A STUDY OF TILLAGE MECHANISMS IN RELATION TO SOIL PROPERTIES AND CROP GROWTH.

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ABSTRACT

Three tillage systems were compared over the 1973-74 spring-summer season on two trial sites. One trial site was tilled and left to fallow over the winter, while the other was left in pasture. The three tillage systems studied were:-

1. traditional plough/disc/harrow
2. direct-drilling or chemical tillage
3. rotary-cultivation.

There were no significant differences between treatments in the subsequent establishment and yield of dry matter of a crop of chou moellier on the trial site which had been left to fallow.

On the non-fallowed site, direct-drilling resulted in a significantly lower number of plants compared to the other tillage treatments. Despite this, dry matter yields were highest on the direct-drilled plots and lowest in the rotavated treatment.

Soil which had been direct-drilled remained the most stable as determined by wet-sieving of soil samples. Soil stability under the rotavated treatment appeared to decrease to a greater extent than under ploughing as the length of time out of pasture increased. Dry-sieving of samples showed the same effect. The rotary cultivation treatment resulted in the greatest proportion of soil in the smaller aggregate size fraction (less than diameter 1.676mm).

Differences between tillage treatments were also observed in soil resistance as measured by a penetrometer, and resistance to wheel compaction between the non-tilled and the two mechanically tilled treatments. In general the ploughed and rotary-cultivated soil required a lower penetrometer force than the undisturbed direct-drilled profile. On the tracked areas, increase in penetrating force of the two mechanically tilled plots was on average

12 times the increase on the direct-drilled plots.

It is probable that soil moisture levels were not affected by cultivation treatment. Differences which occurred, particularly in the non-fallowed trial, were thought to have been an effect of differences in plant density — soil water loss increasing with plant density.

Data from the two trials showed that total fuel consumption for direct-drilled and rotary cultivated treatments to be 9.7 and 1.9 times respectively, less than the traditional ploughing treatment. This did not include the fuel requirements of weed control, which varied between treatments.

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Chapter 1

INTRODUCTION

There has been considerable study in the field of soil tillage and cultivation during the last 30-40 years. Much of this experimentation has taken place in Britain, U.S.A. and in Europe. The work in this field has had the objectives of either, maximising crop yield or minimising soil erosion and drainage problems in cultivated areas.

Within the last 15 years the technique of direct-drilling or chemical-tillage has become possible, due largely to the availability of suitable herbicides. Their effects were to eliminate the need for tilling the soil with machinery in order to kill existing vegetation (e.g. pasture) before sowing a crop. The presence of a dead plant mulch on the relatively undisturbed soil surface has been shown by a number of authors to be beneficial in protecting the soil against erosion and soil drainage problems (Van Storen and Stauffer 1943, Meyer and Mannering 1961, Army et al 1961, Russell 1966).

Unfortunately, the question still remains as to whether or not crop yields are sensitive to the amount of soil manipulation required to create a tilth. Some of the earlier work on this aspect (Russell and Keen 1941), suggested that the method of cultivation did influence yields. Other work suggested that yield was independant of the cultivation treatment if the land was free of weeds which competed for soil fertility and moisture (Moffat 1970, During et al 1963, Pereira 1941). Still other authors (Baker 1969, and Dixon 1972) suggested that seeds may be sensitive to their method of placement in direct-drilled situations.

Despite the seemingly abundant information which has appeared around this subject, many questions apparently remain unanswered e.g. the comparative effects of soil tillage methods on various soil properties. New tillage machines are periodically introduced to farming systems and the technique of direct-drilling is becoming more widely known. Many farmers in New Zealand however still use the traditional plough/disc/harrow system of tillage and apparently give little consideration to easier or more flexible methods such as rotary cultivation or direct-drilling.

The experiments reported below were intended to investigate three alternative methods of establishing a crop on a Tokomaru Silt loam. In relation to the effects that each of these methods might have on physical properties of the soil, and on crop yield, the following parameters were considered important:-

1. Soil structure and stability, (as a possible influencing factor in erosion and drainage properties).
2. Soil moisture regime, organic matter content, compaction and soil density.
3. Crop yields.
4. Relative energy inputs through tractor operation with the tillage and sowing implements.

LITERATURE REVIEW

2.

2.1 GENERAL

A review of the work relevant to the experiments reported herein is presented under the following headings:

1. Objects and Effects of Tillage.
2. Maintenance and modification of soil structure.
3. Responses of plants to tillage techniques.
4. Energy requirements of tillage.
5. Introduction to experimental techniques.

The whole subject of tillage and its interrelated aspects is very wide. An analysis of the subject was given by Kuipers (1963) who stated that the technological effect of a tillage operation depended on:

"1. Soil conditions at the time of cultivation (soil type, pore space, water content, binding forces, the way in which organic materials are mixed throughout the soil etc.)

2. the implement, and

3. the way in which it is used (e.g. working depth, speed, intensity)".

This technological effect changed 'weed population', and in some cases had a direct mechanical effect on the crop. Soil physical conditions were always modified in some way.

Yoder (1937) earlier stated that tillage operations were carried out to create soil structural conditions which met the requirements of various biological agronomic and engineering objectives; and the fact that tillage operations were carried out year after year for seedbed preparation was the best evidence that suitable soil structure was an unstable soil condition.

All traffic on the soil might be considered as tillage (Blake, 1963) and tillage that made the soil 'look good' has often been considered desirable in the past.

Blake pointed out that yield decreases that farmers were prepared to accept for the greater time-cost efficiencies of minimum tillage techniques, have often failed to appear. In addition to the cost advantage, improved soil properties and decreased water runoff and erosion have often resulted.

2.2 THE OBJECTS AND EFFECTS OF TILLAGE

2.2.1. The Objects of Tillage:

The objectives of soil tillage have been stated by many authors. Kuipers (1963) summarized the views of 19th and early 20th century writers who considered that the main purpose of tillage was to improve the physical and nutritive value of the soil. Kuipers reported that the objectives of tillage were often not clear and confusing arguments were sometimes given. For example it was sometimes stated that tillage was done to 'increase the fertility of the soil', 'turn over the top layer', or to 'loosen the soil'; without any apparent knowledge of how these objectives improved soil properties or benefited crop growth. Tillage operations were done with the general idea of increasing the 'fertility' of the soil by creating favourable soil physical conditions and raising the 'natural productivity' of the soil to a higher level than under natural uncultivated conditions. According to Kuipers (1970) the idea of tillage for weed control to reduce competition for nutrients with the crop plants was not put forward until after experiments done at Rothamsted, England during the period between 1925 and 1942.

Similarly, Baver (1948) considered that early tillage operations were performed without much knowledge about the effects of manipulations on the soil and plants and without any clear ideas about what objectives were desired. Baver cited Jethro Tull, an 18th century English farmer, who suggested that tillage improved the productiveness of soil because it caused a breaking down of the large soil particles into smaller ones which increased the surface from which plant roots obtained their food.

The most popular tillage implement down through the centuries has been the plough according to Baver and he suggested that perhaps the first reason for ploughing operations was the loosening of the soil so that seeds could be planted and crops would have a friable layer in which to grow. The curved mouldboard was developed later for the primary purpose of turning under surface residues and live vegetation.

Ideas have developed over the years and Baver (loc cit) cited Slipher (1932) who proposed that a seedbed or rootbed should:

"1. Permit the rapid infiltration and satisfactory retention of usable rainfall.
2. Afford an adequate air capacity and a ready exchange of soil air with the atmosphere.
3. Offer little resistance to root penetration.
4. Resist erosion.
5. Facilitate the placement of surface residues throughout the soil mass.
6. Provide stable traction for machinery."

Kuipers (1963) noted a change of ideas towards soil tillage over the years, and as well as the 'classical' objectives of improving physical properties and increasing crop production, it has been recognised that tillage for crop yield must be fitted into other objectives such as the reducing of production costs of agricultural crops.

The seedbed

Tilth was defined by Baver (1948) as the physical condition of the soil in relation to crop growth, and this definition included all desirable soil properties responsible for providing a suitable physical environment for plant growth. Baver stated that granular or friable soil was a feature of good tilth and could be renewed through the use of sod crops in a rotation and by suitable tillage methods.

Baver (loc cit) postulated that the ideal rootbed or seedbed should contain the finest granules and greatest degree of firmness in the lower part of the profile to provide good seed/soil and seed/soil-water contact. The coarseness of the granules should then increase up to the surface, and these larger granules helped absorb raindrop impact and prevented the formation of seals and crusts which reduced water infiltration and aeration.

Yoder (1937) found that granules of which half were 3mm to 6mm diameter, and half of various sizes smaller than this, were best in his experiments with regard to the germination of cotton seedlings. On the other hand, Larsen (1963) suggested that 30% of the soil mass in the zone of the seed should be composed of secondary aggregates of less than 2.5mm diameter in a clay soil in Ohio. Various other authors have reported that a high proportion of the aggregates should be in the region of 3-10mm diameter or less.

Tillage is often done for such reasons as breaking up compacted pans in the soil profile (Diebold, 1953), to ease harvesting e.g. potatoes (Kuipers, 1963), to incorporate crops e.g. clover (Norton et al, 1943), to create a clean level surface to aid machines such as thinners, harvesters, and planters (Poesse and Perdock, 1970), to create conditions suitable for plant growth e.g. ridging in swampy ground Read et al, 1973), to restore soil structure and incorporate P and K fertilizers into deep layers, and to destroy persistant weeds e.g. couchgrass (Baeumer, 1970). Many other reasons for tillage operations can be found in the literature in addition to the above examples.

In more recent years, ideas have further changed due partly to the influence of modern herbicides. Kuipers (1970) noted that there has been a change from the central theme of tillage for soil structure to tillage for weed control and away from the general idea that tillage made soil fertile and therefore could not be overdone. He also noted that ploughing was laborious and time-consuming and the advent of chemical weedicides, coupled with the idea that the soil structure under pasture was usually in an optimal condition and should be preserved in its natural state as far as possible, has helped the development of various minimum tillage techniques.

2.2.2. The Effects of Tillage.

The effects of tillage will vary from place to place and also at the same location with varying climatic conditions throughout the year. Frese (1963) discussed the changes in the soil that are controllable by tillage and stated that: "we should ask: what happens under the given circumstances (soil location, climate, kind of crop) during the whole vegetative period with regard to its temporary, changing, mutual and overlapping influence on plant growth and why did it happen." He also commented on how it was impossible to predict climatic conditions and adapt tillage operations to these unknown conditions and that an explanation of tillage problems could not give much more than the 'spotlights' of the complicated system.

Low (1972) stated that when old grassland was ploughed and cultivated the physical condition of the soil was usually in an optimal condition for:-

"1. Obtaining good seed-beds over a wide moisture range.
2. good air-water relationships at field capacity
3. maximum resistance to wind and water erosion.
4. ease of root penetration."

Low went on to say that these desirable properties began to deteriorate as soon as the soil was cultivated and the rate of deterioration depended on the soil-type (especially texture) and the system of management.

A large volume of information can be found in literature on the effects of tillage and cultivation on a large number of soil-types under various climatic conditions. As a result, the specific effects of various operations varies also, but some general trends can be found, and have been discussed by numerous authors. Baver (1948) explained that, irrespective of the implements used, the larger the number of manipulations of the soil, the greater will be the eventual breakdown of surface granulation. Discing and harrowing caused loosening of compacted soils, but Baver pointed out that this 'friability' should not be mistaken for the stable type of granulation or tilth that was formed through the influences of plant roots and organic matter. Therefore, he postulated that surface manipulations should be kept to a minimum to avoid the formation of superficial tilths which were only temporary in nature. Baver also commented that soil surfaces should not be left in a compressed state in order to establish a firm seedbed, or heavy rain was almost certain to cause surface sealing with consequent decrease in water infiltration and aeration of the plant root environment.

Baver pointed out the differences in seedbeds obtained when different types of soil were ploughed. For example ploughing a soil when it was too dry resulted in a mixture of clods and dust in the seedbed, ploughing a heavy grass sod caused 'clods' which were held together by roots but which on decomposition gave an ideal granular seedbed, and ploughing when soil was too wet caused puddling and smearing of the soil.

The optimum soil moisture at which to plough varied with soil texture, but was somewhere between the lower plastic limit and the point where the soil was dry enough to form clods (Koenigs 1963). Koenigs explained that soil puddling involved the formation of an infinite number of shear planes, which required the cohesion within the soil units to be low. Cohesion dropped with increasing moisture content and obtained its minimum value near the soil saturation point.

Loosening of the soil by tillage caused an increase in porosity and microdepressions on the soil surface which acted as reservoirs for water storage during rainstorms (Larson, 1963). Larson reported that ploughing on the contour helped reduce runoff and as much as 7.5cm of rainfall could be stored in plough furrows. A smooth soil surface such as is often prepared by conventional tillage techniques could store less than 2.5cm of water.

Page et al (1947) considered that the effect produced by any tillage implement differed so much with the conditions at the time that generalizations on the merits of different tillage implements was dangerous. They did say that rotary tillage was found to form fragments which may look satisfactory but which had little structural stability. They maintained that ploughing gave less destruction of structural units than other methods if it was used well, but later operations (e.g. harrowing, rolling, discing) should be kept to a minimum. Page et al also suggested that there was little benefit in crop residues being near the surface where erosion control was not a factor. Grundey (1970) noted an apparent tendency to plough too deeply and to overwork seedbeds, and often with a tendency to get a deeper tilth than was required.

Compaction:

Tractor wheels exert vertical forces on the soil. They have also been found to exert large horizontal forces which could move a considerable amount of soil, Wong (1967).

The surface pressure below agricultural wheels has been found to be very variable because the contact area of tyres changed with sinkage (Soane, 1970). For example the surface pressure under a wheel varied from 1.44kg/cm^2 for a firm surface to 0.61kg/cm^2 for a soft surface. Compaction was also found to vary markedly with soil moisture (Free 1953, Weaver and Jamison, 1951, Weaver 1950) and unfortunately, the optimum moisture content for compaction was found to be very near the optimum moisture content for tillage to give maximum break-up of soil and minimum draft (Weaver and Jamison, loc cit).

Compaction has been found to effect various soil properties; for example dry bulk density, hydraulic conductivity, the airfilled porosity, various strength characteristics, water retention characteristics and perhaps other soil properties also (Soane 1970, Low 1972, Raney et al 1955). On the other hand soil tillage can improve permeability by opening up compact soil (Marshall 1962).

Free (1953) estimated that during the period from ploughing to drilling cover crops, potato fields (in New York) were subjected to 40km of tractor traffic per acre per year, exclusive of the traffic of trailed implements (40km was equivalent to covering each area 6 times). He added that multiple tillage operations, cultivations, spray programs and multiple harvest operations intensified compaction problems.

Often the consolidation effects of tractor wheels may be too small to be picked up by changes in volume weight measurements. Hawkins and Brown (1963) cited Fountaine and Payne (1952) as having conducted a set of experiments where a ballasted tractor did not bring about a significant consolidation of a clay soil, and yet water ran off such a surface when it was irrigated and penetrated freely into an untreated surface. Ordinary ploughing apparently undid the damage to the surface, although effects on the furrow bottom may have occurred.

Weaver (1950) reported that tractor tyres compacted soil to a depth of 225mm which was below the reach of the plough. Similarly, Raney et al (1955) also reported that the zone of highest density was often found just below the zone disturbed by normal tillage operations. Raney et al noted that induced hardpans (i.e. by management etc) in soil profiles were most common in medium textured soils e.g. loams, sandy-loams and silt-loams.

Effects on Soil Fauna and Fertility:

It has been found by numerous authors that N-fertility was influenced by tillage. Low (1972) reported that the total N content decreased in various soil-types when old grassland was ploughed, the N level showed a greater drop in the first few years after ploughing than in later years. He commented that the total N may have dropped about 75 per cent in about 20 years in some cases.

Low also found that the number of earthworms per hectare under old grassland was 6 to 9 times greater than the number under old arable land of the same type. He added that after 3 years cultivation the number of earthworms was reduced by half.

Waters (1955) found that the weights of earthworms found under pastures at Palmerston North were decreased by restricted drainage and aeration and also by a lack of dead herbage debris.

Bower et al (1944) considered that the method of seedbed preparation had a marked effect on N-deficiency in corn grown on a silt loam (in U.S.A.) Listed and sub-surface tilled seedbeds apparently gave significant responses to fertilizer, whereas there was no N-deficiency in ploughed soil. These authors also considered that there may have been some K-deficiency in some non-ploughed seedbeds. In Bower and his co-author's opinions, ploughing loosened and aerated soil and completely incorporated plant residues, which increased nitrification. This, in turn, increased the availability of nitrogen to crop-plants.

Carter and Saunders (1969) also commented on how tillage increased the numbers of bacteria which participated in nitrogen and carbon mineralisation of soil incorporated organic matter.

Earlier results by Russell & Keen (1941), after 6 years of cultivation experiments, showed that the method of cultivation (e.g. depth of ploughing, or rotodrilling,) gave responses in wheat and mangold crop yields which they put down to differences in nitrogen competition between weeds and crops, rather than to differences in tilth. They reported that mangolds turned dark green on the deep-ploughed plots, and turned lighter green on the rotavated and grubbed plots due to less weed control.

The distribution of mites and springtails within a soil profile was found to be markedly affected by tillage (Bund, 1970) and some of his results are shown in table 1.

TABLE 1 Mites and Springtail distribution (from Bund, 1970)

Soil Profile:	2.5-5cm	7.5-10cm	15-17.5cm	25-27.5cm
Tilled Soil				
Mites	34	21	99	35
Springtails	41	26	224	30
Untilled Soil				
Mites	38	17	15	9
Springtails	208	109	32	7

The counts of mites and springtails were presumably dependant on the distribution of the soil microflora, according to Bund, which was in turn dependant on the soil structure and on the type of organic matter in the soil. In tilled arable soil, organic matter was more evenly distributed in the top soil and so were the springtails and mites.

Ploughing to a depth of 15-20cm from a grass ley was found by Arnott and Clements (1966) to give the zone of greatest fertility and aggregate stability at a depth of about 5-10cm.

Matthews (1972) commented that there was usually a high level of fertility in the top 2.5cm of the soil, but after normal cultivation in Taranaki the phosphate level in the soil could drop from 29 equivalents to 3 equivalents due to loss of phosphate in eroded soil colloids.

