying area of Dili, the capital city of East Timor. The plots were part of a rice field from which rice had been harvested prior to the research. The soil type was a vertisol with 14:51:35 and 13:48:39 sand: silt: loam texture ratio in the top 0-10 cm topsoil and 10-20 cm subsoil, respectively.

### 5.3.1.2 Experimental Design

1. Treatments

Three soil mechanical treatments, in very modest modes, were employed in this experiment on 8-14 June 2002, as follow:

(i) Conventional Tillage (CT)

Tillage was done by a hand tractor with mouldboard plough followed a week later by a single pass of a roller to break up clods and level the surface. The tillage depth was between 15-20 cm range.

(ii) Manual Tillage (MT)

The inversion of soil was done manually using hoes as common tools for seed bed preparation. The depth of the manual tillage was in the range of 10 – 15 cm. The breaking of soil clods was also done manually with hoes and wooden blocks and soil was levelled using steel forks.

(iii) No-tillage (NT)

Under this treatment, the soil was left intact and soil disturbance was kept minimal at the clearing of vegetation. Due to the unavailability of herbicide, the vegetation inside the plots was manually cut, sun dried, and later burnt.

2. Experimental design and lay-out

Due to conditions of the farmer's rice field and the lack of water for irrigation, the establishment of a proper experimental design was not possible. It was aimed at the initial planning stage to set up the experimental lay-out in Figure 5.1 in three different farmer fields, thus regarding each block as a replicate. However, due to seasonal constraints beyond the control of research management, this plan could not be materialized and the treatments, therefore, could not be externally replicated. Unlike in conventional designs, six small rice field plots, close to a tertiary traditional irrigation canal, were purposively chosen. The plot size was, on average, 10 x 15 $m^2$ each. In addition, sub-samples or internal replicates as shown in Figure 5.1 were used for statistical purpose.

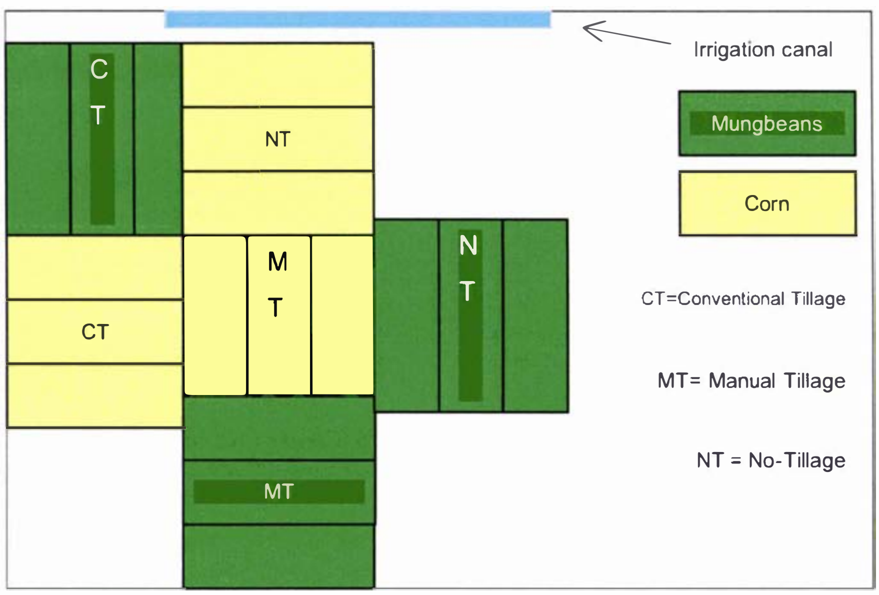



Figure 5.1 Schematic lay-out of the experimental plots at the Dili Site

3. <u>Soil sampling</u>

The soil sampling was carried out on 8 June 2002 prior to the soil preparation, for two different purposes, as described below:

a. *Bulk density and water content*

Thin walled cylindrical aluminium samplers, 48 mm in internal diameter and 50 mm in length, were used to sample soil for bulk density measurement, for each 50 mm layer of the soil down to 200 mm depth. The sampler was manually driven into the soil and the soil core removed with care to preserve its volume. The same soil core was used to determine soil water content of the respective soil layers. The soil water content was gravimetrically measured. In the absence of proper laboratory equipment, rudimentary oven and scale for the drying and weighing of soil samples, respectively, were used.

*b. Soil chemical analysis*

A half spade amount of soil was taken from 0-100 mm and 100-200 mm soil depth from four points in each plot and bulked. The soil samples were firmly wrapped and sent to a laboratory in West Timor, Indonesia for further processing prior to the chemical analysis. Soil pH, organic C, total N, P, and K were measured before and after cropping, for 0 – 100 and 100 – 200 mm soil depths.

4. Crop establishment

Commercial corn and mungbeans were obtained from the local market for the purpose of this study. Both corn and mungbeans were planted manually in each treated plot following the farmer's usual technique on 15 June 2002. No pre-planting fertilizer was applied. In mid-season, however, NPK fertilizer was evenly broadcast in the plots.

5. Soil analysis

Soil pH was determined by using a pH electrode meter. Total organic carbon determination was done by ash (dry combustion) system. Total N content was determined by using the Kjeldhal method while P content was determined by using the Olsen method. K was measured by using the $NH_4OAC$-AAS method. Soil texture was determined by Pipette method.

6. Crop and biomass production

*a. Crop yield and biomass*

Crop biomass was measured at mid cropping season by cutting the sampled crops at the base close to soil surface, at random from 1x1 $m^2$ each plot on 12 July 2002. The resultant biomass was sun dried (oven not available) and dry matter weighed. Plant height and root length from crop samples were also measured. Corn and mungbeans grain yield were assessed by taking 10 crop harvest samples at maturity on 28 September 2002. The grain was manually threshed, cleaned, and weighed.

*b. Weed dry matter*

Weed biomass were determined by collecting weed samples on weed and mungbeans plots on 15 July 2002. Weed samples of 1 $m^2$ were cut at the base and later sun dried and weighed for calculation of the total weed biomass.

### 5.3.2 EXPERIMENT 2

#### 5.3.2.1 Experimental Site

The experiment was conducted in a permanent pasture field at Massey University's Pasture and Crop Research Unit (Moginie Block), Palmerston North, New Zealand. The unit occupies 27 ha of upper terrace land on Highway 57. The soil type was Tokomaru silt loam with an average pH of 5.9 (Awan, 1989). A small part of the pasture was converted to cropping for the purpose of the tillage trial with the slope ranging from 11 to 20°. Unlike in New Zealand where steep agricultural lands are developed with pasture and trees, subsistence farmers in countries such as East Timor still extensively use steep land for cultivation.

#### 5.3.2.2 Experimental Design

1. Main treatments

Three soil mechanical treatments were used in this study, as described below:

(i) Conventional Tillage (CT)

This treatment involved a primary tillage with a mouldboard plough followed by a single pass of roller to break up clods and level the surface. Secondary tillage was done after two weeks by two passes of power harrowing for seedbed preparation.

(ii) Manual Tillage (MT)

The inversion of soil was done manually by the use of shovels. Initially a hoe was deemed the appropriate tool for this treatment, recognizing its common use by farmers elsewhere in the developing countries. However, this option was later found incompatible with the field conditions where the topsoil was heavily covered by dense pasture grass roots making it difficult for the hoe to penetrate.

(iii) No-tillage (NT)

This involved no soil and residue inversion at all, and the surface soil was left intact. Approximately two weeks prior to seeding, weeds were controlled with 4 l/ha of Roundup (360 g/l glyphosate) mixed with 1 l/ha Versatill (300 g/l clopyralid). Seeding was conducted by direct seeding with an Aitchinson seed drill.

(iv) Permanent pasture (PP)

The plots were surrounded by a large area of permanent pasture (PP) fields that were considered as a control treatment during the measurement of some experimental parameters within this study. This was an undisturbed soil with permanent pasture grass cover [ryegrass (*Lolium perene* L.) with clover (*Trifolium repens* L.)].

2. Sub-plot treatments

(i) Two crops were used in this study namely potato (*var. Ilam Hardy*) and barley (*var. Fleet*).

(ii) Two weeding approaches were employed as sub-plot treatments. Half of the plots were weeded and the other half were left unweeded during the course of the study.

3. Experimental design and lay-out

The plots were arranged in a split-plot design with three tillage treatments being in the main plots and two crops (potato and barley) and weed (weeded and unweeded) treatments as sub-plots. The main and sub-plots were placed completely randomly (RCB) into four separate blocks and located at three different field slopes. Four replications of each main and sub-treatment were considered necessary to account for any variation due to field conditions. Thus, a total of 48 plots were used in the trial.

Each plot size was 5 m long and 3 m wide (one drill width is 2.4 m) with a quite large headland for machinery operation on both sides of the field. The lay-out of the plots is shown in Figure 5.2.

4. Soil sampling

There were separate soil samples for the different measurements required in this study. Since the soil samples have to represent the field condition and reflect the variation within the area of study, considerable number, size, and methods of sampling were taken into account. Therefore, the specific sampling method used for each measurement is described below:

*a. Bulk density*

Sampling for bulk density measurement was taken for each 50 mm layer of the soil down to 300 mm depth. Thin walled cylindrical aluminium samplers, 48 mm in internal diameter and 50 mm in length, were used. Each sampler was driven into the soil manually and the soil core carefully removed to preserve a known volume of the sample as it existed in situ.

Six soil samples were taken from each plot at different depths: 0-50, 50-100, 100-150, 150-200, 200-250, and 250-300 mm. The samples were weighed, oven-dried at 105°C overnight, and reweighed. Bulk density was calculated as the ratio of the oven-dry mass of soil to the bulk volume (g $cm^{-3}$) of the sample.

Bulk density was measured on 12 March 2004, after the crops had been harvested, and in the first week of April 2004, after the second measurement of soil penetration resistance. Slightly bigger soil corers were used during the second measurement as a check and balance measure against the standard corer used in the first measurement.

Rep 1

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| MT Bw 1 | MT Puw 2 | MT Buw 3 | MT Pw 4 | CT Buw 5 | CT Pw 6 | CT Bw 7 | CT Puw 8 | NT Bw 9 | NT Puw 10 | NT Buw 11 | NT Pw 12 |

Rep2

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| MT Pw 13 | MT Buw 14 | MT Puw 15 | MT Bw 16 | NT Pw 17 | NT Buw 18 | NT Puw 19 | NT Bw 20 | CT Pw 21 | CT Buw 22 | CT Puw 23 | CT Bw 24 |

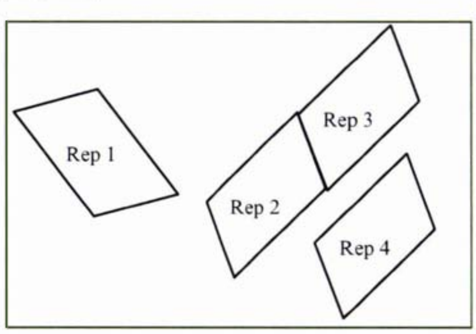
Rep 3

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| NT Bw 25 | NT Puw 26 | NT Buw 27 | NT Pw 28 | CT Buw 29 | CT Pw 30 | CT Bw 31 | CT Puw 32 | MT Bw 33 | MT Puw 34 | MT Buw 35 | MT Pw 36 |

Rep 4

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| CT Buw 37 | CT Pw 38 | CT Bw 39 | CT Puw 40 | MT Bw 41 | MT Puw 42 | MT Buw 43 | MT Pw 44 | NT Bw 45 | NT Puw 46 | NT Buw 47 | NT Pw 48 |

Lay-out




Legend:

Main Plots: CT = Conventional Tillage; MT = Manual Tillage; NT = No-Tillage;

Sub-Plots: Pw = Potato Weeded; Puw = Potato Unweeded; Bw = Barley Weeded; Buw = Barley Unweeded

Figure 5.2 Schematic lay-out of the experimental plots at the Palmerston North Site *b. Soil water content*

Samples for bulk density were also used for volumetric water content measurement. In this case, water content for six soil layers of 50 mm each from the 300 mm top soil were recorded. Sampling at different soil layers from the above were used at the time samples for aggregation stability measurement were extracted i.e. one sample for each layer of 0 - 100 mm, 100 - 200 mm, and 200 – 300 mm.

Soil samples at appropriate depths from each plot were collected at different times, corresponding to the sampling for bulk density, aggregate stability, hydraulic conductivity, and soil moisture release analyses / porosity measurement. The samples were weighed, oven-dried at 105$^{o}$ C overnight, and reweighed. Both volumetric and gravimetric water content was determined from the change of volume / mass after oven-drying. Volumetric soil water content was also assessed in the field during the growing season by Time Domain Reflectometry (TDR).

*c. Hydraulic conductivity*

Aluminium sampling liners of 98 mm internal diameter were used to collect soil samples for both saturated and unsaturated hydraulic conductivity measurement. Liners were lightly greased on the inside to assist in a sealing the soil/liner contact. The collection of samples was done by hand carving the liner into the soil (Figure. 5.3) at 0 – 100 mm and 100 – 200 mm soil depths. This is a time consuming method but produces excellent samples under most conditions encountered. It is especially suitable where the soil is unavoidably dry, is very dense, contains roots or is inaccessible to vehicles (Dando, 2004).

*d. Soil moisture release/ soil porosity measurement*

For the purpose of low tension analysis i.e. up to 10 kPa suction level, the same soil cores for hydraulic conductivity were used. After the low tension analyses had been completed, a smaller sampling liner was used to extract one small sample from each big soil core for further analysis using high tension. The high suction level employed in this study was 100 kPa, needed for the estimation of readily available water.

*e. Aggregate stability*

Spade slices of soil from two depths (0-100 mm and 100-200 mm) were removed from each plot. Air-dried samples from the slices were then sieved through a nest of sieves to obtain aggregate with the diameter sizes between 2 to 4 mm. These 2 - 4 mm aggregate samples were used to determine the aggregate stability by means of wet-sieving analysis. Soil samples were also taken for organic C and N analysis as these were suggested by many studies to have close relationship with soil structural stability.

Figure 5.3 Core samples being taken in the field for hydraulic conductivity measurement

5. Crop establishment

- *Potato and Barley*

Potato (*Solanum tuberosum* L.) and barley (*Hordeum vulgare* L.) were planted on the 18$^{th}$ of November 2003 (Figure 5.4). Ilam Hardy was the potato variety chosen because it is an all purpose potato suitable for most end uses especially mashing and baking. It is a yellow skinned white fleshed potato, full flavoured, tending towards being floury. The planting was 25 cm in row spacing and 75 cm between rows.

Barley was chosen as an above ground crop in contrast to the tubers of the potato. The barley seed rate was 135 kg/ha and was planted by drilling into CT and NT plots with the drill width of 2.40 m. The space between rows was 15 cm. The planting in the MT plots was done by placing the barley seeds manually into the hand-dug rows with the seed requirements of 12.6 g/row.

Figure 5.4 Potato and barley growth at the mid-cropping season (6/1/04)

#### 5.3.2.3 Field Measurements

The key soil indicators measured in the field were: (a) soil penetration resistance, (b) soil bulk density, (c) soil water content, (d) crop and biomass yield, and (e) weed population and dry matter.

1. Penetration resistance

A Bush® recording cone penetrometer (Mark 1 model 1979) with 12.2 mm cone diameter was used to measure soil penetration resistance in each plot to a depth of 300 mm (Figure 5.5). Data were reported as the maximum force recorded as the cone passed through each 2 mm soil layer (for the top 200 mm topsoil) and each 50-mm soil layer at the 200 - 300 mm soil depth. The locations were chosen at random and the penetrometer was pushed into the soil by hand at a constant rate (Viegas and Choudhary, 2002). Measurements of soil penetration resistance were done twice. The first measurement was on 6 January 2004, at approximately mid-cropping season. This time was considered appropriate in order to examine the soil conditions several weeks after cultivation. The second measurement was done more than two months later, on 22 March 2004, after all the crops were harvested and the plots left undisturbed.


Figure 5.5 Soil penetration resistance measurement

2. Crop and biomass yield

Barley grain and biomass yield were assessed by taking crop samples at maturity from a 2 x 1 m row on 17 February 2004. Plants were cut at the base close to soil surface, at random from each plot. The grain was manually threshed and cleaned using a fan, moisture content determined, and net barley grain weight adjusted and calculated. The resultant biomass was oven-dried at 105$^{o}$ C and dry matter weighed.

Similarly, potato tuber yield was measured by collecting 8 crop samples (from 2 x 1 m row) on 26 February 2004. The tubers were manually dug, stored, and later washed. The clean potatoes were then weighed and sorted into three major size categories. The biomass yield was assessed by using similar procedure to the barley biomass.

3. Weed population and dry matter

Weed biomass were determined by collecting weed samples on weeded potato and barley plots on 5 January 2004. Weed samples of 1 $m^2$ were cut at the base and later weighed to determine the wet weight. The samples were then manually sorted and identified to estimate the approximate population and distribution in each plot. They were later oven-dried and weighed for calculation of the total weed biomass.

Weed population in the unweeded plots was similar to those in the weeded plots based on observation. However, the determination of weed biomass on unweeded plots was only done on the potato plots on 9 March 2004. Strong wind prior to that time caused severe lodging to the barley crops, making it difficult to assess the weed population.

### 5.3.2.4 Laboratory Measurements

1. Aggregate stability

Wet-sieving analysis to determine aggregate water stability was carried out on 2.0 - 4.0 mm aggregates using the method of Gradwell (1972). This is basically a modification of Yoder's method described by Kemper and Rosenau (1986).

The main apparatus used in this method is the wet sieving tank. It is approximately 35 cm wide x 45 cm long x 30 cm deep (Figure 5.6). Six stacks of 13 cm sieves were carried in a frame which moved up and down a distance of 3 cm, thirty times a minute. Each sieve stack comprised three sieves stacked from top to bottom with apertures of 2.0, 1.0, and 0.5 mm respectively (Dando, 1999).

Samples were air-dried soon after sampling. The larger clods were broken down by hand and the whole sample placed into shallow trays and air-dried. Once air-dry, the samples were mechanically sieved to extract aggregates between 2-4 mm in diameter (Figure 5.7). Samples of 2-4 mm were analysed soon after air-drying. The aggregates were placed on the top sieves which were then moved up and down under water and the proportion of crumbs remaining on the sieves after the 30 minute period being a measure of stability.

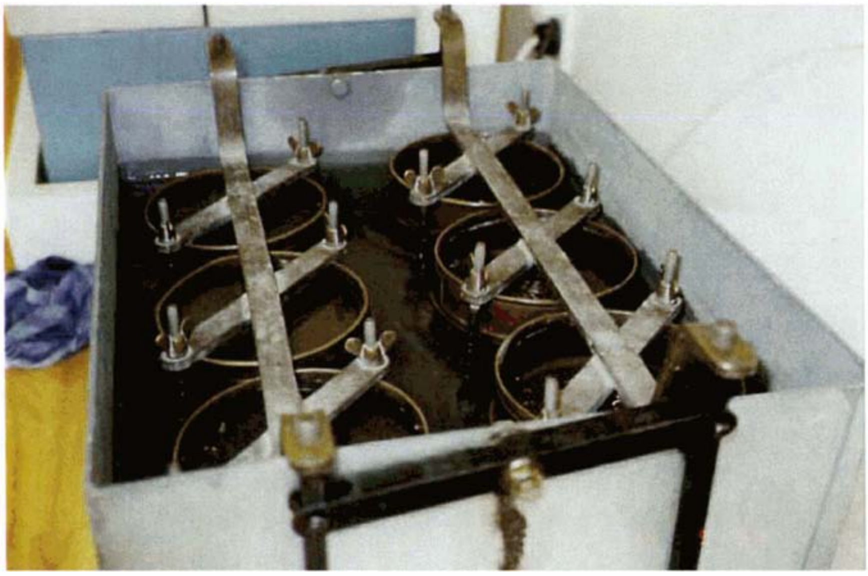


Figure 5.6 Wet-sieving tank

Figure 5.7 Sieving for the extraction of 2 - 4 mm soil aggregates

2. Soil hydraulic conductivity

*a. Saturated hydraulic conductivity (K sat.)*

The 98 mm core soil samples had the top 10 mm of soil picked out (cavity) to expose natural fractures between peds and to produce a soil surface as undisturbed as possible. Samples were *slowly* saturated in a water bath. When saturated, the cores were placed on a draining grid and a pool of water maintained in the cavity (Figure 5.8a). The rate of water moving through the soil was measured. Once a constant rate was reached for an individual sample it was recorded and reported in m/s (Dando, 2004).

*b. Unsaturated hydraulic conductivity (K-40)*

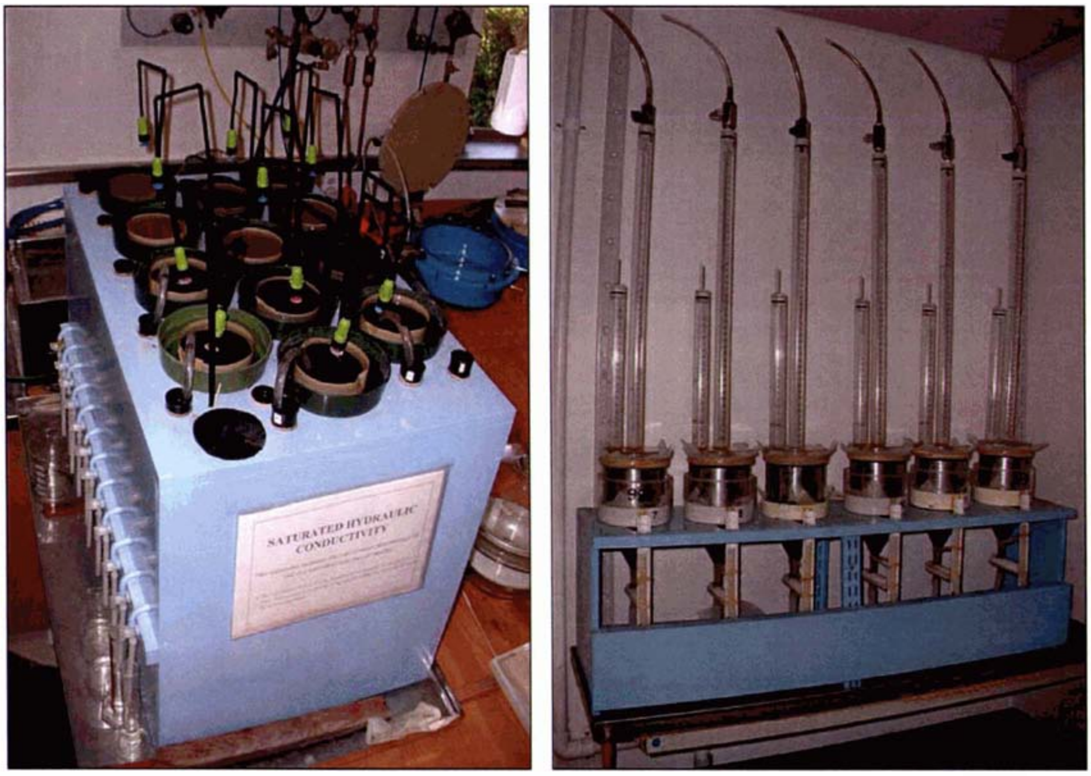
Soil samples in 99 mm cores were placed on a Buchner funnel capable of creating a tension of between -0.1 and -1.0 kPa to control drainage of the soil. A disc permeameter (tension permeameter, suction permeameter) was placed on top of the core to supply water from a reservoir at a tension *equal* to that set on the Buchner funnel (Figure 5.8b). The rate of water moving through the soil (hydraulic conductivity) was measured. The unsaturated rate was recorded once a constant rate was reached for an individual sample. Rates were reported in m/s and mm/hr (Dando, 2004).

3. Soil porosity

The determination of soil porosity was carried out using the same soil cores previously used for hydraulic conductivity measurement. After the unsatutared hydraulic conductivity measurements were completed, the soil cores were then subjected to higher suction levels under the moisture release analysis. The results obtained from each suction level were further used to calculate total, macro, and micro-porosity for each soil core (Gradwell, 1972). At the same time, soil moisture content, particle and bulk densities at different suction levels were also calculated.

4. Soil pH, total C and N, and Olsen P analysis

Soil pH, total C and N were measured at once. Soil pH was determined by using a pH electrode meter. Soil organic carbon content and total N were measured using a Laboratory Equipment Corporation (Leco) high-frequency induction furnace (Blakemore et al., 1987). The P content was determined by using the Olsen method. The measurements were done on sub-samples taken from air-dried soil collected from each plot. Samples were collected from three depths, 0-100, 100-200, and 200-300 mm, from each plot after the crops were harvested, and from the adjacent pasture fields on 27 March 2004. Soil from each plot was bulked before sub-sampling.




(a) (b)

Figure 5.8 Measurement of (a) saturated and (b) unsaturated hydraulic conductivity

### 5.3.3 STATISTICAL ANALYSIS

The analysis of all data obtained during this study was performed using the General Lineal Model (GLM) procedure of SAS (Statistical Analysis System)(SAS, 2002).

## 5.4 RESULTS

### 5.4.1 Experiment 1 (Dili, East Timor)

1. Soil chemical indicators

Table 5.1 presents the results of soil chemical analysis under corn and mungbeans affected by different tillage treatments. Comparing before and after cropping, the average pH of two soil layers (0-10 and 10-20 cm) was reduced after the plants were harvested under all the treatments except under NT where an increase of average pH was noticed both under corn and mungbean crops. Total organic carbon measurement was undetected (near zero) before the cropping but showed some increase after the corn and mungbeans were harvested, with the highest carbon figure (1.52%) found under no-till corn treatment. Total N, like the organic C, showed a slight increase after cropping with the exception of soils under MT mungbeans where organic carbon decreased.

Table 5.1 Selected soil chemical indicators as affected by tillage and cropping management (CT=conventional tillage, MT=manual tillage, NT=No-tillage) before (BC) and after (AC) cropping

| Treat. | Soil layer | pH | | C-org. (%) | | N-tot. (%) | | P (ppm) | | K (me/100 g) | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | BC | AC | BC | AC | BC | AC | BC | AC | BC | AC |
| CT mungbean | 0-10 | 8.36 | 7.55 | - | 1.01 | 0.27 | 0.23 | 110 | 78.54 | 8.81 | 1.30 |
| | 10-20 | 8.03 | 7.64 | - | 0.81 | 0.02 | 0.32 | 73.2 | 20.09 | 23.60 | 0.79 |
| | Aver. | **8.20** | **7.60** | | **0.91** | **0.15** | **0.28** | **91.6** | **49.32** | **16.21** | **1.05** |
| CT corn | 0-10 | 7.78 | 7.41 | - | 1.72 | 0.23 | 0.15 | 307.7 | 95.37 | 31.37 | 1.21 |
| | 10-20 | 7.79 | 7.85 | - | 0.65 | 0.23 | 0.50 | 262.9 | 93.96 | 25.79 | 0.97 |
| | Aver. | **7.79** | **7.63** | | **1.19** | **0.23** | **0.33** | **285.3** | **94.67** | **28.58** | **1.09** |
| NT corn | 0-10 | 7.39 | 7.39 | - | 2.03 | 0.02 | 0.19 | 187.3 | 88.07 | 29.37 | 0.82 |
| | 10-20 | 7.35 | 7.76 | - | 1.01 | 0.02 | 0.06 | 161.7 | 17.33 | 44.23 | 1.12 |
| | Aver. | **7.37** | **7.58** | | **1.52** | **0.02** | **0.13** | **174.5** | **52.7** | **36.80** | **0.97** |
| NT mungbean | 0-10 | 7.09 | 7.35 | - | 1.22 | 0.01 | 0.28 | 64.4 | 67.32 | 42.00 | 2.42 |
| | 10-20 | 7.20 | 7.48 | - | 0.25 | 0.19 | 0.15 | 65.7 | 40.54 | 44.61 | 0.58 |
| | Aver. | **7.15** | **7.42** | | **0.74** | **0.10** | **0.22** | **65.05** | **53.93** | **43.31** | **1.50** |
| MT corn | 0-10 | 7.18 | 7.35 | - | 1.25 | 0.18 | 0.09 | 146.7 | 28.08 | 64.60 | 1.47 |
| | 10-20 | 7.07 | 7.43 | - | 0.86 | 0.02 | 0.24 | 191.5 | 27.04 | 73.65 | 1.13 |
| | Aver. | **7.13** | **7.39** | | **1.06** | **0.10** | **0.17** | **169.1** | **27.56** | **69.13** | **1.30** |
| MT mungbean | 0-10 | 7.03 | 7.35 | - | 1.39 | 0.12 | 0.07 | 150.2 | 89.25 | 20.86 | 1.42 |
| | 10-20 | 7.23 | 7.55 | - | 0.67 | 0.12 | 0.11 | 147.2 | 53.46 | 26.11 | 1.11 |
| | Aver. | **7.13** | **7.45** | | **1.03** | **0.12** | **0.09** | **148.7** | **71.36** | **23.49** | **1.27** |

BC= soil sampled on June 8, 2002; AC= soil sampled on early October 2002

## 2. Soil bulk density and water content

The results show that there was no significant difference in bulk density for soils under cultivation (CT and MT) compared with those in the untilled plots (NT). Similarly, insignificant results were also found for soil water content under all the tillage treatments (Table 5.2).