2.2.3. Direct Drilling or Zero-Tillage

In recent years, with the development of modern herbicides, the technique of direct drilling or zero-tillage has become popular. The technique offers many advantages over conventional methods of tillage, and Bakerman (1970) suggested that it offered better trafficability, more days suitable for working, the possibility of earlier sowing, conservation of moisture in Spring because of light mulches, less erosion, and more versatile use of soils with labile structures.

In addition, Bramley (1962) considered chemical ploughing had uses in areas where conventional cultivation was difficult or impossible because of rough topography, high rainfall, erosion problems, stony soil or in low-lying waterlogged conditions.

Many of the desirable features are related to the presence of a mulch on the soil surface. Van Doren and Stauffer (1943) studied several mulches e.g. soybean, corn and wheat straw, and demonstrated that all were effective in reducing water runoff and soil losses. They stated that some mulches decreased runoff by up to 70 per cent by creating pools of trapped water and increasing infiltration. Army et al (1961), Moody et al (1961) and Russell (1966) also commented on the effectiveness of a surface mulch in preventing surface crusting and evaporation from the soil.

Matthews (1972) considered that reduced evaporation may have been helped by a decrease in temperature of up to 5°C compared with cultivated soils. Burrows and Larson (1962) found that corn stalk mulch reduced soil temperatures as much as 4°C at the hottest part of the day at depths down to 6mm.

Meyer and Mannering (1961) reported that direct drilled soils had a higher soil moisture level than tilled soils. This was also reported by Leonard (1970) in New Zealand who stated that the technique was often done to help conserve moisture, although he went on to say that direct drilled crops seemed to have shallower rooting systems which made them more susceptible to any moisture deficiency. For this reason, Leonard continued, direct drilling in New Zealand was concentrated more in the areas where there was a reasonable summer rainfall.

Work done in Texas by Wiese and Army (1958) failed to show any apparent significant difference in water distribution between chemically weed controlled and tilled plots in a 10 month fallow period. On the other hand, Wiese et al (1960) found that chemically fallowed plots had a lower moisture storage potential, although this was probably caused by the use of 2,4-D, as the herbicide and the grasses were not satisfactorily killed. Ouwerkerk and Boone (1970) found that the water content of non-tilled layers were higher at depths of 1 - 6cm, but lower at the 11 - 16cm and 21 - 26cm depths (average of 7 years). They thought that this might have been related to the water-holding capacity of organic matter.

Ouwerkerk and Boone (loc cit) demonstrated that soil on untilled plots was usually denser than tilled soil by visual examination and penetrometer measurements. They also found from core sample demonstrations that the mean pore space and the standard deviation of the pore spaces were lower on untilled plots i.e. the homogeneity of the soil structure was increased. They also went on to say that the average of a quantity like pore space was not likely to be an important characterization. Stranak (1968) suggested that a higher soil bulk density than is usually recognised, may be required for cereals. The actual optimum bulk density depended partly on soil-type, e.g. $1.45 g/cm^3$ on sandy loam and $1.35 g/cm^3$ on a heavier clay loam. Non-tilled seedbeds were considered to be somewhere near the optimum bulk density, whereas heavy rolling was required on a ploughed soil to compress soil around seeds after sowing.

Soil fertility factors have been reported to differ between direct-drilled and tilled soils. For example, soil test values for pH, phosphate, and potassium have shown that 'no-till' soil profiles had a much higher concentration of soil nutrients, and a higher pH at the soil surface, compared to conventionally cultivated plots in experiments carried out by Gard and McKibbon (1973). Conventionally tilled profiles had soil fertilizers more evenly distributed throughout the profile.

It has often been reported that direct-drilled crops respond to N-fertilizers e.g. Baemer (1970) and Kupers and Ellen (1970). In New Zealand it has been found that additional nitrogenous fertilizers (e.g. a minimum of 45kg N/ha) should be given to a direct-drilled chou moellier crop, whereas none was often required in cultivated crops (Leonard, 1973).

It was postulated by Jupers and Ellen (loc cit) that the differences in nitrogen fertility between ploughed and unploughed plots might have been explained by the limited size and activity of the root system in unploughed soils. This might have been promoted by a n accumulation of chemical soil fertility factors in the upper layer of undisturbed topsoil, and possibly by greater compactness of the unploughed soil. Bakerman (1970) reported that more nitrogen was needed in direct-drilled crops on sandy, clay and peat soils. On the other hand Dawes (1960) found no greater responses to N (with swedes, turnips or chou moellier) in his trials on direct-drilled or ploughed plots, but Cross et al (1964) reported that the second crop on non-tilled ground may give poorer results if N was not applied.

There are some problems associated with direct-drilling techniques. For example Poesse and Perdock (1970) considered that shallow tillage may have been required to destroy plant residues when mechanical thinners were to be used in a crop, and tillage also might be required where harvesting of tubers or root-crops by machines was to be carried out. Mood et al (1964) and Jeater and McIlvenny (1965) commented that slight damage to emerging seedlings may have come about because of residues of paraquat remaining on dead herbage.

Dixon (1972) found that hoe coulters and triple disc coulters (commonly used on direct-drills) created smeared slots in moist conditions. He also found that any advantage untilled soil might have provided through having a higher bulk density than cultivated soil was reduced with commonly used coulters which left the seed exposed in loose soil in the slot.

Apparently little is known about the effects of herbicides used in chemical ploughing on populations of soil fauna and microflora (Bakermans and De wit, 1970).

2.3 MAINTENANCE AND MODIFICATION OF SOIL STRUCTURE.

2.3.1 Soil Aggregates and Their Breakdown

The following definition of soil structure was given by Marshall (1962): 'Soil structure is the arrangement of the soil particles and of the pore space between them. It includes the size, shape and arrangement of the aggregates formed when primary soil aggregates are clustered together into larger separate units'.

In addition, Martin et al (1955) defined a soil aggregate as: 'a naturally occurring cluster or group of soil particles in which the forces holding the particles together are much stronger than the forces between adjacent aggregates.' He went further and claimed that it had been generally accepted that in most soils, aggregates were not resistant to breakdown by tillage.

Many surface soils, that were originally granular or crumb in structure have changed with cultivation and poor management practices to a fine fragmental or massive structure (Klingebiel and O'Neal 1952, Elson and Lutz 1940, Low 1972). Marshall (1962) cited work by Clark and Marshall which illustrated the progressive changes in aggregation and organic matter content (Nitrogen percentage) of a tilled horizon (0 - 10cm) in Adelaide under a cereal-fallow rotation (table 2).

TABLE 2 Soil changes in 0-10cm tilled horizon (from Marshall, 1962)

Years under Cult.	Aggregn %		Total Nitrogen
	0.05mm diam.	0.2mm diam.	%
0	26	62	0.222
1	20	52	0.170
3	18	52	0.161
20	13	41	0.135

Bare soil had its stability lowered by continuous tillage and decreases in certain types of organic matter, and was subject to disaggregation by the stresses of sudden wetting and the impact of raindrops on soft wet aggregates, according to Marshall (loc cit).

In addition to variations in aggregation, brought about by management practices, studies on cropped land by Alderfer (1946) showed that soil aggregation (percentage particles greater than 0.25mm diam.) was subject to wide seasonal variations.

Wilson and Browning (1946) showed that there was an inverse relationship between aggregates greater than 0.25mm diameter and soil losses and runoff. The percentage of aggregates greater than 0.25mm diameter decreased and soil and water losses increased with every successive year of corn following 11 years of alfalfa or bluegrass in Iowa. The above authors considered that the fraction of aggregates greater than 2.00mm diameter was the best index of aggregation as related to soil and water losses.

Aggregate Properties

Friable soil made up of porous water-stable aggregates was a feature of grassland where expanding roots opened up the soil and compressed it into denser masses along the periphery of the channels (Marshall, 1962). According to Marshall, the fibrous roots of grasses, in particular, extended throughout the soil, compressed it into clumps, entangled it, dried it, and incorporated organic matter into it.

Skins around aggregates in certain undisturbed soils have been found to have contained a higher content of clay, iron oxide and organic matter than the rest of the soil. Table 3 shows some properties in the B_3 horizon and its clay skins in a Grey-brown podzolic soil, as found by Buol and Hole, (1959).

TABLE 3 Properties of skins around soil aggregates (from Buol and Hole, 1959)

Property	Clay skin	Whole soil material
Clay content (0.002mm); %	87	24
Free iron (Fe_2O_3); %	3.95	1.90
O.M (Carbon content X 1.72); %	3.09	0.71

After cultivation, field observations by Low (1972) showed a change from fairly rounded crumb-like aggregates and a non-sticky soil to more angular slightly sticky aggregates in 2½ years. Similarly Long and Trow-Smith (1973) reported that following short leys of 1 - 2 years duration, the binding action of undecomposed roots which held crumbs together disappeared within 2 years of ploughing out. Also, much of the binding action and build-up of crumb structure was found to be in the upper layers of the soil and deep ploughing had the effect of diluting this layer.

Large differences in soil type have been shown to exist and generally heavy clay soils required more careful handling than lighter soils (Low 1972). Peele (1937) reported that soils having sandy-loam surfaces may have had a higher percentage of run-off and were more susceptible to erosion than soils with clay surfaces e.g. clay loams.

Emerson and Grundy (1954) found that grassland crumbs had more than twice the strength of those of an

80 year old arable soil at zero rate of wetting. This, they postulated, was probably because the roots in the grassland crumbs provided easy escape passages for entrapped air.

Relatively little work in New Zealand has been reported on this subject, but Gradwell and Arlidge (1971) found that there were some signs of deterioration of soil structure in Putamahoe clay loam after 20 years cultivation in the Pukekohe market gardens. They commented that insufficient attention to cultural practices may have helped the deterioration, and that soil should not be cultivated when wet.

Virgin soil aggregates were found to have a greater mechanical strength at all pF values than unstable cultivated aggregates according to Panabrokke and Quirk (1957). The same authors, in 1962, found that when air dry aggregates were wetted at 2 and 10cm water suctions the cultivated aggregates wetted more rapidly than the virgin aggregates. Work done by rapid wetting caused planes of failure to be set up, and the porous structures collapsed.

Robinson and Page (1950) postulated that the method of formation of aggregates may have been an additional significant factor in determining aggregate stability i.e. in addition to clay mineral type, organic matter, aggregate size and soil wettability.

Aggregates broke up in two stages, (slaking and dispersion,) when immersed in water according to Emerson, 1972). Slaking was the immediate rapid break-up of aggregates into microscopic fragments, and dispersion referred to the slow release of clay sized particles from the slaked fragments. Emerson maintained that soil with good structure could be easily broken down over a wide range of water contents to give aggregates required for a seedbed. When wetted, these aggregates did not disintegrate, and on redrying the soil surface remained porous and did not form crusts.

In addition to the effects of slaking and dispersion impacts of rainfall could cause considerable breakdown of aggregates on the immediate soil surface to form crusts (Chepil, 1952).

Erosion and Drainage

Baver (1948), in his extensive review on the subject of soil physics, suggested that the dispersive action or erosive power of water was determined by the impacts of falling raindrops, the amount and velocity of runoff, and the resistance of the soil to dispersion and movement. (Erosion was only a problem on sloping land. Poor drainage was more of a problem on flat land, according to Baver.)

The following statement by Baver illustrates his view of the importance of aggregate stability in erosion: 'It seems that at the beginning of a long intense rainstorm, soil is eroded as the result of the slaking and beating action of the erosion process. The more granular and resistant the soil to slaking and dispersion, the lower will be the surface density and runoff. As the storm continues, however, and runoff increases, both in amount and velocity, the erosion of the soil depends upon the coherence of the particles in the immediate surface with those underneath. In this case, a highly granular soil will probably erode more per given amount of runoff than one that has a smooth compacted surface.'

Nevertheless - the majority of reported evidence suggests that well aggregated granular soils are more desirable, at least in most situations, because of decreased erosion and improved infiltration and percolation through the soil profile. For example, dispersed soil was found by a number of authors (Peele 1937, Culey 1939, Elson & Lutz 1940, McIntyre 1958, Low 1972, Klingebiel and O'Neal 1952, Peele and Beele 1942) to be less permeable to water and/or liable to increased runoff and susceptibility to erosion.

The following soil losses were recorded by Meyer and Mannering (1961) under various cultivation treatments (table 4)

TABLE 4 Soil losses as a result of cultivation (from Meyer and Mannering, 1961)

	Soil Loss
Conventional tillage	5.9 tonnes/ha
Minimum tillage (Plow-plant) and cultivated during crop	3.0 tonnes/ha
Minimum tillage (uncultivated but protected by weeds)	2.7 tonnes/ha

A decreased soil loss was apparently caused by the elimination of a severe surface crust by cultivation during crop growth, which increased the amount and rate of infiltration.

The majority of the above literature refers to work done in U.S.A. , Australia or the U.K., but Bowler (pers comm) has shown by means of aerial photagraphs how soil structure on a farm at Rongotea (in Manawatu) on Kairanga silt loam, was so damaged by only 3 years cultivation and poor management that further cropping became uneconomical because of severely retarded drainage of surface water through the soil profile.

Soil Crusts:

Lemos and Lutz (1957) defined soil crusting as the hard layer which formed on the soil, principally as a result of the impact of raindrops and drying. They found that crusts with high modulus of rupture values were often found on tilled soils with a high silt content or on some types of clay materials, and also when large amounts of total material less than 0.10mm diameter was present on the soil surface.

Artificial crusts were formed on various soils by McIntyre (1958). He found that crusts formed on two cultivated soils consisted of a thin compact skin seal of 0.1mm thick over the surface and a washed-in layer of varying thickness where porosity had been reduced. He also found that the crust was thicker where water splash was retained (2.5mm) than when splash was lost from the surface (1.5mm) (e.g. as when raindrops bounce off a clod).

Klingebiel and O'Neal (1952), McIntyre (1958), and Duley (1939), all reported decreases in water permeability through crusts, with subsequent increased runoff. Often water infiltration was decreased, whereas the soil layers underneath the crust remained permeable to water. In addition, decreased seedling emergency due to high soil strength, and decreased aeration has been reported by Barley and Graecen (1967).

The Influence of Organic Matter:

Soil organic matter influences a wide range of physical and chemical soil properties, and many experiments have shown that both the quantity and the quality of the organic matter present is important. Martin et al (1955) reviewed the subject of soil aggregation and analysed the many effects of organic matter. They stressed the importance of maintaining a high level of microbial activity to maintain stable aggregation in soils, and this was best brought about by the maintenance of organic residues in the soil. According to Martin and his co-authors, it was generally agreed that organic matter played a key role in soil aggregation. Some workers thought that the main effect was cementation and others that organic matter served to waterproof the soil and so prevented breakdown of aggregates. One point which seemed clear was that the binding action of living micro-organisms and of their products disappeared when the food supply became exhausted and the number of micro-organisms declined; although some organic compounds or by-products may have featured in long-term structure stability.

The subject is extensive, but as a summary, the increased soil aggregation following organic matter application could be brought about by one or more of the following:

'1. Mechanical binding of the soil particles by microbial-filaments or cells during periods of intense microbial activity.

2. Presence of binding substances in the organic residues.

3. Organic waste products formed during the decomposition of the organic material, dead microbial cells or secondary decomposition products.

4. Organic binding substances synthesized by the soil organisms.'

(Martin et al, 1955).

The binding action of undecomposed roots is also important in newly cultivated soils (Long and Trow-Smith, 1973). Rovira and Greacen (1957) reported that exposure of previously inaccessible organic matter by tillage and aggregate disruption increased micro-organism activity as measured by oxygen uptake. Drying and rewetting also caused further increases in microbial activity and subsequent destruction of organic matter. Panabrokke and Quirk (1957) concluded from their experiments that organic matter did not give rise to a finite contact angle for water advancing into virgin aggregates, and so prevented rapid wetting causing planes of failure to be set up.

Low (1972) and Gradwell and Arlidge (1971) reported that maintenance of organic matter levels would have helped prevent soil structural deterioration in many cropped soils. Low (loc cit) demonstrated how the quality of organic matter was important. He found on one soil type that an initial N-content of 0.61%, on ploughing out old grassland, dropped to 0.53% after five years. This was correlated to a marked fall in aggregate stability from 76 to 25% (aggregates greater than 2mm in diameter). The largest single year drop in stability (76 to 35%) occurred in the first year after tillage, as the fresh pasture residues decomposed.

Low (1972) pointed out that the possibility of erosion increased with the number of years out of grass, but suggested that often a balance or equilibrium level of water stability and good structure could be reached by good cropping rotations, which included grass leys and the observation of soil management techniques which maintained the supply of soil organic matter.

Elson and Lutz (1940) considered that the condition of the organic matter was more important than the total amount in causing aggregation, and a 4 year crop rotation which included a leguminous green manure crop gave better aggregation in some of their plots than a continuous sod of shallow rooted grasses. Continuous cultivation of cotton in the same experiments resulted in a significant decrease in aggregation.

2.4 TILLAGE AND PLANT GROWTH

Seed Germination and Plant Growth

It has been generally accepted that the germination, emergence and establishment of crops from seed can be influenced by physical properties of the soil environment in which the seeds are placed.

Often the micro-environment for the seed is greatly influenced by the seed-drill. Morton and Buchele (1960) stated that no single value or group of values expressed the optimum conditions for germination and emergence. Factors such as soil moisture content, seedbed tilth, depth of planting, amount of compacting pressure, aeration, and mechanical impedance needed to be described before designing a planting unit.

Indications from many experiments (Russell 1966, Davies 1960) were that the most critical period in growing a direct-drilled crop was during germination and establishment. This was found to be partly because of problems created during introduction of seed into soil e.g. placing the seed into a smeared or compacted slot under the surface (Dixon, 1972).

Baker (1969) reported that this type of problem might cause the elongation of the hypocotyl and radicle to force the seed away from a potential entry site into the soil. Also, young seedlings might be easily damaged by cutworms, wireworms and slugs which Harrold et al (1970) reported were sometimes a problem in untilled soil.