Table 5.2 Soil bulk density and water content under different tillage and cropping regimes (CT=conventional tillage, MT=manual tillage, NT=No-tillage)

| Parameters | Treatments | | | $LSD_{0.05}$ |
|---|---|---|---|---|
| | CT | MT | NT | |
| Soil bulk density (g $cm^{-3}$) | 1.25 a | 1.25 a | 1.21 a | n.s. |
| Soil water content (%) | 28.33 a | 31.58 a | 34.63 a | n.s. |

n.s. = not significant

## 3. Crop and biomass production

Maize height and root length, mungbeans root length, and maize and mungbeans wet and dry matter was not affected by the tillage treatments. Significant differences were only observed on mungbeans plant height and weed population on maize plots. Mungbeans height was significantly higher under the MT treatment as compared to the CT and NT treatments. A significantly higher weed biomass, not unexpectedly, was found on the NT plots compared to cultivated plots (CT and MT).

Table 5.3 Selected crops and weed indicators during development stage (CT=conventional tillage, MT=manual tillage, NT=No-tillage)

| Treat. | Plant height (mm) | | Root length (mm) | | Weed biomass (kg/ha DM) | | Crop wet matter (kg/ha) | | Crop dry matter (kg/ha) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | *Maize* | *M.beans* | *Maize* | *M.beans* | *Maize plots* | *M.beans plots* | *Maize* | *M.beans* | *Maize* | *M.beans* |
| CT | 533.3 a | 282.2 b | 137.8 a | 142.4 a | 745.6 b | 800.2 a | 2900 a | 1283.3a | 606.9 a | 281.2 a |
| MT | 588.9 a | 310.6 a | 124.4 a | 110.6 a | 898.4 b | 434.2 a | 2400 a | 1800 a | 517.5 a | 322.4 a |
| NT | 467.2 a | 280.0 b | 118.9 a | 97.2 a | 2116.9a | 953.4 a | 1016.7a | 1183.3a | 302 5 a | 274.5 a |
| $LSD_{0.05}$ | n.s. | 27.72 | n.s. | n.s. | 1069.4 | n.s. | n.s. | n.s. | n.s. | n.s. |

Values followed by the same letter in each column are not significantly different (P<0.05), n.s. = not significant

The crop yield measurement results indicated significantly higher maize and cob yields under CT and MT treatments compared to NT treatment. Mungbeans grain and husk yield on the other hand, were unaffected by tillage treatment.

Table 5.4 Crop yield and by-products on 12/10/02 (CT=conventional tillage, MT=manual tillage, NT=No-tillage)

| Treatment | Maize (t/ha) | | Mungbeans (t/ha) | |
|---|---|---|---|---|
| | *Grain* | *Cobs* | *Grain* | *Husk* |
| CT | 18.5 a | 5.0 a | 1.8 a | 0.77 a |
| MT | 15.1 a | 4.6 a | 2.0 a | 0.83a |
| NT | 6.4 b | 1.7 b | 1.2 a | 0.52 a |
| $LSD_{0.05}$ | 6.5 | 1.7 | n.s. | n.s. |

Values followed by the same letter in each column are not significantly different (P<0.05), n.s. = not significant

### 5.4.2 Experiment 2 (Palmerston North, New Zealand)

1. Penetration resistance

The first measurement was taken on the 6th of January 2004, at the middle of the potato and barley-cropping season. There was a significantly higher soil resistance in the PP and NT plots compared to MT and CT plots at soil layers down to 18 cm (Table 5.5). No significant differences were found among all the treatments at 20-30 cm soil layer. Almost similar readings were observed at all depths between the NT and PP plots with only a significantly lower value found in the top 2 cm of the NT plots. A significantly low resistance to penetration was found down to 12 cm soil profile depth under the MT treatment compared to the CT treatment. This is the depth that indicated the average hoeing depth under the MT treatment whereas under the CT the ploughing depth was deeper.

There was a clear indication of the development of a loose tilth depth or rooting zone under the CT treatment down to 18 to 20 cm soil depth. From this point downwards (20-30 cm soil layer), the effects of tillage implements were not noticeable as shown by the similarities in soil strength between the tilled plots (CT and MT treatments) and untilled ones (NT and PP treatments).

Table 5.5 Effects of tillage practices and cropping regime on soil penetration resistance (MPa) (measured on 6th January 2004) (CT=conventional tillage, MT=manual tillage, NT=No-tillage, PP=Permanent pasture)

| Soil Depth (cm) | Treatments | | | | $LSD_{0.05}$ |
|---|---|---|---|---|---|
| | CT | MT | NT | PP | |
| 2 | 1.58 bc | 1.37 c | 1.85 ab | 2.12 a | 0.39 |
| 4 | 2.19 a | 1.59 b | 2.45 a | 2.55 a | 0.42 |
| 6 | 2.30 b | 1.58 c | 2.68 a | 2.66 a | 0.33 |
| 8 | 2.34 b | 1.59 c | 2.67 a | 2.66 a | 0.27 |
| 10 | 2.28 b | 1.66 c | 2.57 a | 2.55 a | 0.23 |
| 12 | 2.20 b | 1.86 c | 2.43 a | 2.46 a | 0.20 |
| 14 | 2.11 b | 2.05 b | 2.33 a | 2.44 a | 0.22 |
| 16 | 2.13 b | 2.24 ab | 2.33 ab | 2.47 a | 0.27 |
| 18 | 2.26 b | 2.40 ab | 2.48 ab | 2.59 a | 0.30 |
| 20 | 2.56 a | 2.57 a | 2.79 a | 2.75 a | n.s. |
| 25 | 3.25 a | 3.14 a | 3.34 a | 3.25 a | n.s. |
| 30 | 3.19 a | 3.42 a | 3.16 a | 3.46 a | n.s. |

Values followed by the same letter in each row are not significantly different ($P<0.05$), n.s. = not significant

The regression analyses (Fig. 5.9) showed that the increase in soil penetration resistance was linearly correlated with the increase in soil depth under all the treatments, the relationship was strongest for MT ($R^2$ = 0.96) and moderate under other treatments (CT: $R^2$ = 0.69; PP: $R^2$ = 0.66; and NT: $R^2$ = 0.55).

The second soil penetration measurement was undertaken on 27 March 2004, after the soil was left undisturbed under potato and barley crops (Table 5.6). In the top 2 cm soil layer there was no significant difference among all the treatments. The top 0-10 cm soil layer under the CT treatment had been compacted to an extent similar to that under the NT and PP treatments. Within this layer, the MT treatment produced significantly lower resistance compared to the other treatments. Below the 0-10 cm soil layer, however, a mixed pattern was observed. In contrast to the layer above, the resistance under the CT and PP were reduced while the penetration resistance under the NT remained the highest. On the other hand, the MT treatment produced significantly lower resistance in the 12 – 14 cm soil layer. Beyond this layer, however, the results show no significant difference among the CT, MT, and PP treatments.

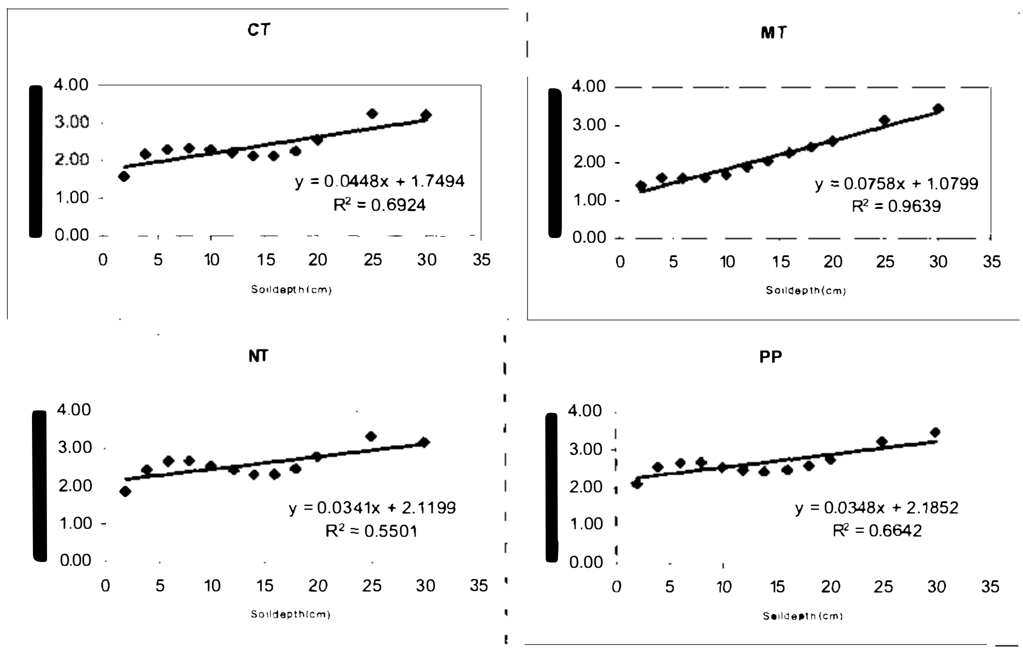



Figure 5.9 Regression analysis between soil depth (cm) and soil penetration resistance (MPa) under the CT (conventional tillage), MT (manual tillage), NT (no-tillage) and PP (Permanent pasture) treatments measured during early summer potato and barley growing season 2003

Table 5.6 Effects of tillage practices and cropping regime on soil penetration resistance (MPa) (measured on 27th March 2004) (CT=conventional tillage, MT=manual tillage, NT=No-tillage, PP=Permanent pasture)

| Soil Depth (cm) | Treatments | | | | $LSD_{0.05}$ |
|---|---|---|---|---|---|
| | CT | MT | NT | PP | |
| 2 | 1.92 a | 1.52 a | 1.67 a | 1.89 a | n.s |
| 4 | 2.10 a | 1.52 b | 1.94 ab | 2.09 a | 0.45 |
| 6 | 2.14 a | 1.39 b | 2.17 a | 2.07 a | 0.43 |
| 8 | 2.08 a | 1.22 b | 2.24 a | 2.04 a | 0.35 |
| 10 | 1.96 a | 1.18 b | 2.18 a | 1.94 a | 0.30 |
| 12 | 1.85 b | 1.24 c | 2.09 a | 1.82 b | 0.23 |
| 14 | 1.72 b | 1.37 c | 1.94 a | 1.72 ab | 0.22 |
| 16 | 1.67 b | 1.48 b | 1.90 a | 1.65 b | 0.22 |
| 18 | 1.73 b | 1.59 b | 1.98 a | 1.71 b | 0.23 |
| 20 | 1.78 ab | 1.75 b | 2.11 a | 1.82 ab | 0.36 |
| 25 | 2.14 b | 2.12 b | 2.57 a | 2.23 ab | 0.35 |
| 30 | 2.33 b | 2.24 b | 2.70 a | 2.36 b | 0.32 |

Values followed by the same letter in each row are not significantly different ($P<0.05$); n.s. = not significant

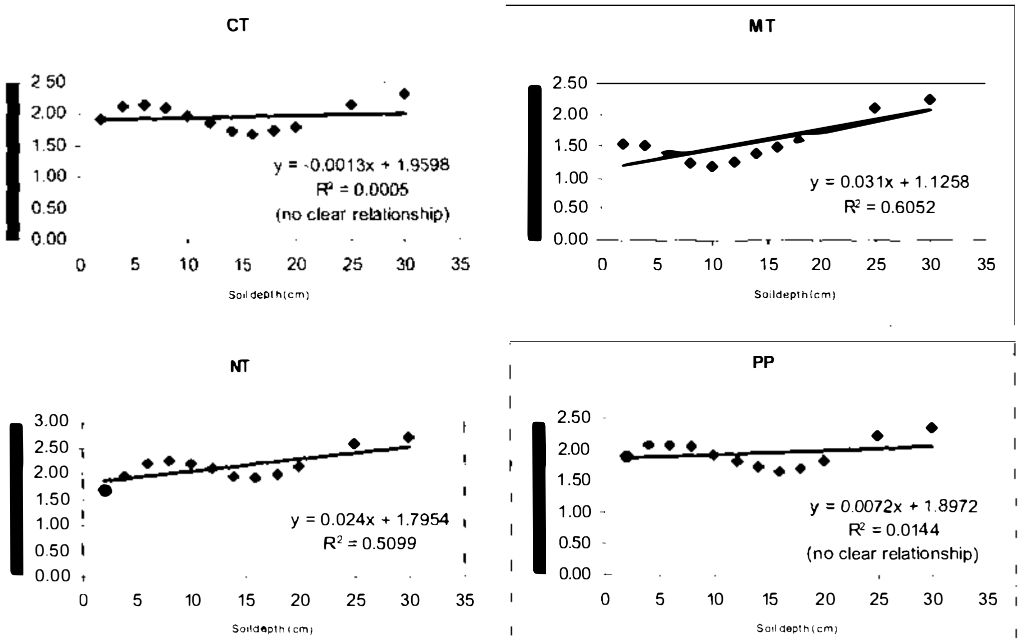



Figure 5.10 Regression analysis between soil depth (cm) and soil penetration resistance (MPa) under the CT (conventional tillage), MT (manual tillage), NT (no-tillage) and PP (Permanent pasture) treatments measured after potato and barley harvest 2004

Soil resistance tended to increase in the lower layers under all the treatments after a period of more than two months. Another observation from the second set of measurements in the MP plots was the decrease in soil resistance observed at the depths below 20 cm. This suggests the characterization of another differing soil horizon just below the cultivated layer. Regression analysis results demonstrated no clear trend between soil depth and soil penetration resistance under MP whereas a linear regression was found under PP and NT (Figure 5.10).

2. Soil bulk density

The results show similar densities of soil in the 0-5 cm topsoil under all the treatments (Table 5.7). A clear pattern is observed where soil bulk density increased with the increase of soil depth especially below 20 cm depth. The soils in the untilled plots (NT and PP) showed a consistently higher soil bulk density compared to those from the tilled plots (CT and MT). CT and MT show almost similar soil densities in all depths except at 5-10 cm soil layer where the soil bulk density is significantly higher under CT. Similarly, the soils under NT and PP treatments show no significant differences throughout the soil profile. On average, however, the soils under MT had a significantly lower bulk density at 0-30 cm depth compared to the soils under the other treatments.

Table 5.7 Effects of tillage practices and cropping regime on soil bulk density ($gcm^{-3}$) measured on 12th March 2004 (CT=conventional tillage, MT=manual tillage, NT=No-tillage, PP=Permanent pasture)

| Soil Depth (cm) | Treatments | | | | $LSD_{0.05}$ |
|---|---|---|---|---|---|
| | CT | MT | NT | PP | |
| 5 | 1.22 a | 1.26 a | 1.21 a | 1.21 a | n.s |
| 10 | 1.20 b | 1.14 c | 1.25 ab | 1.28 a | 0.06 |
| 15 | 1.19 ab | 1.05 b | 1.30 a | 1.27 a | 0.16 |
| 20 | 1.18 b | 1.22 ab | 1.29 a | 1.23 ab | 0.10 |
| 25 | 1.34 a | 1.25 ab | 1.31 ab | 1.20 b | 0.12 |
| 30 | 1.44 a | 1.36 a | 1.49 a | 1.33 a | n.s. |
| Average | 1.26 ab | 1.21 b | 1.31 a | 1.25 ab | 0.07 |

Values followed by the same letter in each row are not significantly different ($P<0.05$)

The second measurement was done using a 98 mm internal diameter corer at two soil depths, 0-10 and 10-20 cm (Table 5.8). There was a significantly higher soil bulk density under the CT compared to the others in the 0-10 cm soil layer. In the layer below, however, the soil bulk densities were similar. On average, CT soils were significantly more compacted than the soils under MT and PP ($P<0.05$) but, insignificantly different with soils under NT at 0-20 cm depth.

Table 5.8 Effects of tillage practices and cropping regime on soil bulk density ($gcm^{-3}$) measured on April 2004 (CT=conventional tillage, MT=manual tillage, NT=No-tillage, PP=Permanent pasture)

| Soil Depth (cm) | Treatments | | | | $LSD_{0.05}$ |
|---|---|---|---|---|---|
| | CT | MT | NT | PP | |
| 0-10 | 1.23 a | 1.11 b | 1.12 b | 1.07 b | 0.06 |
| 10-20 | 1.18 a | 1.16 a | 1.25 a | 1.16 a | n.s. |
| Average | 1.21 a | 1.14 b | 1.19 ab | 1.10 b | 0.07 |

Values followed by the same letter in each row are not significantly different ($P<0.05$); n.s. = not significant

## 3. Soil Water Properties

### *a. Low tension (LT) Moisture Release Analysis*

The moisture release analysis using low tension shows that permanent pasture (PP) soils had consistently a significantly higher field capacity and water content at the 0-10 cm depth under all levels of suction (0 kPa, 5 kPa, and 10 kPa) compared with the soils under the other treatments (Table 5.9). On the contrary, among all the soil treatments, MT produced the lowest level of field capacity while CT had the lowest water content at saturation. At the 5 kPa and 10 kPa suction level, a mixed water content result was observed between CT and MT, however they were generally similar. The NT produced significantly lower soil water content compared to PP at 5 kPa and 10 kPa suction but generally higher or similar results compared to CT and MT.

Table 5.9 Tillage effects on soil water properties at 0 – 10 cm topsoil (measured using Low Tension Moisture Release Analysis) (CT=conventional tillage, MT=manual tillage, NT=No-tillage, PP=Permanent pasture)

| Tillage Treatment | Field capacity (%) | Water content | | | | | |
|---|---|---|---|---|---|---|---|
| | | at saturation | | at 5 kPa | | at 10 kPa | |
| | | %w/w | %v/v | %w/w | %v/v | %w/w | %v/v |
| CT | 41.1 bc | 43.0 b | 52.9 b | 35.5 c | 43.6 b | 33.5 c | 41.1 cb |
| MT | 38.6 c | 51.3 a | 56.9 a | 36.5 bc | 40.5 c | 34.7 bc | 38.6 c |
| NT | 42.8 b | 50.5 a | 56.5 a | 40.3 b | 45.0 b | 38.2 b | 42.8 b |
| PP | 46.1 a | 54.8 a | 58.5 a | 44.9 a | 47.9 a | 43.2 a | 46.1 a |
| $LSD_{0.05}$ | 2.8 | 4.8 | 2.2 | 4.1 | 2.7 | 3.9 | 2.8 |

Values followed by the same letter in each column are not significantly different (P<0.05)

Table 5.10 Tillage effects on soil water properties at 10 – 20 cm subsoil (measured using Low Tension Moisture Release Analysis) (CT=conventional tillage, MT=manual tillage, NT=No-tillage, PP=Permanent pasture)

| Tillage Treatment | Field capacity (%) | Water content | | | | | |
|---|---|---|---|---|---|---|---|
| | | at saturation | | at 5 kPa | | at 10 kPa | |
| | | %w/w | %v/v | %w/w | %v/v | %w/w | %v/v |
| CT | 41.1 a | 46.9 a | 54.6 a | 37.1 a | 43.5 a | 35.1 a | 41.1 a |
| MT | 37.8 c | 48.1 a | 55.5 a | 34.3 ab | 39.7 c | 32.6 ab | 37.8 c |
| NT | 39.0 bc | 42.0 a | 52.5 a | 32.9 b | 41.0 bc | 31.3 b | 39.0 bc |
| PP | 40.3 ab | 48.2 a | 55.6 a | 37.0 a | 42.7 ab | 34. 9 ab | 40.3 ab |
| $LSD_{0.05}$ | 1.5 | n.s. | n.s. | 4.0 | 2.1 | 3.6 | 1.5 |

Values followed by the same letter in each column are not significantly different (P<0.05), n.s. = not significant

At the 10-20 cm soil depth, the CT, interestingly, produced the highest field capacity and water content at 5 and 10 kPa suction levels although insignificantly different with PP treatment (Table 5.10). Water content at saturation (0 kPa) was similar under all the treatments. MT and CT have generally similar values of field capacity and water content at all levels of water suction.

*b. High tension (HT) Moisture Release Analysis*

The high tension analysis on soils from 0-10 cm depth shows that PP, like in the low tension analysis results described earlier, had the highest field capacity and water content at all suction levels (Table 5.11). MT had the lowest field capacity but showed no significant differences with CT and NT. NT had similarities with PP in field capacity and volumetric water content (10 and 100 kPa suction) but significant differences in gravimetric water content (0, 10, and 100 kPa suction) and volumetric water content at saturation (0 kPa suction). CT and MT shared many similarities except for gravimetric water content (0 and 10 kPa suction) and volumetric water content at 0 kPa suction. Readily available water (RAW) was not affected by tillage and pasture treatments as no significant differences were found.

Table 5.11 Tillage effects on soil water properties at 0 – 10 cm topsoil (measured using High Tension Moisture Release Analysis) (CT=conventional tillage, MT=manual tillage, NT=No-tillage, PP=Permanent pasture, RAW=readily available water)

| Tillage Treatment | Field capacity (%) | RAW 10 - 100 kPa (%) | Water content | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | at saturation | | at 10 kPa | | at 100 kPa | |
| | | | %w/w | %v/v | %w/w | %v/v | %w/w | %v/v |
| CT | 39.3 b | 9.3 a | 40.7 c | 51.5 c | 31.0 c | 39.3 b | 23.7 b | 30.0 b |
| MT | 39.0 b | 8.6 a | 47.4 ab | 55.0 ab | 33.6 b | 39.0 b | 26.2 b | 30.4 b |
| NT | 40.2 ab | 8.4 a | 43.7 bc | 53.0 bc | 33.2 bc | 40.2 ab | 26.3 b | 31.8 ab |
| PP | 42.1 a | 6.6 a | 48.8 a | 55.6 a | 38.9 a | 42.1 a | 31.1 a | 35.5 a |
| $LSD_{0.05}$ | 2.4 | n.s. | 4.2 | 2.4 | 2.3 | 2.4 | 3.6 | 4.1 |

Values followed by the same letter in each column are not significantly different (P<0.05), n.s. = not significant

At 10-20 cm soil depth, the tillage and pasture treatments in general, did not have any significant impact on the field capacity and soil water content (Table 5.12). This was shown by the similarities among the values under all the treatments except volumetric water content under MT at 10 kPa and field capacity which had significantly lower values compared to the other soil treatments.

Table 5.12 Tillage effects on soil water properties at 10 – 20 cm subsoil (measured by High Tension Moisture Release Analysis) (CT=conventional tillage, MT=manual tillage, NT=No-tillage, PP=Permanent pasture, RAW=readily available water)

| Tillage Treatment | Field capacity (%) | RAW 10 - 100 kPa (%) | Water content at saturation %w/w | Water content at saturation %v/v | Water content at 10kPa %w/w | Water content at 10kPa %v/v | Water content at 100 kPa %w/w | Water content at 100 kPa %v/v |
|---|---|---|---|---|---|---|---|---|
| CT | 39.7 a | 9.0 a | 44.1 a | 52.9 a | 32.8 a | 39.7 a | 25.5 a | 30.7 a |
| MT | 37.8 b | 8.9 a | 43.1 a | 52.8 a | 30.8 a | 37.8 b | 23.6 a | 28.9 a |
| NT | 38.4 ab | 9.5 a | 39.5 a | 50.7 a | 29.9 a | 38.4 ab | 22.5 a | 29.0 a |
| PP | 38.5 ab | 9.6 a | 42.2 a | 52.3 a | 31.0 a | 38.5 ab | 23.3 a | 28.9 a |
| $LSD_{0.05}$ | 1.3 | n.s | n.s. | n.s. | n.s. | 1.3 | n.s. | n.s. |

Values followed by the same letter in each column are not significantly different (P<0.05), n.s. = not significant

4. Temporal volumetric soil water content (TDR measurement)

Table 5.13 shows that MT had the lowest volumetric water content at both depths (0-15 and 15-30 cm) over the course of the experiment, from late spring 2003 to late summer 2004. Usually the soils under NT had the highest volumetric water content. There were, however, three instances when CT had higher water content value than NT, on 27/11/03 (0-15 cm soil depth), 12/12/03 (15-30 cm), and 23/02/04 (0-15 cm).

Table 5.13 Temporal volumetric soil water content by TDR measurement (CT= conventional tillage, MT=manual tillage, NT=No-tillage)

| Soil Treat | Soil Depth | Dates 20/11/03 | 27/11/03 | 12/12/03 | 6/01/04 | 23/02/04 | Aver. | St Dev. |
|---|---|---|---|---|---|---|---|---|
| CT | 0 - 15 | 30.1 | 39.2 | 37.3 | 18.7 | 27.6 | 30.7 | 9.5 |
| | 15 - 30 | 28.5 | 35.0 | 36.8 | 20.0 | 27.8 | 29.9 | 7.6 |
| MT | 0 - 15 | 27.0 | 33.9 | 33.9 | 17.5 | 28.5 | 28.5 | 7.7 |
| | 15 - 30 | 27.0 | 33.8 | 34.3 | 18.7 | 28.5 | 28.8 | 7.2 |
| NT | 0 - 15 | 32.6 | 39.1 | 38.5 | 24.6 | 24.6 | 31.7 | 8.2 |
| | 15 - 30 | 29.4 | 37.7 | 36.7 | 24.0 | 29.4 | 31.9 | 6.5 |

The temporal variation of soil volumetric water content in the 0-15 cm topsoil is clearly demonstrated by a sharp decrease in water content around mid summer in January 2005, down from a range of 33.1 – 39.2 % in late November 2003 to 17.5 – 24.6 in early January 2004. A slight increase in soil water content was noticed towards the end of summer 2005. Similar trends were observed for the 15-30 cm soil layer.

5. Soil Aggregate Stability

At the 0-10 cm soil depth, the remaining aggregates in the sieve after 30 minutes wet-sieving were generally similar for all the treatments (Table 5.14).

Table 5.14 Effects of tillage practices on soil water-stable aggregates of the 0-10 cm soil layer using 30 minutes wet-sieving ( % ) (CT=conventional tillage, MT=manual tillage, NT=No-tillage, PP=Permanent pasture, MWD=mean weight diameter)

| Treatment | *Soil Aggregate Size* | | | | MWD (mm) |
|---|---|---|---|---|---|
| | >2 mm | 1-2 mm | 0.5-1 mm | <0.5mm | |
| CT | 25.2 a | 19.3 b | 12.2 a | 43.5 a | 1.2 |
| MT | 35.2 a | 24.5 a | 8.7 b | 31.7 a | 1.6 |
| NT | 36.9 a | 18.7 b | 9.4 b | 34.9 a | 1.6 |
| PP | 29.6 a | 20.7 ab | 12.2 a | 37.4 a | 1.4 |
| $LSD_{0.05}$ | n.s. | 4.3 | 2.1 | n.s. | |

Values followed by the same letter in each column are not significantly different (P<0.05), n.s. = not significant

Significant differences were observed at the 0.5 – 1 mm aggregate size range where soils under CT and PP had significantly higher stability compared to those under MT and NT. In addition, differences also existed in the 1-2 mm aggregate size range where CT, NT, and PP soils had significantly lower stability compared to the MT soils. The MT and NT soils had greater mean weight diameter (MWD) of aggregates remaining on sieve after 30 minute wet-sieving (1.6 mm) as compared to 1.2 and 1.4 mm for soils under CT and PP, respectively.

Overall, the MT had the greatest number of aggregates on sieve after the 30 minute wet-sieving (68.3%) followed by NT (65.1%), PP (62.6%) and CT (56.52%). Similarly with the <0.5 mm aggregates (soil loss by water) it can be assumed that the differences in cumulative aggregates on sieve were also not statistically significant.