Trouse (1971) stated that seeds required some firming of loose tilled soil around the seed-coat to establish a moisture contact with the soil. The extent of firmness required was not known but varied with soil texture and moisture content. Stout et al (1961) studied the question and found that sugar-beet, beans and corn emergence was suppressed by pressures in excess of 0.5p.s.i. applied to the soil surface. However, pressures of 5 to 10 p.s.i. applied at seed-level improved emergence. Stout et al's results indicated that planters should be designed to apply the higher pressures to the soil at seed level, but should leave the soil relatively loose above the seed.

Poor drainage or insufficient aeration is referred to as adverse to germination by many authors. For example, Vlamis and Davies (1943) and Drew et al (1971) reported extreme sensitivity in cereal seeds to O_2 deficiency or decreased aeration.

Seedlings emergence has often been shown to be affected by soil surface seals which restrict aeration and surface crusts which mechanically hinder emergence, by Hanks and Thorpe (1956), and McIntyre (1955). Arndt (1956) found that surface seals may have caused impedance to seedlings up to nine times that of loose non-crusted soil. Pea seedlings were found by Arndt to survive 30 days of delayed emergence under a soil seal. Failure to lift the seal was apparently due to low lateral resistance on the shoots rather than high vertical resistances.

Grable and Siener (1968) stated that a large volume of air porosity in a soil sample did not necessarily mean that the whole volume of the soil was well aerated. For example sufficient water drained from samples of non-compacted soil and large aggregates at -2cm of water suction to produce from 14-22% air porosity, yet corn seeds in the soil were still covered with water, which prevented germination.

Cocks and Donald (1973) pointed out the importance of having soil conditions suitable for germination, since the more rapidly a seed could germinate the greater its immediate and long-term advantages over weed seeds in the area. It has been generally accepted that a moist, loose, fine, well aerated tilth in close contact with the seed was most desirable for germination and emergence (Baver, 1948). However, a number of more recent authors have considered that the conditions under an undisturbed soil profile were in a more suitable condition and should be preserved. This view was well expressed by Kuipers (1970).

2.5. CROP GROWTH AND YEILDS

Usually a farmer is primarily interested in the yield of a crop and has the idea that he is increasing the potential yield when carrying out tillage operation. Blake (1963) noted that seeds were usually placed 1 - 5cm deep in loose and finely pulverized soil, yet many experiments have indicated that crop yields were surprisingly independant of the cultivation treatment if the land was free of weeds. Moffatt (1970), During et al (1963), Pereira (1941) and Cook et al (1953) found that yields of crops did not vary greatly with tillage treatment. Cook et al (loc cit) considered that it was usually unnecessary to till soil more than was necessary to make accurate or uniform planting possible. During et al (loc cit) suggested that one of the major factors in determining crop yields was the influence of cultivation on the mineralisation of organic nitrogen.

However, other experiments have shown that many crops are sensitive to soil conditons, especially pore space and air content. For example, Boekel (1963) increased crop yields 25% by improving structure of a heavy clay soil. He found that a silt loam had an optimum pore space (for crop yield) of 48-50 vol. % which corresponded to an air content, at pF 2, of 14-17 vol %. In coarser grained, sandy soils, the best air content, at pF 2, was about 20-25 vol %. Boekel reported that at higher air contents, water deficiencies occurred, and at lower air contents mechanical resistance of the sandy soil to root growth, occurred. On the other hand, Gradwell (1965) found that the growth of grass fell with increasing soil bulk density only when it was accompanied by low soil aeration. According to Gradwell, the lowest content of air pores associated with optimum growth varied from 7 or 8 vol % down to about 2 vol % in one trial.

Boone and Kuipers (1970) considered that the mean pore space (as recorded in most experiments) was less important than the necessity for pores to be adequately distributed throughout the soil mass. They put forward the idea that roots needed channels no larger than 1mm in diameter, and a well developed root system (of about 20 tonnes roots/ha) could grow in a channel system of only about 1% ($^v/_v$) of the soil in a 20cm deep arable layer. They explained that the pores and channels must be continuous, mainly vertical, enable water diffusion, and must be distributed so that they suited the root system.

Soil density and root penetration

The ability of roots to penetrate dense soils or soil layers varied with soil type, and also with moisture availability and aeration in many experiments. Veihmeyer and Hendrickson (1948) found that a bulk density of 1.75g/cm^3

in sands and $1.5g/cm^3$ in clay materials excluded roots in their experiments. Hettiaratchi and Ferguson (1973) described how roots penetrated compact soils by elastic and plastic deformation of the soil. Some roots could penetrate very compact soils capable of developing up to 5 times the resistance the root cap could overcome by straightforward growth. Zimmerman and Kardos (1961) found a significant correlation between soil bulk density and the weight of penetrating soybeans and sudan grass roots. They considered that oxygen was not limiting in their experiments. Veihmeyer and Hendrickson (1946) reported that grapevines and sunflower roots could not penetrate a gravelly loam at density of $1.8g/cm^3$, and Barley et al (1965) provided evidence that soil strength had an important influence on the penetration of clods or finely structured layers by roots.

Soil crumbs and root growth

It is not possible to say what the 'optimum crumb size' of a seedbed or rootbed should be, especially when requirements of erosion control, drainage, and crop growth and soil management have to be considered. Currie (1961) put forward the concept that a universally accepted 'optimum crumb size' for a given soil would preclude the onset of anaerobic conditions in the range between wilting point and field capacity during the crop growth period. Internal crumb structure must also be considered, noted Currie, and this was partly influenced in turn by plant roots, micro-organisms, nutrient supplies, and water content.

Direct-drilling and plant yields

Bakermans (1970) reported that small-grained crops, maize, and cereals did not usually show yield decreases on naturally compacted soils (e.g. direct-drilled soils), but root crops, peas and beans may have been more risky. Blake (1963) cited an experiment where potato tubers were of lower specific gravity and nearer the surface in deliberately packed silt loam.

Table 5 shows yields of crops reported by Bakermans (loc cit).

TABLE 5 Yield of potatoes (100kg/ha) on light sandy loam. (from Bakermans (1970)

N-fert kg/ha	Cultivated soil yield	Nat. compacted soil yield
100	351	277
200	367	375
300	382	381
	Seed yield of rye (100kg/ha) on sandy soil	
30	31.4	25.5
80	44.3	42.5
130	47.5	48.0
180	44.7	46.0

Bakermans noted that greater flexibility of planting dates was an advantage on non-tilled soils.

Baeumer (1970) observed that the reason for yield depressions in direct-drilled crops was often due to failure of seeding techniques and weed control. Lower stand densities were caused by inadequate performance of drills (table 6).

TABLE 6 Stand densities of (means of wheat barley and oats) (from Baeumer, 1970)

	Stand	Yield (3 years results)
Ploughing	100	100
direct-drilling	86	85

Often poorer germination and establishment of crops may have been compensated for later in the growth cycle. Black (1966) described how it was found that plants adjacent to a gap compensated for a missing plant by increased growth, sometimes up to 80-90% of the lost yield being compensated. Baeumer (loc cit) claimed that direct-drilled plots could equal or surpass conventionally tilled crops by adding nitrogen fertilizer, even with 30% less plants, but that generalizations were not possible because of variable results.

2.6. ENERGY REQUIREMENTS OF TILLAGE

There is little doubt that different tillage methods and operations have different energy requirements, as illustrated in table 7 as typical fuel consumptions for some field operations:

TABLE 7 Fuel consumption during cultivation (from Baron, 1974)

Operation	Fuel consumption litres/ha
ploughing	17.9
rotary cultivating	14.6
sub-soiling	10.2
disc-harrowing	9.0
spring-tine harrowing	5.6
drilling, mowing, distributing fertilizer	3.4
rolling	2.2
spraying	1.1

Similarly, Browning et al (1944) showed that the relative labour inputs and power requirements of various field operations varied greatly. Te Pori and Stapleton (1967) further considered that the function, capacity, energy input and the yield of a crop must be considered to effectively compare different machinery systems. They carried out experiments in Arizona with cotton. Some of their results are shown in table 8.

TABLE 8 Machine system and energy input (from Te Pori and Stapleton, 1967)

Machine system	Decrease in energy input (Fuel) %
1. Disc, float, disc, float list	0
2. List	77
3. Chisel list	76
4. Chisel/Chisel list	70

Le Pori and Stapleton noted that zone tillage produced up to 80% savings in total time input for land preparation, (zone tillage created fine soil in rows with a cloddy structure between rows to aid water infiltration and help against wind erosion). Dowding et al (1967) also studied tillage methods in U.S.A. and found that energy requirements varied greatly with the method used.

Factors Affecting Energy Requirements:

Many factors which affect energy requirements of a tillage operation can be imagined. Bateman et al (1965) demonstrated in laboratory experiments how the energy requirements of tillage were affected by soil physical conditions, by the amount of pulverization, and by the method of applying failure forces to the soil. From their experiments it was indicated that soil compaction increased the energy requirement more for secondary tillage (e.g. discing or harrowing) where the soil was pulverized to a fine condition; than for initial tillage such as ploughing. Bateman et al cited similar experiments which found that the strain needed to break clods by impact was less than the strain needed for clod failure by applying a static load, but the energy required by the impact method was greater (89j/kg cf 18j/kg soil). This was so for clay soil, but there was little increase in shear strength of sand under the same load comparisons.

Bowditch (1969) reported that the energy required by tillage operations increased rapidly as the size of the clods produced was decreased and as prior compaction of the soil was increased. Other factors such as clay content, soil drainage and organic matter content were found by Haines and Keen (1925) to affect draw-bar pull. These authors made maps showing isodyne contours (i.e. lines of equal drawbar pull) which correlated with the relative levels of clay in the soil within the paddock.

Payne (1956) considered that the property to which draft of implements was most sensitive to, was soil cohesion. He reported that soil cohesion varied over a wide range of conditions with such things as soil texture, soil moisture content, state of soil aggregation, the presence of binding roots and perhaps the base status of the soil under cultivation. According to Payne the draft of cultivation tines increased almost linearly with soil cohesion, and he also noted that draft increased with working depth and the design of the tool faces.

The design of the tillage implements and machine working conditions:

Various experiments have been carried out to determine the effects of machine design on draft characteristics. The angle of shearing resistance, angle of soil/metal friction and adhesion are relatively constant for any non-pto driven machine, according to Payne (1956). He claimed that these properties had the greatest effect on the resultant force on the implement and were therefore important in machinery design. Volume of soil upheaval also influenced draft of an implement.

It is possible to design 'speed' blades or 'power' blades for rotary cultivators, and Beeny (1973) showed that 'speed' blades used only 75% of the tractor power demanded by 'power' blades with no observable differences between the puddled seedbeds created by both types of blade. Earlier, Beeny (1964) summed up what he considered to be the disadvantages of rotary cultivators as follows: 'the cutting surface area/volume ratio of soil worked is too high and the tool speed is too fast - both resulting in extremely high specific work requirements.'

Machines such as the 'Lely rotavator' could decrease the number of operations required from at least two, with an ordinary rotavator, to one, according to Hoogerkamp (1970). The Lely rotavator tossed up fine soil which then passed over a grid, struck a metal plate, and fell down above the larger soil clods and turf pieces, when used to till an old grassland sward.

Work carried out by Hepherd (1967) with ploughs, cultivator tines, discs and hoes, showed how changes in draft were caused by speed variations, soil gradients and depths of working. For example, increasing speed from 4.2kph to 8.9kph increased draft of ploughing from 12450 N to 16000 N, while changing plough depth from 192-260mm resulted in a draft increase of 80% from 11100 - 20000 N.

Speed and related aspects

There are various methods by which a tillage operation can be speeded up. However it can sometimes be difficult to decide how an operation can be speeded up for the least increase in machine operating costs. For example, Lehoczky (1967) reported that the rate of work of a 2-furrow plough can be increased by 50% either by converting the plough to three furrows or by increasing its speed by 50%. In the first case a 50% more powerful tractor weighing 50% more was required; in the second case a tractor having 60% more power but only 10% more weight would do the job. Lehoczky cited work which showed that ploughing could be performed more economically by travelling faster even if it meant reducing the number of furrows. The hourly rate of fuel consumption increased but the fuel use per unit area decreased.

Ghosh (1967) studied the power requirements of a rotary cultivator at different rotor or travel speeds, when working at different depths, and under various soil moisture conditions. He found that the rotor torque requirements varied directly with forward speed and the depth of working, and inversely with the speed or rotation.

2.7 AN INTRODUCTION TO EXPERIMENTAL TECHNIQUES

2.7.1. The Measurement of Structure and Stability:

Of the various ways of assessing the physical condition of a soil, measurements concerned with porosity were considered by Low (1972) to be the most helpful. Low measured such things as total pore space, pore space occupied by water, and pore space occupied by air in his experiments which commenced in 1945. In addition, Low measured such things as the water stability of aggregates, aggregate sizes (by dry-sieving), changes in the 'sticky point' of the soil mass, and changes in draw-bar pull. Field observations were also important in characterizing changes in soil structure with time. Other authors, (Yoder, 1937, Byers and Webber, 1957, Alderfer, 1946, Kuipers and van Ouwerkerk, 1963) measured similar characteristics in order to describe soil structure.

Ideas have changed in some part, in recent years, and it was strongly suggested by Boone and Kuipers (1970) that a measurement such as mean pore space may not have been very relevant, either to a plant root or to soil drainage and aeration. The reason given was that soil porosity was a highly variable soil parameter, and the average of a large number of measurements eliminated the extreme values which were relevant, to determine the soil characteristics of usual interest. The continuity and distribution of pores and channels were also not revealed by parameters such as mean pore space.

Measurement of soil stability

According to Kemper (1965) and Emerson (1972), the main method of assessing the structural stability of a soil has been to determine the percentage of water stable aggregates, and a review of this method of soil analysis was given by Kemper (loc cit). Kemper stated that the stability of clods and aggregates was important for the continued existence of an abundant soil porosity favorable for high infiltration rates, good tilth, and adequate aeration for plant growth, usually present immediately after cultivation.

Various methods of separating and measuring wet aggregates have been reported e.g. sedimentation, and elutriation. However, wet sieving has commonly been used and could be complemented by dry sieving (Kemper 1965). Russell and Feng (1947) studied the water stability of aggregates sieved from four Iowa soils, and indicated the different stabilities and rates of disintegration of aggregates from the soils.

Other authors have often developed their own particular methods of measuring soil stability, sometimes influenced by the particular field of study they are interested in. For example, Reeve (1953) described a method for determining the stability of soil structure based on the change in permeability of the soil to air caused by the instability of the soil to wetting. Marshall and Quirk (1950) determined the stability of dry aggregates by a drop-shatter method, and Chepil (1952) considered that the mechanical stability of dry aggregates as measured by dry sieving was more useful than wet sieving. Nijhawan and Olmstead (1947) discussed wet sieving techniques and stated that there was no standard procedure. This, they suggested, was probably because the procedures used were purely empirical with no clear relationships between laboratory tests and behaviour in the field.

Expression of Wet Sieving Results:

The various methods of expressing aggregation data were reviewed briefly by Kemper and Chepil (1965). They supported the opinions of Schaller and Stockinger (1953) that the best parameters for expressing aggregate-size distribution data were either mean-weight-diameter, geometric-mean-diameter, or the log standard deviation. Kemper and Chepil (1965) considered that the mean-weight-diameter was easiest to calculate, and easiest to understand. Graphical methods of calculating it and plotting it were demonstrated by Van Bavel (1949). A shorter and quicker method of obtaining mean-weight-diameter was later given by Youker and McGuinness (1956).

Schaller and Stockinger, (1953) maintained that the expression of sieving restuls, by a single size fraction of sieved soil, was a reliable as other methods, but indices which utilised all size fractions needed fewer replications.

Gardner (1956) found that the aggregate-size distribution in most soils was log-normal rather than normal and described a method of graphically representing a log-normal distribution from soil sieving data.

Stirk (1958) pointed out advantages and disadvantages of various ways of expressing data and concluded that the use of simple values which were convenient for use in individual situations, or the use of a uniform method with the acceptance of its particular limitations were the only alternatives. Stirk emphasized that the implication that mean weight-diameter was some 'real' property of the soil aggregate distribution should not be encouraged. However, it was nevertheless a useful parameter to use in interpreting experimental results.

2.7.2 The Use of Penetrometers

Methods of determining the bulk density and penetrability of soils were reviewed by Vomocil (1957). He stated that the penetrability of a soil depended on the texture, structure, mineralogical composition, moisture content and the compactness of the soil. He also noted that other soil variants affected a penetrometer e.g. plant roots, and that it was often difficult to interpret the empirical results obtained, especially when comparing different soil types or methods of soil management.

Farrell and Greacen (1966) found that the penetrability of a pointed probe was reduced by about 50% by rotating it, but rotation had only a small effect on a blunt probe.

Barley et al (1965), Barley and Greacen (1967) and Greacen et al (1968) suggested that plant roots allow penetration of soils other than by the mechanism of an ordinary metal penetrometer, and that this had to be considered when interpreting results. Penetrometers were used by these authors to determine soil strength.

2.7.3. <u>Measuring Power Output Through Fuel Consumption</u>:

The measurement of power output of various machines in field studies by measuring fuel consumption was considered by Baillie (1969) to be of interest to people requiring a cheap and easy method, and a not too high order of accuracy. Other methods e.g. determining power/speed relationships from tractor performance data, tended to be complicated, especially when pto-driven and towed implements were being used, although more accurate results might be obtained.

Chapter 3. EXPERIMENTAL METHODS AND MATERIALS

3.1 Organisation of Trials

3.1.1. Experimental Site

The site selected was situated on a terrace on the Massey University sheep farm on the north side of the Palmerston North-Aokautere road. The trials were located on a very slightly sloping ground with a northerly aspect.

Soil-type was Tokomaru silt loam with poor natural drainage, but which had been mole-drained within the previous 5 years.

It was expected that this relatively heavy soil-type would be sensitive to cultivation management systems and was therefore suitable for comparison of tillage methods.

3.1.2 Design of Trials

Two main field trials were carried out. The first trial was commenced in early April, 1973. Four treatments were established, these were:-

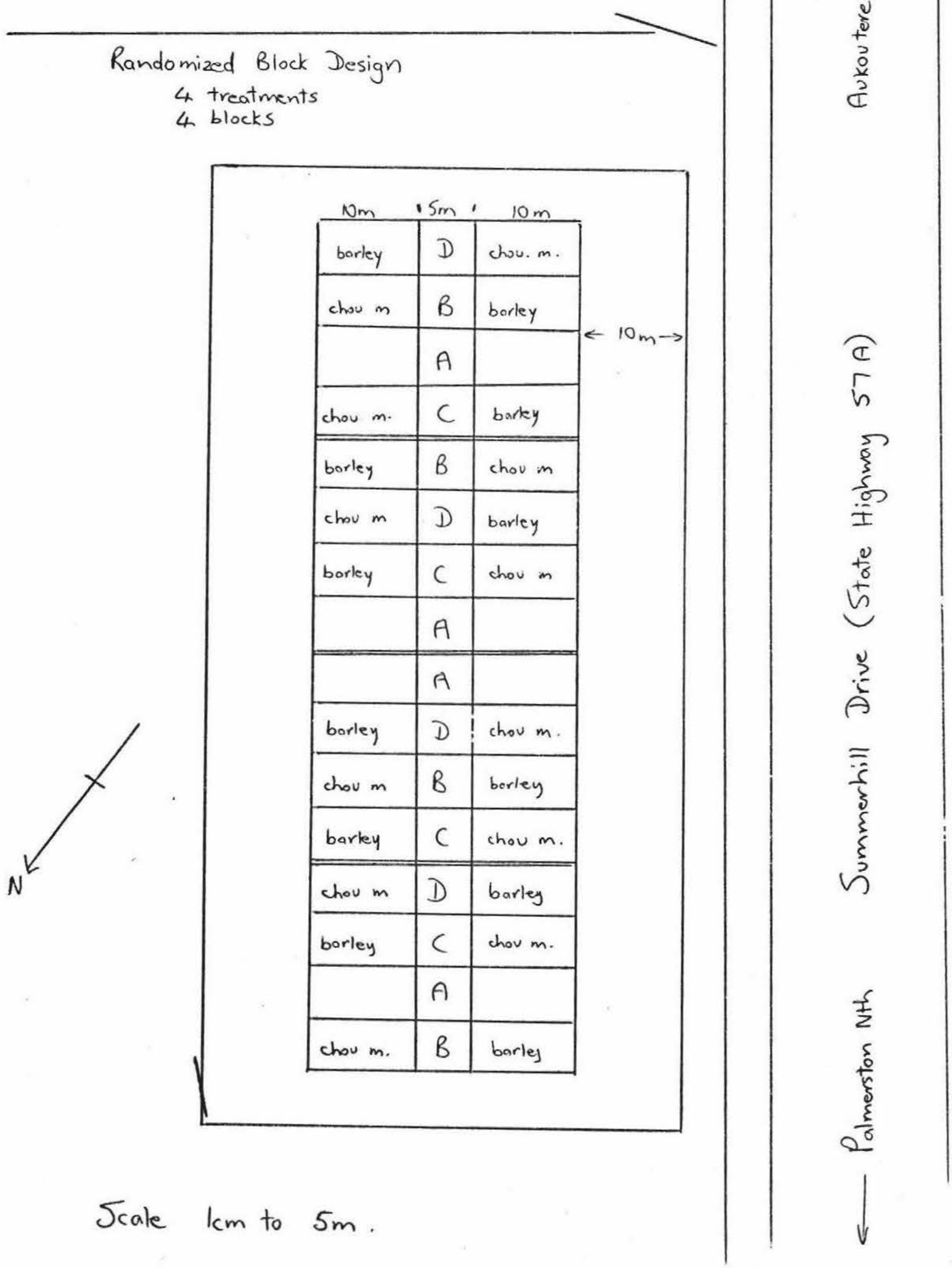
- A - control; left in ryegrass-clover pasture.
- B - direct drilled, non-tilled.
- C - traditional plough/disc/harrow tillage.
- D - rotary cultivator (Howard Rotovator) as main tillage implement.

The appropriate plots of the first trial were tilled and left fallow over the winter period. The second trial was laid down in August, 1973 and was similar in design to the first ('fallowed') trial except that this second trial involved no fallowing. It is referred to as the 'non-fallowed' trial.

The respective treatments were chosen as being representative of commonly used tillage methods used throughout New Zealand. The paddock in which the 'non-fallowed' trial was situated was adjacent to the 'fallowed' trial, but there may have been slight physical differences

Figure 1 Plan of Trial 1

Fallowed over winter 1973

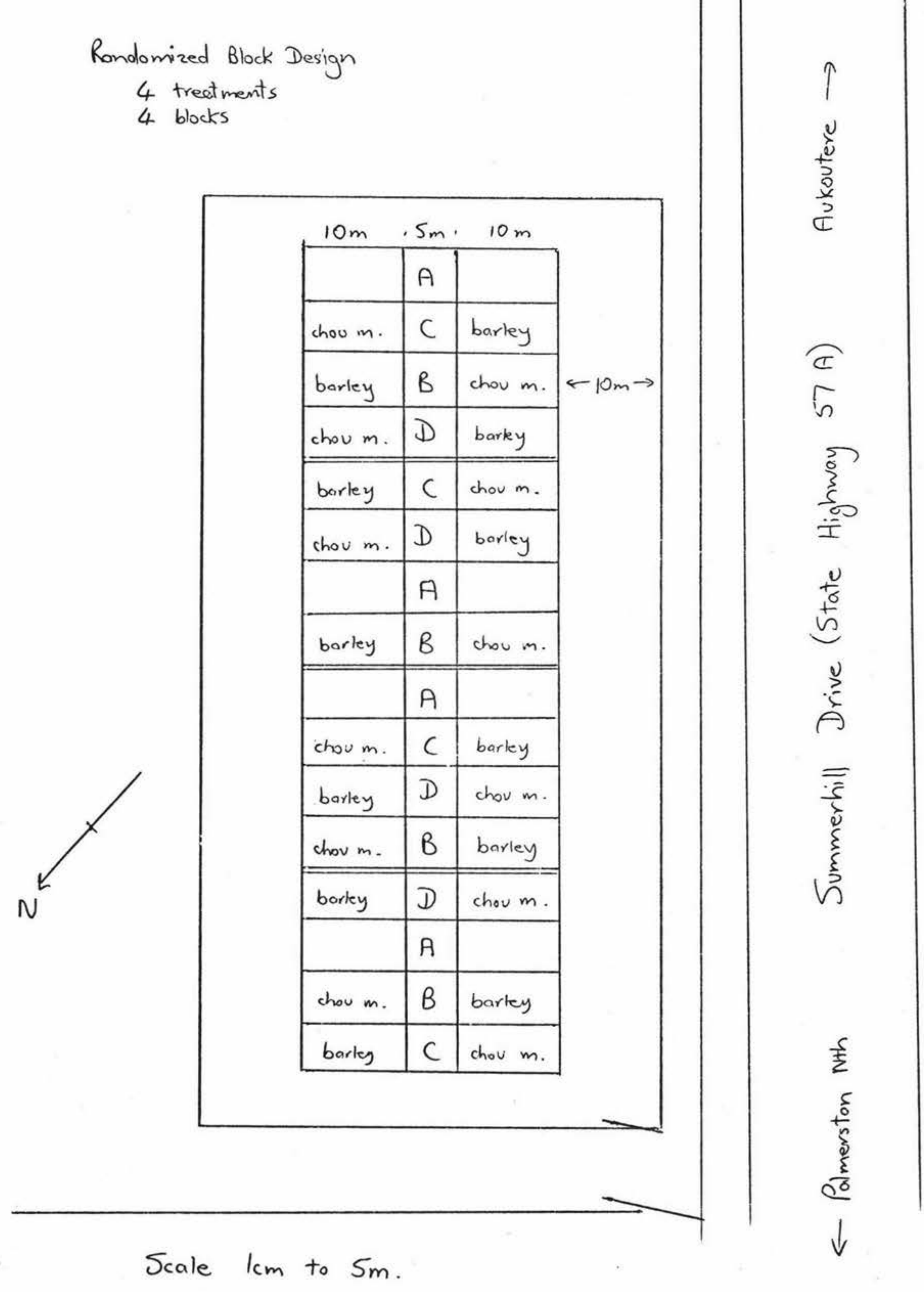


Scale 1cm to 5m.

Figure 1 (Contd.) Plan of Trial 2

Left in Pasture over winter 1973

Randomized Block Design
4 treatments
4 blocks



Scale 1cm to 5m.

because cattle had spent part of the winter on the second trial area and had noticeably pugged the ground before the trial commenced. Statistical comparisons between the results from the two trials were therefore not carried out (i.e. the results from the two trials were not 'pooled'). Instead, each trial was regarded as being on d ifferent soil conditions.

Before tillage operations were commenced, the plots were mown to bring the pasture to a common base height. The direct-drilled, (non-tilled) plots were sprayed with 5.6 litres/ha Paraquat and 2.8 litres/ha Dicamba, in 345 litres/ha water, to kill existing pasture plants.

3.1.3. Plot Layout

Plots were laid out as shown in figure 1 in a randomized block design with four blocks of four treatments in each trial. A minimum of four replications of each treatment were considered necessary, but the overall size of the trials was determined to some extent by the dimensions of the available ground. Thus, a total of 32 plots were involved in the two trials.

Each "cultivation" treatment plot was divided into two as shown in figure 1 for the purpose of sowing two crops. Control plots were left in pasture throughout the experiments and periodically mown.

Each plot was 5m wide (2 drill widths) by 25m long with a 5m headland between the two 10m lengths, to permit operation of the seed-drill when sowing the two crops. Block headlands of 10m were used to give the tractor and implement distance to accelerate to working speed before the plot was reached. This enabled better estimates to be obtained of fuel use per plot.

3.1.4 Tillage Operations

The tillage operations were carried out as shown in the results of fuel measurement (Appendix 1).

Discussions with Messrs Baker, Bowler and Simms of the Agronomy and Soil Science Department at Massey University were often undertaken prior to tillage operations. Decisions as to which particular tillage operation was necessary at any time were largely subjective, and a panel of opinion was therefore thought to be more meaningful.

Timing of operations depended on the weather, and working of the ground when the soil was wet was avoided as much as possible. It could be reasonably assumed that tillage operations thus followed a "normal" pattern, consistent with the limitations imposed by weather and human judgement.

3.1.5. Sowing of the Crops

Medium stemmed chou moellier (at 2.97kg/ha) and Carlsberg barley (at 114kg/ha) were sown (see figure 7 for planting layout) on 29th and 30th October 1973. A basal broadcast dressing of 200kg/ha, 30% potassic superphosphate was also given to the plots at the same time. A "Duncan 730 Multi-seeder" drill equipped with experimental chisel coulters, set at 150mm row spaces was used.

On December 18th, 1973 all chou moellier planted sub-plots were sprayed with "Fodderkleen" (at 3.35kg/ha). The most serious problem with weeds was in the non-fallowed rotary cultivated plots. The two predominant weed species in the trial 2 (non-fallowed) plots appeared to be fathen (Chenopodium album) and twin cress (Coronopus didymus)

In the trial 1)winter fallowed plots) the predominant weeds appeared to be flatweeds (Plantago sp.) docks, (Rumex sp.) Prince of Wales Feather, (Amaranthus hybridus) and other rhizomatious species. All the chou moellier plots were sprayed in order that crop differences due to the spray treatment would be minimised.

3.2 MEASUREMENT OF ENERGY INPUTS

During the course of the reported trials, estimates of the relative energy inputs to the soil in each tillage treatment were obtained by measuring the approximate nett fuel consumption of implements used in each treatment. Comparisons could then be made of the relative efficiency of tillage methods in terms of the amounts of fuel energy used, the soil structures obtained, and the responses of a crop.

During the course of the trials, this aspect became even more relevant due to the greatly increased cost and decreased availability of tractor fuels during the year 1973 and 1974, compared with previous years.

A devise for measuring the relative amounts of fuel used on each plot was designed. A petrol-engined "Massey Ferguson 135" tractor was used during the project, because difficulties might have been experienced when using a diesel-engined tractor in excluding air bubbles from the fuel system. The Massey Ferguson 135 tractor was considered to be reasonably typical of tractors used on New Zealand farms, so results using this tractor should be relevant to many farm situations.

3.2.1 Design of Measuring Apparatus

In designing the fuel measuring system it was considered that a high order of accuracy was not required, since only the relative amounts of fuel used in each tillage treatment was of interest and not the absolute amounts. However, requirements which were considered to be important included the following:-

(a) - The measuring apparatus had to be easy to use while driving the tractor.

(b) - The method of recording the results and setting up the apparatus had to be quick and reliable under the working conditions at the experimental site.

(c) - The apparatus had to be inexpensive to construct.

(d) - The apparatus was required not to interfere with

normal day-to-day operation of the tractor when not being used in the experiments.
The completed apparatus is shown in Plate 1, attached to the tractor frame, and a diagram is shown in figure 2.

PLATE 1 Fuel Measurement Apparatus

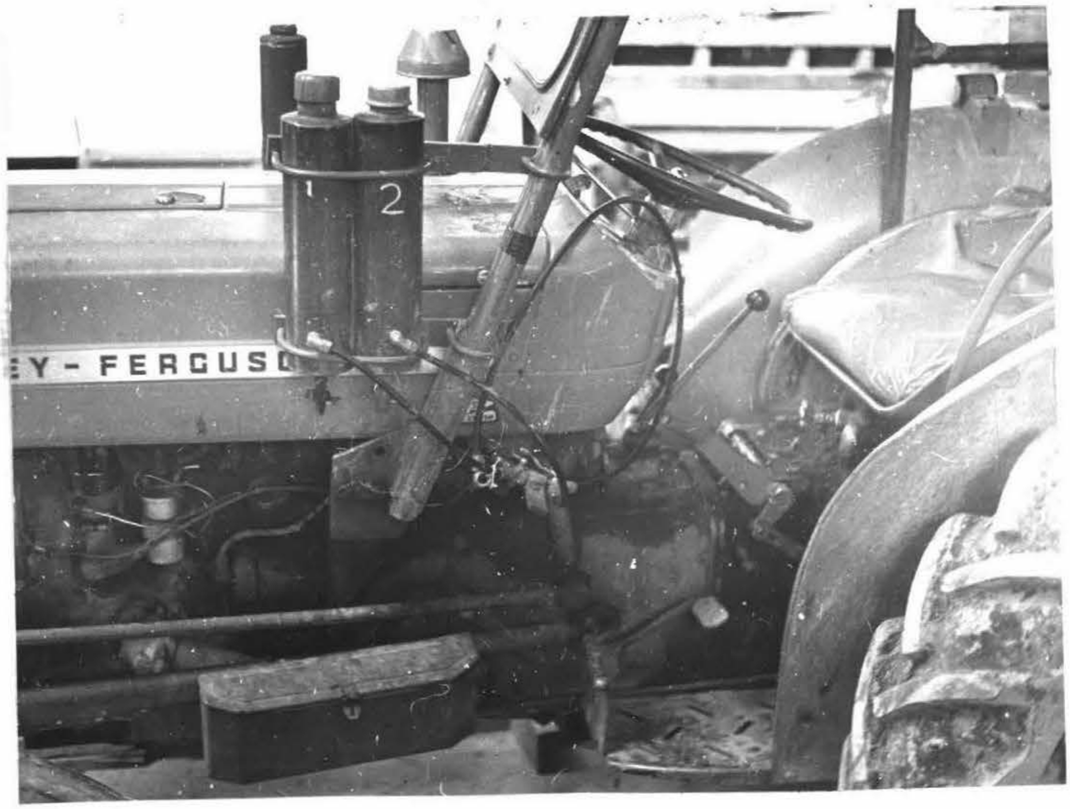
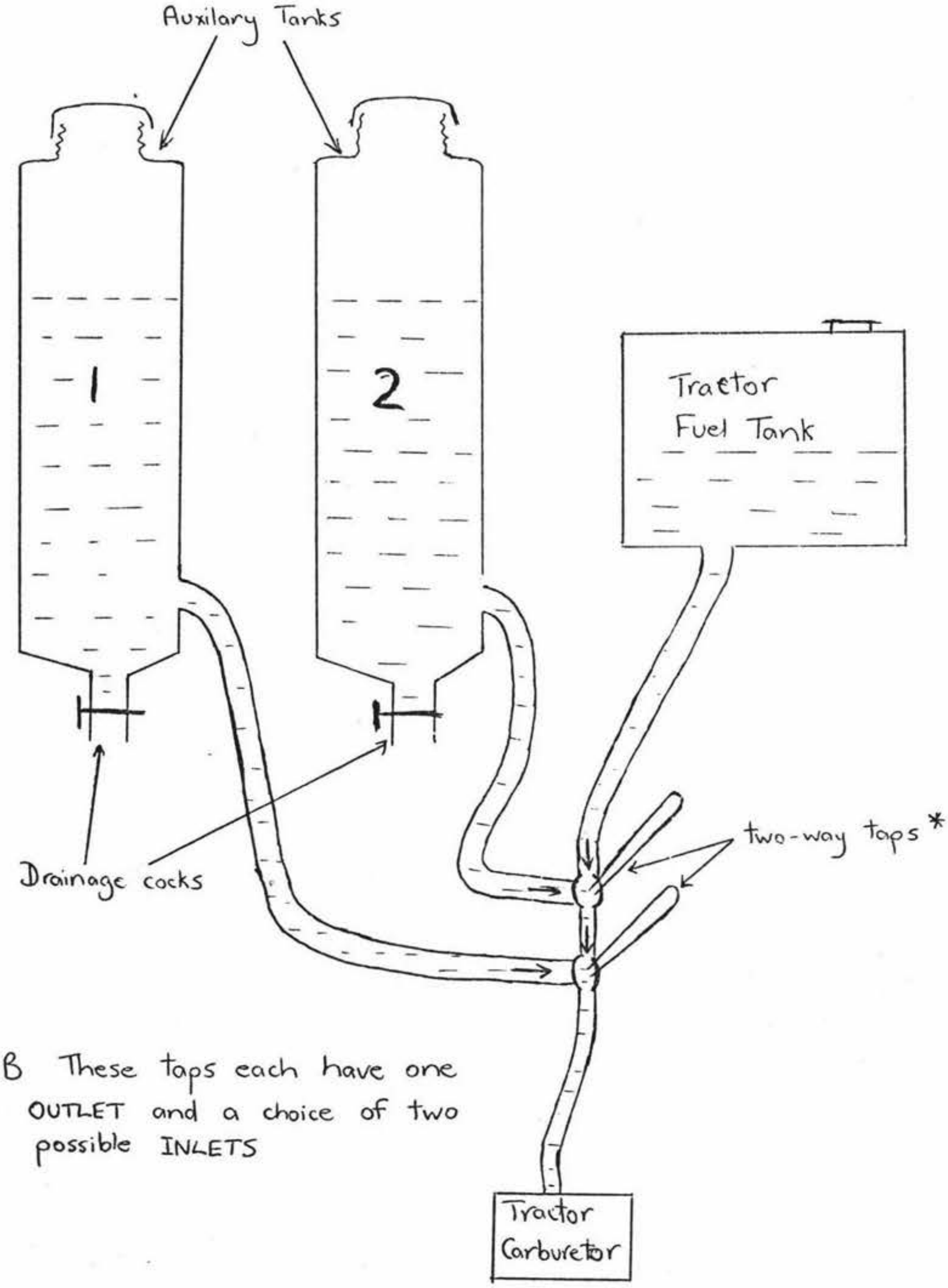


Figure 2 Diagram of Fuel Measuring Apparatus



* NB These taps each have one OUTLET and a choice of two possible INLETS

The method of operation involved filling numbered bottles with measured quantities of fuel in the laboratory before going out into the field. Fuel was poured into the auxiliary tanks before starting an operation, and after the tillage operation the tanks were drained back into the appropriate bottles, which were weighed again on returning to the laboratory. The amount of fuel used was calculated by subtracting the amount of petrol left in the bottle from the original amount put in.