Soils from 10-20 cm depth exhibited a different picture compared to the 0-10 cm depth soils particularly in regards to the >2 mm and <0.5 mm aggregate size ranges (Table 5.15). The CT and NT produced significantly more >2 mm stable aggregates compared to PP (P<0.05), but statistically similar amounts compared with MT. In the 1-2 mm aggregate size range, MT produced significantly higher amounts of stable aggregates compared to CT and PP (P<0.05), but not different amounts from NT. No significant differences were observed among treatments on the 0.5 – 1 mm aggregate size range. PP had significantly more unstable soils (<0.5 mm aggregate size) compared to NT and MT (P<0.05), but similar amounts with CT after 30 minute wet-sieving. NT had the greatest MWD of soil aggregates of 1.02 mm followed by CT (0.94 mm), MT (0.92 mm), and PP (0.72 mm).

Table 5.15 Effects of tillage practices on soil water-stable aggregates of the 10-20 cm soil layer using 30 minutes wet-sieving (%) (CT=conventional tillage, MT=manual tillage, NT=No-tillage, PP=Permanent pasture, MWD=mean weight diameter)

| Treatment | *Soil Aggregate Size* | | | | MWD (mm) |
|---|---|---|---|---|---|
| | >2 mm | 1-2 mm | 0.5-1 mm | <0.5mm | |
| CT | 15.9 a | 15.5 b | 12.1 a | 56.5 ab | 0.94 |
| MT | 13.5 ab | 18.7 a | 13.6 a | 54.2 b | 0.92 |
| NT | 17.6 a | 17.7 ab | 12.5 a | 52.3 b | 1.02 |
| PP | 7.8 b | 15.1 b | 14.1 a | 63.1 a | 0.72 |
| $LSD_{0.05}$ | 7.1 | 3.1 | n.s. | 7.8 | |

Values followed by the same letter in each column are not significantly different (P<0.05); n.s.=not significant

Cumulatively, NT had the largest number of stable aggregates (47.7%) followed by MT (45.8%), CT (45.5%), and PP with 36.9%. The statistical differences followed the case of <0.5 mm aggregate size range described in Table 5.14.

## 6. Soil Porosity

### *a. Low tension (LT) Moisture Release Analysis*

Soil porosity was determined by using moisture release analysis and this resulted in the series of porosity related parameters in Table 5.16 for 0-10 cm soil depth. Total porosity and void ratio were significantly lower under CT treatment compared with the other three treatments. MT on the other hand, had significantly more macroporosity, soil air capacity, and air-filled porosity (at 5 and 10 kPa) but less water-filled porosity (at 5 and 10 kPa) compared to the other treatments. Pore size distribution (60 – 30 mu) was insignificantly affected by tillage and pasture treatments.

Table 5.16 Soil porosity and related parameters in the 0-10 cm topsoil as affected by tillage and pasture management (measured using Low Tension Moisture Release Analysis) (CT=conventional tillage, MT=manual tillage, NT=No-tillage, PP=Permanent pasture, PSD=Pore size distribution, AFP=Air-filled porosity, WFP=Water-filled porosity)

| Treat. | Total porosity (%) | Macro porosity (%) | Soil air capacity (%) | PSD 60 – 30 mu (%) | Void ratio | AFP @ 5 kPa (%) | AFP @ 10 kPa (%) | WFP @ 5 kPa (%) | WFP @ 10 kPa (%) |
|---|---|---|---|---|---|---|---|---|---|
| CT | 52.9 b | 9.23b | 11.7 b | 4.7 a | 1.1 b | 9.2 b | 11.7 b | 82.6 a | 77.9 a |
| MT | 56.9 a | 16.4 a | 18.3 a | 3.4 a | 1.3 a | 16.4 a | 18.3 a | 71.3 b | 67.9 b |
| NT | 56.5 a | 11.5 b | 13.7 b | 4.0 a | 1.3 a | 11.5 b | 13.7 b | 79.7 a | 75.7 a |
| PP | 58.5 a | 10.6 b | 12.4 b | 3.0 a | 1.4 a | 10.6 b | 12.4 b | 81.8 a | 78.8 a |
| $LSD_{0.05}$ | 2.2 | 2.6 | 3.1 | n.s. | 0.12 | 2.6 | 3.11 | 4.3 | 5.2 |

Values followed by the same letter in each column are not significantly different (P<0.05), n.s. = not significant

NT and PP appeared to have similar impacts on soil porosity and its related parameters in the top 10 cm soil as indicated by statistically similar values across all the measurements. Total porosity, pore size distribution (60 – 30 mu), and void ratio seemed unaffected by the soil treatments as no significant differences were found in the 10-20 cm soil layer as shown in Table 5.17. Similar with the layer above, MT appeared to have significantly higher macroporosity, soil air capacity, and air-filled porosity (at 5 and 10 kPa) but less water filled porosity (at 5 and 10 kPa) compared to the other treatments. PP and NT shared similar soil porosity characteristics as no significant differences were found comparatively between the two (Table 5.17).

Table 5.17 Soil porosity and related parameters in the 10-20 cm subsoil as affected by tillage and pasture management (measured using Low Tension Moisture Release Analysis) (CT=conventional tillage, MT=manual tillage, NT=No-tillage, PP=Permanent pasture, PSD=Pore size distribution, AFP=Air-filled porosity, WFP=Water-filled porosity)

| Treat. | Total porosity (%) | Macro porosity (%) | Soil air capacity (%) | PSD 60 – 30 mu (%) | Void ratio | AFP @ 5 kPa (%) | AFP @ 10 kPa (%) | WFP @ 5 kPa (%) | WFP @ 10 kPa (%) |
|---|---|---|---|---|---|---|---|---|---|
| CT | 54.6 a | 11.1 b | 13.5 ab | 4.5 a | 1.22 a | 11.1 b | 13.5 ab | 80.1 a | 75.6 a |
| MT | 55.5 a | 15.9 a | 17.8 a | 3.4 a | 1.25 a | 15.9 a | 17.8 a | 71.5 b | 68.1 b |
| NT | 52.2 a | 11.2 b | 13.3 b | 3.9 a | 1.09 a | 11.2 b | 13.3 b | 78.6 a | 74.7 a |
| PP | 55.6 a | 13.0 ab | 15.4 ab | 4.3 a | 1.25 a | 13.0 ab | 15.4 ab | 76.7 ab | 72.4 ab |
| $LSD_{0.05}$ | n.s. | 4.6 | 4.3 | n.s. | n.s. | 4.6 | 4.3 | 7.0 | 6.1 |

Values followed by the same letter in each column are not significantly different (P<0.05), n.s. = not significant

### *b. High tension (HT) Moisture Release Analysis*

Moisture release analysis using high tension resulted in a quite different set of porosity parameters to the analysis using low tension. In the 0-10 cm soil depth, pore size distribution (30 – 3 mu), air-filled porosity (at 10 and 100 kPa), and water-filled porosity (at 10 kPa) were not affected by the tillage and pasture treatments (Table 5.18). PP had higher total porosity and void ratio than other treatments, and was significantly higher compared to CT and NT treatments. In addition, PP also had a significantly higher water-filled porosity compared with MT, while showing similarities with CT and NT treatments. Bulk density determined using high tension moisture release analysis, unlike in the previous measurements, was significantly higher under CT compared to others, while the lowest value was found under PP.

The results for the 10-20 cm soil depth showed that the tillage and pasture treatments did not have significant effects on the soil porosity and related parameters (Table 5.19).

Table 5.18 Soil porosity and related parameters at the 0-10 cm topsoil as affected by tillage and pasture management (measured using High Tension Moisture Release Analysis) (CT=conventional tillage, MT=manual tillage, NT=No-tillage, PP=Permanent pasture, PSD=Pore size distribution, AFP=Air-filled porosity, WFP=Water-filled porosity)

| Treat. | Bulk density ($Mgm^{-3}$) | Total porosity (%) | PSD 30–3 mu (%) | AFP@ 10 kPa (%) | AFP@ 100 kPa (%) | Void ratio | WFP@ 10 kPa (%) | WFP@ 100 kPa (%) |
|---|---|---|---|---|---|---|---|---|
| CT | 1.30 a | 51.5 c | 9.3 a | 12.2 a | 21.5 a | 1.06 c | 76.4 a | 58.4 ab |
| MT | 1.19 bc | 55.0 ab | 8.6 a | 16.0 a | 24.6 a | 1.22 ab | 70.9 a | 55.3 b |
| NT | 1.23 b | 53.0 bc | 8.4 a | 12.8 a | 21.2 a | 1.13 bc | 76.0 a | 60.1 ab |
| PP | 1.16 c | 55.6 a | 6.6 a | 13.5 a | 20.1 a | 1.26 a | 75.9 a | 63.9 a |
| $LSD_{0.05}$ | 0.06 | 2.4 | n.s. | n.s. | n.s. | 0.11 | n.s. | 8.5 |

Values followed by the same letter in each column are not significantly different (P<0.05), n.s. = not significant

Table 5.19 Soil porosity and related parameters at the 10-20 cm subsoil as affected by tillage and pasture management (measured using High Tension Moisture Release Analysis) (CT=conventional tillage, MT=manual tillage, NT=No-tillage, PP=Permanent pasture, PSD=Pore size distribution, AFP=Air-filled porosity, WFP=Water-filled porosity)

| Treat. | Bulk density ($Mgm^{-3}$) | Total porosity (%) | PSD 30–3 mu (%) | AFP@ 10 kPa (%) | AFP@ 100 kPa (%) | Void ratio | WFP@ 10 kPa (%) | WFP @ 100 kPa (%) |
|---|---|---|---|---|---|---|---|---|
| CT | 1.22 a | 52.9 a | 9.0 a | 13.2 a | 22.2 a | 1.1 a | 75.5 a | 58.2 a |
| MT | 1.23 a | 52.8 a | 8.9 a | 14.9 a | 23.8 a | 1.1 a | 71.8 a | 54.9 a |
| NT | 1.29 a | 50.7 a | 9.5 a | 12.2 a | 21.7 a | 1.0 a | 76.0 a | 57.2 a |
| PP | 1.24 a | 52.3 a | 9.6 a | 13.9 a | 23.4 a | 1.1 a | 73.6 a | 55.3 a |
| $LSD_{0.05}$ | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. |

n.s. = not significant

7. Hydraulic Conductivity

The soil hydraulic conductivity measurements at the end of the cropping season were inconclusive, due primarily to the high level of variation among the replicates in each treatment as indicated by the high $LSD_{0.05}$ values. Thus Table 5.20 below shows that both saturated and unsaturated hydraulic conductivity were similar under all the treatments except for the hydraulic conductivity at 10-20 cm soil depth which appeared to be significantly higher under MT treatment compared to the others.

Table 5.20 Saturated and unsaturated hydraulic conductivity of soil layers under different tillage and pasture management (CT= conventional tillage, MT=manual tillage, NT=No-tillage, PP=Permanent pasture)

| Tillage Treatments | $K_{sat}$ | | $K_{unsat}$ | |
|---|---|---|---|---|
| | 0 – 10 cm | 10 – 20 cm | 0 – 10 cm | 10 – 20 cm |
| CT | 562.8 a | 132.0 b | 45.0 a | 38.1 a |
| MT | 747.4 a | 454.2 a | 56.3 a | 59.5 a |
| NT | 334.6 a | 61.1 b | 24.3 a | 39.4 a |
| PP | 376.5 a | 86.6 b | 16.4 a | 42.8 a |
| $LSD_{0.05}$ | n.s. | 258.1 | n.s. | n.s. |

Values followed by the same letter in each column are not significantly different (P<0.05), n.s. = not significant

8. Chemical Properties

The soil chemical analysis for selected macro nutrients showed that the treatments had few significant effects on the nutrients especially for Olsen P in both 0-10 and 10-20 cm soil depths, and total C and total N in the 10-20 cm soil layer which showed no statistical differences among treatments (Table 5.21). The percentage of total carbon in the 0-10 cm soil layer found under the PP treatment was similar with that under NT, but significantly higher compared with those under MT and CT treatments. Likewise, total nitrogen at the 0-10 cm topsoil was similar under PP, NT and MT but the CT treatment produced significantly lower total N compared to the other treatments.

Table 5.21 Tillage effects on soil chemical properties (CT= conventional tillage, MT=manual tillage, NT=No-tillage, PP=Permanent pasture)

| Tillage Treatment | Total C (%) | | Total N (%) | | Olsen P (ugP/g soil) | |
|---|---|---|---|---|---|---|
| | *0-10* | *10-20* | *0-10* | *10-20* | *0-10* | *10-20* |
| CT | 2.14 c | 1.95 a | 0.25 b | 0.16 a | 26.67 a | 21.79 a |
| MT | 2.34 bc | 1.79 a | 0.27 ab | 0.15 a | 39.29 a | 17.02 a |
| NT | 2.48 ab | 1.76 a | 0.27 ab | 0.16 a | 52.26 a | 17.50 a |
| PP | 2.70 a | 1.74 a | 0.28 a | 0.15 a | 51.43 a | 65.71 a |
| $LSD_{0.05}$ | 0.31 | n.s. | 0.03 | n.s. | n.s. | n.s. |

Values followed by the same letter in each column are not significantly different (P<0.05), n.s. = not significant

When extrapolated to an area basis the statistical differences no longer existed although a generally similar trend was present (Table 5.22).

Table 5.22 Total C, total N (t/ha), and CN ratio at the top 0-10 cm soil affected by tillage treatments and pasture management (CT=conventional tillage, MT=manual tillage, NT=no-tillage, PP=permanent pasture)

| Treatments | C | N | CN ratio |
|---|---|---|---|
| CT | 26.24 | 3.05 | 8.6 |
| MT | 25.99 | 2.94 | 8.8 |
| NT | 27.74 | 3.06 | 9.1 |
| PP | 28.92 | 3.03 | 9.5 |
| $LSD_{0.05}$ | n.s. | n.s | |

n.s. = not significant

9. Crop and biomass yield

The potato tuber and above ground biomass yield was significantly lower under the NT treatment, both in the weeded and unweeded plots, compared to those from the tilled (CT and MT) plots (Table 5.23).

Table 5.23 Potato tuber and biomass yield (t/ha) under different tillage treatments (CT= conventional tillage, MT=manual tillage, NT=No-tillage)

| Tillage treatments | Potato Yield | | Potato Biomass DM | |
|---|---|---|---|---|
| | Weeded plots | Unweeded plots | Weeded plots | Unweeded plots |
| CT | 46.58 a | 44.08 a | 3.99 ab | 4.59 a |
| MT | 51.03 a | 43.38 a | 4.54 a | 4.40 a |
| NT | 28.13 b | 28.40 b | 2.67 b | 1.80 b |
| $LSD_{0.05}$ | 12.51 | 10.37 | 1.58 | 1.40 |

Values followed by the same letter in each column are not significantly different ($P<0.05$)

An exception was found in potato biomass from unweeded plots where the lowest yield under NT treatment was insignificantly different with that from the CT treatment. In contrast to the potato, the barley grain and biomass production under all the treatments were found to be statistically similar, both in the weeded and unweeded plots (Table 5.24).

The weed biomass as expected was greater in the cultivated plots than the untilled plots (NT) (Table 5.25). An exception was the manually tilled (MT) and unweeded potato plots, two months after the first assessment, where the weed biomass showed no significant differences with those under the CT and NT treatments. As mentioned earlier, the assessment of weeds in the unweeded barley plots was not possible due to a storm wind which caused damage to the already mature crops.

Table 5.24 Barley grain and biomass yield (t/ha) under different tillage treatments (CT= conventional tillage, MT=manual tillage, NT=No-tillage)

| Tillage treatments | Barley grain | | Barley biomass DM | |
|---|---|---|---|---|
| | Weeded plots | Unweeded plots | Weeded plots | Unweeded plots |
| CT | 4.85 a | 4.55 a | 5.84 a | 5.33 a |
| MT | 5.02 a | 4.76 a | 5.97 a | 5.78 a |
| NT | 5.07 a | 4.38 a | 5.82 a | 5.67 a |
| $LSD_{0.05}$ | n.s. | n.s. | n.s. | n.s. |

n.s. = not significant

Table 5.25 Weed biomass on potato and barley plots (t/ha) (CT= conventional tillage, MT=manual tillage, NT=No-tillage)

| Tillage treatments | Weeded plots (5/1/04) | | Unweeded plots (9/3/04) |
|---|---|---|---|
| | Potato | Barley | Potato |
| CT | 0.78 b | 0.77 b | 1.13 b |
| MT | 1.08 b | 0.93 b | 1.41 ab |
| NT | 2.67 a | 2.42 a | 1.95 a |
| $LSD_{0.05}$ | 0.67 | 0.73 | 0.57 |

Values followed by the same letter in each column are not significantly different (P<0.05)

Visual observation suggested that conventional and manual till plots contained more erect, dicot weeds, most evident in the form of black night shade, compared to grass weeds. On the other hand, the NT plots were mostly dominated by clover as shown in Table 5.26. Basically, clover and black night shade were the most distinctive types of weed characterizing the effects of tilled and untilled treatments, respectively, in the experimental plots. There were, however, some other weeds which appeared only in minor quantities.

Table 5.26 Distribution of 10 most evident weeds* in the unweeded potato plots (%) (CT=conventional tillage, MT=manual tillage, NT=no-tillage)

| Weed | Tillage Treatments | | |
|---|---|---|---|
| | CT | MT | NT |
| Clover *(Trifolium repens)* | | 7.0 | 57.0 |
| Ryegrass (*Lolium perenne)* | 8.0 | 5.0 | 9.5 |
| Black night shade *(Solanum nigrum)* | 70.5 | 48.4 | 8.5 |
| Broad leaved dock *(Rumex obtusifolius)* | 9.5 | 6.0 | |
| Broad leaved plantain *(Plantago major)* | 5.6 | 4.0 | 2.5 |
| Fathen *(Chenopodium album)* | 5.2 | 11.2 | |
| Hawksbeard (*Crepis capillaries*) | | | 10.0 |
| Hawkbit *(Leontodon taraxacoides)* | 0.5 | 6.0 | 12.5 |
| Scarlet pimpernel *(Anagallis arvensis)* | 0.7 | | |
| Willow weed *(Polygonum persicaria)* | | 12.4 | |
| | 100 | 100 | 100 |

* Weeds were hand sorted and identified from samples collected from each plot. Figures were calculated from the percentage of the weight of a designated weed in the sampled weed population in each plot. Some plots contained small (to negligible) amounts of weeds such as: californian thistle (*Cirsium arvense)*, hairy buttercup (*Ranunculus sardous)*, pennyroyal (*mentha pulegium* L.), and creeping cudweed (*Euchiton involucratus)*.

# 5.5 DISCUSSION

## 5.5.1 Introduction

This section endeavours to synthesize the findings of this study and relate them with those obtained under similar conditions elsewhere supported by tillage research data from different agro-ecosystems and climatic conditions. The impacts of tillage, as has been stated before, are site and crop-specific. The analysis is pursued in a manner to avoid the inclination to overlook contrasting differences in the nature of two experimental agro-ecosystem settings of this study and of those of the research data sources cited in the discussion and to generalize or simplify the issues related to soil and environmental degradation due to tillage. The issues are indeed complex, and this research analysis is, nevertheless, aimed at contributing to a better understanding of the issues and to hopefully suggest some useful insights for a viable tillage research and agricultural development and policy design in East Timor and, to a certain extent, New Zealand.

## 5.5.2 Soil compaction: penetration resistance and bulk density

The soil compaction due to tillage and traffic is reflected by the degree of penetration resistance and bulk density, two parameters largely used to assess compaction (Tarawally et al., 2004).

1. <u>Penetration resistance</u>

The results of the first penetration resistance (PR) measurement presented in Table 5.5. clearly indicated that the recently cultivated soils in the CT and MT plots were, not unexpectedly, significantly less compacted than the soils under the NT and PP treatments. Down to 12 cm soil depth, MT caused the least resistance to penetration, which was most probably due to MT soils having larger total porosity, comparatively to CT, and quite surprisingly to NT as well, as indicated by total porosity values in Tables 5.12 and 5.14 for the topsoil 0-10 cm. In compacted soils, according to Gajri et al. (2002), total porosity decreases largely at the expense of macropres, while loosening has the opposite effect. Soil moisture content and bulk density may have contributed as well to differences in penetration resistance among treatments, particularly for the CT and MT, as suggested by Ehlers et al. (1983).

Soil moisture in some soils, however, does not always have a relationship with penetration resistance (Govaerts et al., 2006). Field assessment of volumetric water content with TDR around the time of the first PR measurement, indicated MT to have on average lower volumetric water content in the 0-15 and 15-30 cm soil layers compared to the other treatments (refer to Table 5.13). Despite having less moisture content in these two respective layers, hydraulic conductivity figures under MT (Table 5.20) suggest that water may have infiltrated and was probably stored in deeper subsoil layers.

Signs of compaction were evident at the second measurement two months later (Table 5.6). PR values of soils under CT, in contrast with the first measurement, increased and became statistically similar with the soils of NT and PP treatments. This confirms earlier findings by Guo et al. (1999). In a 5-year tillage experiment on a silt loam, the PR measured one week after winter oats were sown was about twice as much in the two top layers (0-5 and 5-10 cm) in the PP and NT plots as in the CT plots conventionally tilled with mouldboard plough (Viegas and Choudhary, 2002). However, six months later, after the oats were grazed and the field left fallow during spring, soils in the CT were more compacted than the other two treatments especially in the 0-20 cm soil depth.

The PR values for MT were demonstrably lower than those under the other treatments, well below the threshold PR of 2 MPa that has been indicated to affect root growth (Fabrizzi et al., 2005). This contrasts with the findings of Osunbitan et al. (2005) in Nigeria, who found high soil PR under manual tillage (MT) treatment and conventional tillage (plough-plough / PP and plough harrow / PH). The increase in penetration resistance with the increase in soil depth as indicated by the regression analysis (clearly demonstrated by Figure 5.10) has also been previously suggested (Ozpinar and Cay, 2006, Viegas and Choudhary, 2002). This may be attributed to the soil structure below the cultivated soil horizon being different, affected by conditions such as low soil water status, total porosity, and air-filled porosity, but high mechanical impedance and bulk density. It is rare to find a loose subsoil (Hakansson and Voorhees, 1998), however, there are reports indicating compaction in subsoil (Logsdon et al., 1992, Hakansson and Reeder, 1994).

A slight decrease was noticeable when comparing the PR values of the first measurement with that of the second, especially under CT, NT and PP treatments. Soils became softer over a period of more two months which was probably due to the rainfall during the experimental period. Although situated in a steep landscape, water through infiltration and percolation within the plots may have reached the subsoil layers and have been stored. The seasonal volumetric water content results discussed in the next sub-section will confirm the water status in these subsoil layers.

2. Soil bulk density

Soil bulk density (BD) data from the first experiment in Dili showed no effects of tillage treatment (Table 5.2). However, using proper laboratory means, BD results from the second experiment demonstrated a similar trend to that of PR, and more obvious was the increase of BD with increase of soil depth. There were at least two sets of BD data, using different sizes of soil corer. The first measurement, taken approx. 2 weeks prior to the second PR readings, using a standard 50 mm diameter corer, showed that the top 5 cm of soil under all treatments was of the same degree of compaction, indicated by similar BD values (Table 5.7). This agreed with the PR values measured two weeks later which showed statistically similar values for the top 2 cm in all soil. On average, of six values from 0 – 30 cm depth, MT and NT soil had significantly the lowest and the highest BD, respectively, while BD of CT and PP soils were in the middle range.

Bulk density is not invariant for a given soil because it changes according to structural condition of the soil (Blake and Hartge, 1986) and most changes in soil physical environment are mediated through bulk density (Gajri et al., 2002). The second BD measurement was done one month after the first one, using a 100 mm diameter corer (Table 5.8). The results demonstrated that, for the 0 – 20 cm soil depth, CT had the highest soil BD followed by NT, while MT and PP had the lowest.

With regards to soil BD under MT, however, contrasting results were obtained in Nigeria (Osunbitan et al., 2005). Soil BD was assessed every week after cultivation for eight weeks and it was found that manually tilled (MT) soils had a BD between that of soils under NT and the tilled soils (PP and PH). The differences in the effects of the two manual tillage (MT) experiments may derive from the different methods of manual tilling used, with a shovel in experiment 2 of the present study and a hoe in the case of Osunbitan et al. (2005) experiment. Other reasons may be attributed to the subjective nature of the human power involved in doing the tilling and the different characteristics of soil types used in the respective studies.

High soil BD under zero-tillage or no-tillage has been confirmed by recent studies (Bescansa et al., 2006, Bhattacharyya et al., 2006). The high bulk density found in the NT plots was an indication of higher soil density and lower total porosity, especially at the subsoil layers (refer to Tables 5.17 and 5.19), relatively compared to the other treatments. A separate study by Karamanos et al. (2004) reported bulk density and penetration resistance were initially higher in the no-tilled plots, but they became significantly lower after 2–3 months from sowing. Despite this, NT had a comparatively high volumetric water content compared to other treatments, in 0-15 and 15-30 cm soil layers as reflected by TDR assessment results in Table 5.13, except for the last reading on 23/02/04. Early studies also suggest that even though soil bulk density was greater for no-till systems compared with tilled systems in the experimental fields of Sauer et al. (1990), Horne et al. (1992), Karlen et al. (1994) and Hussain et al. (1998), water retention and infiltration for the no-till soils were as great or greater than for the tilled soils.

### 5.5.3 Soil water properties

1. Field capacity

The experimental results indicated significant effects of tillage treatment on soil field capacity (Fc), in both the 0 - 10 and 10 – 20 cm soil layers (Table 5.9 and 5.10). Field capacity results, both at low and high tension moisture release (MR), for both soil layers, indicated that NT and PP soil held more water compared to MT and CT, implying that NT and PP soil had better infiltration or less runs off. These results correspond with the soil water content at various suction levels, and agree with Gajri et al. (2002) who suggest that increased porosity associated with a decrease in bulk density increases the amount of water held at high soil water potentials and decreases the amount held at lower potentials.

2. Water content and readily available water (RAW)

Water content was unaffected by tillage treatment during the Dili experiment (Table 5.2). In the absence of proper laboratory equipment, and due to the use of rudimentary oven and scale for the drying and weighing of soil samples, respectively, this result may not reflect the true field conditions. The results from experiment 2, however, showed that water content (WC), similar to the field capacity, was affected by tillage treatments especially in the top 0 – 10 cm soil layer (refer to Tables 5.9 and 5.11). PP, not unexpectedly, had significantly higher soil water content at all potentials, gravimetric and volumetric, generally followed by NT (Table 5.9). Down in the 10-20 cm soil layer, only low tension MR analysis detected significant differences in WC due to tillage, whereas under high tension MR water properties under all the treatments appeared similar, except for small differences in field capacity.

Based on low tension moisture release analysis, NT usually had greater water content at 0-10 cm than CT and MT (Table 5.9), while at the 10-20 CT usually had a higher WC (Table 5.10). The results agree with those reported by Karamanos et al. (2004). The higher water retention of the NT plots than the CT and MT plots could be attributed to, apart from WFP, the increased surface residue under NT resulting in a significantly high organic matter under this treatment. As shown later in Table 5.17, NT produced a significantly higher total organic C at the 0-10 cm topsoil, compared especially with CT. Similar reasons were argued by Fuentes et al. (2004). Another possible explanation is that water loss through evapotranspiration in the NT plots was inhibited by the high amount of residue left on the surface, thus allowing higher conservation of soil moisture in the root zone.

The water retention at low suction levels (5 and 10 kPa) in the top 0-10 cm topsoil was similar to the findings of Osunbitan et al. (2005) whose study also involved manual tillage (MT). Similarities included NT retaining the greatest amount of water, especially at 50, 100, and 150 kPa suction, and MT soil the least amount of water. Their study also suggested conventional tilled soil had significantly higher field capacity (approx. at 4.5 kPa suction) compared to the manual and untilled soils. They observed tillage operations significantly decreased the water holding capacity of the sandy loam soil used. In a clay loam calcic soil (*Calcic Haploxerept*) in semiarid northern Spain, Bescansa *et al.* (2006) found higher soil water content under conservation tillage systems (NT, NTSB and RT) than under tillage with mouldboard plough. This was mainly attributable to greater available water content (AWC) and to the mulching effect of crop residues. Early studies by Karlen *et al.* (1994) and Hussain et al. (1998) also reported NT to have more water filled and residual pores compared to conventionally tilled soils due to the presence of more soil residue on the soil surface, which improved infiltration, decreased runoff, and restricted evaporation.

Despite differences in Fc and WC, the soil mechanical treatments had no influence on the amount of water readily available (RAW) to plants. Findings by Tarawally (2004) suggested that the use of field capacity water content as the upper limit of plant available soil water was considered inappropriate for compacted soils.

3. <u>TDR soil field volumetric water content</u>

Soil under NT and CT had higher volumetric water content compared to MT in 0 – 15 and 15 – 30 cm soil layers (Table 5.13). This was probably due to significantly higher water-filled porosity under NT and CT as discussed later in this chapter. Despite having higher total macroporosity, MT produced fewer water-filled pores and lower field capacity. The precipitation could have all infiltrated through the macropores down to subsoil layers, a point confirmed by the higher saturated and unsaturated hydraulic conductivity values in soils under MT than those under CT and NT. The findings of Osunbitan et al. (2005) also suggested MT soils have the highest hydraulic conductivity, after NT, compared to soils under conventional tillage using plough-plough (PP) and plough-harrow (PH) sequence. Hydraulic conductivity experiment results will be further discussed later in this chapter.

### 5.5.4 Soil aggregate stability and MWD

The stability of aggregates is measured as a function of whether the cohesive force between particles withstands the applied disruptive force, and most frequently, the destructive action of water (Hillel, 1998). CT, PP, NT, and MT had similar topsoil loss (Table 5.14). In the 10-20 cm soil layer, the losses were also similar among tillage treatments (CT, NT, and MT) (Table 5.15). A significant loss, however, was observed on soil from the adjacent permanent pasture (PP) plots from the 10-20 cm layer.

The short-term nature of the experiments may have contributed to these results. The findings of a tillage trial in a silt loam, established over 5 years, comparing mouldboard plough (MP), no-tillage (NT), and permanent pasture (PP), clearly demonstrated enhanced soil structural stability (Viegas and Choudhary, 2002). In the top 0-10 topsoil for example, the results indicated that the loss of soil aggregate < 0.5 mm was in the decreasing order of MP>NT>PP with nominal values of 73.8, 29.2, and 24.8 %, respectively. A similar pattern as the topsoil also occurred for the subsoil. Previous work using soil in the Manawatu region, New Zealand reported by Horne et al. (1992) and Sparling et al. (1992) suggested similar soil stability trends. Haynes (1999), working on a Wakanui silt loam (Udic Dystrochrept; USDA) in the Canterbury region of New Zealand, also found aggregation stability to be higher under long-term permanent pasture and zero tilled annual grass, than long-term arable cropping and conventionally cultivated annual grass.

While Horne et al. (1992) found only small differences in organic carbon content between treatments in the 0-20 cm soil depth, Watts and Dexter (1997) using a simulated tillage found an increase in water stable aggregates with increase in soil organic carbon. Findings of the latter study appeared to confirm earlier data reported by Sparling et al. (1992). Their results suggested a strong relationship between the proportion of water-stable macroaggregates and microbial C, much stronger than that between macroaggregate stability and organic C. A recent study by Mikha and Rice (2004) reported that no-tillage (NT) and manure (M) alone each significantly increased soil aggregation and aggregate-associated C and N; however, NT and M together further improved soil aggregation and aggregate-protected C and N.

### 5.5.5 Soil porosity

1. <u>Total porosity</u>

Intensive tillage affected pore structure in the topsoil resulting in a significantly lower total porosity under CT compared to the other treatments based on both low and high moisture release tension analyses (refer to Tables 5.16 and 5.18). This result confirmed the findings of tillage research that suggest the improvement in soil pore size distribution and continuity under no- and minimum-tillage systems (Bhattacharyya et al., 2006, Eynard et al., 2004). Increased total porosity under no-tillage, as well as under MT in this study, may have had a positive impact on the movement and retention of solutes, chemical processes, aeration, erosion, and biological activity suggested by Park and Smucker (2005). The effects of tillage on total porosity in the soil layer below the topsoil were not as statistically comparable as those of the topsoil (refer to Tables 5.17 and 5.19). In can be assumed that differences in soil porosity between tillage systems were mainly confined to the top 10 cm soil, or surface 0–8-cm soil depth in the case of previous work by Carter (1988).

2. Macroporosity, air-filled porosity, water-filled porosity

Topsoil macroporosity was significantly increased in the manually tilled (MT) plots compared to soil under other treatments (Table 5.16). Conversely, CT had the lowest macroporosity. Channels near the surface under the tilled systems (CT) were not as continuous, probably owing to the destructive nature of tillage (Heard et al., 1988). Park and Smucker (2005) found no response of $K_{sat}$ to porosity change in CT aggregates indicating that there were no increases in the effective interconnected porosities within CT aggregates. A macroporosity of between 8 to 10% (v/v) would maintain adequate soil permeability (Carter, 1988).

It can be noted, from the related parameters, that the macroporosity under MT, as shown by the supporting data, was probably largely contributed by the high level of air capacity and air-filled porosity (AFP). It can be assumed that a better aeration has taken place on the manually cultivated soils than other soils under study as AFP is most often used to evaluate soil aeration (Lipiec and Hatano, 2003). AFP of <10% (v/v) is regarded as critical for plant growth and that at a similar AFP, the equivalent pore diameter can be much smaller in compacted than in uncompacted soil (Lipiec and Hatano, 2003). On the contrary, water-filled porosity (WFP) made up the largest part of the total porosity in the cases of CT, NT, and PP as shown by generally higher field capacity, water retention, and volumetric water content under these treatments compared to MT at the top 10 cm soil (Table 5.16). In Carter's (1988) study, a close relationship ($R^2$ = 0.952) was found between water-filled porosity and macroporosity and soil water content, indicating that the volume of macropores should exceed 14% to provide an optimum level of air-filled pore space. Similar trends in macroporosity, air- and water-filled porosity under all the treatments were observed for the lower 10-20 soil layer.

3. Pore size distribution and void ratio

The distribution of pore size was unaffected by the tillage methods (refer to Tables 5.16 and 5.17). Void ratio was significantly reduced by CT in the surface soil (Table 5.16), which indicated a greater degree of compaction in the CT soil than under NT and MT, in confirmation of the results for PR and BD. Pore size distribution is a fundamental and highly degradable soil property (Tarawally et al., 2004).

### 5.5.6 Hydraulic conductivity

The high saturated hydraulic conductivity of the tilled layer under CT and MT was because of the preponderance of large inter-aggregate macro-pores (Addiscott and Dexter, 1994). Lal et al. (1989) pointed out that the initial infiltration was significantly greater in continuous plough-till than in no-till treatments, apparently caused by high total porosity in the freshly ploughed plots. The results of the current study, however, were not significant due to a large coefficient variation. The coefficient of variation of soil hydraulic conductivity, which is often dictated by the soil structural pores, ranged from 100 to 400% (Libardi et al., 1980), which suggests that the spatial variability of soil structural pores measured by using core- or block-sized samples was very large. As a result, the size spectrum of large structural pores measured at several random locations by small sample sizes in a field may not represent the spectrum of the entire field. The high coefficient of variation of hydraulic conductivity was also encountered by Cameira et al. (2003).

Contrasting results were reported by Park and Smucker (2005). They reported increased $K_s$ through bulk soils and through intra-aggregates in the NT management system suggesting greater diffusive exchange and possibly longer retention times of soil solutions. Conversely, much lower $K_s$ was found within CT aggregates which implied that diffusive exchanges of nutrients might be limited to exterior regions of macroaggregates. Viegas and Choudhary (2002), similarly, reported that the average infiltration rate was in the order of MP<NT=PP. Other studies have

suggested the earthworm channels are one of the factors contributing to the macropore continuity improvement under NT (Aslam, 1998, Guo et al., 1999). Chan and Mead (1989) demonstrated that conventional tillage reduced macropore density as well as their continuity which caused infiltration to be greatly hampered leading to significantly higher run-off. Similarly, Lal and Vandoren (1990) concluded that both the cumulative infiltration and infiltration rates were somewhat higher for no-tillage than mouldboard plough and chisel plough treatments. Benjamin (1993) suggested the no-tillage system to have 30 to 180% greater saturated hydraulic conductivity than either the chisel plough or mouldboard plough systems.

### 5.5.7 Chemical properties

1. Experiment 1 (Dili, East Timor)

Due to constraints mentioned earlier in the introduction, a proper experimental layout was not possible to implement, thus no statistical analysis was performed to compare the different mechanical treatments employed in the field. The soil chemical and physical analysis revealed that soils were vertisol, mainly alkaline, and composed largely of alluvial silt and clay.

The plots were previously harvested with rice prior to the field work. The level of organic carbon was negligible (content undetected), assuming all taken up during the earlier rice cropping season. However, after about 4 months of maize and mungbeans cropping, the soils had regained some organic carbon (average range of 0.74 – 1.52 %). In addition, total N also showed a modest increase after the crops were harvested. In contrast, the soil phosphorus (P) and potassium (K) were decreased after the field trial.

The results were not unusual for soils which have long been under intensive cultivation. Sustainable farming systems require that crop yields are stable through the maintenance of soil fertility and the balance of nutrients in the system. Increases in soil C levels for example require sustained periods of balanced fertilization and residue retention (Whitbread et al., 2003). Whitbread et al. (2003) concluded that poor management of fertilizers and crop residues, and excessive cultivation has also resulted in large soil fertility losses in the grain growing areas of Eastern

Australia. Cropping decreases C everywhere except where residue retention is high and fallow crops are used.

2. Experiment 2 (Palmerston North, New Zealand)

*a. Total C*

Tillage effects on total soil organic C were more evident in the 0-10 cm soil depth. The order in which the marked decline in % total C level was observed was PP ≥ NT ≥ MT > CT (Table 5.21). These changes, however, were only significant when calculated on the basis of percentage of total C and N out of the soil samples thus it may not reflect the real nutrient status on the site. When extrapolated to an area basis the statistical differences no longer existed although a generally similar trend was present (Table 5.22). Considering the permanent pasture soils as control treatment, the reduction of total C after a short-term cultivation was 10.1, 9.3, and 4.1% under MT, CT, and NT, respectively. The CN ratio was in the decreasing order of PP > NT > MT > CT.

Total C losses from native soils and long-term pasture following cropping were also reported for similar studies in New Zealand (Sparling et al., 1992, Aslam et al., 1999, Haynes, 2000). In the 10-20 cm soil layer, the total C level was lower than that of the upper layer and distributed quite equally in all plots as only insignificant differences were noticed among the treatments.

The high retention of crop residue and less soil disturbance on the NT plots may have resulted in higher % of C than in the tilled treatments. A study by Zibilske et al. (2002) revealed that no-till resulted in greater soil organic C in the top 4 cm of soil, where the organic C concentration was 58% greater than in the top 4 cm of the plough-till treatment. In the 4–8 cm depth, organic C was 15% greater than the plough-till control. Beare et al. (1994) and Campbell et al. (1996) have also reported similar results. The former, comparing NT and CT reported that the whole-soil organic C was 18% higher in the NT (30.7 mg C $ha^{-1}$) than CT (26.1 mg C $ha^{-1}$). In the latter study, it was found that cropping frequency did not affect soil organic C, but soil C content was greater under NT than under mechanically tilled continuous wheat (cont. W) and fallow-wheat (F-W) rotations. The effects were apparent in the 0-15 cm soil depth. According to Sparling et al. (1992), the marked organic C content decline in the cultivated soils is caused mainly by the reduced organic matter inputs and the decomposition of existing organic matter enhanced by tillage.

*b. Total N*

Similar to the trend for % C in the top soil, total N was significantly reduced by CT (Table 5.21). According to Zibilske et al. (2002), tillage-induced changes in soil organic N are often directly related to changes in soil organic C. Usually, increased use of N-fertilizers in crop production has been accompanied by increased amounts of N compounds in the general soil-water environment. However, this was not the case in this study as no fertilizer was used. The reduction in total N, therefore, was mainly attributed to the utilization by crops. At 10-20 cm soil depth, the total N was lower than for the topsoil, and similarly to C, it was equally distributed in all plots. This partly agrees with the results of Zibilske et al. (2002) who suggest that both no-till and ridge-till promoted greater concentrations of soil organic N at the soil surface, but it was uniformly distributed with depth under plough tillage.

The above results are in line with the study of Biederbeck et al. (1996) who found a higher potentially mineralizable N under zero-tillage compared to a conventional tillage system. Their study also suggested that tillage depressed microbial populations and the ability of the soil to mineralize C and N in the 0-5 cm soil layer. A close correlation between microbial biomass N and anaerobic mineralizable N was proposed by Dalal et al. (1991), who also suggested that the former provide a labile source of N in soil. The labile fractions, as stated by Haynes (1999) are important components of organic matter quality, which influence crop productivity. Mineralizable N for instance, can contribute greatly to crop N requirements but also to leaching losses of nitrate to groundwater.

For pasture in particular, the study of Haynes (1999) demonstrated the positive effect that a short-term (5 years) pasture can have on soil organic matter quantity and quality and its attendant benefits on N fertilizer and soil structure. Their results also indicated that the particulate organic matter (POM) comprised a higher percentage of total aggregate N in surface soils of the NT than CT soils. Campbell *et al*. (1996) also reported total N to be higher under NT than under tilled systems in continuous wheat and wheat-fallow rotations.

*c. Olsen P*

Conservation tillage results in the concentration of plant-available P near the soil surface. The present short-term study, however, demonstrated no significant differences in Olsen P under the different tillage treatments, both in the 0-10 and 10-20 cm soil depths (Table 5.21). Essington and Howard (2000) found that total P did not vary with depth, but was greater in no-tillage (NT) than in disc-tillage (DT) and increased with P rate. Mehlich 3-P and Olsen-P were greatest in the surface 4 cm and in the 60-kg P ha-1 plots, with higher levels observed in NT plots. Because the impact of tillage was limited to a thin, soil surface layer (<4 cm), soil P-test rating would not be affected by tillage practice. They also suggested that improper collection of soil samples from NT (i.e., too shallow) for P-testing may provide erroneous P-test results and fertilizer recommendations.

### 5.5.8 Crop yield and biomass production

1. Experiment 1 (Dili, East Timor)

Under modest experimental circumstances, the crop and weed measurements generally agreed with those already known with respect to no-tillage cropping in comparison to conventional means of cultivation (refer to Table 5.4) (Arshad et al., 1994, Fisk et al., 2001, Mas and Verdu, 2003, Ozpinar, 2006). Maize and mungbean height as well as dry matter, measured in the mid-cropping season, suggested a lower level of performance in the NT treatment. By contrast, weed population, not unexpectedly, was more abundant in the no-till plots. These conditions, however, did not inhibit the growth conditions for both crops, resulting in a generally similar grain and by-product yields under all the tillage treatments.

2. Experiment 2 (Palmerston North, New Zealand)

Potato tuber and biomass yield were significantly reduced under no-tillage compared to CT and MT treatments (Table 5.23). Presumably this was due to the greater soil compaction in NT which may have restricted growth of potato tubers and roots. The reduced yield in potato tuber and biomass in NT, however, were offset by the higher amount of weed biomass dry matter (Table 5.25). Barley grain and biomass yield, on the other hand, was similar for all the treatments (Table

5.24). Better moisture conservation under NT may have promoted an equally better nutrient uptake for barley growth.

Variable results with regards to crop and biomass yield under no-tillage treatments have been widely reported. Hughes et al. (1992) found a 10-year average of maize dry matter to be significantly lower under zero tillage than fully tilled treatment. In a similar trial, Ekeberg and Riley (1996) reported a generally good performance of cereals and potatoes with shallow or minimum tillage, and this was attributed to the favourable soil physical conditions, and to the successful control of weeds. Lower crop yields (Acharya and Sharma, 1994) and variable results (Lindwall et al., 1994) were reported under no-tillage treatment as compared with conventional tillage systems. A recent report suggests that in general, NT, and in the second instance, minimum tillage (MT) considerably improved plant water status, and hence foliage growth and yield in comparison with CT by maintaining higher levels of soil water and improving root growth. It was also concluded that manuring positively interacted with the reduced tillage practices for most soil and plant parameters (Karamanos et al., 2004).

In essence, as far as crop yields are concerned, it is difficult to establish any clear and major advantage of no-tillage. However, in general, given favourable conditions are met, such as adequate soil water, sufficient rainfall and good drainage, reasonable soil fertility and good weed control, crop yields under conservation tillage can be equal to or higher than under conventional tillage systems.

## 5.6 CONCLUDING REMARKS

Despite being based on short-term experiments in both locations, the study provides empirical effects of tillage, and no-tillage in particular, on the edaphic changes affecting the plant growing environment. Generally, the findings concur with those already in the literature. Organic carbon levels are generally restored with cropping. In addition, soil bulk density and crop grain and biomass yield were not affected by tillage treatments. Soil compaction was significantly affected by tillage as shown by data from the Palmerston North experiment. Soil aggregate stability in the 0-10 cm topsoil was similar under all the tillage treatments. MT had the greatest number of soil aggregates on sieve after 30-minute wet-sieving (68.3%)

followed by NT (65.1), PP (62.6) and CT (56.52). Similarly, top 0-10 cm soil under MT had significantly larger macroporosity (16.4%) than CT (9.23), NT (11.5), and PP (10.6). MT and CT significantly reduced the total C whereas N levels were significantly decreased by tillage (CT, MT and NT) compared to permanent pasture at the top 0-10 cm soil layer. Barley grain and biomass were unaffected by tillage whereas potato tuber and biomass were significantly less under no-tillage. Conventional tillage significantly increased water runoff but less leachate compared to no-till and permanent pasture. Total soil sediment loss was significantly lower under PP (95.8 kg/ha) and NT (132.9) compared to CT (3556.7) and MT (4652.2). pH of water runoff was significantly reduced under tillage treatments compared to that from permanent pasture whereas nitrogen losses were unaffected.

While a large volume of research data is available on long-term tillage research in temperate climate regions in developed countries, short-term experiments such as the present study, provide significant information to support agricultural policy design in developing countries of the tropics, for the sound use of their fragile soil and scarce water resources.

# REFERENCES

Acharya, C. L. & Sharma, P. D. (1994) Tillage and mulch effects on soil physical environment, root growth, nutrient uptake and yield of maize and wheat on an Alfisol in north-west India. *Soil & Tillage Research,* **32,** 291-302.

Addiscott, T. M. & Dexter, A. R. (1994) Tillage and crop residue management effects on losses of chemicals from soils. *Soil and Tillage Research,* **30,** 125-168.

Adisarwanto, T., Utomo, W. H., Kirchhof, G. & So, H. B. (1996) *Response of food legume crops to different soil management practices after rainfed lowland rice in East Java.* ACIAR Proceedings No. 70.

Ahuja, L. R., Cassel, D. K., Bruce, R. R. & Barnes, B. B. (1989) Evaluation of spatial distribution of hydraulic conductivity using effective porosity data. *Soil Science,* **148,** 404-411.

Aimrun, W., Amin, M. S. M. & Eltaib, S. M. (2004) Effective porosity of paddy soils as an estimation of its saturated hydraulic conductivity. *Geoderma,* **121,** 197-203.

Aina, P. O., Lal, R. & Roose, E. J. (1991) Tillage methods and soil and water conservation in West Africa. *Soil and Tillage Research,* **20,** 165-186.

Al-Kaisi, M. M. & Yin, X. (2005) Tillage and Crop Residue Effects on Soil Carbon and Carbon Dioxide Emission in Corn-Soybean Rotations. *J Environ Qual,* **34,** 437-445.

Allen, H. P. (1981) *Direct Drilling and Reduced Cultivations.* Farming Press Limited, Great Britain.

Allmaras, R. R., Ward, K., Douglas, J., C. L. & Ekin, L. G. (1982) Long-term cultivation effects on hydraulic properties of a Walla Walla silt loam. *Soil and Tillage Research,* **2,** 265-279.

Andreini, M. S. & Steenhuis, T. S. (1990) Preferential paths of flow under conventional and conservation tillage. *Geoderma,* **46,** 85-102.

Arshad, M. A., Gill, K. S. & Coy, G. R. (1994) Wheat yield and weed population as influenced by three tillage systems on a clay soil in temperate continental climate. *Soil and Tillage Research,* **28,** 227-238.

Arvidsson, J., Rydberg, T. & Feiza, V. (2000) Early sowing -- a system for reduced seedbed preparation in Sweden. *Soil and Tillage Research,* **53,** 145-155.

Aslam, T. (1998) *The effects of tillage practices on soil microbial biomass and CO2 emission.* MAppSc. Thesis (unpublished), Massey University, Palmerston North, New Zealand.

Aslam, T., Choudhary, M. A. & Saggar, S. (1999) Tillage impacts on soil microbial biomass C, N and P, earthworms and agronomy after two years of cropping following permanent pasture in New Zealand. *Soil and Tillage Research,* **51,** 103-111.

Awan, M.-u.-H. (1989) *Comparison of Oversowing Methods for Legume Establishment into a Hill Country Sward.* PGDip. Thesis (unpublished), Massey University, Palmerston North, New Zealand.

Azooz, R. H. & Arshad, M. A. (1996) Soil infiltration and hydraulic conductivity under long-term no- tillage and conventional tillage systems. *Canadian Journal of Soil Science,* **76,** 143-152.

Azooz, R. H., Arshad, M. A. & Franzluebbers, A. J. (1996) Pore size distribution and hydraulic conductivity affected by tillage in Northwestern Canada. *Soil Science Society of America Journal,* **60,** 1197-1201.

Baggs, E. M., Stevenson, M., Pihlatie, M., Regar, A., Cook, H. & Cadisch, G. (2003) Nitrous oxide emissions following application of residues and fertiliser under zero and conventional tillage. *Plant and Soil,* **254,** 361-370.

Baker, C. J., Saxton, K. E. & Ritchie, W. R. (1996) *No-Tillage Seeding: Science and Practice.* CAB International, Wallingford, Oxon, UK.

Ball, B. C., Scott, A. & Parker, J. P. (1999) Field N2O, CO2 and CH4 fluxes in relation to tillage, compaction and soil quality in Scotland. *Soil and Tillage Research,* **53,** 29-39.

Barber, R. G., Orellana, M., Navarro, F., Diaz, O. & Soruco, M. A. (1996) Effects of conservation and conventional tillage systems after land clearing on soil properties and crop yield in Santa Cruz, Bolivia. *Soil & Tillage Research,* **38,** 133-152.

Barkin, D. (2001) Development: Sustainable Agriculture. *International Encyclopedia of the Social &Behavioral Sciences* (eds N. J. Smelser & P. B. Baltes), pp. 3597-3599. Elsevier Science Ltd, Oxford.

Beare, M. H., Hendrix, P. F. & Coleman, D. C. (1994) Water-stable aggregates and organic matter fractions in conventional and no-tillage soils. *Soil Science Society of America Journal,* **58,** 777-786.

Benites, J. R. & Ofori, C. S. (1993) Crop production through conservation-effective tillage in the tropics. *Soil and Tillage Research,* **27,** 9-33.

Benjamin, J. G. (1993) Tillage effects on near-surface soil hydraulic properties. *Soil and Tillage Research,* **26,** 277-288.

Bescansa, P., Imaz, M. J., Virto, I., Enrique, A. & Hoogmoed, W. B. (2006) Soil water retention as affected by tillage and residue management in semiarid Spain. *Soil and Tillage Research,* **87,** 19-27.

Bhattacharyya, R., Prakash, V., Kundu, S. & Gupta, H. S. (2006) Effect of tillage and crop rotations on pore size distribution and soil hydraulic conductivity in sandy clay loam soil of the Indian Himalayas. *Soil and Tillage Research,* **86,** 129-140.

Biamah, E. K., Gichuki, F. N. & Kaumbutho, P. G. (1993) Tillage methods and soil and water conservation in eastern Africa. *Soil and Tillage Research,* **27,** 105-123.

Biederbeck, V. O., Campbell, C. A. & Hunter, J. H. (1996) Tillage effects on soil microbial and biochemical characteristics in a fallow-wheat rotation in a Dark Brown soil. *Canadian Journal of Soil Science,* **77,** 309-316.

Birkas, M., Jolankai, M., Gyuricza, C. & Percze, A. (2004) Tillage effects on compaction, earthworms and other soil quality indicators in Hungary. *Soil & Tillage Research,* **78,** 185-196.

Blake, G. R. & Hartge, K. H. (1986) Bulk Density In Methods of Soil Analysis, Part 1. *Physical and Mineralogy Methods* (ed A. Klute), pp. 363-375. ASA, Inc., SSSA, Inc., Madison, Wisconsin USA.

Boersma, O. H. & Kooistra, M. J. (1994) Differences in soil structure of silt loam Typic Fluvaqents under various agricultural management practices. *Agriculture, Ecosystems & Environment,* **51,** 21-42.

Bradford, J. M. (1986) Penetrability In Methods of Soil Analysis, Part 1. *Physical and Mineralogy Methods* (ed A. Klute), pp. 463-478. ASA, Inc., SSSA, Inc., Madison, Wisconsin USA.

Bradford, J. M. & Huang, C.-h. (1994) Interrill soil erosion as affected by tillage and residue cover. *Soil and Tillage Research,* **31,** 353-361.

Braim, M. A., Chaney, K. & Hodgson, D. R. (1992) Effects of simplified cultivation on the growth and yield of spring barley on a sandy loam soil. 2. Soil physical properties and root growth; root: shoot relationships, inflow rates of nitrogen; water use. *Soil and Tillage Research,* **22,** 173-187.

Briggs, D. & Courtney, F. (1985) *"Agriculture & Environment" The Physical Geography of Temperate Agricultural Systems.* Longman Group Ltd., USA.

Cameira, M. R., Fernando, R. M. & Pereira, L. S. (2003) Soil macropore dynamics affected by tillage and irrigation for a silty loam alluvial soil in southern Portugal. *Soil and Tillage Research,* **70,** 131-140.

Campbell, C. A., Janzen, H. H., Paustian, K., Gregorich, E. G., Sherrod, L., Liang, B. C. & Zentner, R. P. (2005) Carbon Storage in Soils of the North American Great Plains: Effect of Cropping Frequency. *Agronomy Journal,* **97,** 349-363.

Campbell, C. A., McConkey, B. G., Zentner, R. P., Selles, F. & Curtin, D. (1996) Long-term effects of tillage and crop rotations on soil organic C and total N in a clay soil in southwestern Saskatchewan. *Canadian Journal of Soil Science,* **76,** 395-401.

Carter, M. R. (1988) Temporal variability of soil macroporosity in a fine sandy loam under mouldboard ploughing and direct drilling. *Soil and Tillage Research,* **12,** 37-51.

Carter, M. R. (1994) Strategies to Overcome Impediments to Adoption of Conservation Tillage. *Conservation Tillage in Temperate Agrosystems* (ed M. R. Carter), pp. 1-19. Lewis Publishers, London.

Cass, A., Gusli, S. & MacLeod, D. A. (1994) Sustainability of soil structure quality in rice paddy-- soya-bean cropping systems in South Sulawesi, Indonesia. *Soil and Tillage Research,* **31,** 339-352.

Cassel, D. K. & Nelson, L. A. (1985) Spatial and temporal variability of soil physical properties of norfolk loamy sand as affected by tillage. *Soil and Tillage Research,* **5,** 5-17.

Castro Filho, C., Henklain, J. C., Vieira, M. J. & Casao, J., R. (1991) Tillage methods and soil and water conservation in southern Brazil. *Soil and Tillage Research,* **20,** 271-283.

Castro Filho, C., Lourenco, A., de F. Guimaraes, M. & Fonseca, I. C. B. (2002) Aggregate stability under different soil management systems in a red latosol in the state of Parana, Brazil. *Soil and Tillage Research,* **65,** 45-51.

Chan, K. Y. & Mead, J. A. (1989) Water movement and macroporosity of an Australian Alfisol under different tillage and pasture conditions. *Soil and Tillage Research,* **14,** 301-310.

Chareonsilp, N., Buddhaboon, C., Promnart, P., Wassmann, R. & Lantin, R. S. (2000) Methane Emission from Deepwater Rice Fields in Thailand. *Nutrient Cycling in Agroecosystems,* **58,** 121-130.

Choudhary, M. A. & Baker, C. J. (1993) Conservation tillage and seeding systems in the South Pacific. *Soil and Tillage Research,* **27,** 283-302.

Choudhary, M. A. & Baker, C. J. (1994) Overcoming Constraints to Conservation Tillage in New Zealand. *Conservation Tillage in Temperate Agrosystems* (ed M. R. Carter), pp. 183-207. Lewis Publishers, London.

Clements, D. R., Weise, S. F., Brown, R., Stonehouse, D. P., Hume, D. J. & Swanton, C. J. (1995) Energy analysis of tillage and herbicide inputs in alternative weed management systems. *Agriculture, Ecosystems & Environment,* **52,** 119-128.

Conacher, J. & Conacher, A. (1986) *Herbicides in Agriculture: Minimum Tillage, Science and Society.* University of Western Australia, Nedlands, Western Australia.