When the tractor was in normal operation, the taps shown in fig. 2 were adjusted so that fuel flowed directly from the fuel tank to the carburettor. When it was required to measure the amount of fuel being used, petrol was directed to flow from an auxiliary tank, (when the taps were appropriately arranged), as the tractor passed between marker pegs delineating the dimensions of a plot. By using two auxiliary tanks, two plots were able to be worked without the need to empty and refill the tank from the numbered bottles at the completion of each.

A study of the diagram in Figure 2 will show that it should never be necessary to move more than one of the two taps to select either of the two auxiliary tanks or to switch from either of the two back to main fuel supply.

3.2.2 Accuracy of Fuel Measuring Method

Initial tests on the auxiliary tank resulted in several minor adjustments being made to the apparatus, and it was concluded that the accuracy of the recording of fue l consumption by the tanks was dependant on:-

(a) - The elbow outlets from each tank being at a constant and similar vertical angle (to ensure consistant residual fuel remaining, upon "emptying" each tank).

(b) - The tanks being prefilled and drained before experimentation to allow for petrol adhering to the insides of the tank, and to fill the outlet hoses with petrol.

(c) – The operator turning taps on and off at correct times when passing markers.

Unaccounted-for losses occurred, probably through evaporation and adherence of petrol to drainage taps and boittles etc. This was deomonstrated by putting a known weight of fuel into the tank and immediately draining it out again and reweighing. Repetition of this operation nine times showed that approximately 0.3% of the petrol put in a tank is lost to unaccounted-for reasons. However it was decided to ignore this, since errors in operator judgement and accuracy when operating the fuel tank selector taps were likely to be a source of greater error when using the apparatus.

Some idea of the sensitivity of the method can be gained from Table 9 which shows results obtained when operating the tractor on slightly sloping ground while driving a rotary cultivator at two speeds. The fuel used over a distance of 10 metres was measured going both up and down the slope.

TABLE 9 Fuel used by rotary cultivator

Tractor gear 1st ("Mulitpower" selector on high). Engine speed, 1700 rpm.

	Petrol used (g)	
Howard Rotovator cultivator	up slope	down slope
Drive Gear ratio 17 – 18 tooth sprockets	35.2	28.5
	31.7	30.0
20 – 15 tooth sprockets	28.0	25.8
	27.2	26.0

3.2.3 Tractor Operation in the Experiments

Three gear ratios were used througnout the reported trials, each with the "multipower" selector set on "high". These were 3rd, 2nd, and 1st. The gear selected, depended on the implement being used. For example 1st was usually used to drive the rotary cultivator since the tractor lacked the power to drive it in any higher gear, and 3rd was used to pull the roller since the optimum results appeared to be obtained at this speed with this implement. Faster speeds than those listed here, were not used even when desirable (e.g. when using a leveller). This was because of the difficulty in accelerating and controlling the tractor in the confined space of the headlands, in order that a constant engine speed of 1700 rpm could be maintained on the 20 metre length plots. A constant engine speed of 1700 rpm was chosen because it enabled easier comparisons to be made of results between treatments. This was because of an assumed constant specific fuel consumption at one engine speed and also because this was the engine speed consistent with standard 540 p.t.o. speed. (No test report could be found on this model of tractor so engine efficiency at the stated speed is not known).

The 3 gears corresponded to the following nominal road speeds respectively - 6.6 kph, 3.6 kph, and 2.4 kph (Operator Instruction Book MF 135). No allowance is made for tyre-slip with these speeds.

During the trials, the amount of energy used by the various implements on the soil was of most interest. It was therefore decided to obtain some idea of the energy used in overcoming rolling resistance of the tractor. The tractor was run without implements at the gear ratios listed on cultivated plots of the same size as the trial plots. A summary of the results is shown in Table 10. Other minor variable energy losses or gains would be expected to have occurred, (including those arising from hydraulic operation), but these were ignored.

TABLE 10

Mean amount of Petrol (g) used by tractor alone/20m length at 1700 rpm. (5 reps)

Gear selected			
3rd	2nd	1st	
11.9g	22.3g	26.8g	LSD 0.01 = 6.5g LSD 0.05 = 4.4g

These values were used to obtain (by difference) the net amounts of fuel used per plot by the implements in each tillage treatment.

The results shown in Table 10, were obtained on a cultivated seedbed, consolidated with a roller but with many clods 50-75mm in diameter on the surface. Differences in the rolling resistance component of the total power used in operating the tractor alone will vary with the state of the soil surface, e.g. rolling resistances will be higher on a newly ploughed area than on a rolled seedbed or hard pasture. For the purposes of this experiment the values obtained in Table 10, were considered sufficiently representative to be used over all the tillage treatments to obtain comparisons of the energy exerted on the soil through the various implements.

3.2.4 Drilling & Fuel Use

Drilling of the crops was done with a "Duncan 730 Multi-seeder" drill on which the coulters were raised and lowered by a hydraulic ram. The ram was operated by the internal hydraulic pump of a "Ford 5000" tractor which was used during the drilling operations, beca use the Massey Ferguson 135 used in the other operations was not equipped to handle this particular drill. Estimates of fuel use during drilling could not be obtained using the 'Ford 5000' tractor.

Estimates of the amount of fuel used while drilling cultivated and non-cultivated plots were done later in the year using the Massey Ferguson 135. By that time the drill had been fitted with an independent closed circuit hydraulic system driven by a 2hp auxiliary engine, which enabled the drill to be used behind any tractor.

An estimate of the total amount of fuel used in operating the drill in non-cultivated ground was made by making four 20m runs with the drill coulters at approximately 25mm depth in a dry pasture soil (i.e. about 15% m c.w/w). The results are shown in Table 11 along with the results obtained doing similar experiments on a cultivated seedbed.

TABLE 11 Fuel used in drilling

(g) petrol/20m run. Using 2nd gear.

Non-cultivated Soil		Cultivated Soil	
Run 1.	85.1	1.	82.2
2.	92.6	2.	75.6
3.	99.1	3.	85.7
4.	80.7	4.	86.1
Mean	89.7		82.4
Nett less Tractor R.R.	44.8		37.8

The above mean values can be regarded as rough estimates only as petrol consumption will vary with many factors such as soil moisture level, speed of travel, the presence of plant roots in the soil, drilling depth and soil density. However, they can still be considered to be valid estimates of the fuel consumption of the drilling operations carried out with the "Ford 5000" earlier in the year. This because the cultivation treatments were expected to require widely differing amounts of fuel. Furthermore, errors in the estimation of the fuel required for drilling are likely to be of lesser importance when considered in relation to the sum of the tractor operations.

3.2.5 Correction for Implement Widths

The implements used in the trials were of various widths and often could not be fitted into the 5m plots without excessive overlap or without missing a little ground at the edges.

An overlap of 150mm was allowed with each implement traverse through the length of the plot, (except the plough).

This was subtracted from physical width of the implement, and so gave the effective working width of the individual implements. It was known how many runs were required to cover a plot, so the conversion factor used was as follows:-
Conversion factor =

$$\frac{\text{Effective width of Implement X No of runs/plot}}{5\text{m.}}$$

If a little ground was missed at the edges of the plot, the appropriate conversion factor was the reciprocal of the above.

The calculated conversion factors are shown in table 12 and were used in the determination of each fuel measurement.

TABLE 12 Implement width conversion factors.

Implement	Full working width	Effective width	C.F.
0.35m furrow plough	.71m	.71m	1.0
Rotary cultivator	1.30m	1.15m	0.7
Dutch harrow/leveller	3.05m	2.90m	0.8
Bar leveller	3.35m	3.20m	0.8
Cambridge roller	2.10m	1.95m	1.3
Tandem disc harrows	2.20m	2.05m	1.2

3.3 PENETROMETER MEASUREMENTS

Measurements of soil bulk density or penetrability of the soil was considered to be useful in helping to characterize the soil properties found under the various tillage treatments. An attempt was first made to measure bulk density of the soil in each treatment with a 650cc bulk density soil sampler, similar to one described by Blake (1965). Three samples of soil were taken from each plot (on Trial 1) on 14.5.73. The samples were then dried for 72 hours in an oven at which time they had come to a stable weight. The average soil density/plot was calculated with the results shown in table 13.

TABLE 13 Bulk density measured by soil sampler

Treatment	Control	Direct-drilled	Plough etc.	Rotavated
Means	1.01	1.09	1.00	0.91

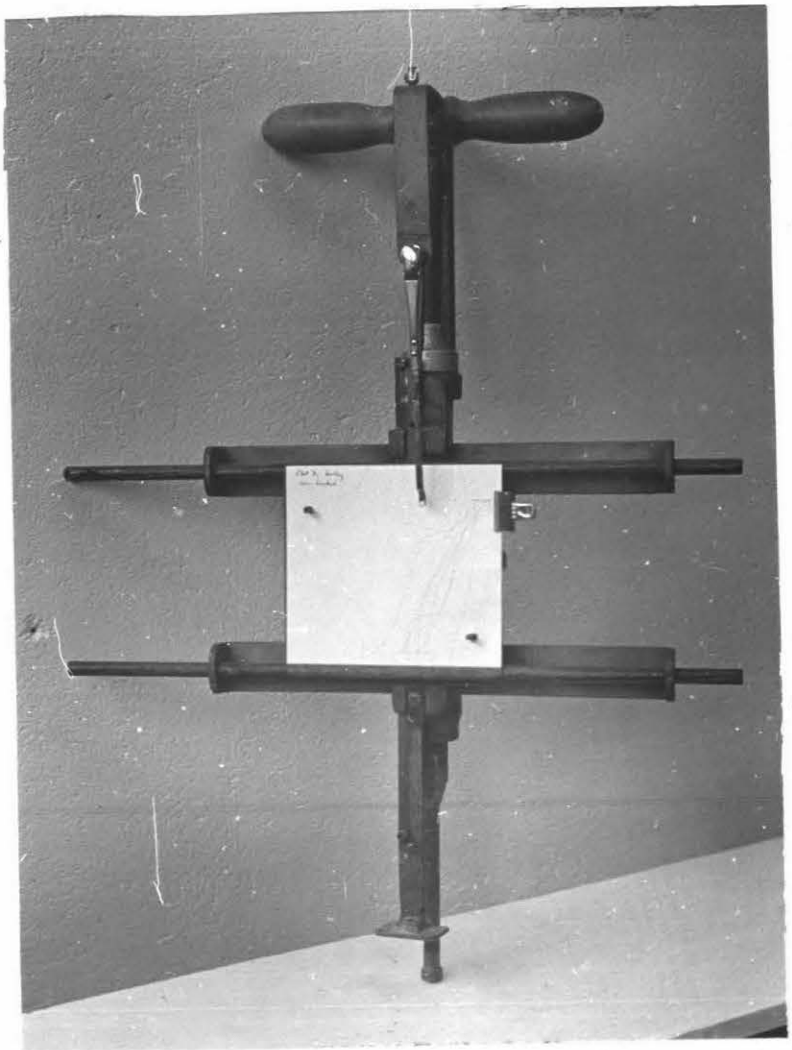
A study of the results in Table 13, resulted in the conclusion that the soil sampler was not suitable for measuring bulk density in cultivated soils. It was thought that the sampler compacted the loose cultivated soil when extracting the sample and resulted in the bulk density being over-estimated in the tilled plots. This view was supported by later results obtained with a penetrometer.

Blake (loc cit) described an 'excavation' method of determining bulk density which could have been used, but once the penetrometer became available, it was preferred because of convenience and ease of use. Also it was considered that a better idea of the soil profile was gained with the penetrometer.

3.3.1 The Penetrometer

The penetrometer used in the experiments was designed by R. Scott (personal communication) and is shown in the photograph. (plate 2).

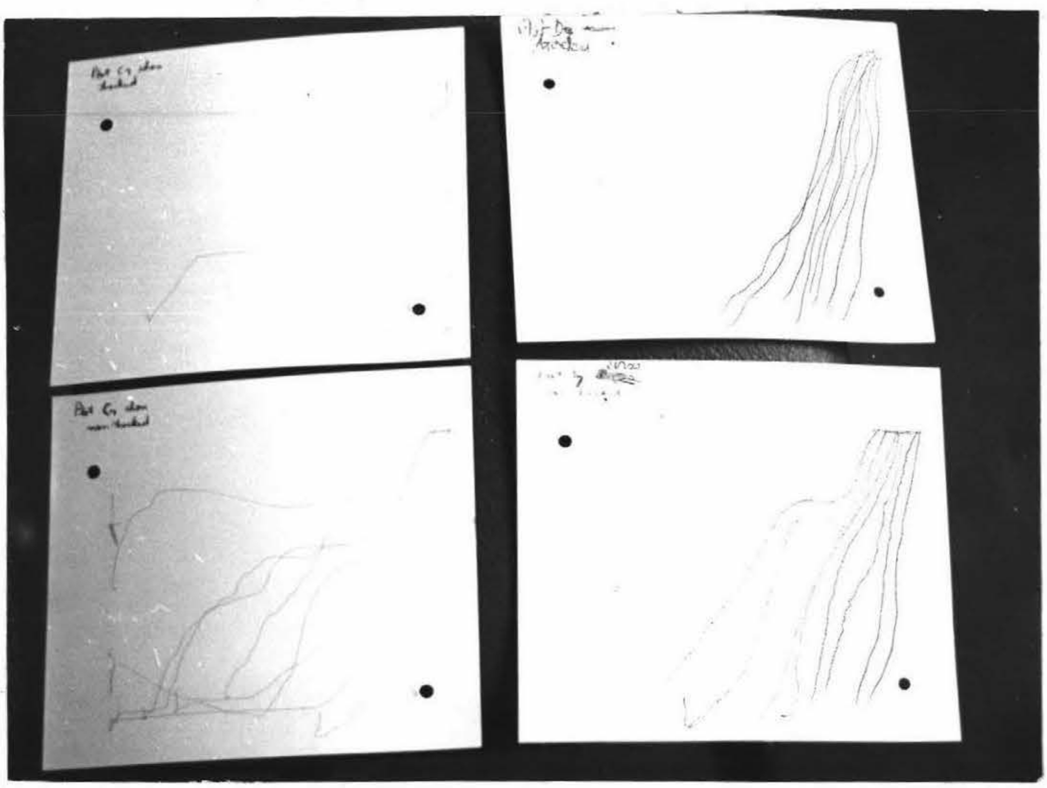
Plate 2 The Penetrometer



The penetrometer tip is pressed into the ground by a vertical force applied to the handles of the apparatus. The penetrometer tip is mounted on a coil spring which is compressed in proportion to the force applied to the tip. Differences in soil penetration effort are recorded by a pen mounted above the spring which marks a card mounted below the spring.

In order to record the force at various depths, a leg is attached to the card mounting and a platform at the lower end of the leg rests on the surface of the soil. As the penetrometer sinks into the soil the leg moves upwards in relation to the penetrometer tip and this upward movement is converted into a sidewards movement of the card holder through a rack and pinion arrangement. The result is that a graph with Newtons on the vertical axis and depth on the horizontal axis is obtained, samples of which are shown in plate 3. The tip could be unscrewed and replaced by one of a different diameter in order to keep the pen nib within the limits of the card on treatments exhibiting wide variability.

PLATE 3 Penetrometer Graphs



3.3.2 Disadvantages of the Penetrometer Method

The force needed to move a penetrometer tip through the soil can vary with many factors: some of these include, soil bulk density, soil moisture content, presence of plant roots, obstacles such as stones, and soil texture.

At any one time and within any one trial site it would be expected that soil moisture content and soil texture would be reasonably consistant so these factors were ignored, (although it was noted that small, statistically significant differences in soil moisture can occur between tillage treatments in these trials). Factors such as the presence of plant roots and stones in the soil can cause difficulty when trying to interpret results. It was, therefore, considered unwise to rely on the penetrometer alone to measure bulk density, especially in plots left in pasture, where many roots were present. Very few stones were present in the soil on the trial site, but where a stone or other obstacle was obviously encountered by the penetrometer tip it showed up immediately on the resulting graph, and that measurement was discarded and another taken in its place.

3.3.3 Penetrometer Measurements and Data

Penetrometer readings were taken on three occasions throughout the experimental period. A maximum tip force of 500N and a maximum depth of 12.0cm was within the capacity of the apparatus and satisfactory results were obtained on all occasions using a penetrometer tip of diameter 10mm (i.e. minimum tip size which could be used).

Sufficient readings were taken on each plot to give 8 traces. This usually meant that 10 or 11 readings were taken to allow for 2 or 3 upper or lower extreme readings to be discarded when the penetrometer tip hit a stone or a hole in the soil. Each, with its 8 graphical recordings was then analysed using a plastic card marked with a matrix corresponding with the 0 - 500N on the vertical axis of the cards and 0 - 12cm depths on the horizontal axis.