Coughenour, C. M. & Chamala, S. (2000) *Conservation Tillage and Cropping Innovation: Constructing the New Culture of Agriculture.* Iowa State University Press, Ames, Iowa.

Dalal, R. C., Henderson, P. A. & Glasby, J. M. (1991) Organic matter and microbial biomass in a Vertisol after 20 yr of zero-tillage. *Soil Biology and Biochemistry,* **23,** 435-441.

Dam, R. F., Mehdi, B. B., Burgess, M. S. E., Madramootoo, C. A., Mehuys, G. R. & Callum, I. R. (2005) Soil bulk density and crop yield under eleven consecutive years of corn with different tillage and residue practices in a sandy loam soil in central Canada. *Soil and Tillage Research,* **84,** 41-53.

Dando, J. L. (1999) *Methods of Analysis: Water-stability of soil aggregates.* Landcare Research New Zealand Ltd., Palmerston North New Zealand.

Dexter, A. R. (1997) Physical properties of tilled soils. *Soil and Tillage Research,* **43,** 41-63.

Dick, W. A. (1997) Tillage system impacts on environmental quality and soil biological parameters. *Soil and Tillage Research,* **41,** 165-167.

Dickson, J. W. & Ritchie, R. M. (1996) Zero and reduced ground pressure traffic systems in an arable rotation 2. Soil and crop responses. *Soil and Tillage Research,* **38,** 89-113.

Diekow, J., Mielniczuk, J., Knicker, H., Bayer, C., Dick, D. P. & Kogel-Knabner, I. (2005) Soil C and N stocks as affected by cropping systems and nitrogen fertilisation in a southern Brazil Acrisol managed under no-tillage for 17 years. *Soil and Tillage Research,* **81,** 87-95.

Ehlers, W. (1977) Measurement and calculation of hydraulic conductivity in horizons of tilled and untilled loess-derived soil, Germany. *Geoderma,* **19,** 293-306.

Ehlers, W., Kopke, U., Hesse, F. & Bohm, W. (1983) Penetration resistance and root growth of oats in tilled and untilled loess soil. *Soil and Tillage Research,* **3,** 261-275.

Ekeberg, E. & Riley, H. C. F. (1996) Effects of mouldboard ploughing and direct planting on yield and nutrient uptake of potatoes in Norway. *Soil and Tillage Research,* **39,** 131-142.

Erkossa, T., Stahr, K. & Gaiser, T. (2006) Soil tillage and crop productivity on a Vertisol in Ethiopian highlands. *Soil and Tillage Research,* **85,** 200-211.

Essington, M. E. & Howard, D. D. (2000) Phosphorus Availability and Speciation in Long-term No-till and Disk-till Soil. *Soil Science,* **165,** 144-152.

Eynard, A., Schumacher, T. E., Lindstrom, M. J. & Malo, D. D. (2004) Porosity and Pore-Size Distribution in Cultivated Ustolls and Usterts. *Soil Sci. Soc. Am. J.,* **68,** 1927-1934.

Eynard, A., Schumacher, T. E., Lindstrom, M. J. & Malo, D. D. (2005) Effects of agricultural management systems on soil organic carbon in aggregates of Ustolls and Usterts. *Soil and Tillage Research,* **81,** 253-263.

Fabrizzi, K. P., Garcia, F. O., Costa, J. L. & Picone, L. I. (2005) Soil water dynamics, physical properties and corn and wheat responses to minimum and no-tillage systems in the southern Pampas of Argentina. *Soil and Tillage Research,* **81,** 57-69.

Fawcet, R. S. (1987) Overview of Pest Management for Conservation Tillage Systems. *Effects of conservation tillage on groundwater quality* (eds T. J. Logan, J. M. Davidson, J. L. Baker & M. R. Overcash), pp. 19-37. Lewis Publishers, Inc., Michigan U.S.A.

Fisk, J. W., Hesterman, O. B., Shrestha, A., Kells, J. J., Harwood, R. R., Squire, J. M. & Sheaffer, C. C. (2001) Weed Suppression by Annual Legume Cover Crops in No-Tillage Corn. *Agronomy Journal,* **93,** 319-325.

Franzluebbers, A. J. & Arshad, M. A. (1996) Water-stable aggregation and organic matter in four soils under conventional and zero tillage. *Canadian Journal of Soil Science,* **76,** 387-393.

Freebairn, D. M., Loch, R. J. & Cogle, A. L. (1993) Tillage methods and soil and water conservation in Australia. *Soil and Tillage Research,* **27,** 303-325.

Fuentes, J. P., Flury, M. & Bezdicek, D. F. (2004) Hydraulic Properties in a Silt Loam Soil under Natural Prairie, Conventional Till, and No-Till. *Soil Sci Soc Am J,* **68,** 1679-1688.

Gajri, P. R., Arora, V. K. & Prihar, S. S. (2002) *Tillage for Sustainable Cropping.* Haworth Press, Binghamtom, NY.

Garcia-Prechac, F., Ernst, O., Siri-Prieto, G. & Terra, J. A. (2004) Integrating no-till into crop-pasture rotations in Uruguay. *Soil and Tillage Research,* **77,** 1-13.

Gicheru, P., Gachene, C., Mbuvi, J. & Mare, E. (2004) Effects of soil management practices and tillage systems on surface soil water conservation and crust formation on a sandy loam in semi-arid Kenya. *Soil and Tillage Research,* **75,** 173-184.

Gish, T. J. & Coffman (1987) Solute Transport Under No-Till Field Corn. *Transactions of ASAE,* **30,** 1359-1363.

Gliessman, S. R. (1998) *Agroecology: ecological process in sustainable agriculture.* Ann Arbor Press, Chelsea MI, USA.

Govaerts, B., Sayre, K. D. & Deckers, J. (2006) A minimum data set for soil quality assessment of wheat and maize cropping in the highlands of Mexico. *Soil and Tillage Research,* **87,** 163-174.

Gradwell, M. W. (1972) *Methods for physical analysis of soils.* N.Z. Soil Bureau, Lower Hutt, New Zealand.

Green, T. R., Ahuja, L. R. & Benjamin, J. G. (2003) Advances and challenges in predicting agricultural management effects on soil hydraulic properties. *Geoderma,* **116,** 3-27.

Guo, P., Choudhary, M. A. & Rahman, A. (1999) Tillage-induced changes in a silt loam under continuous cropping. I - Soil physical properties. *Agricultural Engineering Journal,* **8,** 149-159.

Hadas, A. (1997) Soil tilth--the desired soil structural state obtained through proper soil fragmentation and reorientation processes. *Soil and Tillage Research,* **43,** 7-40.

Hakansson, I. & Lipiec, J. (2000) A review of the usefulness of relative bulk density values in studies of soil structure and compaction. *Soil and Tillage Research,* **53,** 71-85.

Hakansson, I. & Reeder, R. C. (1994) Subsoil compaction by vehicles with high axle load--extent, persistence and crop response. *Soil and Tillage Research,* **29,** 277-304.

Hakansson, I. & Voorhees, W. B. (1998) Soil Compaction. *Methods for Assessment of Soil Degradation* (eds R. Lal, W. H. Blum, C. Valentine & B. A. Stewart), pp. 167-179. CRC Press, New York, U.S.A.

Halvorson, A. D., Wienhold, B. J. & Black, A. L. (2002) Tillage, Nitrogen, and Cropping System Effects on Soil Carbon Sequestration. *Soil Sci Soc Am J,* **66,** 906-912.

Hamza, M. A. & Anderson, W. K. (2005) Soil compaction in cropping systems: A review of the nature, causes and possible solutions. *Soil and Tillage Research,* **82,** 121-145.

Haynes, R. J. (1999) Labile organic matter fractions and aggregate stability under short-term, grass-based leys. *Soil Biology and Biochemistry,* **31,** 1821-1830.

Haynes, R. J. (2000) Labile organic matter as an indicator of organic matter quality in arable and pastoral soils in New Zealand. *Soil Biology and Biochemistry,* **32,** 211-219.

Heard, J. R., Kladivko, E. J. & Mannering, J. V. (1988) Soil macroporosity, hydraulic conductivity and air permeability of silty soils under long-term conservation tillage in Indiana. *Soil and Tillage Research,* **11,** 1-18.

Hemmat, A. & Eskandari, I. (2006) Dryland winter wheat response to conservation tillage in a continuous cropping system in northwestern Iran. *Soil and Tillage Research,* **86,** 99-109.

Hillel, D. (1980) *Application of soil physics.* Academic Press, New York, U.S.A.

Hillel, D. (1998) *Environmental Soil Physics.* Academic Press, U.S.A.

Holland, J. M. (2004) The environmental consequences of adopting conservation tillage in Europe: reviewing the evidence. *Agriculture, Ecosystems & Environment,* **103,** 1-25.

Horn, R., Taubner, H., Wuttke, M. & Baumgartl, T. (1994) Soil physical properties related to soil structure. *Soil and Tillage Research,* **30,** 187-216.

Horne, D. J., Ross, C. W. & Hughes, K. A. (1992) Ten years of a maize/oats rotation under three tillage systems on a silt loam in New Zealand. 1. A comparison of some soil properties. *Soil & Tillage Research,* **22,** 131-143.

Hughes, K. A., Horne, D. J., Ross, C. W. & Julian, J. F. (1992) A 10-year maize/oats rotation under three tillage systems. 2. Plant population, root distribution and forage yields. *Soil and Tillage Research,* **22,** 145-157.

Hussain, I., Olson, K. R. & Siemens, J. C. (1998) Long-term tillage effects on physical properties of eroded soils. *Soil Science Society of America Journal,* **163,** 971-981.

Husson, O., Lienhard, P., Seguy, L., Tuan, H. D. & Doanh, L. Q. (2001) Development of direct sowing and mulching techniques as alternatives to slash-and-burn systems in northern Vietnam. *Conservation Agriculture, A Worldwide Challenge. First World Congress on conservation agriculture, Madrid, Spain, 1-5 October, 2001* (eds L. Garcia-Torres, J. Benites & A. Martinez-Vilela), pp. 29-33. XUL, Cordoba, Spain.

Janson, C. G. (1984) Conservation tillage studies under intensive arable cropping. *Proceedings of the 1984 Seminar* (ed Monsanto), pp. 39-53. Monsanto, Christchurch, New Zealand.

Jiao, Y., Hendershot, W. H. & Whalen, J. K. (2004) Agricultural Practices Influence Dissolved Nutrients Leaching through Intact Soil Cores. *Soil Sci Soc Am J,* **68,** 2058-2068.

Karamanos, A. J., Bilalis, D. & Sidiras, N. (2004) Effects of Reduced Tillage and Fertilization Practices on Soil Characteristics, Plant Water Status, Growth and Yield of Upland Cotton. *Journal of Agronomy and Crop Science,* **190,** 262-276.

Karlen, D. L., Wollenhaupt, N. C., Erbach, D. C., Berry, E. C., Swan, J. B., Eash, N. S. & Jordahl, J. L. (1994) Long-term tillage effects on soil quality. *Soil & Tillage Research,* **32,** 313-327.

Katsvairo, T., Cox, W. J. & van Es, H. (2002) Tillage and Rotation Effects on Soil Physical Characteristics. *Agron J,* **94,** 299-304.

Kay, B. D. & Munkholm, L. J. (2004) Management-induced Soil Structure Degradation - Organic Matter Depletion and Tillage. *Managing Soil Quality: Challenges in Modern Agriculture* (eds P. Schjønning, S. Elmholt & B. T. Christensen), pp. 185-197. CABI Publishing CAB International, Wallingford, Oxon, UK; Cambridge, USA.

Kay, B. D. & VandenBygaart, A. J. (2002) Conservation tillage and depth stratification of porosity and soil organic matter. *Soil and Tillage Research,* **66,** 107-118.

Kelley, K. W. & Sweeney, D. W. (2005) Tillage and Urea Ammonium Nitrate Fertilizer Rate and Placement Affects Winter Wheat following Grain Sorghum and Soybean. *Agron J,* **97,** 690-697.

Kemper, W. D. & Rosenau, R. C. (1986) Aggregate stability and size distribution. *Methods of Soil Analysis, Part 1- Physical and Mineralogy Methods* (ed A. Klute), pp. 425-442. ASA, Inc., SSSA, Inc., Madison, Wisconsin, U.S.A.

Khanh, T. D., Chung, M. I., Xuan, T. D. & Tawata, S. (2005) The Exploitation of Crop Allelopathy in Sustainable Agricultural Production. *Journal of Agronomy and Crop Science,* **191,** 172-184.

Kirchhof, G., Priyono, S., Utomo, W. H., Adisarwanto, T., Dacanay, E. V. & So, H. B. (2000) The effect of soil puddling on the soil physical properties and the growth of rice and post-rice crops. *Soil and Tillage Research,* **56,** 37-50.

Koch, H.-J. & Stockfisch, N. (2006) Loss of soil organic matter upon ploughing under a loess soil after several years of conservation tillage. *Soil and Tillage Research,* **86,** 73-83.

Köller, K. (2003) Techniques of soil tillage. *Soil Tillage in Agroecosystems* (ed A. E. Titi), pp. 1-25. CRC Press, London.

Kukal, S. S. & Aggarwal, G. C. (2003) Puddling depth and intensity effects in rice-wheat system on a sandy loam soil: I. Development of subsurface compaction. *Soil and Tillage Research,* **72,** 1-8.

Lal, R. (1991) Tillage and agricultural sustainability. *Soil and Tillage Research,* **20,** 133-146.

Lal, R. (1995) Tillage systems in the tropics: management options and sustainability implications. *FAO Soils Bulletin No. 71.* FAO.

Lal, R. (1998) Soil quality and sustainability. *Methods for Assessment of Soil Degradation* (eds R. Lal, W. H. Blum, C. Valentine & B. A. Stewart), pp. 17-30. CRC Press, New York, USA.

Lal, R. (2004a) Historical Development of No-Till Farming. *Sustainable Agriculture and the International Rice-Wheat System* (eds R. Lal, P. R. Hobbs, N. Uphoff & D. O. Hansen), pp. 55-81. Marcel Dekker, Inc., New York.

Lal, R. (2004b) Soil and Water Resources of South Asia in an Uncertain Climate. *Sustainable Agriculture and the International Rice-Wheat System* (eds R. Lal, P. R. Hobbs, N. Uphoff & D. O. Hansen), pp. 19-35. Marcel Dekker, Inc., New York.

Lal, R., Hobbs, P., Uphoff, N. & Hansen, D. O. (2004) Sustainable Agriculture and the International Rice-Wheat System. pp. 532. Marcel Dekker, Inc., New York.

Lal, R., Logan, T. J. & Fausey, N. R. (1989) Long-term tillage and wheel traffic effects on a poorly drained mollic ochraqualf in northwest Ohio. 2. Infiltrability, surface runoff, sub-surface flow and sediment transport. *Soil and Tillage Research,* **14,** 359-373.

Lal, R. & Vandoren, J., D. M. (1990) Influence of 25 years of continuous corn production by three tillage methods on water infiltration for two soils in Ohio. *Soil and Tillage Research,* **16,** 71-84.

Lampurlanés, J. & Cantero-Martínez , C. (2003) Soil Bulk Density and Penetration Resistance under Different Tillage and Crop Management Systems and Their Relationship with Barley Root Growth. *Agron J,* **95,** 526-536.

Leij, F. J., Ghezzehei, T. A. & Or, D. (2002) Analytical Models for Soil Pore-Size Distribution After Tillage. *Soil Science Society of America Journal,* **66,** 1104-1114.

Libardi, P. L., Reichardt, K., Nelsen, D. R. & Biggar, J. W. (1980) Simple field methods for estimating soil hydraulic conductivity. *Soil Sci. Soc. Am. J.,* **44,** 3–6.

Lindwall, C. W., Larney, F. J. & Carefoot, J. M. (1994) Rotation, tillage and seeder effects on winter wheat performance and soil moisture regime. *Canadian Journal of Soil Science,* **75,** 109-116.

Lipiec, J. & Hakansson, I. (2000) Influences of degree of compactness and matric water tension on some important plant growth factors. *Soil and Tillage Research,* **53,** 87-94.

Lipiec, J. & Hatano, R. (2003) Quantification of compaction effects on soil physical properties and crop growth. *Geoderma,* **116,** 107-136.

Logsdon, S. D., Allmaras, R. R., Nelson, W. W. & Voorhees, W. B. (1992) Persistence of subsoil compaction from heavy axle loads. *Soil and Tillage Research,* **23,** 95-110.

Lowther, W. L., Horrell, R. F., Fraser, W. J., Trainor, K. D. & Johnstone, P. D. (1996) Effectiveness of a strip seeder direct drill for pasture establishment. *Soil and Tillage Research,* **38,** 161-174.

Machado, P. L. O. A. & Freitas, P. L. (2004) No-Till Farming in Brazil and its Impact on Food Security and Environmental Quality. *Sustainable Agriculture and the International Rice-Wheat System* (eds R. Lal, P. Hobbs, N. Uphoff & D. O. Hansen), pp. 291-310. Marcel Dekker, Inc., New York.

Malone, R. W., Logsdon, S., Shipitalo, M. J., Weatherington-Rice, J., Ahuja, L. & Ma, L. (2003) Tillage effect on macroporosity and herbicide transport in percolate. *Geoderma,* **116,** 191-215.

Mannering, J. V. & Fenster, C. R. (1983) What is conservation tillage? *Journal of Soil & Water Conservation,* **38,** 141-143.

Mannering, J. V., Schertz, D. L. & Julian, B. A. (1987) Overview of conservation tillage. *Effects of conservation tillage on groundwater quality* (eds T. J. Logan, J. M. Davidson, J. L. Baker & M. R. Overcash), pp. 3-17. Lewis Publishers, Inc., Michigan, U.S.A.

Mas, M. T. & Verdu, A. M. C. (2003) Tillage system effects on weed communities in a 4-year crop rotation under Mediterranean dryland conditions. *Soil and Tillage Research,* **74,** 15-24.

McDonald, A. J., Riha, S. J., Duxbury, J. M., Steenhuis, T. S. & Lauren, J. G. (2006) Soil physical responses to novel rice cultural practices in the rice-wheat system: Comparative evidence from a swelling soil in Nepal. *Soil and Tillage Research,* **86,** 163-175.

McKyes, E. (1985) *Soil Cutting and Tillage.* Elsevier.

McLaren, R. G. & Cameron, K. C. (1996) *Soil science, sustainable production and environmental protection.* Oxford University Press.

Mikha, M. M. & Rice, C. W. (2004) Tillage and Manure Effects on Soil and Aggregate-Associated Carbon and Nitrogen. *Soil Sci Soc Am J,* **68,** 809-816.

Miller, R. W. & Donahue, R. L. (1990) *Soils, an introduction to soils and plant growth.* Prentice-Hall, Inc., USA.

Mishra, B. K. & Ramakrishnan, P. S. (1982) Energy flow through a village ecosystem with slash and burn agriculture in North-eastern India. *Agricultural Systems,* **9,** 57-72.

Mohanty, M., Painuli, D. K. & Mandal, K. G. (2004) Effect of puddling intensity on temporal variation in soil physical conditions and yield of rice (Oryza sativa L.) in a Vertisol of central India. *Soil and Tillage Research,* **76,** 83-94.

Nielsen, D. C. & Vigil, M. F. (2005) Legume Green Fallow Effect on Soil Water Content at Wheat Planting and Wheat Yield. *Agron J,* **97,** 684-689.

Nissen, T. M. & Wander, M. M. (2003) Management and Soil-Quality Effects on Fertilizer-Use Efficiency and Leaching. *Soil Sci Soc Am J,* **67,** 1524-1532.

Osunbitan, J. A., Oyedele, D. J. & Adekalu, K. O. (2005) Tillage effects on bulk density, hydraulic conductivity and strength of a loamy sand soil in southwestern Nigeria. *Soil and Tillage Research,* **82,** 57-64.

Ozpinar, S. (2006) Effects of tillage systems on weed population and economics for winter wheat production under the Mediterranean dryland conditions. *Soil and Tillage Research,* **87,** 1-8.

Ozpinar, S. & Cay, A. (2006) Effect of different tillage systems on the quality and crop productivity of a clay-loam soil in semi-arid north-western Turkey. *Soil and Tillage Research,* **88,** 95-106.

Pachepsky, Y., Rawls, W. J. & Gimenez, D. (2001) Comparison of soil water retention at field and laboratory scales. *Soil Sci Soc Am J,* **65,** 460-462.

Park, E.-J. & Smucker, A. J. M. (2005) Saturated Hydraulic Conductivity and Porosity within Macroaggregates Modified by Tillage. *Soil Sci. Soc. Am. J.,* **69,** 38-45.

Pirmoradian, N., Sepaskhah, A. R. & Hajabbasi, M. A. (2005) Application of Fractal Theory to quantify Soil Aggregate Stability as influenced by Tillage Treatments. *Biosystems Engineering,* **90,** 227-234.

Ramesh, K. & Chandrasekaran, B. (2004) Soil Organic Carbon Build-up and Dynamics in Rice-Rice Cropping Systems. *Journal of Agronomy and Crop Science,* **190,** 21-27.

Rhoton, F. E. (2000) Influence of Time on Soil Response to No-Till Practices. *Soil Sci Soc Am J,* **64,** 700-709.

Riley, H., Borresen, T., Ekeberg, E. & Rydberg, T. (1994) Trends in reduced tillage research and practice in Scandinavia. *Conservation Tillage in Temperate Agrosystems* (ed M. R. Carter), pp. 23-45. Lewis Publishers, London.

Robinson, C. A., Cruse, R. M. & Kohler, K. A. (1994) Soil Management. *Sustainable Agriculture Systems* (eds J. L. Hatfield & D. L. Karlen), pp. 109-134. Lewis Publishers CRC Press, Inc., USA.

Sá, J. C. d. M., Cerri, C. C., Dick, W. A., Lal, R., Filho, S. P. V., Piccolo, M. C. & Feigl, B. E. (2001) Organic Matter Dynamics and Carbon Sequestration Rates for a Tillage Chronosequence in a Brazilian Oxisol. *Soil Science Society of America Journal,* **65,** 1486-1499.

SAS (2002) *The SAS System 8.2.* SAS Institute Inc., Cary, NC 27513, USA.

Sasal, M. C., Andriulo, A. E. & Taboada, M. A. (2006) Soil porosity characteristics and water movement under zero tillage in silty soils in Argentinian Pampas. *Soil and Tillage Research,* **87,** 9-18.

Sauer, T. J., Clothier, B. E. & Daniel, T. C. (1990) Surface measurements of the hydraulic properties of a tilled and untilled soil. *Soil and Tillage Research,* **15,** 359-369.

Schillinger, W. F., Cook, R. J. & Papendick, R. I. (1999) Increased Dryland Cropping Intensity with No-Till Barley. *Agron J,* **91,** 744-752.

Schipper, L. A. & Sparling, G. P. (2000) Performance of Soil Condition Indicators Across Taxonomic Groups and Land Uses. *Soil Sci Soc Am J,* **64,** 300-311.

Schlegel, A. J., Grant, C. A. & Havlin, J. L. (2005) Challenging Approaches to Nitrogen Fertilizer Recommendations in Continuous Cropping Systems in the Great Plains. *Agron J,* **97,** 391-398.

Scopel, E. & Findeling, A. (2001) Conservation tillage impact on rainfed maize production in semi-arid zones of western Mexico: importance of runoff reduction. *Conservation Agriculture, A Worldwide Challenge. First World Congress on conservation agriculture, Madrid, Spain, 1-5 October, 2001* (eds L. Garcia-Torres, J. Benites & A. Martinez-Vilela), pp. 179-184. XUL, Cordoba, Spain.

Sharma, K. L., Mandal, U. K., Srinivas, K., Vittal, K. P. R., Mandal, B., Grace, J. K. & Ramesh, V. (2005) Long-term soil management effects on crop yields and soil quality in a dryland Alfisol. *Soil and Tillage Research,* **83,** 246-259.

Shestak, C. J. & Busse, M. D. (2005) Compaction Alters Physical but Not Biological Indices of Soil Health. *Soil Sci Soc Am J,* **69,** 236-246.

Shukla, M. K. & Lal, R. (2005) Erosional effects on soil organic carbon stock in an on-farm study on Alfisols in west central Ohio. *Soil and Tillage Research,* **81,** 173-181.

Sidiras, N., Bilalis, D. & Vavoulidou, E. (2001) Effects of Tillage and Fertilization on Some Selected Physical Properties of Soil (0-30 cm Depth) and on the Root Growth Dynamic of Winter Barley (Hordeum vulgare cv. Niki). *Journal of Agronomy and Crop Science,* **187,** 167-176.

Singh, B. R. & Lal, R. (2005) The Potential of Soil Carbon Sequestration Through Improved Management Practices in Norway. *Environment, Development and Sustainability,* **7,** 161-184.

Singh, G., Laryea, K. B., Karwasra, S. P. S. & Pathak, P. (1993) Tillage methods related to soil and water conservation in south Asia. *Soil and Tillage Research,* **27,** 273-282.

Smil, V. (1994) China's greenhouse gas emissions. *Global Environmental Change,* **4,** 325-332.

Smucker, A. J. M. & Erickson, A. E. (1988) Tillage and Compactive Modifications of Gaseous Flow and Soil Aeration. *Mechanics and Related Processes in Structured Soils* (ed W. E. Larson). Kluwer Academic Publishers, London.

Sparling, G. P., Graham Shepherd, T. & Kettles, H. A. (1992) Changes in soil organic C, microbial C and aggregate stability under continuous maize and cereal cropping, and after restoration to pasture in soils from the Manawatu region, New Zealand. *Soil and Tillage Research,* **24,** 225-241.

Sprague, M. A. (1986) Overview. *No-tillage and Surface-Tillage Agriculture* (eds M. A. Sprague & G. B. Triplett), pp. 1-18. John Wiley & Sons, New York.

Steed, G. R., Ellington, A. & Pratley, J. E. (1994) Conservation Tillage in the Southeastern Australian Wheat-Sheep Belt. *Conservation Tillage in Temperate Agroecosystems* (ed M. R. Carter), pp. 231-251. Lewis Publishers, London.

Stewart, B. A. (2004) Impact of No-Till Farming in the United States. *Sustainable Agriculture and the International Rice-Wheat System* (eds R. Lal, P. R. Hobbs, N. Uphoff & D. O. Hansen), pp. 283-290. Marcel Dekker, Inc., New York.

Tarawally, M. A., Medina, H., Frometa, M. E. & Itza, C. A. (2004) Field compaction at different soil-water status: effects on pore size distribution and soil water characteristics of a Rhodic Ferralsol in Western Cuba. *Soil and Tillage Research,* **76,** 95-103.

Tieszen, L. L., Tappan, G. G. & Toure, A. (2004) Sequestration of carbon in soil organic matter in Senegal: an overview. *Journal of Arid Environments,* **59,** 409-425.

Toky, O. P. & Ramakrishnan, P. S. (1982) A comparative study of the energy budget of hill agro-ecosystems with emphasis on the slash and burn system (JHUM) at lower elevations of North-Eastern India. *Agricultural Systems,* **9,** 143-154.

Unger, P. W. (1996) Soil bulk density, penetration resistance, and hydraulic conductivity under controlled traffic conditions. *Soil and Tillage Research,* **37,** 67-75.

Unger, P. W. & Cassel, D. K. (1991) Tillage implement disturbance effects on soil properties related to soil and water conservation: a literature review. *Soil and Tillage Research,* **19,** 363-365.

Uphoff, N. (2004) Agroecological Thoughts on Zero-Tillage: Possibilities for Improving Both Crop Components of Rice-Wheat Farming Systems with Rice Intensification. *Sustainable Agriculture and the International Rice-Wheat System* (eds R. Lal, P. Hobbs, N. Uphoff & D. O. Hansen), pp. 83-100. Marcel Dekker, Inc., New York.

Uri, N. D. (1999) The effect of energy on the adoption of conservation tillage in the United States. *Environmental Geology,* **37,** 9-18.

Valmis, S., Dimoyiannis, D. & Danalatos, N. G. (2005) Assessing interrill erosion rate from soil aggregate instability index, rainfall intensity and slope angle on cultivated soils in central Greece. *Soil and Tillage Research,* **80,** 139-147.

Van Genuchten, M. T. (1980) A closed-form equation for predicting the hydraulic conductivity of unsaturated soils. *Soil Science Society of America Journal,* **44,** 892-898.

Viegas, E. & Choudhary, M. A. (2002) Tillage effects on physical characteristics and crop yield of a silt loam under five years of continuous cropping. *Agricultural Engineering Journal,* **11,** 107-119.

Vlek, P. L. G., Rodriguez-Kuhl, G. & Sommer, R. (2004) Energy Use and CO2 Production in Tropical Agriculture and Means and Strategies for Reduction or Mitigation. *Environment, Development and Sustainability*, pp. 213-233.

Wahl, N. A., Bens, O., Buczko, U., Hangen, E. & Huttl, R. F. (2004) Effects of conventional and conservation tillage on soil hydraulic properties of a silty-loamy soil. *Physics and Chemistry of the Earth, Parts A/B/C,* **29,** 821-829.

Wang, K., Zhang, R. & Wang, F. (2005) Testing the Pore-Solid Fractal Model for the Soil Water Retention Function. *Soil Sci Soc Am J,* **69,** 776-782.

Watts, C. W. & Dexter, A. R. (1997) The influence of organic matter in reducing the destabilization of soil by simulated tillage. *Soil and Tillage Research,* **42,** 253-275.

Watts, D. W. & Hall, J. K. (1996) Tillage and application effects on herbicide leaching and runoff. *Soil and Tillage Research,* **39,** 241-257.

West, T. O. & Post, W. M. (2002) Soil Organic Carbon Sequestration Rates by Tillage and Crop Rotation: A Global Data Analysis. *Soil Sci Soc Am J,* **66,** 1930-1946.

Whitbread, A., Blair, G., Konboon, Y., Lefroy, R. & Naklang, K. (2003) Managing crop residues, fertilizers and leaf litters to improve soil C, nutrient balances, and the grain yield of rice and wheat cropping systems in Thailand and Australia. *Agriculture, Ecosystems & Environment,* **100,** 251-263.

Wilhelm, W. W. & Wortmann, C. S. (2004) Tillage and Rotation Interactions for Corn and Soybean Grain Yield as Affected by Precipitation and Air Temperature. *Agron J,* **96,** 425-432.

Willcocks, T. J. & Twomlow, S. J. (1993) A review of tillage methods and soil and water conservation in southern Africa. *Soil and Tillage Research,* **27,** 73-94.

Willocks, M. J. (1984) Overview of conservation tillage in arable sector. *Proceedings of the 1984 Seminar* (ed Monsanto), pp. 13-20. Monsanto, Christchurch, New Zealand.

Wolf, B. & Snyder, G. H. (2003) *Sustainable Soils: The Place of Organic Matter in Sustaining Soils and Their Productivity.* The Halworth Press, Inc., New York.

Wright, A. L. & Hons, F. M. (2005a) Soil Carbon and Nitrogen Storage in Aggregates from Different Tillage and Crop Regimes. *Soil Sci. Soc. Am. J.,* **69,** 141-147.

Wright, A. L. & Hons, F. M. (2005b) Tillage impacts on soil aggregation and carbon and nitrogen sequestration under wheat cropping sequences. *Soil and Tillage Research,* **84,** 67-75.

Yoder, R. E. (1936) A direct method of aggregate analysis of soils and a study of the physical nature of erosion losses. *Journal American Society Agronomy,* **28,** 337-351.

Zentner, R. P., Lafond, G. P., Derksen, D. A., Nagy, C. N., Wall, D. D. & May, W. E. (2004) Effects of tillage method and crop rotation on non-renewable energy use efficiency for a thin Black Chernozem in the Canadian Prairies. *Soil and Tillage Research,* **77,** 125-136.

Zentner, R. P., Stumborg, M. A. & Campbell, C. A. (1989) Effect of crop rotations and fertilization on energy balance in typical production systems on the Canadian Prairies. *Agriculture, Ecosystems & Environment,* **25,** 217-232.

Zhao, S. L., Gupta, S. C., Huggins, D. R. & Moncrief, J. F. (2001) Tillage and Nutrient Source Effects on Surface and Subsurface Water Quality at Corn Planting. *J Environ Qual,* **30,** 998-1008.

Zhu, Y., Fox, R. H. & Toth, J. D. (2003) Tillage Effects on Nitrate Leaching Measured by Pan and Wick Lysimeters. *Soil Sci Soc Am J,* **67,** 1517-1523.

Zibilske, L. M., Bradford, J. M. & Smart, J. R. (2002) Conservation tillage induced changes in organic carbon, total nitrogen and available phosphorus in a semi-arid alkaline subtropical soil. *Soil and Tillage Research,* **66,** 153-163.

Zotarelli, L., Alves, B. J. R., Urquiaga, S., Torres, E., dos Santos, H. P., Paustian, K., Boddey, R. M. & Six, J. (2005) Impact of Tillage and Crop Rotation on Aggregate-Associated Carbon in Two Oxisols. *Soil Sci Soc Am J,* **69,** 482-491.

# 6 TILLAGE EFFECTS ON WATER RUNOFF, LEACHATE, AND SOIL SEDIMENT AND NUTRIENT LOSSES

## 6.1 INTRODUCTION

### 6.1.1 General background

In recent years, research on soil management has put increasing emphasis on improving soil quality, by promoting sensible soil conservation practices, based on sound management of soils, crops, and water (Lal, 2004). Tropical soil management, in particular, is often concerned with soil management strategies, which improve the structure of the surface soil thereby making it less susceptible to activities of erosive agents (Idowu, 2003). These practices and strategies aim to: (i) maintain good soil structure, (ii) protect the soil surface by adequate crop and residue cover, and (iii) use special structural erosion control practices where necessary. The decline in soil structure is increasingly seen as a form of soil degradation (Chan *et al.*, 2003) and is often related to land use and soil/crop management practices. As has been discussed in the previous chapter, soil structure influences soil water movement and retention, erosion, crusting, nutrient recycling, root penetration and crop yield. Externalities such as runoff, surface- and ground-water pollution and $CO_2$ emissions are influenced by soil structure (Bronick and Lal, 2005), which in many respects, can be controlled and mitigated by implementing proper tillage practices for crop production.

In developing countries, in particular, soil tillage has predominantly been promoted through large scale mechanized land development and management schemes with the hope of increasing food production. Accelerated soil erosion and the resulting soil degradation are among the reasons for the failure of these schemes, which often cause a rapid decline in soil fertility and create vast tracts of barren and unproductive land in areas that were once biologically productive. This has been the case in Thailand (Turkelboom et al., 1997), Nepal (Thapa and Paudel, 2002), and China (Sheng and Liao, 1997), to mention a few cases. To assess the impacts of these practices, it is often time consuming, not to mention the high cost involved (Laflen and Roose, 1998). Public sector budgets are generally largely allocated to production generating projects while leaving insufficient fund for research, let alone, for long-term studies. Under these circumstances, short-term study results often provide useful information, and in many cases are the only reliable sources to support decision making process. This short-term study, as part of a large academic pursuit, was designed to assess the impacts of soil tillage on soil erosion on hill slopes under simulated rainfall and laboratory conditions. Given its simulated conditions, cautionary approach needs to be taken when extrapolating the results to the field conditions.

### 6.1.2 Scope and limitations

The ideal assessment of soil erosion processes is by means of setting up experimental runoff plots in the field over a period during which storm and rainfall with varied intensities occur. This method, however, is beyond the resource capability of this research project. Obtained under a set of laboratory conditions, the experimental results of this study, should therefore, be regarded as an estimative approach to the factual soil erosion, and soil and nutrient losses. In addition, the implications may only be applicable to areas with similar yet specific site characteristics where the study was conducted. Some lessons, however, could be derived from this study and modified methods could be created and implemented to different agroecosystem conditions accordingly.

### 6.1.3 Objectives

The objectives of this study were:

1. To investigate the effects of different tillage practices on soil erosion under a simulated rainfall,

2. To measure soil and selected nutrient losses from sloped land affected by simulated rainfall intensity in combination with prior tillage treatment.

### 6.1.4 Rainfall simulator

Erosion research using rainfall simulators has been conducted for more than 50 years (Shelton et al., 1985). Erosion deals with a complexity of interactions of variables such as rainfall, soil characteristics, topography and tillage. For these to be well understood, more controlled conditions than those under natural rainfall need to be attained. This is basically the main logic for the design and development of the most recent rainfall simulators.

Desirable characteristics of a rainfall simulator have been suggested by many studies (Moore et al., 1983, Shelton et al., 1985, Meyer, 1994), which can be summarized as follows:

(i) Similarity to natural rainfall in drop size distribution and fall velocity.

(ii) Most drops have a nearly vertical angle of impact.

(iii) Capability to reproduce rainstorms with intensity, duration, uniformity and continuity which are of interest of any specific purpose.

(iv) Applicability to a research area sufficiently large to represent the treatments and conditions under investigation.

(v) Mobility from one research site to another.

## 6.2 SOIL DEGRADATION AND TILLAGE-INDUCED EROSION

### 6.2.1 Introduction

Agriculture in semi-arid areas suffers from strong annual variations both in crop yield and profitability; two factors that directly depend on rainfall volume and distribution during the growing season (Bescansa et al., 2006). In this context and in the formation of a new conventional agriculture, it will be necessary to scrutinize current management systems to determine those practices that sustain the soil resource and those that degrade it (Robinson et al., 1994).

Soil degradation is a resultant of a wide variety of interacting factors. Blum (1998) suggested two types of soil degradation: (i) natural degradation (without human interference) and (ii) soil degradation caused by anthropogenic activities, especially by the competition between the various types of land use. Lal (1998) further specified the soil degradation by anthropogenic activities into: (a) industrial (b) urban, and (c) agricultural. A soil is agriculturally degraded when its functions of direct concern to human well-being, agricultural productivity and environmental regulatory capacity have been lost or reduced (Lal, 1998, Blum, 1998). It implies a decline in soil's inherent capacity to produce economic goods and perform environmental regulatory functions, which is very much dependent on soil quality and relevant properties. Therefore, soil degradation involves adverse changes in its properties that limit or reduce soil's capacity to perform the above mentioned functions.

Agricultural productivity is strongly influenced by management such as fertilizer use, water management, and tillage methods. Resilient soils are productive and respond positively to management whereas inappropriate management in agriculture is often the main cause of soil degradation. The most severe form of agricultural degradation according to Lal (1998) is that caused by accelerated erosion and nonpoint source pollution. Key soil properties, such as soil structure, soil organic carbon content, clay and clay minerals, and available water capacity are, among others, properties being affected by these degradative mechanisms. The net effect would be the degradation of soil quality which in turn adversely affects the agriculture productivity and sustainability. However, judicious land use and choice of appropriate crop management systems would reverse these degradative trends. This brief outlook of soil degradation complements the discussion in chapter 5 with descriptive literature analysis and experimental data emphasizing soil erosion, particularly tillage-induced erosion, and nonpoint source pollution.

### 6.2.2 Soil erosion

Soil erosion is a serious threat to the quality of soil, land, and water resources as a basis for a sustainable agriculture and land use. The problem with erosion is found in its consequences. Problems and prospects associated with soil erosion by wind and water were reviewed at length by Lal (1994). Although it is recognised as part of natural landscape-forming processes, it is the extensive acceleration of the soil erosion processes induced by human activities that is of concern (Rose, 1998). Soil erosion, accelerated by human activities relative to natural rates, reduces crop productivity and causes soil damage resulting in sediment transport and deposition (Pierce and Lal, 1994). Deforestation, in particular, can result in severe erosion patterns and erosion intensities which can lead to dramatic nutrient losses (Zheng et al., 2005, Fernandes et al., 1997). As has been discussed in the previous chapter, tillage has also been recognised as a cause of intense landscape modification and as a major source of soil erosion and redistribution along hillslopes (Alba et al., 2006, Zheng et al., 2005), and remains the focus of continuous research covering a wide range of erosion aspects (among the recent ones: Fu et al., 2006, Kimaro et al., 2005, Van Muysen et al., 2006, Wu and Cheng, 2005).

The susceptibility of a soil to erosion, however, is influenced by diverse factors. These include physical and hydrologic, chemical and mineralogical, and biological and biochemical properties as well as its soil profile characteristics (Lal, 1998). In regard to soil physical properties that affect the resistance of a soil to erosion, texture, structure, water retention and transmission properties, and unconfined compressive and shear strength are the most relevant. Simota et al. (2005) further include other protection parameters of specific relevance such as stoniness, organic matter, carbonate content, bulk density, infiltration rate, surface roughness, surface crusting, workability status, topsoil pulverisation, subsoil compaction and contamination risk. All these soil attributes must be considered in order to formulate sustainable agricultural management systems according to the characteristics of each particular site.

The importance of these properties has been reviewed, by among others, Briggs and Courtney (1985), Quirk and Murray (1991), and Hillel (1998). Moreover, the effects of agricultural activities such as tillage practices on these properties with respect to water runoff and soil losses are under research. Among the studies in the recent past include long-term tillage effects on physical properties of eroded soils (Hussain et al., 1998), quantification (Montgomery et al., 1999), assessment (Thapa et al., 1999), and modelling (Lobb and Kachanoski, 1999) of soil tillage erosion and translocation. One of the main difficulties related to erosion control, however, is the reliability and the precision of erosion assessment in terms of extension, magnitude, and rate of soil erosion and its economic and environmental consequences (Lal, 1998). Many studies have been undertaken for this purpose. Laflen and Roose (1998) have suggested methodologies for assessment of soil degradation due to water erosion including measurement and estimation techniques for both interril and channel (rill and gully) erosion. Also mathematical models of water and wind erosion have been widely developed and reviewed (Nearing et al., 1994, Skidmore, 1994, Rose, 1998).

Tillage-induced erosion has been widely studied across nations, with particular emphasis on mouldboard plough (Alba et al., 2006, Heckrath et al., 2005, Kimaro et al., 2005, Van Muysen et al., 2006) and manual hoeing/tillage (Zhang et al., 2004, Kimaro et al., 2005, de Rouw and Rajot, 2004, Turkelboom et al., 1999). Similarly, a variety of different study methods on erosion patterns in the form of gully erosion have been reported. Among these were erosion monitoring by the use of GPS (Wu and Cheng, 2005), erosion assessment with photogrammetric techniques (Daba *et al.*, 2003), and erosion evaluation using 137Cs and 210Pb/137Cs ratio (Li *et al.*, 2003). Likewise, some recent assessment reports on interril erosion have been established ranging from using survey methodology (Bewket and Sterk, 2003), to incorporating the soil instability index (Valmis et al., 2005), to investigating the effects of rainfall intensity, slope length, and gradient on runoff amount and pathways for interrill erosion in tilled fields (Chaplot and Le Bissonnais, 2003).

The determination of soil erosion and compaction and their inter-relations requires detailed analysis as well as inclusion of the mechanical and hydrological aspects in the definition of erosion prevention methods (Simota et al., 2005). The Universal Soil Loss Equation (USLE), is the empirical erosion model which has been used most widely for predicting soil erosion (Nearing et al., 1994). It is hailed as one of the most significant developments in soil and water conservation in the 20$^{th}$ century (Flanagan et al., 2003). The basic structure of USLE is given by:

$$A = RKLSCP$$

where A is the computed soil loss, R is the rainfall-runoff erosivity factor, K is the soil erodibility factor, L is the slope length factor, S is the slope steepness factor, C is the cover-management factor, and P is the supporting practices factor. This empirically-based equation, derived from a large mass of field data, computes sheet and rill erosion using values representing the four major factors affecting erosion. These factors are climate erosivity represented by R, soil erodibility represented by K, topography represented by LS, and land use represented by CP (Renard et al., 1994, Flanagan et al., 2003). Despite its wide acceptance, this model has been shown to be ineffective when applied outside the range of conditions for which it was developed. This has lead to the emergence of new models, among them the revised USLE (RUSLE) and the USDA-Water Erosion Prediction Project (WEPP) models. The latter, categorized by Nearing *et al.* (1994) as physically-based models, are intended to represent synthesis of the individual components which affect erosion, the complex interaction between various factors, and their spatial and temporal variabilities.

### 6.2.3 Nonpoint source pollution: soil and water quality

Sources of water pollution are recognized as either of point or nonpoint origin (Schwab *et al.*, 1996). Point sources include animal feedlots, chemical dumpsites, storm drain and sewer outlets, acid mine outlets, and other identifiable points of origin. Nonpoint source (NPS) pollution originates from diffuse land areas that intermittently contribute pollutants to surface and groundwater. Agriculture is the major cause of NPS pollution, whereby storm runoff carries pesticides, particles of soil, nutrients, and organic wastes. Irrigation water return is also a nonpoint source pollutant, when it is saline and contains nutrients (Poincelot, 1986).

Water quality is determined by the presence of biological, chemical, and physical contaminants. Biological contaminants result from human and animal wastes plus some industrial processes. Chemicals enter the water supply from industrial processes and agricultural use of fertilizers and pesticides. Physical contaminants result from erosion and disposal of man-made objects (Schwab et al., 1996). The most troublesome agriculture pollutants in terms of soil quality are pesticides. Certain toxic wastes, if used as fertilizers or organic amendments can also be harmful. An area in need of research is whether the use of pesticides damages the soil ecosystem to the extent that the crop productivity is lessened over a long period of time (Poincelot, 1986). The lack of soil mixing and heavy herbicide usage with no-till and minimal till systems suggests a potential problem of NPS pollution. Studies on NPS pollution have been reviewed by Line *et al.* (1999) and reported at length by Overcash and Davidson (1980) concerning pesticides, pathogens, nitrogen and phosphorus, sediment, and land use. Similarly, Baker (1980) has largely discussed the issue of agricultural areas as nonpoint sources of pollution with data on loads and time-concentration trends for nutrients such as N and P, and pesticides in surface runoff from agricultural areas as affected by management practices such as cropping, tillage, and chemical application methods. More specifically on tillage impacts on groundwater quality, Logan *et al.* (1987) indicated a number of resource studies, covering aspects of soil physical, chemical, and biological processes as well as the fate and transport of applied pesticides and fertilizers.

Preventing or controlling nonpoint source pollution can accomplish two purposes i.e. sustainability of an agricultural resource and reduction of pollution (Poincelot, 1986). However, it is technically difficult and costly to monitor NPS pollution. Consequently, most economic instruments directed towards reducing this type of pollution have focused on circumventing the monitoring problem by focusing on readily observable factors. In some developed economies, such instruments include taxes or tradable permits on inputs or other incentives to induce changes in farming practices. The latter may include fertilization, manure spreading and tillage practices that are assumed to form strong linkages to farm field runoffs (Romstad, 2003).

Not surprisingly however, the challenges for NPS pollution and erosion control in the developing countries are even greater, largely due to the lack of social and economic instruments. The degree of severity of soil erosion and water runoff under traditional farming systems in these countries depends largely on the soil, land-use intensity, relief and cultural practices adopted (Lal, 1995), much of which has been previously discussed in chapter 2. Erosion and runoff are generally reduced if the fallow period is long enough to restore soil physical properties and increase the soil organic matter content.

### 6.2.4 Surface water runoff and leachate

Soil erosion research must be based on experimental results of some form as it involves a complexity of interacting factors. Often, laboratory and field plots are used to obtain experimental data for predicting and evaluating soil erosion and sediment yield (Mutchler *et al.*, 1994). Empirical studies suggest that tillage systems that do not incorporate surface residue and amendments (conservation tillage) appear to be more vulnerable to soluble nutrient losses mainly in surface runoff but also in subsurface drainage (due to macropore flow). In contrast, tillage practices that thoroughly mix residue and amendments in the surface soil (conventional tillage) are more susceptible to sediment and sediment-bound nutrient losses (e.g. particulate P) through surface water runoff (Zhao *et al.*, 2001). In general, as reported by earlier studies, surface amendments (Rao et al., 1998a, Rao et al., 1998b), watershed characteristics (Shipitalo and Edwards, 1998), and landscape features (Lobb and Kachanoski, 1999) are the leading factors contributing significantly to the differences of soil erosion and runoff among tillage treatments.

A 2-year experiment study by Myers and Wagger (1996) on runoff and sediment losses under conventional tillage (CT) for corn grain production, no-tillage grain production (NTG) with surface residue, and no-tillage silage production (NTS) without residue cover found sediment losses in the order of NTG<NTS<CT and this was clearly associated with the residue cover. The study also suggested that the

surface roughness that existed immediately after tillage operations in CT may have aided in more rainfall water catchment and infiltration leading to decreased surface water runoff. However, in the second event each year, the runoff loss was doubled with CT suggesting that soil surface seal development had taken place, thus decreasing water retention and infiltration. Under no-tillage systems on the other hand, as has been largely discussed in the previous chapter, a gradual accumulation of soil organic matter and greater porosity develops in the near-surface zone contributing to enhanced aggregate stability at the soil surface. Thus, surface sealing tendencies are diminished which promotes an increase in infiltration rates and reduced water runoff (Rhoton *et al.*, 2002).

A similar study in the Nepalese hills reported that total annual soil loss from conventional and reduced tillage was 16.6 and 11.1 Mg/ha, respectively, while the annual sediment-associated nutrient losses were 188 kg OC/ha, 18.8 kg N/ha, <1 kg P/ha and 3.8 kg K/ha for conventional tillage and 126 kg OC/ha, 11.8 kg N/ha, <1 kg P/ha and 2.4 kg K/ha for reduced tillage. The study also indicated the significantly higher soil organic carbon and N losses under conventional tillage to be one of the major causes of fertility depletion in the region (Atreya *et al.*, 2006).

### 6.2.5 Concluding remarks

It is important to account for risks of soil quality degradation, particularly soil erosion and sediment-bound nutrient losses, when designing agricultural policies for long-term sustainability. This is particularly true given the great pressure that has always been laid on land-based activities to meet the food demands of the increased population in the developing countries and the importance to reconcile these two ends sustainably. Having discussed the tillage-induced aspects of soil erosion, the derived lessons for the dryland farming areas would be to: (i) increase the level of soil organic matter, (ii) reduce the tillage intensity, (iii) follow the contour for tillage direction, (iv) diversify the tillage implements, (v) reduce the subsoil compaction and (vi) consider the optimum soil workability as suggested by Simota *et al.* (2005).

# 6.3 RESEARCH METHODOLOGIES

## 6.3.1 Experimental Site

The experiment was carried out in a laboratory at the Practical Teaching Complex (PTC) of Massey University in Palmerston North, New Zealand.

## 6.3.2 Soil sampling for runoff and leachate measurement

Due to time and resource limitations the soil samples were purposively taken only from the unweeded potato sub-plots and from the adjacent permanent pasture fields with a total number of 16 samples. A soil sample size of 300 mm long x 200 mm wide x 150 mm deep was taken from each plot for this purpose. The size was considered large enough to account for any variability in soil physical conditions on the one hand, which also allowed ease of extraction and transportation to the laboratory with little or no soil disturbance on the other. The steel corers with the above size and 3 mm wall thickness were installed manually into the soil and the soil cores were then carefully extracted avoiding soil disturbance (Figure 6.1).

Figure 6.1 A soil core soon after extraction from the field

The bottom end of each soil core was cut flush with the end of the core and carefully transported and placed into a laboratory at Massey University. Any vegetative cover at the top of the soil cores was cut level to a height of ± 15 mm before cores were placed for experimentation. A rainfall simulator, under which, three soil cores were placed at a time, will be described in the next section. Special equipment (Figure 6.2) was constructed to be attached to each soil core for the collection and measurement of soil and water runoff and leachate under the rainfall simulator (Guo *et al.*, 1999).

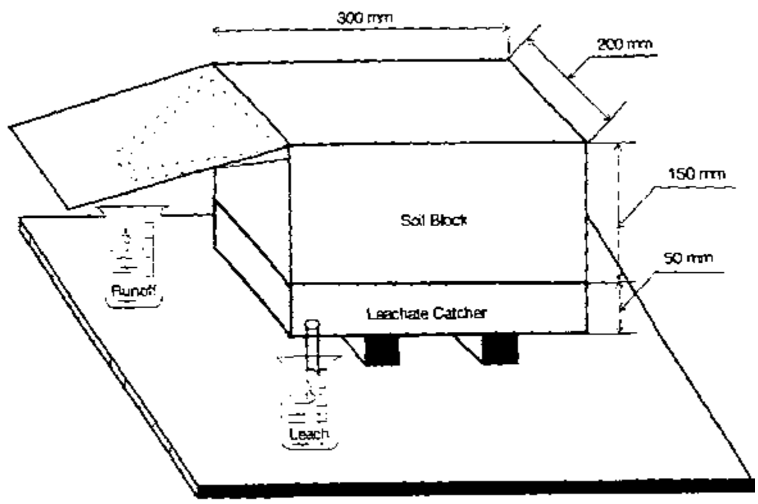



Figure 6.2 Schematic diagram of the apparatus specially designed for runoff and leachate measurements (Guo *et al.*, 1999)

### 6.3.3 Rainfall Simulator

Massey University's Institute of Natural Resource, has developed a laboratory rainfall simulator based on the design of USDA-ARS demonstration rainfall simulator developed by Dr. John Laflen at the Ohio State University (Hairsine, 1999). This portable rainfall simulator suits many purposes in soil and hydrology research, especially studies related to soil erosion and soil and water quality. It consists of fan oscillating spray nozzles which produce rainfall rates, drop sizes and drop velocities similar to natural rainfall. Water is pumped from a reservoir to the nozzles and excess water is confined and drained back to the reservoir by a roof canopy and a hose. This tool can also simulate variable rainfall intensities by varying the time between sweeps.

As laboratory equipment, it has been designed specifically for laboratory research, as shown in Figure 6.3. The experiments with this rainfall simulator were limited to evaluating three types of tillage and permanent pasture and their effects on soil and water runoff and leachate. The slope of approximately 20% inclination in the field was also taken into account in the simulation process.

The target rainfall parameter used was intensity of ± 50 mm/hr. This is in accordance with Meyer (1994) who suggested that rainfall intensities between 0.2 and 2 mm/min are usually of greatest importance. Intensities below and above this range are not of major interest in soil and hydrologic studies.


Figure 6.3 A rainfall simulator developed by Massey University's Institute of Natural Resources

### 6.3.4 Runoff, sediment and leachate measurement

The experiments were carried out twice starting on 25 March 2004, with the first being a pilot experiment. The volume of water runoff was collected at ten-minute intervals. The total volume of surface runoff was determined by adding all runoff samples thus collected.

The volume of water-sediment mix for each sample was obtained from the surface water runoff. A part of the water-sediment mix was used to determine the amounts of soil sediment in surface water runoff. The dry mass of sediment was determined after evaporating the water off in an oven at 105°C for 24 hours. The sediment concentration in surface water runoff was determined by multiplying the mean mass of sediment by the mean volume of surface water runoff from each ten-minute interval.

The water leachate was collected in a catching tray placed immediately below the soil cores (refer to Figure 6.2). The leachate samples were collected at ten-minute intervals. The sum of six collections over one hour was equivalent to the total volume of water leachate.

### 6.3.5 pH of runoff and leachate

The pH of surface water runoff and leachate was measured by using a Standard pH meter into surface runoff and leachate samples.

### 6.3.6 Nutrient concentration of runoff and leachate

The surface water runoff and leachate samples were chemically analyzed to determine the amount of nitrogen (N) losses. N was extracted and determined according to Kurmies (1972).

### 6.3.7 Statistical Analysis

The analysis of all data obtained during this study was performed using the General Lineal Model (GLM) procedure of SAS (Statistical Analysis System)(SAS, 2002).

## 6.4 Results

### 6.4.1 Water runoff

Water runoff was substantially affected by cultivation. The results in Table 6.1 show that, after the first 10-minute interval, surface water runoff data started to show a significant variation between the cultivated soils (CT and MT) and the untilled soils in the NT and PP plots towards the end of one-hour period of observation. A trend was observed from 20-minutes rainfall consistently through to 60-minutes, where manual and conventional tillage practices produced significantly higher surface water runoff compared to no-tillage and permanent pasture. The results also show that there were no significant differences between CT and MT as well as between NT and PP.