Mean readings for each plot were taken at arbitrary depths 1cm, 2cm, 4cm, 6cm, 8cm, 10cm and 12cm for the purpose of making representative graphical presentations of each tillage treatment.

In the case of the measurements taken on 4.1.74, the soil was very dry and 8 readings on all plots could be obtained to depths of only 1cm (see Appendix 2). This meant that at depths lower than 1cm the force on the penetrometer tip was often greater than 500N and the pen moved off the bottom of the graph. In the cases where 8 traces could not be obtained for all plots, the results could not be averaged because the resultant would have been weighted towards the lower values, since all values above 500N were not known and had to be disregarded.

In the relatively narrow plots, the tractor wheels tended to run approximately in the same place and this enabled the areas to be identified and measurements taken. On the 4.1.74, measurements were taken separately on tracked and non-tracked areas of each plot. It was recognised that there was a large amount of subjectivity present in determining which part of a plot should be considered 'tracked' and which part 'non-tracked', since it was difficult to visually determine where the tractor wheels had run after an implement had passed over the wheelmarks. The tractor wheels also did not run exactly in the same place with implements of various widths being used, but general tracked and non-tracked areas could be identified.

3.4 SOIL MOISTURE MEASUREMENTS

Soil moisture samples were taken with a 25mm core sampler when possible, at random position over each plot. Each core was divided into two sections of 0-75mm, and 75mm-125mm depths. During the summer and autumn of 1973-74 the soil on most plots became very hard due to the dry weather experienced, and it became necessary to use a spade to collect samples. A core sampler and an auger sampler were tried but were both found unsatisfactory in hard dry ground.

Samples were dried in an oven at 85°C for 36 hours before reweighing and calculating the soil moisture percentage. It should be noted that usually a drying time of 24 hours at a temperature of 110°C is recommended, but because of the unavailability of ovens of suitable capacity, a large oven which was set at 85°C was used, and the samples were left in it for a longer period of time. A small trial was carried out to determine whether there was any observable differences between these methods which resulted in the conclusion that there were none. Results of the trial are shown in table 14.

TABLE 14 Moisture content of random soil samples taken from pasture:

Dried at 110°C for 24 hrs.		Dried at 85°C for 36 hrs.	
Mean	20.9	Mean	20.3

All soil moisture contents are expressed as percentages on a wet basis.

Soil moisture measurements were taken on six occasions to enable comparison of soil responses to tillage treatments. Measurements were also taken at various times during tillage operations.

3.5 ORGANIC MATTER DETERMINATIONS

Samples of soil were taken from each treatment on 3 occasions from depths 0-75mm and 75-125mm with the purpose of determining the distribution of organic matter in the soil profiles. A determination of the organic carbon content of each sample was done by using the Walkley-Black rapid titration method (Allison, 1965) which involved digesting the soil with chromic and sulphuric acids. The excess chromic acid, not reduced by the organic matter of the soil was then determined by titration with standard ferrous ammonium sulphate, and the percentage organic matter in the soil calculated.

This method was very time-consuming and required large volumes of chemicals to be prepared. For this reason, only two determinations were carried out per tillage treatment on each sampling occasion. These determinations were done on soil samples taken at randon from bulked soil from each tillage treatment, and satisfactory results were obtained.

The Walkley-Black Titration method was chosen in preference to other available methods because of its relative rapidity and the simplicity of the equipment required. The method also apparently compared favourably with other methods in terms of accuracy on the soil type (Allison 1965).

3.6 WET SIEVING AND DRY SIEVING

3.6.1 Dry Sieving

Soil samples from the two tilled treatments (ploughed and rotary cultivated) were dry sieved on five occasions throughout the experimental period. This was done to gain some idea of the size distribution of soil clods and aggregates at various times throughout the trial. Dry sieving was not practicable on the control and direct-drilled plots because the soil was held together by plant roots or by soil cementing agents, so that individual soil aggregates were joined together. Any attempt to break down the soil structure on the control and direct-drilled plots to enable samples to be dry sieved would have resulted in a largely artificial and meaningless size distribution of soil aggregates.

Soil samples from the ploughed and rotary cultivated plots were carefully and randomly taken with a spade from the plots, at depths of 0-100mm and sieved by hand in the laboratory into three size fractions, using two sieve sizes. The sieves were of the circular wooden-frame type with meshes made up of square-holed netting, with hole measurements 1.8mm and 9.5mm (measured on the diagonal). These sieves were the only ones easily available. These mesh sizes also corresponded roughly to the desirable aggregate sizes in a tilled seedbed (3-10mm).

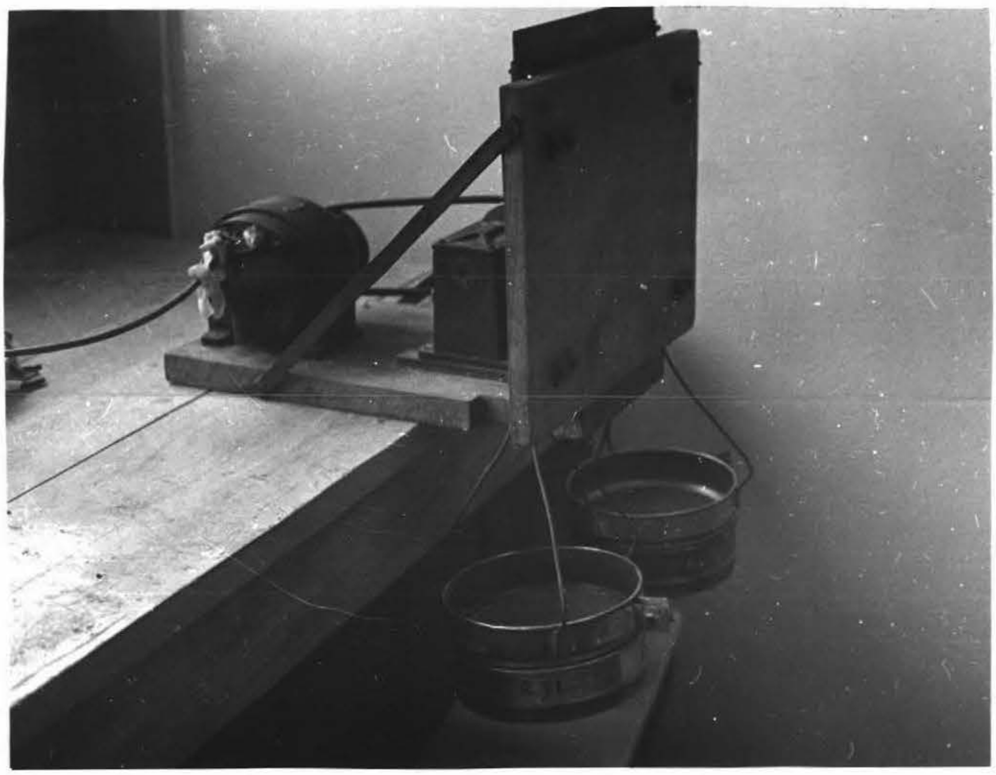
One sample from each plot was sieved. This gave four repetitions per treatment which resulted in a coefficient-of-variation of less than 0.1, calculated for percentage of weight of soil in Fraction 3 (i.e. less than 1.8mm diameter).

It was found necessary to limit the weight of soil sieved to approximately 1.5 to 2kg to avoid overloading the sieves which made it necessary to shake the sieves excessively to separate out the respective fractions. If the soil samples were treated too roughly, clods and aggregates broke down into smaller particles with consequent loss of the original characteristics of the size distribution. After a little experimentation, a sieving technique was evolved, which involved shaking each sieve gently 20 times. This method gave satisfactory results with little apparent breakdown of clods.

3.6.2 Wet Sieving

A wet-sieving apparatus used by Robinson (1955) was available. In Robinson's experiments measurements of the effects of different grass species in atabilizing soil aggregates were undertaken. His description of the apparatus is given below, along with a picture of the machine (plate 4)

PLATE 4 Wet-sieving apparatus



'The machine is based partly on one developed by A.J. Low of Jealott's Jill but both sets of sieves are raised and lowered at the same time (each in a container of water). The machine was made at Massey, and consists of a 124 W. electric motor connected by belt and pulleys to an Alger reduction gear box which reduces revolutions to 32 per minute. The gear box is connected by an offset shaft to a rigid frame moving in brass slots, which gives a 37.5mm movement up and down in the frame. Two arms of the frame are connected by three pieces of No 8 wire to a galvanised iron slip fashioned to hold a 200mm sieve which is held in by a small nut and bolt'.

There were several basic points to consider before wet-sieving soil samples, these are given as follows:-

1. How should the soil samples from the field be prepared before sieving?
2. What size and how many sieves should be used?
3. Over what time period should each sample be sieved?

3.6.3 Preparation of Samples

Wet sieving was carried out with the intention of obtaining some measure of the stability of the soil aggregates in the field and their resistance to erosion, crusting and slumping (which, amongst other things, causes drainage problems). Kemper & Chepil (1956) suggested breaking down the clods in soil samples from the field before wetting, so that all the soil passed through a screen (Kemper & Chepil suggested an 8mm hole sieve). This was done so that the wet sieving process was started with samples as near uniform as possible. This suggestion is reasonable when comparing samples of very nearly similar structure e.g. Robinson was comparing soils under various grass turfs. But as Kemper & Chepil (1965) pointed out, any disrupting forces exerted on the soil samples should be as near as possible related to forces which would be experienced in the field. Breaking up clods and turf by impact and shearing forces can be generally related to forces exerted by cultivation, but in the experiments reported here, it was desired to gain some insight into the responses of the soil to tillage forces which had already been exerted on the soil, as compared to soil which had been left undisturbed, (as in the direct-drilled treatments and soil left under pasture).

Abrasive and impact forces experienced by the soil during the sieving process could be related to forces experienced by water erosion. The disrupting influences of the water during wetting procedures could be related to wetting of the soil in the field.

Soil samples were collected at random from each plot on the trials with a sharp spade and taken to the laboratory where they were left undisturbed for 48 hours to air-dry. This made them easier to handle without disruption, especially if the soil had been wet when samples were taken. The samples were taken at a depth of 0-75mm and one sample approximately 200mm square was taken from each plot. The fraction 0-75mm was chosen, as it was considered to be roughly representative of the surface soil and as being most sensitive in the short-term to erosive and slumping effects. This portion of the profile was also regarded as the surface soil in the organic matter determinations.

After air-drying, the samples from the plots in pasture (A) and to a lesser extent the direct-drilled plots (B) were in the form of squares of turf held together by matted roots. The soil from tilled plots was much more broken and each clod or aggregate was loose.

To enable easier wetting of the samples and exposure of soil surfaces to the disrupting forces of the water during sieving, the samples from treatments A and B were cut into pieces approximately 25mm square with a sharp knife. Soil samples from the two tilled treatments, (ploughed, and rotary cultivated,) were not interfered with to any great extent, although any excessively large clods (e.g. greater than 35-40mm in diameter) were avoided when transferring soil to the sieves before wet-sieving.

3.6.4 Pre-Wetting of the Soil Samples

Several methods of pre-wetting of soil before sieving were considered. These methods were discussed by Baver (1948), Kemper (1965) and Kemper & Chepil (1965). The methods are listed as follows:-

(a) Immersion. This method involved immersing the samples in water, and is simplest and easiest to carry out. However, all of the above authors stressed that soil in the field is wetted under a tension, and if water is forced into aggregates as it would be if they are immersed in water, excessive disruption of aggregates is caused by internal pressures, as air trapped in the aggregates is compressed. Robinson (1965) used this method of pre-wetting turf samples, and found it satisfactory for his purpose, but it was decided to reject the method in this study because, in some cases, fragile cultivated soil was being used.

(b) Vacuum Wetting. As discussed by Kemper (1965), the most common type of aggregate disintegration of cultivated soils is slumping or slaking during the first wetting after tillage, and this wetting occurs under a tension. This can be similated by wetting in a vacuum. Unfortunately equipment to create a large vacuum is required (about 1 atmos. negative pressure) and was not available.

(c) Spraying with a fine mist. This method caused a much lower degree of disruption than immersion (Kemper & Chepil, 1965) and the fine water mist slowly wetted the soil under a tension.

Spraying the samples with mist was considered to be the most practicable method in these experiments.

Soil samples in aluminium dishes, were wetted by a fine mist produced by a motorized fan with a water-hose and adjustable nozzle squirting at right angles to it.

Large droplets and streams of water from the water nozzle were only slightly deflected by the air from the fan, but a very fine mist of droplets was blown by the fan at right angles to the hose nozzle when the arrangement had been correctly adjusted. Relatively large quantities of soil samples could be placed in the most created by the fan, and after 3-4 hours were thoroughly wetted with practically no observable disruption of the existing soil structures. However, once cultivated soil was wetted, the clods were very fragile and although practically no disruption was caused by wetting, some unavoidable damage to aggregates was caused during the transference of soil from the dishes to the sieves.

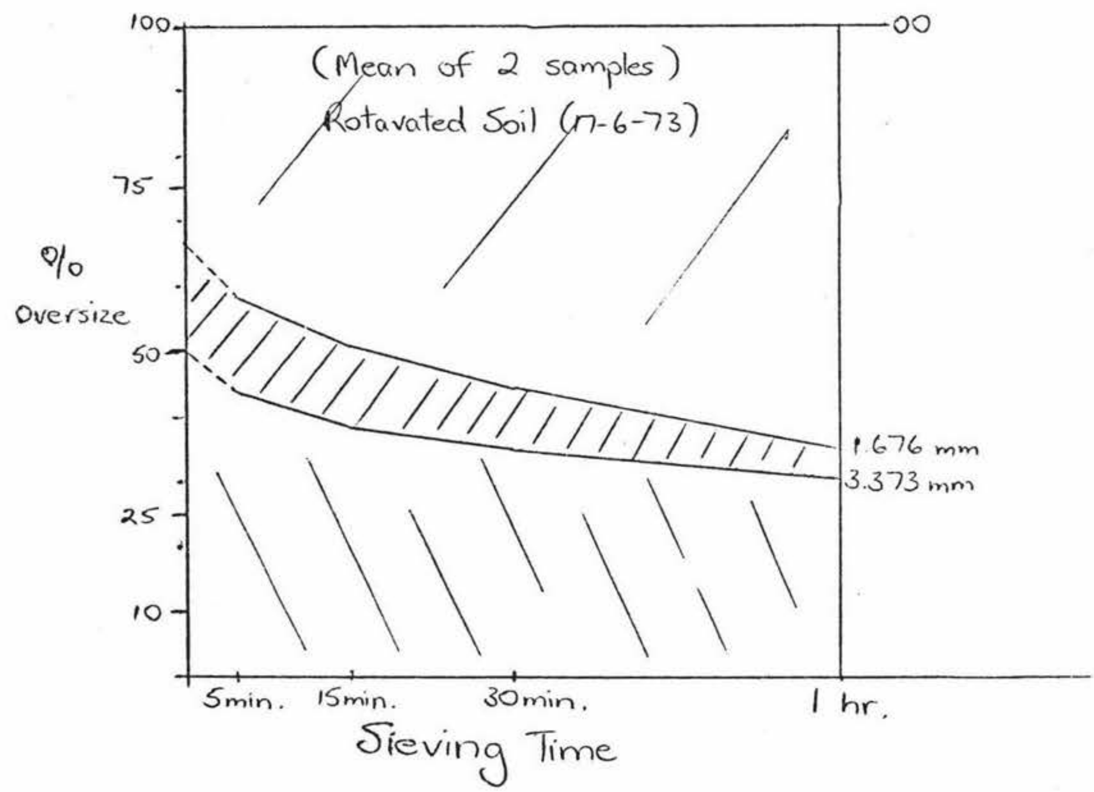
It was found necessary to restrict sample size placed on the sieves to approximately 100-150gm, to obtain reproducable results. Highly variable results were obtained when larger weights were used, probably because a longer sieving time was necessary than the one used to completely separate out size fractions..

3.6.5 Number and Size of Sieves

The sieving apparatus could handle two soil samples at a time, and a maximum of two sieves per sample could be attached to each arm of the machine. This enabled each sieve set to be constantly immersed in a bucket of water as the sieves reciprocated up and down. The number of sieves which could be used per sample was therefore restricted to two, and little objection to this could be found since the relative stability of the soils in the experiment was of primary interest and the actual sizes of aggregates present of lesser interest.

The sieves chosen in each set were No 10 and No 5 Endecott 200mm sieves with square mesh holes of maximum "diameters" 3.373mm and 1.676mm respectively. The No 10 sieve hole size corresponded to approximately the theoretically

Figure 3. Percentage Oversize vs Sieving Time



accepted size of particle which makes up a high proportion of the aggregates in a seed bed of fine tilth. The No 5 size hole corresponded to half that of the No 10 sieve and was largely an arbitary choice although soil particles of less than the No 5 hole size may be liable to cause decreased aeration and soil drainage of soil in wet weather.

These sieves enabled three size fractions of soil to be separated and an estimation of the relative stability of the soil tillage-treatments to be obtained.

In theory, one sieve per set would be sufficient to give an estimation of the relative stability of the soil treatments. However, in that case the samples would have to be pre-sieved to ensure that all samples started off the wet-sieving process with aggregates of the same size to avoid bias towards samples made up of aggregates of larger or smaller size than the mean. In these experiments the soil samples were not pre-sieved and the use of two sieves enabled a greater range of aggregates to be separated using the soil in the state in which it had been found in the field. Not pre-sieving the soil also enabled the effects of factors influencing the stability of the soil in the sample to be estimated, rather than merely the stability of a certain size range of aggregates present in the sample.

3.6.6 Time Period of Sieving

Robinson (1965) found that the relative differences between treatments varied little between sieving times 3 to 30 minutes, although the total soil in the top sieve decreased. He used 30-50g of soil in each sample and sieved each one for 5 minutes. Kemper (1965) also suggested 5 minutes as sieving time although he gave no reason and the choice seemed arbitrary.

A small experiment was conducted to determine how a tilled soil from a rotary cultivated plot responded to different sieving times. The results are shown in figure 3.