Table 6.1 Water runoff (ml) as affected by tillage and pasture management (measured under simulated rainfall on 25th March 2004) (CT= conventional tillage, MT=manual tillage, NT=No-tillage, PP=Permanent pasture)

| Time (min) | Treatments | | | | $LSD_{0.05}$ |
|---|---|---|---|---|---|
| | CT | MT | NT | PP | |
| 10 | 22.25 a | 25.25 a | 5.05 a | 17.00 a | n.s. |
| 20 | 121.25 a | 114.75 a | 5.13 b | 52.00 ab | 91.02 |
| 30 | 240.00 a | 202.25 ab | 18.38 c | 83.00 bc | 131.74 |
| 40 | 279.75 a | 286.50 a | 39.38 b | 108.25 b | 147.9 |
| 50 | 306.00 a | 356.00 a | 69.50 b | 126.00 b | 149.34 |
| 60 | 308.00 a | 379.00 a | 79.75 b | 147.75 b | 159.57 |

*Values followed by the same letter in each row are not significantly different (P<0.05); n.s.=not significant.*

An increased trend overtime, based on 10-minute measurement, was observed. At the last 10-minute observation, almost 4 ml/min water runoff rate was observed under the MT treatment. MT treatment produced the highest (1363.75 ml) total water runoff during one-hour simulated rainfall followed by CT (1277.25), PP (534.00), and NT (217.18) (Figure 6.4). Consistent with the results of every ten-minute interval measurement described above, it is clear that total water runoff were significantly reduced under NT and PP treatments compared to that from the cultivated soils under CT and MT. However, the variability among replicates within treatments was quite high as shown by the LSDs.

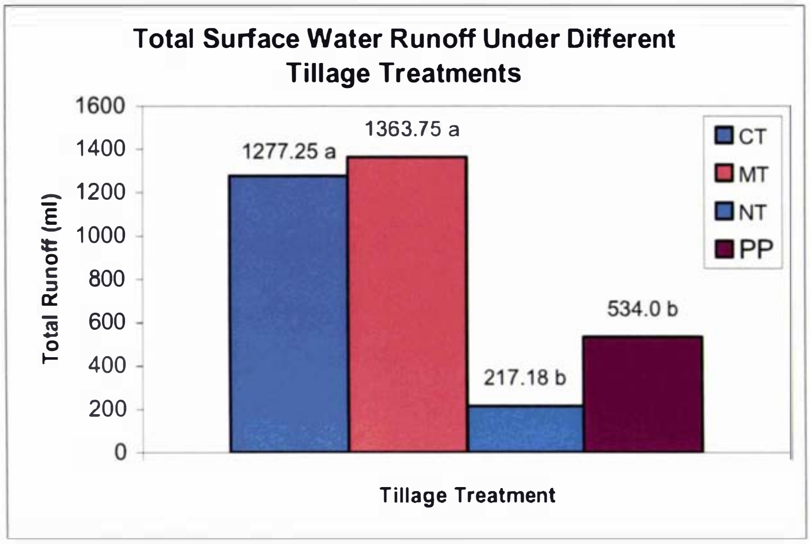



Figure 6.4 Tillage effects on total surface water runoff under one-hour simulated rainfall

### 6.4.2 Water leachate

The water leachate during the first 20 minutes was similar under all the treatments, but significant differences started to appear from 30 minutes onwards (Table 6.2). At the end of the observation (60-minutes), NT and PP produced significantly higher leachate than CT and MT. The leachate from NT after one hour simulated rainfall was approximately 5 and 4 times compared to that for MT and CT, respectively.

Table 6.2 Water leachate (ml) every ten minutes as affected by tillage and pasture management (measured under simulated rainfall on 25th March 2004) (CT= conventional tillage, MT=manual tillage, NT=No-tillage, PP=Permanent pasture)

| Time (min) | Treatments | | | | $LSD_{0.05}$ |
|---|---|---|---|---|---|
| | CT | MT | NT | PP | |
| 10 | 11.50 a | 31.00 a | 15.00 a | 13.38 a | n.s. |
| 20 | 59.25 a | 136.25 a | 120.75 a | 103.00 a | n.s. |
| 30 | 99.75 b | 142.25 ab | 242.50 a | 139.50 ab | 121.0 |
| 40 | 87.00 b | 94.50 b | 292.75 a | 169.75 ab | 140.92 |
| 50 | 77.13 b | 71.75 b | 320.25 a | 191.50 b | 122.4 |
| 60 | 74.25 bc | 58.50 c | 306.50 a | 205.50 ab | 132.8 |

*Values followed by the same letter in each row are not significantly different (P<0.05); n.s.=not significant.*

As expected, total water leachate was significantly greater under no-tillage, whereas leaching in the CT and MT plots was lower (Figure 6.5). The leachate under permanent pasture was somewhat moderate, being in between that from the tilled and untilled plots, but showed not significantly different from either of the treatments.

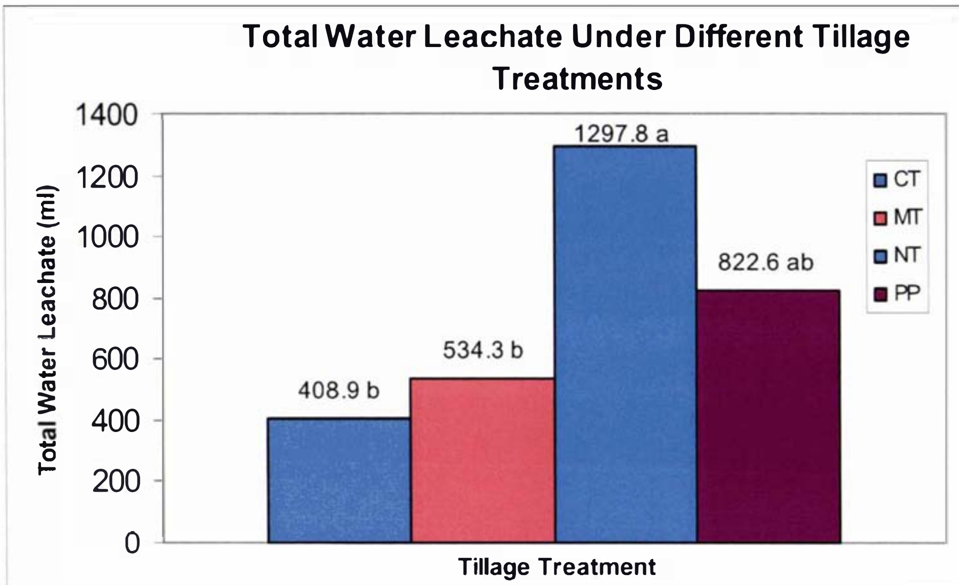



Figure 6.5 Tillage effects on total water leachate under one-hour simulated rainfall

The leachate from each 10-minute observation during an hour increased until 30 minutes under CT and MT then declined (Table 6.2). Similarly with NT, the leachate volume increased for 50 minutes then declined. PP soils, in contrast, had an increased leachate volume per 10 minutes during the one-hour measurement.

### 6.4.3 Soil sediment

The measured soil losses due to surface water runoff were in line with the amount of water runoff (Table 6.1). During the first 10-minutes simulated rainfall, MT had the greatest soil loss, estimated at 82.3 kg/ha, followed by CT (32.3), NT (12.45), and PP (5.49) (Table 6.3). A large increase in soil loss was observed during the second 10-minutes in CT and MT, and a lesser increase in PP whereas, in NT the soil loss decreased (Table 6.3).

After one-hour simulated rainfall, the soil sediment loss from the manual tillage (MT) treatment was 70 and 47 times higher than from the PP and NT treatments, respectively (Table 6.3). There was no difference in soil loss in one hour between MT and CT, and between CT, NT and PP (Table 6.3).

Table 6.3 Estimated soil sediment losses (kg/ha) as affected by tillage and pasture management (measured under simulated rainfall on 25th March 2004) (CT= conventional tillage, MT=manual tillage, NT=No-tillage, PP=Permanent pasture; ANOVA was performed on log transformed data)

| Time (min) | Treatments | | | | $LSD_{0.05}$ |
|---|---|---|---|---|---|
| | CT | MT | NT | PP | |
| 10 | 32.3 | 82.3 | 12.45 | 5.49 | |
| | (1.38) ab | (1.54) a | (0.99) ab | (0.72) b | 0.70 |
| 20 | 210.6 | 279.4 | 5.59 | 10.20 | |
| | (2.11) a | (2.37) a | (0.69) b | (0.98) b | 0.53 |
| 30 | 567.7 | 628.6 | 8.84 | 18.95 | |
| | (2.6) a | (2.68) a | (0.84) b | (1.27) b | 0.58 |
| 40 | 942.4 | 974.7 | 40.05 | 19.76 | |
| | (2.79) a | (2.89) a | (1.28) b | (1.28) b | 0.75 |
| 50 | 1006.0 | 1108.4 | 32.09 | 18.91 | |
| | (2.82) a | (2.99) a | (1.23) b | (1.26) b | 0.70 |
| 60 | 797.7 | 1578.8 | 33.86 | 22.48 | |
| | (2.77) a | (3.07) a | (1.23) b | (1.35) b | 0.69 |

*Values followed by the same letter in each row are not significantly different (P<0.05); n.s.=not significant.*

The total soil sediment losses were significantly greater under cultivated soils (CT and MT) than untilled (NT) and permanent pasture (PP) soils (Figure 6.6). The magnitude of soil sediment loss was in the increasing order of PP (95.79 Kg/Ha) > NT (132.87) > CT (3556.7) > MT (4652.2). The longer the period of rainfall, the greater was the amount of soil sediment loss through surface water runoff. This was particularly the case for cultivated soils under CT and MT as indicated in earlier presentations.

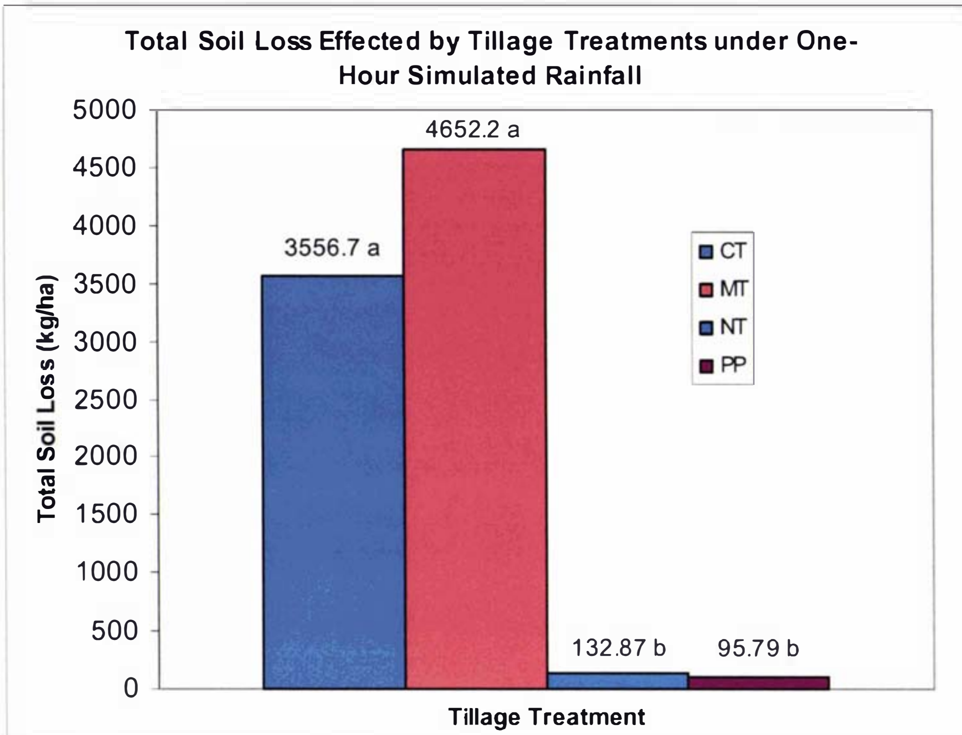



Figure 6.6 Tillage effects on total soil loss under one-hour simulated rainfall (ANOVA was performed on log transformed data)

### 6.4.4 Soil nutrients

Water runoff pH under permanent pasture was significantly increased compared to other treatments while it was unaffected under tillage practices. Water leachate pH was similar under all the treatments. There was no effect on ammonia and nitrate losses by any of the treatments (Table 6.4).

Table 6.4 Tillage effects on soil water pH and nitrogen losses (CT= conventional tillage, MT=manual tillage, NT=No-tillage, PP=Permanent pasture)

| Tillage | pH | | N as NH4+ (ppm) | | N as NO3- (ppm) | |
|---|---|---|---|---|---|---|
| | *runoff* | *leachate* | *runoff* | *leachate* | *runoff* | *leachate* |
| CT | 7.25 b | 6.95 a | 0.37 a | 0.30 a | 0.67 a | 8.40 a |
| MT | 7.24 b | 6.94 a | 1.74 a | 8.19 a | 0.48 a | 10.77 a |
| NT | 7.17 b | 6.91 a | 0.54 a | 1.11 a | 0.64 a | 6.18 a |
| PP | 7.55 a | 6.75 a | 0.68 a | 0.65 a | 0.50 a | 8.98 a |
| $LSD_{0.05}$ | 0.24 | n.s | n.s | n.s. | n.s. | n.s. |

*Values followed by the same letter in each column are not significantly different (P<0.05); n.s.=not significant.*

## 6.5 Discussion

### 6.5.1 Water runoff, soil sediment and nutrient losses

Soil tillage breaks up the soil surface and lowers the stability of soil aggregates and thus decreases the soil's resistance to detachment by raindrop impact or flowing water, and when rainfall exceeds the surface depression storage, tillage can lead to concentrated flow erosion (Turkelboom et al., 1999, Valmis et al., 2005). The results clearly showed that conventional tillage (mouldboard plough and manual hoeing) produced more surface water runoff than no-tillage and permanent pasture. This concurs with results from overseas tillage and erosion studies, especially on manual hoeing and mouldboard ploughing (Basic et al., 2004, Zhang et al., 2004, Turkelboom et al., 1999, Turkelboom et al., 1997, de Rouw and Rajot, 2004, Osunbitan et al., 2005).

The results of this study, not surprisingly, partially confirm those from other studies already available in the literature. The point of interest, however, was that soil structural damage, and the obvious causal differences among mechanical treatments employed, happened and were noticeable just over a period of one cropping season. The results show that manual tillage (MT) resulted in the most serious short-term soil structural deterioration, as far as water erosion indicated by runoff and soil losses was concerned. This however, appears to contradict the aggregate stability data discussed in Chapter 5, which showed that MT, cumulatively, produced the most stable aggregates in the top 0-10 cm topsoil (refer to Figure 5.15). Moreover, it also disagrees with the porosity and hydraulic conductivity data which indicated insignificant differences among treatments. In combination with stronger soil aggregate stability, these soil properties could have, theoretically, led to MT producing similar results, or even lower runoff and soil losses compared to conventional tillage (CT) using mouldboard plough. This disparity is a matter for further investigation. However, the penetration resistance data at the time the soil samples were collected (Table 5.6) may offer some explanation. The soils under MT were less compacted in the few centimetres of the topsoil, probably exposing more loose soil particles susceptible to erosion. The simulated degree of field slope (± $20^o$) could also have been a determining factor in decreasing water infiltration, thus producing a higher amount of surface water and sediment runoff under MT.

These empirical findings about water runoff and sediment loss can be crucial for cropping systems in the steeply sloped lands of the tropics, where farmers, under social and economic pressure, are forced to farm on very marginal soils of the hill sides. Even with a superficial manual cultivation, the tillage translocation rates can be very high on the steepest slopes as was reported for the Uluguru Mountains of Tanzania (Kimaro *et al.*, 2005). It was also presumed that manual tillage could be responsible for the occurrence of most shallow soils observed on the steepest slopes and the accumulation of colluvium behind grass barriers along contour bands. The calculated tillage erosion rates along contour bands in the Uluguru Mountains can reach values of up to 180 t $ha^{-1}$ per year for plots of 8.5 m length (Kimaro *et al.,* 2005). A similar study in Niger recorded short-term soil transport by means of saltation and creep and in the long-run by means of suspension (de Rouw and Rajot, 2004) . The former was reported as loose soils in the mobile upper layers under manual cultivation being swept away during storms causing the less fertile lower soil layers, often crusted, acid and very low in organic matter content, to come nearer to the surface. The latter, under prolonged cultivation, describes a condition where increased exposure to rainstorm reduces soil organic matter thus implying loss of soil structure and subsequently less stable aggregates. Enhanced by wind erosion this condition eventually led to an extremely sandy top soil (de Rouw and Rajot, 2004). Also, Heckrath et al. (2005) found that tillage translocation rates were strongly correlated with SOC contents, A-horizon depth, and P contents. This, in turn, had led to truncated soils on shoulderslopes and deep, colluvial soils on the foot- and toeslopes, substantially affecting within-field variability of soil properties.

The erosional effects of mouldboard ploughing as opposed to no-tillage under this study generally concur with those already known. A study by Rhoton et al. (2002) reported runoff under conventional tillage (CT) and no-tillage (NT) treatments averaged 27.8 and 16.5 mm, respectively, while soil loss from CT treatments averaged 3.9 t $ha^{-1}$ and 0 for the NT. The decreased runoff under NT was due to the development of greater porosity in the near-surface zone attributable to enhanced aggregate stability at the soil surface, and diminished surface sealing which promotes an increase in infiltration rates. Choudhary et al. (1997) comparing mouldboard plough (MP), chisel plough (CP), and no-till (NT) also reported that soil erosion and surface runoff were markedly affected by tillage methods. The order in which the runoff increased was MP > CP > NT. The reverse order was obtained for leachate.

The nitrogen losses associated with runoff were insignificantly different, probably due the study being run only within a short period of time. Atreya et al.(2006), recorded annual nutrient losses in the Nepalese hills associated with the eroded sediment that were 188 kg OC/ha, 18.8 kg N/ha, <1 kg P/ha and 3.8 kg K/ha for conventional till and 126 kg OC/ha, 11.8 kg N/ha, <1 kg P/ha and 2.4 kg K/ha for reduced till. An earlier study by Guo et al. (1999), similarly, reported significantly higher amounts of sediment-bound nutrient losses under conventional tillage (CT) than no-tillage (NT) by the amount of 1.45 mg $N.m^{-2}$, 1.02 mg $P.m^{-2}$, 8.3 mg $K.m^{-2}$ under CT and 0.76 mg $N.m^{-2}$, 0.65 mg $P.m^{-2}$, and 6.8 mg $K.m^{-2}$ under NT.

### 6.5.2 Water leachate and nutrient losses

Water leachate results showed an inverse trend from those of water runoff. Greater water volume was transmitted down the soil profile than as surface runoff under no-tillage (NT) and pasture (PP) treatments comparative to the cultivated soils (CT and MT). Similarly, Guo *et al.* (1999) reported significantly higher amounts of water leachate under NT and PP than the mouldboard plough. Choudhary *et al.* (1997) also reported water leachate to be markedly affected by moldboard plough (MP), chisel plough (CP) and no-tillage (NT) treatments in the order of NT>CP>MP. Early findings from both Guo et al. (1999) and Lal (1997) suggested that higher nutrient losses were found in water leachate than water runoff.

### 6.5.3 Non-point source pollution

The runoff and leachate losses are a matter of concern in relation to non-point source pollution as pinpointed earlier in Chapter 5. The short-term tillage effects on nutrient losses through surface and leaching were not significant. However, a 3-year tillage experiment in Manawatu New Zealand by Guo et al. (1999) indicated that total N losses (in runoff and leachate) were significantly reduced with decreased intensity of tillage. The N losses were 3.06, 7.70, and 8.29 $mg.m^{-2}$ under CT, NT, and PP, respectively. The losses under NT and PP derived largely from leaching.

These results were confirmed later by Zhao et al. (2001), investigating the effects of tillage and nutrient source on water quality. It was revealed that sediment, total P, soluble P, and $NH^{+}_{4}$–N losses mainly occurred in surface runoff and the $NO^{-}_{3}$–N losses primarily occurred in subsurface tile drainage. Analyzing the combined surface and subsurface flow, the study further indicated that the mouldboard plough (MP) treatment resulted in nearly two times greater sediment loss than ridge tillage (RT) ($P < 0.01$). Ridge tillage with urea lost at least 11 times more $NH^{+}_{4}$–N than any other treatment ($P < 0.01$). Ridge tillage with manure also had the most total and soluble P losses of all treatments ($P < 0.01$). Similar findings were made by Nissen and Wander (2003), studying the management and soil-quality effects on fertilizer-use efficiency and leaching. Although total leached N was similar in all cropping systems under study, increased macropore flow in NT cores led to greater leaching of fertilizer N and less leaching of soil-derived N, as well as greater moisture stress and decreased plant N uptake.

Contrasting results, however, were found in a similar study by Jiao et al. (2004) where dissolved N and dissolved P loads were not affected by tillage and were similar following corn (*Zea mays* L.) in a continuous corn rotation, and soybean [*Glycine Max* (L.) Merr.)] in a soybean/corn rotation production. The study revealed that soils receiving inorganic fertilizer had a 70% greater nitrate ($NO_3$-N) load and 48% less dissolved reactive P than soils receiving organic fertilizer (Jiao *et al.*, 2004). This evidence suggests that fertilizing soils with a combination of inorganic and organic fertilizers might be a good way to reduce both $NO_3$-N and dissolved reactive P transport to water systems. The overall results suggest that the leaching of dissolved N and dissolved P compounds is influenced more by the type of fertilizer applied than tillage or cropping practices. Similarly, Zhu et al. (2003) reported that tillage had no effect on total leachate collected during the 6-yr experiment by either pan (228 mm $yr^{-1}$) or wick (558 mm $yr^{-1}$) lysimeters. Their study found that the flow-weighted $NO^{-}_{3}$–N concentrations and $NO^{-}_{3}$–N masses in leachate were not significantly different between tilled and NT, but increased with increasing N-rate (at 0, 100, and 200 kg N $ha^{-1}$, flow-weighted $NO^{-}_{3}$–N concentrations were 3.5, 8.2, and 23.9 mg $L^{-1}$ and $NO^{-}_{3}$–N masses were 17, 39, and 112 kg $ha^{-1}$ $yr^{-1}$, respectively). They concluded that under their experimental conditions, NT did not result in more $NO^{-}_{3}$ leaching than chisel-tillage over a multiyear period.

## 6.6 Concluding remarks

The experimental results show that conventional tillage practices cause more water and sediment erosion than no-tillage. Conventional tillage significantly increased water runoff but less leachate compared to no-till and permanent pasture. Total soil sediment loss was significantly lower under PP (95.8 kg/ha) and NT (132.9) compared to CT (3556.7) and MT (4652.2). pH of water runoff was significantly reduced under tillage treatments compared to that from permanent pasture whereas nitrogen losses were unaffected. The results emphasize tillage as one of major contributing factors to erosion, as has been proven elsewhere, particularly in the undulating to steep and fragile lands.

# REFERENCES


Alba, S. D., Borselli, L., Torri, D., Pellegrini, S. & Bazzoffi, P. (2006) Assessment of tillage erosion by mouldboard plough in Tuscany (Italy). *Soil and Tillage Research,* **85,** 123-142.

Atreya, K., Sharma, S., Bajracharya, R. M. & Rajbhandari, N. P. (2006) Applications of reduced tillage in hills of central Nepal. *Soil and Tillage Research,* **88,** 16-29.

Baker, J. L. (1980) Agricultural Areas as a Nonpoint Pollution Source. *Environmental Impact of Nonpoint Source Pollution* (eds M. R. Overcash & J. M. and Davidson), pp. 275-310. Ann Arbor Science, Michigan, USA.

Basic, F., Kisic, I., Mesic, M., Nestroy, O. & Butorac, A. (2004) Tillage and crop management effects on soil erosion in central Croatia. *Soil and Tillage Research,* **78,** 197-206.

Bescansa, P., Imaz, M. J., Virto, I., Enrique, A. & Hoogmoed, W. B. (2006) Soil water retention as affected by tillage and residue management in semiarid Spain. *Soil and Tillage Research,* **87,** 19-27.

Bewket, W. & Sterk, G. (2003) Assessment of soil erosion in cultivated fields using a survey methodology for rills in the Chemoga watershed, Ethiopia. *Agriculture, Ecosystems & Environment,* **97,** 81-93.

Blum, W. E. H. (1998) Basic Concepts: Degradation, Resilience, and Rehabilitation. *Methods for Assessment of Soil Degradation* (eds R. Lal, W. H. Blum, C. Valentine & B. A. Stewart), pp. 1-16. CRC Press, New York, USA.

Briggs, D. & Courtney, F. (1985) *"Agriculture & Environment" The Physical Geography of Temperate Agricultural Systems.* Longman Group Ltd., USA.

Bronick, C. J. & Lal, R. (2005) Soil structure and management: a review. *Geoderma,* **124,** 3-22.

Chan, K. Y., Heenan, D. P. & So, H. B. (2003) Sequestration of carbon and changes in soil quality under conservation tillage on light-textured soils in Australia: a review. *Australian Journal of Experimental Agriculture,* **43,** 325 - 334.

Chaplot, V. A. M. & Le Bissonnais, Y. (2003) Runoff Features for Interrill Erosion at Different Rainfall Intensities, Slope Lengths, and Gradients in an Agricultural Loessial Hillslope. *Soil Sci Soc Am J,* **67,** 844-851.

Choudhary, M. A., Lal, R. & Dick, W. A. (1997) Long-term tillage effects on runoff and soil erosion under simulated rainfall for a central Ohio soil. *Soil and Tillage Research,* **42,** 175-184.

Daba, S., Rieger, W. & Strauss, P. (2003) Assessment of gully erosion in eastern Ethiopia using photogrammetric techniques. *CATENA,* **50,** 273-291.

de Rouw, A. & Rajot, J.-L. (2004) Soil organic matter, surface crusting and erosion in Sahelian farming systems based on manuring or fallowing. *Agriculture, Ecosystems & Environment,* **104,** 263-276.

Fernandes, E. C. M., Motavalli, P. P., Castilla, C. & Mukurumbira, L. (1997) Management control of soil organic matter dynamics in tropical land-use systems. *Geoderma,* **79,** 49-67.

Flanagan, D. C., Laflen, J. M. & Meyer, L. D. (2003) American Society of Agricultural Engineers Historic Landmark Dedication: Honoring the Universal Soil Loss Equation. Purdue University, Agricultural & Biological Engineering, and USDA.

Fu, G., Chen, S. & McCool, D. K. (2006) Modeling the impacts of no-till practice on soil erosion and sediment yield with RUSLE, SEDD, and ArcView GIS. *Soil and Tillage Research,* **85,** 38-49.

Guo, P., Choudhary, M. A. & Rahman, A. (1999) Tillage-induced changes in a silt loam under continuous cropping. II - Soil erosion and infiltrability under simulated rainfall. *Agricultural Engineering Journal,* **8,** 161-174.

Hairsine, P. (1999) *The portable rainfall simulator, A practical guide.* Institute of Natural Resource, Massey University, Palmerston North, New Zealand.

Heckrath, G., Djurhuus, J., Quine, T. A., Van Oost, K., Govers, G. & Zhang, Y. (2005) Tillage Erosion and Its Effect on Soil Properties and Crop Yield in Denmark. *J Environ Qual,* **34,** 312-324.

Hillel, D. (1998) *Environmental Soil Physics.* Academic Press, U.S.A.

Hussain, I., Olson, K. R. & Siemens, J. C. (1998) Long-term tillage effects on physical properties of eroded soils. *Soil Science Society of America Journal,* **163,** 971-981.

Idowu, O. J. (2003) Relationships Between Aggregate Stability and Selected Soil Properties in Humid Tropical Environment. *Communications in Soil Science and Plant Analysis,* **34,** 695 - 708.

Jiao, Y., Hendershot, W. H. & Whalen, J. K. (2004) Agricultural Practices Influence Dissolved Nutrients Leaching through Intact Soil Cores. *Soil Sci Soc Am J,* **68,** 2058-2068.

Kimaro, D. N., Deckers, J. A., Poesen, J., Kilasara, M. & Msanya, B. M. (2005) Short and medium term assessment of tillage erosion in the Uluguru Mountains, Tanzania. *Soil and Tillage Research,* **81,** 97-108.

Laflen, J. M. & Roose, E. J. (1998) Methodologies for assessment of soil degradation due to water erosion. *Methods for Assessment of Soil Degradation* (eds R. Lal, W. H. Blum, C. Valentine & B. A. Stewart), pp. 31-55. CRC Press, New York, U.S.A.

Lal, R. (1994) Soil erosion by wind and water: Problems and prospects. *Soil Erosion Research Methods* (ed R. Lal), pp. 1-9. SWCS & St. Lucie Press, USA.

Lal, R. (1995) Tillage systems in the tropics: management options and sustainability implications. *FAO Soils Bulletin No. 71*. FAO.

Lal, R. (1997) Deforestation, tillage and cropping systems effects on seepage and runoff water quality from a Nigerian Alfisol. *Soil and Tillage Research,* **41,** 261-284.

Lal, R. (1998) Soil quality and sustainability. *Methods for Assessment of Soil Degradation* (eds R. Lal, W. H. Blum, C. Valentine & B. A. Stewart), pp. 17-30. CRC Press, New York, USA.