A sieving time of 15 minutes was decided on. This enabled larger samples than Robinson's to be used because of the longer sieving time. It was also thought that a period in excess of 5 minutes was more suitable for measuring the stability of the soil since at that stage the graph (Figure 3) still exhibits a relatively steep slope, and appeared to decrease in slope slightly only after 15 minutes. It was considered that sieving times longer than 15 minutes would be too time consuming.

Once the samples had been sieved, the three size fractions were transferred to drying tins, the sieving water was decanted from the buckets after the suspended soil in them had settled and the remaining soil made up the size fraction 00m-1.676mm. The tins were then put in a small drying oven (105°C) for 24 hours and the contents weighed.

3.6.7 Expression of Sieving Results

Various ways of expressing sieving results have been suggested and were discussed briefly in Chapter 2.6.1.

One of the more enlightening recent discussions of the subject was given by Stirk (1958), who stressed that the idea that there was some elusive parameter which could be applied to all aggregation measurements was probably not realistic.

Youker and McGuinness (1957) proposed a short method of computing mean weight-diameter (MWD), values of aggregate analyses of soils which made it unnecessary to plot and graph results as in the method described by Van Bavel (1949).

The computing method of Youker and McGuinness is illustrated in the example given in Table 15 and was used in this study with the object of using the values obtained to help compare the relative breakdown of aggregates under cultivation.

TABLE 15 Computing method for Mean-weight-diameter (from Youker and McGuinness, 1957)

Mid pt of Range	Per cent retained	Product of midpoint and per cent retained
0.10	49.9	0.04990
0.35	17.4	0.06090
0.75	11.5	0.08625
1.50	8.6	0.12900
5.00	12.6	0.63000
		0.95605

The method of comptuing mean-weight-diameter for the example in Table 15 is given as follows:

Substitute 0.956 for X in the formula MWD = 0.876 X - 0.079

MWD = 0.758mm (From Youker and McGuinness, 1957)

The method of Van Bavel (1949) involved measuring the area under a plotted curve of the accumulated frequency function of the aggregate distribution with a planimeter, and took up considerable time e.g. 15 minutes compared to the computing method which took approximately 30 seconds on a desk calculator. Correlation coefficient between the two methods equalled 0.986 (Youker and McGuinness).

Stirk (1958) emphasized that the MWD as measured by Youker and McGuinness was useful if the main purpose of the experiment was to differentiate between soils, but the idea that it was some real property of soil aggregate distribution should have been discarded. Kemper (1965) claimed that results from simple one and two sieve methods of determining aggregate stability were closely correlated with results using several size ranges of aggregates and sieves and the results expressed in terms of mean weight-diameters. In this study sieving results were in three size fractions and comparison of treatments was done by the percentage oversize method as shown in the results (Chapter 4) in addition to MWD.

The plotting of data in a logarithmic probability distribution as proposed by Gardner (1956) was discarded as it was considered of minimal use where only three size fractions are obtained because it enabled only two points to be plotted in each distribution. On one occasion during the trials several soil samples were dry-sieved with three sieves to find out if in fact the soil aggregate distribution did conform to Gardner's theory that soil aggregates are log-normally distributed. Three points for each sample were than plotted on log-normal probability paper and were found to lie very closely in straight lines which confirmed that the soil aggregates apparently were log-normally distributed. It was not thought worth pursuing the method any further since it was considered of more use where a larger number of sieves were available than were used in this trial.

3.7 HARVESTING OF CROP

The chou moellier crop was harvested on 6.2.74 for yield estimations. Four metre-square samples of chou moellier were harvested at random from each plot (except control plots) and weighed individually on field scales. Samples of whole plants (except roots) were also taken to the laboratory and dried at 85°C for 24 hours for dry matter content estimation.

The barley portion of the planted crops was not harvested, because much of the grain had shed before harvesting was possible.

The number of individual chou moellier plants per m^2 was also obtained at time of harvesting.

3.8 PHOTOGRAPHS AND VISUAL ASSESSMENT OF SOIL AND CROPS.

Throughout the experimental period, numerous monochrome photographs of the soil and crops on the various plots were taken. Some were vertical shots taken with the 35mm camera lens at a height of 1.45m above the surface of the soil. This enabled physical features of the soil on various plots to be visually and accurately compared e.g. sizes of surface clods, because the features on each print were enlarged to the same scale.

It was found necessary to visually assess many features of the tillage treatments which were considered of interest but could not be defined adequately by measurement. This was often done throughout the experimental period and the opinions of Messrs Baker, Bowler and Simms of the Agronomy and Soil Science Departments at Massey University were also considered, since visual assessments are unavoidably subjective and depend somewhat on the preconceived ideas of the observor.

On 12th December 1974, six 0.3m sections of a direct-drilled row from the non-fallowed plots (Trial 2) were taken with a U-shaped sampler shovel. These samples were taken back back to the laboratory and dissected to attempt to determine why some barley seeds had not established. The samples were all taken from areas in the plots where few or no plants were growing.

3.9 SURFACE CRUSTING EVALUATIONS

Surface soil samples were taken from Trial 1 (winter fallow plots) on 29.4.74 for the purposes of evaluating the relative levels of crusting on the trial treatments. Samples were also taken from two ploughed, disced and harrowed areas of the Agronomy Department's field plot area at the University.

The soil surface of one field plot area was noticeably cemented together by non-aggregated soil materials, forming a hard surface crust which could be walked on without breaking. The other area was in a similar condition, but to a lesser extent and the surface crust was relatively thin and of a lower strength. Both the areas had been intensively cropped for several years but the soil exhibiting the lesser cap had been under a lucerne crop during the summer of 1973-74, whereas the poorer area had been under a potato crop and had undergone relatively vigorous soil cultivation associated with potato cropping. Soil was taken from the two areas to compare them with the ploughed and rotary cultivated treatments of the trial.

Most of the soil crusts were very fragile so it was impossible to take samples according to any set design. Samples were taken with a spade, randonly from the plots and were taken back to the laboratory (many of them breaking up on the way), and evaluated.

Organic matter analyses were done on all the samples.

3.9.1. Evaluation of the Crusts

A multi-point penetrometer (described in detail by Dixon, 1972) was used to evaluate the relative strengths of the soil crusts. Briefly, the penetrometer enabled four "blunt-ended" probes (1.60mm diameter and 80mm long) to be pushed into the soil by a motorized and threaded shank (rate of penetration 19.5mm/min.) Before penetration was started the probes were unclamped by thumbscrews and dropped on to the soil sample so that they conformed to minor irregularities in the surface. The probes were then wound down by the motor. They penetrated the soil, and the resistance acting on the probes compressed a proving ring which recorded proportionate displacement on a micrometer scale.

It was found necessary to mount the samples in a tray of sand to hold them steady during evaluation. In the case of the badly crusted area from the field plots, the sample was mounted in wet sand to give a more resistant medium, and prevent the soil from being pressed into the sand during penetration of the probes. Obviously, the evaluation had to be done relatively quickly, before the soil sample itself absorbed water and weakened the crust.

It was desired to illustrate the relative levels of crusting by obtaining graphs of force (or reading on the micrometer dial) versus depth.

It was hoped to photograph the micrometer dial at 1 second intervals with an automatic camera, but the appropriate camera was unavailable at that time. This proved a difficulty because it wss impossible to read the swiftly changing micrometer dial at 1 second intervals and record the results on paper at the same time. After some experimentation, it was found practicable to read the dial at 2 second intervals using a tape recorder playing 'bleeps' every 2 seconds as a time keeper.

The study of the soil crusting aspect was very brief and results should be evaluated with the realization that the study was not done between replicated teeatments.

Five evaluations were obtained for each treatment. Each evaluation was continued until the soil sample broke due to penetration of the probes or until the reading on the micrometer dial became steady or a period of approximately 25 seconds had elapsed. Where a crust was present, the reading on the dial reached a peak and then dropped back, and where a crust was not present the dial reading either kept rising (control and direct-drilled plots especially), or reached a relatively steady reading.

If the probes continued to penetrate a crust for 25 seconds, they would penetrate to a depth of approximately 8.2mm into the soil. Calibration of the penetrometer by Dixon, (1972) showed that 1.0 micrometer unit corresponded to 12Qp (bars) of pressure.

Chapter 4. DISCUSSION OF RESULTS

4.1. Measurement of Energy Inputs

The petrol measuring apparatus performed adequately, although it was found to be difficult to control the tractor and implements on the small plots, and concentrate on turning fuel taps on and off at the same time. For this reason the sensitivity of the method was not as great as expected (Coeff. of var. was 23% on results from autumn 1973 cultivations), but it was found that operator errors tended to decrease with experience, and later results were less variable (coeff. of var. was found to be 7% in Trial 1 plots in the spring 1973 cultivation).

4.1.1 Comparison of the Two Tilled Plots

Results of the fuel use measurements are summarized in table 16 which shows that differences between the amounts of fuel used in all comparisons of the ploughed and rotary cultivated treatments are significant at the 1% probability level.

TABLE 16 Fuel used in cultivation.

grm.

Treatment	Ploughed etc.		Rotary Cultivated		L.S.D.
Period	Winter Fallow 1973	Non-Fallowed	Winter Fallow 1973	Non-Fallowed	0.01
Autumn 1973 Trial 1		349.8		111.9	223.9
Autumn 1973 Trial 2		-		-	
Spring 1973 Trial 1	361.0		189.5		69.7
Spring 1973 Trial 2		374.3		304.0	67.3
Autumn 1974 Trial 1	279.6		153.9		77.5
Autumn 1974 Trial 2		327.2		152.9	113.4

No comparison is inferred between the three periods as soil shear strength as influenced by soil moisture content and environmental condtions could not be expected to have been constant in each case.

In all three tillage periods, ploughed treatments used more fuel than rotary cultivated treatments. It was noted from the breakdown of results (appendix 1) that ploughing alone used a relatively large amount of fuel compared with rotary cultivating. This is probably, in part due to the high proportion of 'parasitic' forces associated with the plough which must be overcome by the towing tractor (Bainer et al, 1955).

If the efficiency of a particular tillage method is considered as being a function of the amount of soil breakdown per unit of petrol used, rotary cultivation seems superior. On the other hand it should be noted that ploughing is usually superior in other ways e.g. weed burial.

Plate 5 shows samples of surface soil taken from ploughed and rotary cultivated treatments in autumn 1974 after discing the ploughed plots and after rolling the rotary cultivated plots. At that time the mean amount of fuel used on the eight ploughed plots was 153.6 g and on the eight rotary cultivated plots 115.6 g. The relative breakdown of soil aggregates per fuel unit appears to be greater on the rotary cultivated treatments, although account must be taken of the inherent differences that could be expected from rolling and non-rolling. Results of dry sieving of the samples are shown later in the text.

PLATE 5 Surface soil samples (refer Text p. 76)

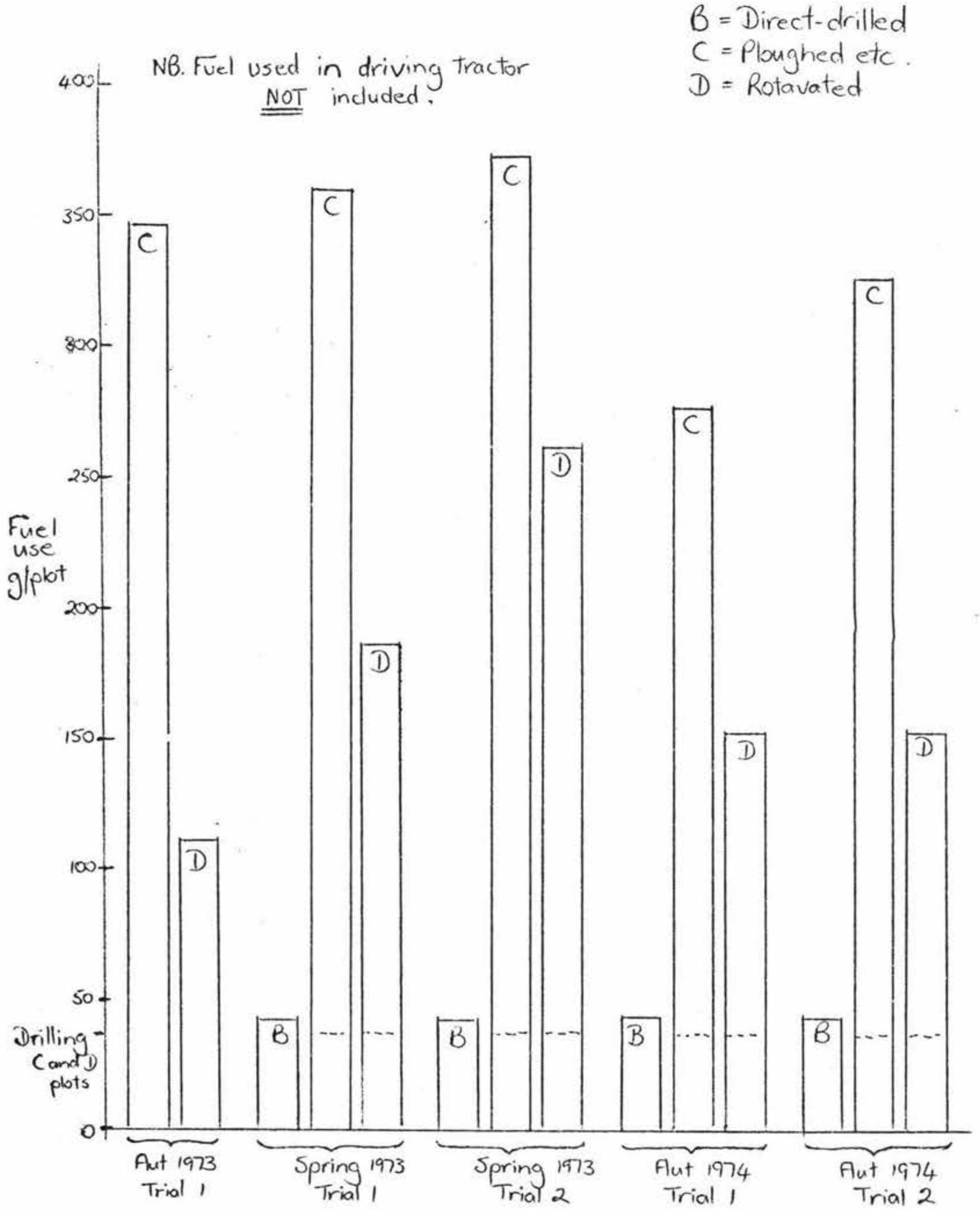
4.1.2 Comparison of Direct Drilled, Ploughed, and Rotary Cultivated Treatments.

The three treatments are compared with each other in figure 4 . If the total petrol used throughout the trial period in the traditional tillage treatment (ploughing etc.) is considered as being of a value equal to 100%, then the respective values for the direct drilled and rotary cultivated treatments are 10.6% and 53.9% and are significant. These figures suggest that fuel costs under traditional cultivation methods are considerably greater than under direct-drilling or rotary cultivating methods, but it must be remembered that no consideration of factors associated with the chemical spraying of pastures (direct-drilled plots) or of spraying weeds (in rotary-cultivated plots) has been undertaken.

Another point to consider is that the average number of tillage and sowing operations per plot was: 0.8 with direct-drilled plots, 6.2 with ploughed plots, and 3.6

with rotary cultivated plots. Notable also, is that in comparing the ploughed and rotary cultivated 'non-fallowed' (trial 2) treatments in the spring of 1973, six operations were carried out on both treatments; but the ploughed plots still used an average of 18.8% more fuel per plot than rotary cultivated plots ($P = 0.01$).

Figure 4 Total Fuel useage in Crop Establishment gr/plot



NB Trial 1 - Fallowed over winter 1973
Trial 2 - Non-fallowed

4.2 Results of Penetrometer Analysis

The penetrometer showed differences between treatments, as illustrated in figures 5 and 6.

Analyses of variance were done to determine whether the differences in penetrometer force were significant at selected depths of 1.0cm, 4.0cm and 8.0cm. These arbitrary depths were chosen as they gave a reasonable cross section of the areas of the profile, thought to be sensitive in a cultivation programme.

In the case of results obtained on 4.1.74 (shown in figure 6) it was necessary to make judgements as to what was a 'tracked' and what was a 'non-tracked' area of a plot when the areas merged into one another, and no clear predetermined line divided the two. The results, therefore, of this particular aspect should be regarded as suggestive only and not strictly representative.

The differences between 'tracked' and non-tracked' areas appeared to be marked, once the results were graphed (figure 6). It is considered, therefore, that differences 'within' treatments may be of more relevance than differences 'between' treatments. Discussions by various authors (e.g. Boone and Kuipers 1970) seemed to suggest that parameters such as mean pore space, which will be closely related to compactness of the soil, is less important to plant growth and water flow than the actual distribution and form of pores and channels within the soil. Visual appraisal of the treatments in the trials resulted in the conclusion that obvious differences were present in the arrangements of pores and channels between treatments.

On the other hand, authors such as Hawkins and Browne (1963) reported how consolidation by tractors could noticeably increase water runoff. Leonard (1970) stated that direct-drilled crops had shallower rooting systems (presumably because of a high overall soil density) and

Blake (1963) reported how potatoes were detrimentally affected by soil packing.

Other evidence such as was reported by Stout et al (1961), Baker (1969) and Dixon (1972), seems to suggest that micro-environmental influences on a seed or seedling may be of greater importance to a crop-plant than more general soil properties such as bulk density.

There is some doubt as to the practical value of much of the penetrometer data, arising from a lack of knowledge about the micro-structure of the soils present in the trial treatments. However, the results shown in figure 6 are considered to be worthy of study for the reason put forward by Hawkins and Browne (1963), and by a number of other authors (e.g. Boekel 1963, Zimmerman and Kardos 1961), who reported how roots could be detrimentally affected by decreased soil porosity and increased bulk densities. The results shown in figures 5 and 7 are therefore considered to be of value in that they help to illustrate differences which do apparently exist between the soils of each treatment and add to their general characterization.

The results of the penetrometer analysis are summarized in table 17 .

TABLE 17 Comparative penetrometer readings, cultivated and uncultivated soil.