Lal, R. (2004) Soil Quality in Industrialized and Developing Countries - Similarities and Differences. *Managing Soil Quality: Challenges in Modern Agriculture* (eds P. Schjønning, S. Elmholt & B. T. Christensen), pp. 297-313. CABI Publishing, CAB International, Wallingford, Oxon, UK; Cambridge, USA.

Li, Y., Poesen, J., Yang, J. C., Fu, B. & Zhang, J. H. (2003) Evaluating gully erosion using 137Cs and 210Pb/137Cs ratio in a reservoir catchment. *Soil and Tillage Research,* **69,** 107-115.

Line, D. E., Jennings, G. D., McLaughlin, R. A., Osmond, D. L., Harman, W. A., Lombardo, L. A., Tweedy, K. L. & Spooner, J. (1999) Nonpoint Sources, Literature Review 1999. *Water Environment Research,* **71,** 1055-1069.

Lobb, D. A. & Kachanoski, R. G. (1999) Modelling tillage erosion in the topographically complex landscapes of southwestern Ontario, Canada. *Soil and Tillage Research,* **51,** 261-277.

Logan, T. J., Davidson, J. M., Baker, J. L. & Overcash, M. R. (1987) Effects of conservation tillage on groundwater quality. Lewis Publishers, Inc., Michigan, U.S.A.

Meyer, L. D. (1994) Rainfall simulators for soil erosion research. *Soil Erosion Research Methods* (ed R. Lal), pp. 83-103. SWCS & St. Lucie Press, USA.

Montgomery, J. A., McCool, D. K., Busacca, A. J. & Frazier, B. E. (1999) Quantifying tillage translocation and deposition rates due to moldboard plowing in the Palouse region of the Pacific Northwest, USA. *Soil and Tillage Research,* **51,** 175-187.

Moore, I. D., Hirschi, M. C. & Barfield, B. J. (1983) Kentucky rainfall simulator. *Transactions of ASAE,* **26,** 1085-1089.

Mutchler, C. K., Murphree, C. E. & McGregor, K. C. (1994) Laboratory and field plots for erosion research. *Soil Erosion Research Methods* (ed R. Lal), pp. 11-37. SWCS & St. Lucie Press, USA.

Myers, J. L. & Wagger, M. G. (1996) Runoff and sediment loss from three tillage systems under simulated rainfall. *Soil and Tillage Research,* **39,** 115-129.

Nearing, M. A., Lane, L. J. & Lopes, V. L. (1994) Modeling soil erosion. *Soil Erosion Research Methods* (ed R. Lal). SWCS & St. Lucie Press, USA.

Nissen, T. M. & Wander, M. M. (2003) Management and Soil-Quality Effects on Fertilizer-Use Efficiency and Leaching. *Soil Sci Soc Am J,* **67,** 1524-1532.

Osunbitan, J. A., Oyedele, D. J. & Adekalu, K. O. (2005) Tillage effects on bulk density, hydraulic conductivity and strength of a loamy sand soil in southwestern Nigeria. *Soil and Tillage Research,* **82,** 57-64.

Overcash, M. R. & Davidson, J. M. (1980) *Environmental Impact of Nonpoint Source Pollution.* Ann Arbor Science, Michigan, USA.

Pierce, F. J. & Lal, R. (1994) Monitoring soil erosion's impact on crop productivity. *Soil Erosion Research Methods* (ed R. Lal), pp. 235-263. SWCS & St. Lucie Press, USA.

Poincelot, R. P. (1986) *Toward a more sustainable agriculture.* Avi Publishing Company, Inc., Westport, Connecticut, USA.

Quirk, J. P. & Murray, R. S. (1991) Towards a model for soil structural behaviour. *Australian Journal of Soil Research,* **29,** 829-867.

Rao, K. P. C., Steenhuis, T. S., Cogle, A. L., Srinivasan, S. T., Yule, D. F. & Smith, G. D. (1998a) Rainfall infiltration and runoff from an Alfisol in semi-arid tropical India. I. No-till systems. *Soil and Tillage Research,* **48,** 51-59.

Rao, K. P. C., Steenhuis, T. S., Cogle, A. L., Srinivasan, S. T., Yule, D. F. & Smith, G. D. (1998b) Rainfall infiltration and runoff from an Alfisol in semi-arid tropical India. II. Tilled systems. *Soil and Tillage Research,* **48,** 61-69.

Renard, K. G., Laflen, J. M., Foster, G. R. & McCool, D. K. (1994) The revised universal soil loss equation. *Soil Erosion Research Methods* (ed R. Lal), pp. 105-124. SWCS & St. Lucie Press, USA.

Rhoton, F. E., Shipitalo, M. J. & Lindbo, D. L. (2002) Runoff and soil loss from midwestern and southeastern US silt loam soils as affected by tillage practice and soil organic matter content. *Soil and Tillage Research,* **66,** 1-11.

Robinson, C. A., Cruse, R. M. & Kohler, K. A. (1994) Soil Management. *Sustainable Agriculture Systems* (eds J. L. Hatfield & D. L. Karlen), pp. 109-134. Lewis Publishers CRC Press, Inc., USA.

Romstad, E. (2003) Team approaches in reducing nonpoint source pollution. *Ecological Economics,* **47,** 71-78.

Rose, C. W. (1998) Modeling erosion by water and wind. *Methods for Assessment of Soil Degradation* (eds R. Lal, W. H. Blum, C. Valentine & B. A. Stewart), pp. 57-88. CRC Press, New York, USA.

SAS (2002) *The SAS System 8.2.* SAS Institute Inc., Cary, NC 27513, USA.

Schwab, G. O., Fangmeier, D. D. & Elliot, W. J. (1996) *Soil and water management systems.* John Wiley & Sons, Inc., Canada.

Shelton, C. H., von Bernuth, R. D. & Rajbhandari, S. P. (1985) A continuous application rainfall simulators. *Transactions of ASAE,* **28,** 1115-1119.

Sheng, J.-a. & Liao, A.-z. (1997) Erosion control in South China. *CATENA,* **29,** 211-221.

Shipitalo, M. J. & Edwards, W. M. (1998) Runoff and erosion control with conservation tillage and reduced-input practices on cropped watersheds. *Soil and Tillage Research,* **46,** 1-12.

Simota, C., Horn, R., Fleige, H., Dexter, A., Czyz, E. A., Diaz-Pereira, E., Mayol, F., Rajkai, K. & Rosa, D. d. l. (2005) SIDASS project: Part 1. A spatial distributed simulation model predicting the dynamics of agro-physical soil state for selection of management practices to prevent soil erosion. *Soil and Tillage Research,* **82,** 15-18.

Skidmore, E. L. (1994) Wind Erosion. *Soil Erosion Research Methods* (ed R. Lal), pp. 265-293. SWCS & St. Lucie Press, USA.

Thapa, B. B., Cassel, D. K. & Garrity, D. P. (1999) Assessment of tillage erosion rates on steepland Oxisols in the humid tropics using granite rocks. *Soil and Tillage Research,* **51,** 233-243.

Thapa, G. B. & Paudel, G. S. (2002) Farmland Degradation in the Mountains of Nepal: A Study of Watersheds 'With' and 'Without' External Intervention. *Land Degradation & Development,* **13,** 479–493.

Turkelboom, F., Poesen, J., Ohler, I. & Ongprasert, S. (1999) Reassessment of tillage erosion rates by manual tillage on steep slopes in northern Thailand. *Soil and Tillage Research,* **51,** 245-259.

Turkelboom, F., Poesen, J., Ohler, I., Van Keer, K., Ongprasert, S. & Vlassak, K. (1997) Assessment of tillage erosion rates on steep slopes in northern Thailand. *CATENA,* **29,** 29-44.

Valmis, S., Dimoyiannis, D. & Danalatos, N. G. (2005) Assessing interrill erosion rate from soil aggregate instability index, rainfall intensity and slope angle on cultivated soils in central Greece. *Soil and Tillage Research,* **80,** 139-147.

Van Muysen, W., Van Oost, K. & Govers, G. (2006) Soil translocation resulting from multiple passes of tillage under normal field operating conditions. *Soil and Tillage Research,* **87,** 218-230.

Wu, Y. & Cheng, H. (2005) Monitoring of gully erosion on the Loess Plateau of China using a global positioning system. *CATENA,* **63,** 154-166.

Zhang, J. H., Lobb, D. A., Li, Y. & Liu, G. C. (2004) Assessment of tillage translocation and tillage erosion by hoeing on the steep land in hilly areas of Sichuan, China. *Soil and Tillage Research,* **75,** 99-107.

Zhao, S. L., Gupta, S. C., Huggins, D. R. & Moncrief, J. F. (2001) Tillage and Nutrient Source Effects on Surface and Subsurface Water Quality at Corn Planting. *J Environ Qual,* **30,** 998-1008.

Zheng, F., He, X., Gao, X., Zhang, C.-e. & Tang, K. (2005) Effects of erosion patterns on nutrient loss following deforestation on the Loess Plateau of China. *Agriculture, Ecosystems & Environment,* **108,** 85-97.

Zhu, Y., Fox, R. H. & Toth, J. D. (2003) Tillage Effects on Nitrate Leaching Measured by Pan and Wick Lysimeters. *Soil Sci Soc Am J,* **67,** 1517-1523.

# 7 GENERAL DISCUSSION
# Implications of Research Findings to East Timor Agricultural Development

## 7.1 Introduction

This thesis has examined issues concerning sustainable crop production technologies in East Timor, using relevant case studies and experimental data. The objective has been to offer prospective long-term outcomes for the development of the country's largely rural and agriculture-base industry. The introductory part of the thesis outlines the research agenda, followed by an overview of the agricultural development in East Timor emphasizing the traditional farming and cropping systems. This analysis was further complemented with discussion of aspects of agricultural mechanization, and the staging of agricultural and technological change. The social and economic ramifications and implications for food security are jointly considered in a food policy approach. Empirical data were gathered from experiments, attempted both in East Timor and New Zealand, on soil and water conservation through the comparison of different tillage practices.

This chapter brings together all the topics covered, highlights the linkages, and summarizes the main policy implications for East Timor's rural and agricultural development. Moreover, it sets up the likely agenda components for future research, which, in the foreseeable time horizon, will be undertaken mainly by public funding and institutions.

## 7.2 The traditional setting of agricultural development

One of the major debates of recent times has been focused on how best to lead a smooth and less socially disrupting transformation from a traditional social landscape towards a reasonable stage of modernization. In the context of East Timor, a variety of centralized policies have been trialled in the past, so often through uncoordinated boards and sporadic developmental projects. After many decades to centuries, of both foreign occupation and negligence, the social fabric remains that of an agrarian and backward looking society. The post-independence era brings about an opportunity to start anew. Strategic action plans have been designed and implemented, tailored at increasing land and human resources productivity with the ultimate goal of alleviating hunger and poverty, still chronically experienced nationwide. However, a cautionary approach and measures are equally necessary so as to avoid putting excessive pressure on scarce resources, thus degrading the environmental quality, as well as to use the available resources effectively.

On a more narrow scope, the baseline for the discussion is based on the social environmental sphere, covering geographic and demographic features, and most essentially the cultural mindset which governs almost the entire range of farming activities and rural lives. In addition, the legacies of the past, particularly dealing with forced mass resettlements and the accompanied arbitrary and uncontrolled environment destruction, poses a tremendous challenge. Central to this specific setting, particularly in the context of East Timor and many other developing countries, is the common practice of shifting cultivation with the slash and burn method of land clearing. It continues to be the economic mainstay of upland communities in many developing countries worldwide, as suggested by Dendi *et al.* (2005) and Porro (2005) despite the introduction of technological innovations.

The increasing imbalance between the rural and urban economies is encouraging urbanization. To reverse the current trend of mass movement to the urban centres, livelihood sources from farming and rural environments must be transformed so as to become attractive, productive, and lucrative. Of major concern is that conditions that helped sustain the shifting cultivation rotations with long fallows for many generations in the past have largely vanished (Sunderlin, 1997), exacerbated mainly by rapid population growth (Cramb, 1993), intensification of shifting cultivation (Arnason *et al.*, 1982), and public policies to settle permanent agriculture and discourage the use of fallows and fires (Cairns and Garrity, 1999). What public policies failed to address, or to address adequately, was to put in place a proper diagnostic framework of the traditional farming system through an integrated research approach and methodologies. This is particularly important for shifting cultivation effects as they are not isolated from the community. Fujisaka (1994), for example, highlights the importance of recognizing the constraints experienced by farmers that underpin their rejection of researcher-driven solutions to their problems.

A participatory, on-farm research approach to identify viable alternatives to shifting cultivation is required (Hazell and Wood, 2000, Astatke et al., 2003, Poudel et al., 2000, Sanginga et al., 2004). As recommended by Cairns and Garrity (1999), this process may involve, but not be limited to, identification of promising indigenous practices, characterization of the practices, validation of the utility of the practice for other communities, extrapolation to other locations, verification with key farmers, and wide-scale dissemination through well-resourced extension channels. The agro-climatic zones of East Timor provide a well-defined set of ecological boundaries upon which further collaborative research work can be developed.

Apart from the rice fields and coffee plantations which, to some degree, have been touched by technological waves in the past, large parts of the country, mainly hilly and mountainous, remain distant from innovative actions. The latter areas are a major concern of this thesis, being in large part the living environment of the rural population, practising traditional farming methods over many years. Case studies suggest that for many reasons beyond their control, these rural farmers cannot adopt high labour and cash cost innovations. Therefore, it is relevant to suggest following Fijisaka (1991) that intermediate steps such as improved fallows for these hilly and mountainous areas are needed prior to crop diversification, adoption of agro-forestry technologies, and sedentary agriculture. Other studies have also indicated that well managed alternative systems to shifting cultivation can reduce soil structure deterioration, maintain soil fertility, and promote long-term productivity (Alegre and Cassel, 1996).

## 7.3 Agricultural productivity: managing technological change

It is argued that in the context of the traditional setting of East Timor that agricultural productivity, both in terms of human capital and land resources, should be enhanced and promoted. Given land resources are one of the major capital investments in agriculture development, the drive towards improvement and technical change in agriculture should be directed in a balanced combination, whenever appropriate, between technologies of *land-saving* (hybrid seeds, irrigation, and drainage) or *labour-saving* (mechanization, herbicides, varieties and cropping techniques) characteristics. Where shortage of labour exists, for example in rice-production areas such as Maliana and Viqueque, mechanization for seedbed preparation is deemed necessary. The same degree of mechanization may not be required, or a different form of mechanization can be employed during the time of harvest where, the availability of labour increases due to the less laborious nature of the work, and also because of the increased presence of family labour for seasonal festivities.

When weighing the merits of new innovations, farmers tend to make rational decisions (French and Schmidt, 1985) and traditional farmers in general, are efficient allocators of available resources according to their knowledge of technology (Schultz, 1964). As Morris (1985) points out, the justification for acquiring an improved technology for traditional farmers, to some extent, needs to conform to the features of their subsistence mode of farming. Thus the introduction of any external intervention to this subsistence setting, which causes disequilibrium (Schultz, 1964), has to go through a learning and experimentation phase. By doing this in a proper manner, the disruption of the traditional mechanisms can be kept minimal and a new equilibrium will be achieved. Empirical evidence suggests that investment in human capital through education enhances early technology adoption and promotes greater productivity (Schultz, 1964). The emphasis in technology dissemination, therefore, will have to shift from communication to education.

The arduous task ahead is to find best management practices to guide the technological change, which in the case of subsistence and traditional communities may imply cultural adaptations as well. Given the role of agricultural mechanization and its important social ramifications, mechanization policy becomes an important aspect of agricultural planning, as has been widely adopted and implemented worldwide (Clarke, 2000, Rijk, 1989). For East Timor, a selective mechanization is deemed appropriate, taking into account the traditional farmers' power constraints, and avoiding the wasteful and undesirable effects of over-mechanization, particularly labour displacement (Morris, 1985, Schultz, 1964).

## 7.4 Agricultural productivity: food policy implications

Questions arise on whether such technological innovations and cultural adaptations mentioned above should be directed to enhance productivity of certain grain, tuber, root, staple food crops, or more oriented to cash crops to meet the food security needs of the whole population. Three dimensions of food security, namely food availability, accessibility, and utilization have been briefly highlighted (Chapter 4). Because food security concerns primarily the buying power of ordinary citizens, it is inseparable with poverty. Furthermore, poverty in turn, is a problem that can be solved only by profitable and equitable economic development. In this context, an appropriate domestic food policy may help reduce hunger and poverty. The importance of incorporation of the traditional food crops into the domestic food policy is emphasised.

Literature studies strongly support the close linkage between achieving food security and overcoming poverty. Tweeten (1997) observed that because poverty is a function of the level and distribution of national income, food security cannot be separated from economic development. Because it embraces a much larger topic than merely a crop production issue, it is in the realm of the government to design a food policy which encompasses all the public collective efforts to influence the decision-making environment of food producers, food consumers, and food marketing agents (Timmer *et al.*, 1983). These collective actions cover a wide range of activities from research and extension, the provision of basic infrastructure, price interventions, to land legislation.

The major issues in this regard, include urbanization and production demand in urban centres, shortage of labour and the need for mechanization, and productivity growth as indicated above. Of these, productivity growth is the umbrella topic, which in the theme of this thesis, covers the productivity of human capital and land resources, the two most significant factors in agricultural development. Empirical studies suggest that future productivity growth is likely to come from three main sources: agricultural research, technology transfer systems (extension and education), and agricultural support policies (Morris and Byerlee, 1998). For East Timor, however, this thesis argues that it is worthwhile to de-emphasize the introduction of the high yielding varieties (HYV's) seeds, allowing more focus on the improvement of local seeds.

## 7.5 Paradigm shift towards sustainability?

Conservation has been the guiding principle ruling the discussion of major topics in this thesis. The basic philosophy is that to sustain over time the agriculture sector of a country such as East Timor, it has to be productive and lucrative, actively generated by local human capital and selective imported expertise, while based on a judicious and balanced use of its traditional environmental resources (MAFP, 2005).

Any agricultural system to which the current traditional system will be transformed must be both sustainable and highly productive in the future if it is to feed the growing human population. For this twin challenge to be met Poincelot (1986) recommended a new approach to agriculture and agricultural development that builds on resource-conserving aspects of traditional, local, and small-scale agriculture while at the same time drawing on modern ecological knowledge and methods. It is empirically proven that traditional agriculture, despite its market limitations, can provide models and practices valuable in developing sustainable agriculture. The mainstream approach to modernizing agriculture on the other hand, apart from its successes promoted by scientific advances and technological innovations, has led to dependency on external inputs, e.g. seed, fertilizer, pesticides, machinery and fossil fuels.

In essence, agricultural practices tend to degrade the resource base and the challenge for modern agriculture is to minimize this degradation. East Timor, as a semi-arid region with low-input technology and resource-poor farmers working in a highly unpredictable agro-climate is particularly challenged in regards to protecting the natural resource base. In this context, sustainable agriculture is largely a function of, and frequently controlled by, socioeconomic conditions.

The literature also reveals the prevalence of soil degradation in many agricultural production and agroecology systems. To avert further degradation, the soil productivity balance must be shifted from degrading processes to conserving processes, and more urgently, in the fragile eco-regions and marginal lands of the tropics. The issue of environment and especially soil quality is as paramount to advanced and soil rich countries as to developing countries with fragile tropical land such as East Timor. While research work and supporting resources are generally largely available in the former category of countries that is not the case for the latter. Due to limited capital and human resources in developing countries, government-funded research projects are too often single disciplined studies using a top-down approach with inadequate farmer involvement.

## 7.6 Soil and water conservation

Soil and water are the largest resources required for agriculture and need to be managed sustainably. Literature and empirical studies also strongly suggest that conventional agriculture tends to deteriorate the soil and water quality comparatively to alternative agricultural practices such as direct drill or minimum tillage (Chapter 5). In the context of East Timor, an improved shifting cultivation practice in rotation with a better fallow system would guarantee better soil and water conservation (see Chapter 2).

It is also relevant to consider suggestions made by Willcocks and Twomlow (1993) that tillage research and development should give increased attention to: (i) understanding farmer constraints to reliable rainfed crop production systems and identifying existing and potential technology supply systems available to local farmers through a multidisciplinary approach; (ii) creating interim systems that are sustainable with existing resources and selective external information and technological input; (iii) establishing long-term tillage and agricultural production systems that conserve energy (labour and draught power), water and soil resources.

Experimental results in this thesis on the effects of tillage and no-tillage, in particular, on the edaphic changes affecting the cropping environment generally concur with the findings in the literature. They also strongly support conventional tillage practices causing more water and sediment erosion than no-tillage. It also emphasises tillage as one of major contributing factors to erosion, as has been proven elsewhere, particularly on the undulating to steep and fragile lands. Despite being in the emerging phase, these short-term experimental results (Chapter 6) indicate that tillage erosion could be a major source of nutrient losses as well as non-point pollution affecting the soil and water quality in general.

While a large volume of research data are available on long-term tillage research in temperate climates and developed countries, short-term experiments such as the present study, may well provide significant information to support agricultural policy design in developing countries of the tropics for a sound use of their fragile soil and scarce water resources.

## 7.7 Policy implications for East Timor agricultural development

Despite the macro nature of hunger, poverty alleviation, and environmental degradation depicted earlier in the first chapter and the subsequent economic development measures to address these issues on a national scale there are at least four major public policy components that will play vital roles:

(i) Agricultural research and development

This is fundamental and constitutes the core of an agricultural and rural development system, being at this stage primarily the role of the government. It aims at researching and identifying farmers' constraints to innovation, opportunities for improvement, and offers solutions to socially and economically beneficial development breakthroughs. Funds and related resources should be made available for this purpose.

(ii) Agricultural extension and education

Historically, this has been under the provision of government, however, given the financial and bureaucracy shortfalls, this trend has to be reversed, allowing greater participation of the civil society, particularly the NGOs. In a sense, this is likely to be a form of national or domestic networking to disseminate technology information with a gradual emphasis shift from communication to education.

Education, or investment in human capital, is the key to any agricultural transformation (Schultz, 1964). Therefore, the current agricultural schools in Fuiloro, Natarbora, and Maliana could well be gradually developed as centres of excellence coupled by the naturally well-resourced areas in which they are situated.

(iii) International and regional networking

A systematic agricultural and rural research development and extension framework should be put forward to the international development partners' forum where key strategic development areas can be identified and viable channels are created through which exchange and transfer of technology and information knowledge can occur continuously. This has been initiated, however areas of cooperation need to be redefined allowing projects to develop on a more self-sustained fashion especially in the long-run basis.

(iv) Shift of policy focus

Policy focus in agricultural development needs to be reoriented in two major ways: firstly, decentralized and broad-based orientation covering the most remote village and community centres. Secondly, conservation agriculture as opposed to production agriculture aimed at securing an environmentally friendly agriculture sector for generations to come.

## 7.8 Agenda for future research

A workable research agenda in the short to medium term as follow-up of this study may cover three major areas as follows:

(i) Integrated Farming Systems

This is primarily aimed at understanding the local and indigenous farming practices, ranging from rural technologies, farming tools, energy balance, soil fertility management, crop and plant diversity, weeds and pest control, to animal husbandry and forestry management.

(ii) Soil tillage and erosion

Tillage and erosion trials can be established at specific sites, covering different soil types and cropping systems. This can be on local farms or on purposively established sites.

(iii) Applied science and technology

Advanced and complex trials can be initiated under this scheme with projects such as: food policy analysis, farm machinery selection and testing, soil testing and mapping, land evaluation and GIS, bio-energy technologies, improved local seed varieties, adaptive fodder crops for improved grazing and pasture management, appropriate agro-forestry and soil and water conservation technologies and cash crop initiatives.

## References

Alegre, J. C. & Cassel, D. K. (1996) Dynamics of soil physical properties under alternative systems to slash-and-burn. *Agriculture, Ecosystems & Environment,* **58,** 39-48.

Arnason, T., Lambert, J. D. H., Gale, J., Cal, J. & Vernon, H. (1982) Decline of soil fertility due to intensification of land use by shifting agriculturists in Belize, Central America. *Agro-Ecosystems,* **8,** 27-37.

Astatke, A., Jabbar, M. & Tanner, D. (2003) Participatory conservation tillage research: an experience with minimum tillage on an Ethiopian highland Vertisol. *Agriculture, Ecosystems & Environment,* **95,** 401-415.

Cairns, M. & Garrity, D. P. (1999) Improving shifting cultivation in Southeast Asia by building on indigenous fallow management strategies. *Agroforestry Systems,* **47,** 37-48.

Clarke, L. J. (2000) Strategies for Agriculture Mechanization Development, The Role Of Private Sector And The Government. AGSE, FAO, Rome, Italy.

Cramb, R. A. (1993) Shifting cultivation and sustainable agriculture in East Malaysia: A longitudinal case study. *Agricultural Systems,* **42,** 209-226.

Dendi, A., Shivakoti, G. P., Dale, R. & Ranamukhaarachchi, S. L. (2005) Evolution of the Minangkabau's Shifting Cultivation in the West Sumatera Highland of Indonesia and its Strategic Implications for Dynamic Farming Systems. *Land Degradation & Development,* **16,** 13–26.

French, E. C. & Schmidt, D. L. (1985) Appropriate Technology: An Important First Step in Sustainable Agriculture & Integrated Farming Systems. *1984 Conference Proceedings* (eds T. C. Edens, C. Fridgen & S. L. Battenfield), pp. 262-267. Michigan State University Press, East Lansing.

Fujisaka, S. (1991) A diagnostic survey of shifting cultivation in northern Laos: targeting research to improve sustainability and productivity. *Agroforestry Systems (Historical Archive),* **13,** 95-109.

Fujisaka, S. (1994) Learning from six reasons why farmers do not adopt innovations intended to improve sustainability of upland agriculture. *Agricultural Systems,* **46,** 409-425.

Hazell, P. & Wood, S. (2000) From science to technology adoption: the role of policy research in improving natural resource management. *Agriculture, Ecosystems & Environment,* **82,** 385-393.

MAFP (2005) Preliminary Report on Donor's Agricultural and Rural Development Conference, 3-5 March 2005. Ministério da Agricultura, Florestas e Pescas, RDTL, Dili, East Timor.

Morris, J. (1985) The economics of small farm mechanization. *Small Farm Mechanization for Developing Countries* (eds P. Crossley & J. Kilgour), pp. 171-184. John Wiley & Sons, New York.

Morris, M. & Byerlee, D. (1998) Maintaining Productivity Gains in Post-Green Revolution Asian Agriculture. *International Agricultural Development* (eds C. K. Eicher & J. M. Staatz), pp. 458-473. John Hopkins University Press, Baltimore, Md.

Poincelot, R. P. (1986) *Toward a more sustainable agriculture*. Avi Publishing Company, Inc., Westport, Connecticut, USA.

Porro, R. (2005) Palms, Pastures, and Swidden Fields: The Grounded Political Ecology of "Agro-Extractive/Shifting-cultivator Peasants" in Maranhão, Brazil. *Human Ecology,* **33,** 17-56.

Poudel, D. D., Midmore, D. J. & West, L. T. (2000) Farmer participatory research to minimize soil erosion on steepland vegetable systems in the Philippines. *Agriculture, Ecosystems & Environment,* **79,** 113-127.

Rijk, A. G. (1989) *Agricultural mechanization Policy and Strategy, The Case of Thailand*. Asian Productivity Organization, Tokyo.

Sanginga, P. C., Best, R., Chitsike, C., Delve, R., Kaaria, S. & Kirkby, R. (2004) Linking smallholder farmers to markets in East Africa - empowering mountain communities to identify market opportunities and develop rural agroenterprises. *Mountain Research and Development,* **24**.

Schultz, T. W. (1964) *Transforming Traditional Agriculture*. Yale University Press, New Haven and London.

Sunderlin, W. D. (1997) Shifting Cultivation and Deforestation in Indonesia: Steps Toward Overcoming Confusion in the Debate. Network Paper 21b; Rural Development Forestry Network; Overseas Development Institute, London UK.

Timmer, C. P., Falcon, W. P. & Pearson, S. R. (1983) *Food Policy Analysis.* John Hopkins University Press, Baltimore Md.

Tweeten, L. G. (1997) Food security. *Promoting Third-World Development and Food Security* (eds L. G. Tweeten & D. G. McClelland), pp. 225-256. Praeger Publishers, Connecticut.

Willcocks, T. J. & Twomlow, S. J. (1993) A review of tillage methods and soil and water conservation in southern Africa. *Soil and Tillage Research,* **27,** 73-94.