PLOT					LSD	
Depth	Control	Direct drill.	Plough	Rotavated	0.05	0.01
Sampling date 16-7-73 Fallowed Trial						
1cm	105 Newtons	88	67	68	22,5	-
4cm	211	215	128	152	36,5	52,4
8cm	266	291	169	216	36,6	43,3
Sampling date 15-11-73 Fallowed Trial						
1cm	139	139	146	84	21,8	29,9
4cm	169	186	130	135	24,3	33,3
8cm	205	232	182	208	23,2	31,7
Non-fallowed Trial						
1cm	140	115	79	86	19,3	27,7
4cm	181	166	147	129	12,8	38,2
8cm	231	216	180	192	23,3	33,5

The results are perhaps more easily compared from the graphs. In general, the two tilled treatments (ploughed and rotary cultivated) required a lower penetrometer force for penetration, with very few exceptions. This was expected, since non-tilled soil tends to have an inherently higher density than tilled soil.

The results shown in figure 5 , of readings taken on 16-7-73 show a tendency for ploughed soil to be less dense than rotary cultivated soil, (but with the difference only significant at the 8cm depth.) This may have been associated with the manner in which a plough inverted the furrows. Small spaces appeared to have been left in the lower tilled profile, and these may have shown up as decreased soil density on the penetrometer tracings. The same tendency seemed to show up in the graphs of readings taken on 15.11.73.

The penetration required in the rotary cultivated plots tended to increase more sharply at lower depths in the profile. This was thought to be partly because the rotary cultivator was at a shallower depth than the plough, especially after the initial breaking out of pasture. The soil in the lower profiles might be expected to be more nearly at the same density as in the non-tilled treatments.

Nearer the surface, rotavated treatments also tended to require a higher penetrating force than ploughed treatments, perhaps due to the resistances caused by entangled pieces of vegetation mixed into the profile by the cultivator. At no depths were the differences between ploughed and rotavated treatments at 1cm and 4cm significant, except for one notable exception in the non-fallowed plots (15.11.73). In this case the rotavated treatment experienced a significantly lower penetrating force than ploughed treatments at a depth 4cm (P = 0.05). It is not known what caused this deviation from the pattern.

4.2.1. Wheel Compaction

Figure 6 clearly shows the order of increase (due to wheel-tracking) in soil density or penetrating force for different tillage systems. The soil was very hard and dry at the time penetrometer measurements were taken (4.1.74) and results are shown at depth 1cm.

Differences in penetrating force between the fallowed and non-fallowed trials are thought to be caused by an inherent difference in physical properties between the soils in the two trials. The difference is illustrated in the results from the control plots, and was probably caused by cattle pugging the area on which the non-fallowed

Figure 5 Soil Resistance to Penetrometer Probe — Fallowed Plots (16-7-73)

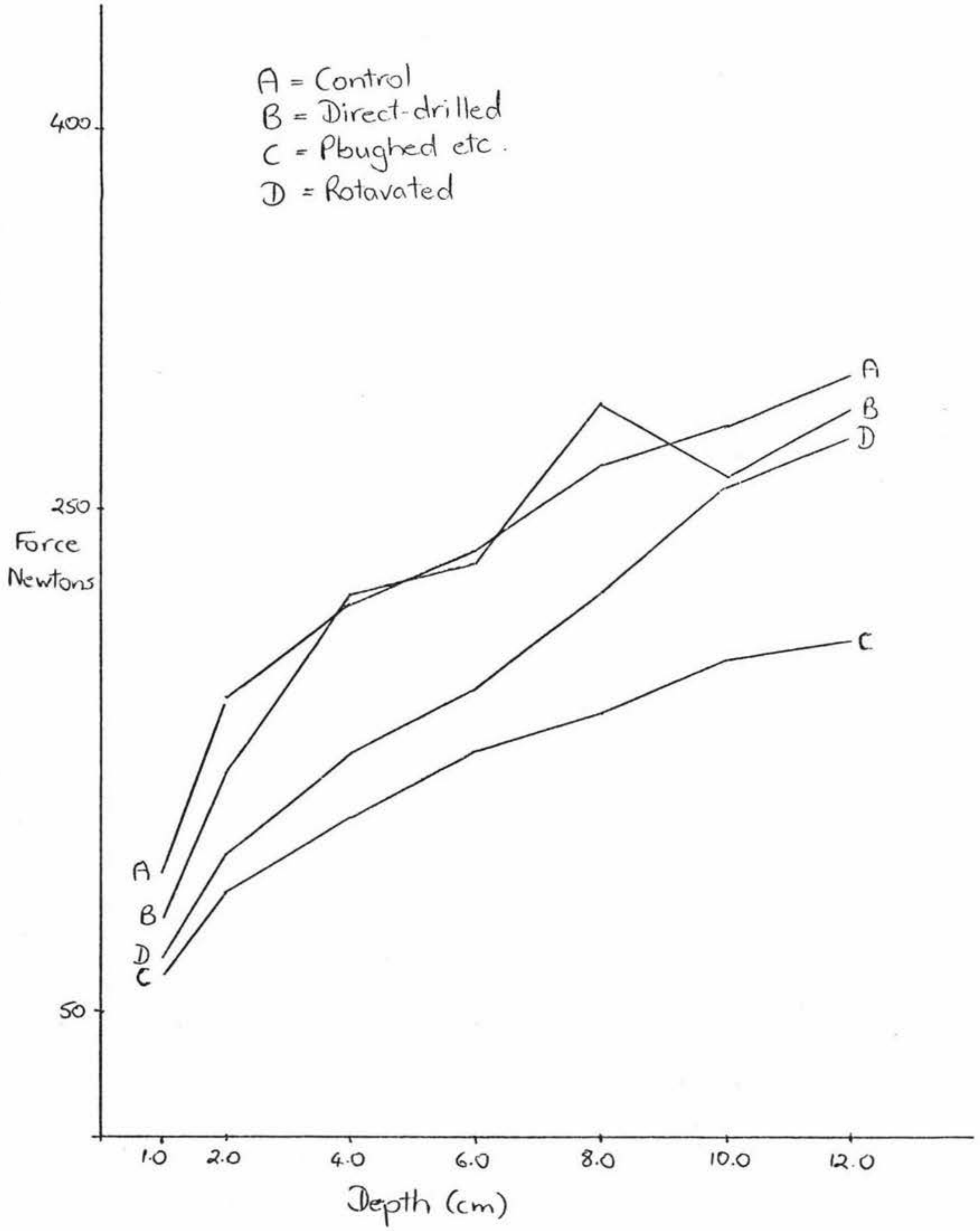
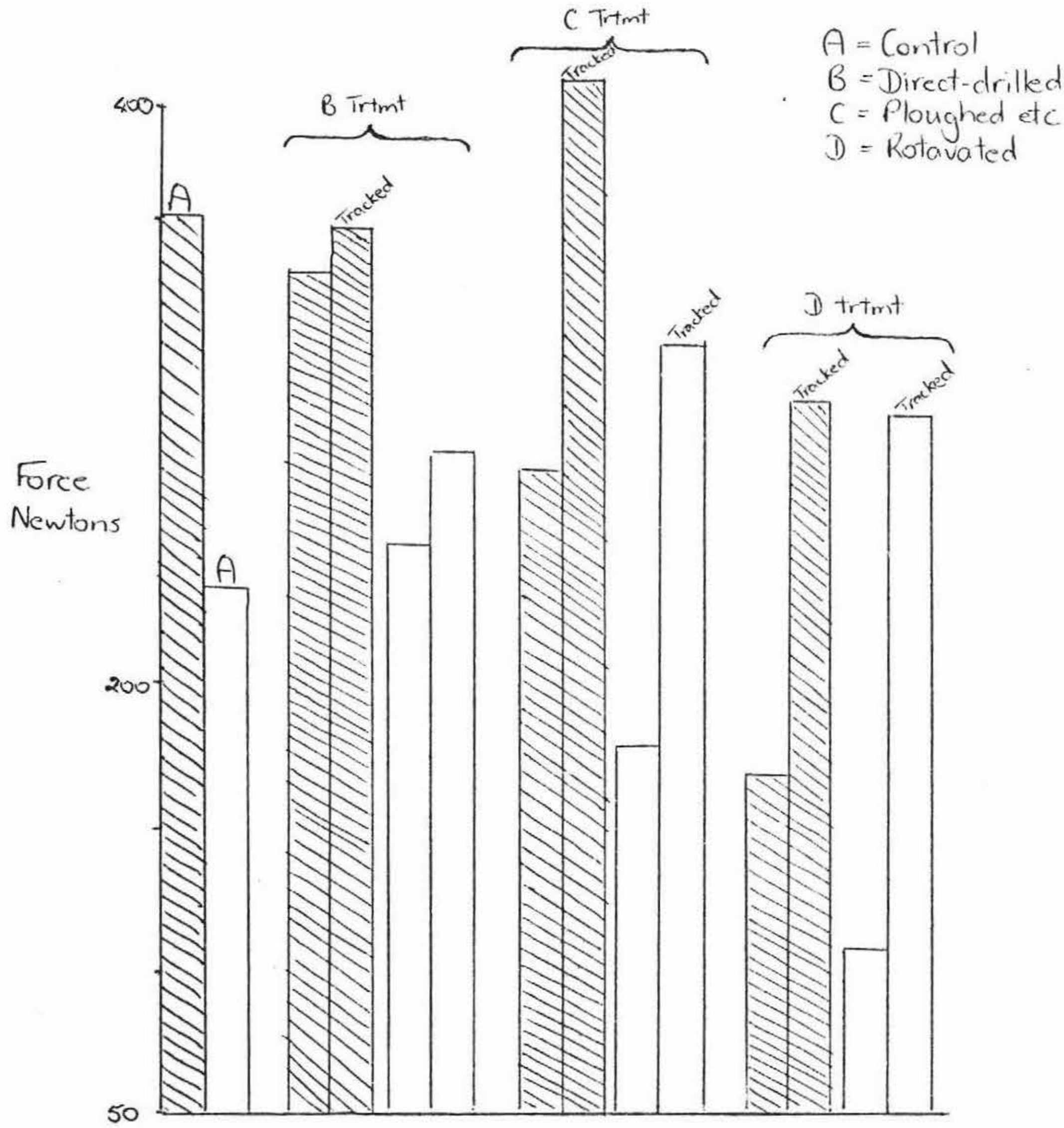
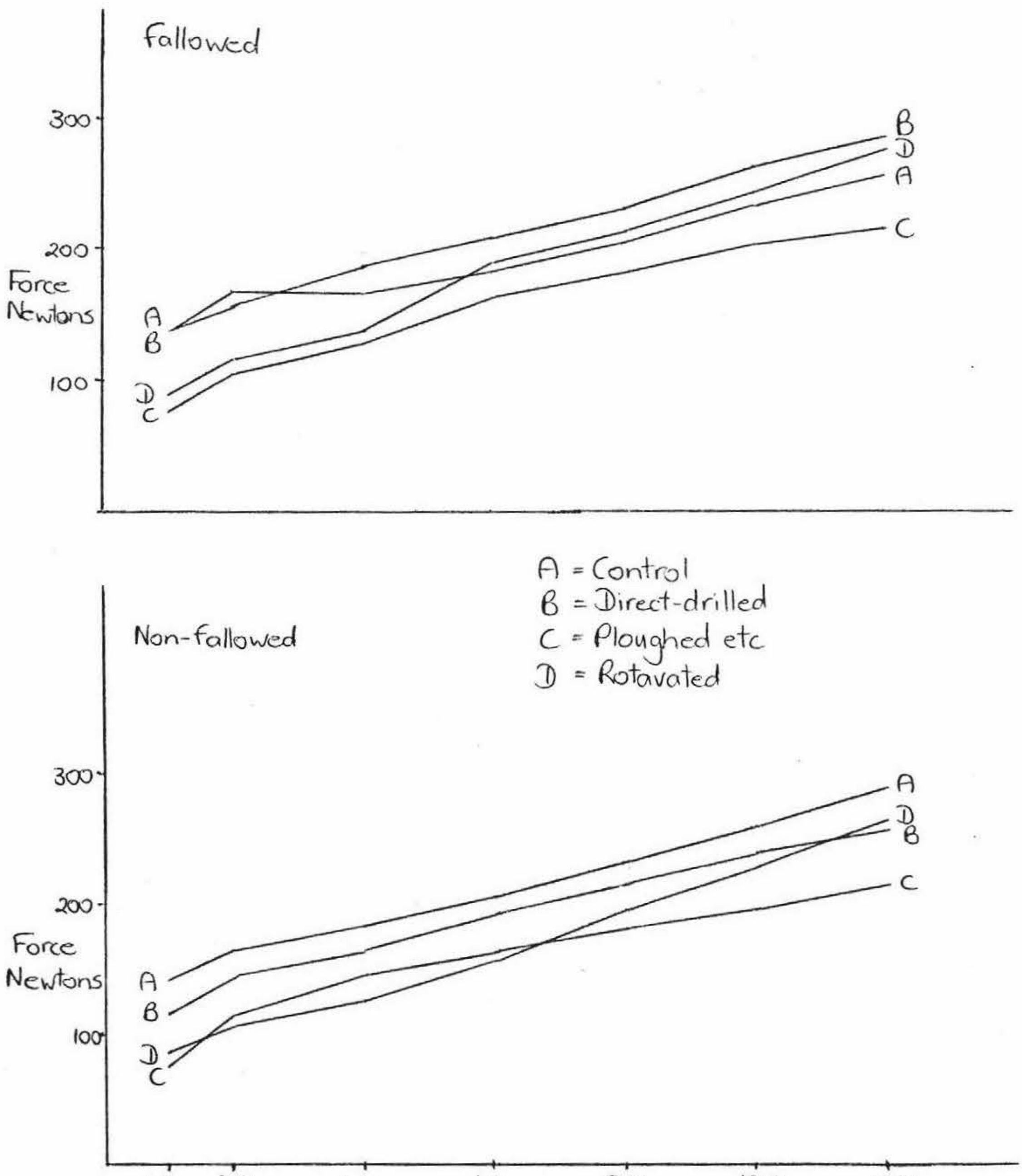


Figure 6. Comparison of Soil Resistance to Penetrometer Probe (4-1-74)



Key - fallowed Plots - shaded
nonfallowed Plots - non-shaded

Figure 7 Soil Resistance to Penetrometer Probes (15-11-73)



trial was situated in winter 1973.

The average increase in penetrating force caused by wheel-tracking on each treatment were

			Std. error
Direct-drilled	7.4%	±	1.82
Ploughed etc.	84%		4.16
Rotary cultivated	87%		4.64%

The apparent increase in soil compaction with wheel-tracking would be expected to be a function of both the ability of the soil to withstand wheel pressures and the number of times wheels travel over the soil. A high incidence of wheel compaction would be expected on tilled plots because of the fragile nature of most of the soil clods and the high proportion of air spaces present in a freshly tilled profile.

The factor of most interest is the presence of measurable compaction on the direct-drilled plots where not more than two or three wheel passes were made over the undisturbed soil profile. A more detailed study of this aspect might also determine whether or not some care needs to be taken to ensure that excessive compaction does not occur on direct-drilled seedbeds.

4.3 Soil Moisture Results

Graphical presentation (figure 8) of soil moisture indicated possible interactions between this factor and time of sampling. Table 18 shows the relevant soil moisture percentage means for each depth and time of sampling. Analyses of variance on a split plot in time bas s, indicated the levels of significance.

Soil moisture content results from the 'fallowed' control and 'non-fallowed' control plots were compared and were found to differ significantly at some times of sampling e.g. on 1.11.73; 'non-fallowed' control plots had a mean soil moisture of 19.5% (depth 75-125mm) while the corresponding 'fallowed' plots at the same depth, had a moisture content of 23.4%. This phenomenon may have been associated with the slight pugging by cattle of the pastures in the paddock which contained the 'non-fallowed' trial in the winter of 1973. This appeared to cause a change in the physical properties of the soil, which may have either prevented wetting of the soil at the 75-125mm profile or have somehow increased moisture loss from that profile in the pugged soil. The nature of the pasture cover was visably different under pugging than elsewhere, but it is not clear in what manner this may have contributed to the lower moisture contents.

In figure 8 , measurements are shown only on the dates indicated on the X axis of the graphs. There is thus no justification in attempting to fit curves to these points.

TABLE 18 SOIL MOISTURE (Wet Basis)

Sampling Date	Depth 0-75 mm						Depth 75-125 mm					
	Control	Direct Drilled	Ploughed etc	Rotavated	LSD 0.05	LSD 0.01	Control	Direct Drilled	Ploughed etc.	Rotavated	LSD 0.05	LSD 0.01
Fallowed Plots												
16-5-73	32.7	30.7	28.6	30.7	1.0	1.4	24.7	24.8	27.4	26.0	1.4	1.9
18.6.73	34.1	32.8	29.0	31.8	"	"	23.9	25.9	27.9	27.6	"	"
15.7.73	34.1	32.9	29.1	31.6	"	"	26.4	26.1	28.8	26.6	"	"
1.11.73	23.4	22.9	22.3	23.7	"	"	23.4	22.0	26.2	22.6	"	"
15.12.73	11.0	11.6	12.9	11.8	"	"	11.5	15.2	15.4	14.3	"	"
6.2.74	9.5	8.0	7.7	8.4	"	"	9.0	9.4	9.6	10.7	"	"
Non-fallowed Plots												
1-11-73	21.4	22.0	20.2	22.8	0.8	1.1	19.5	21.0	25.1	22.7	0.6	0.8
15-12-73	11.9	10.1	15.3	10.8	"	"	11.5	16.8	13.2	12.5	"	"
6-2-74	8.8	9.4	7.3	8.7	"	"	9.2	9.4	10.7	9.7	"	"

Differences between treatments are illustrated in the graphs. A statistically significant ($P = 0.01$) interaction in graphs (fig 10) of the non-fallowed plots is probably caused by the relatively slower drying rate of the soil of the direct-drilled plots, compared to the other three treatments over the period of crop growth. This is thought to have been in part, a result of the lower density of plants present on the direct-drilled plots (which could be expected to have removed less moisture from the soil) rather than a phenomenon of soil structure. This view is supported in some part by the absence of the same interaction in the fallowed plots, where the relative density of plants in the direct-drilled plots was not as low.

In general, it is difficult to determine the effects of tillage method on soil moisture from the graphs. The presence of growing plants at various densities on the plots may have affected soil moisture, and this may possibly have overridden the effects of tillage treatment.

Figure 8. Soil Moisture Content at 0-75mm Depth
Fallowed Plots

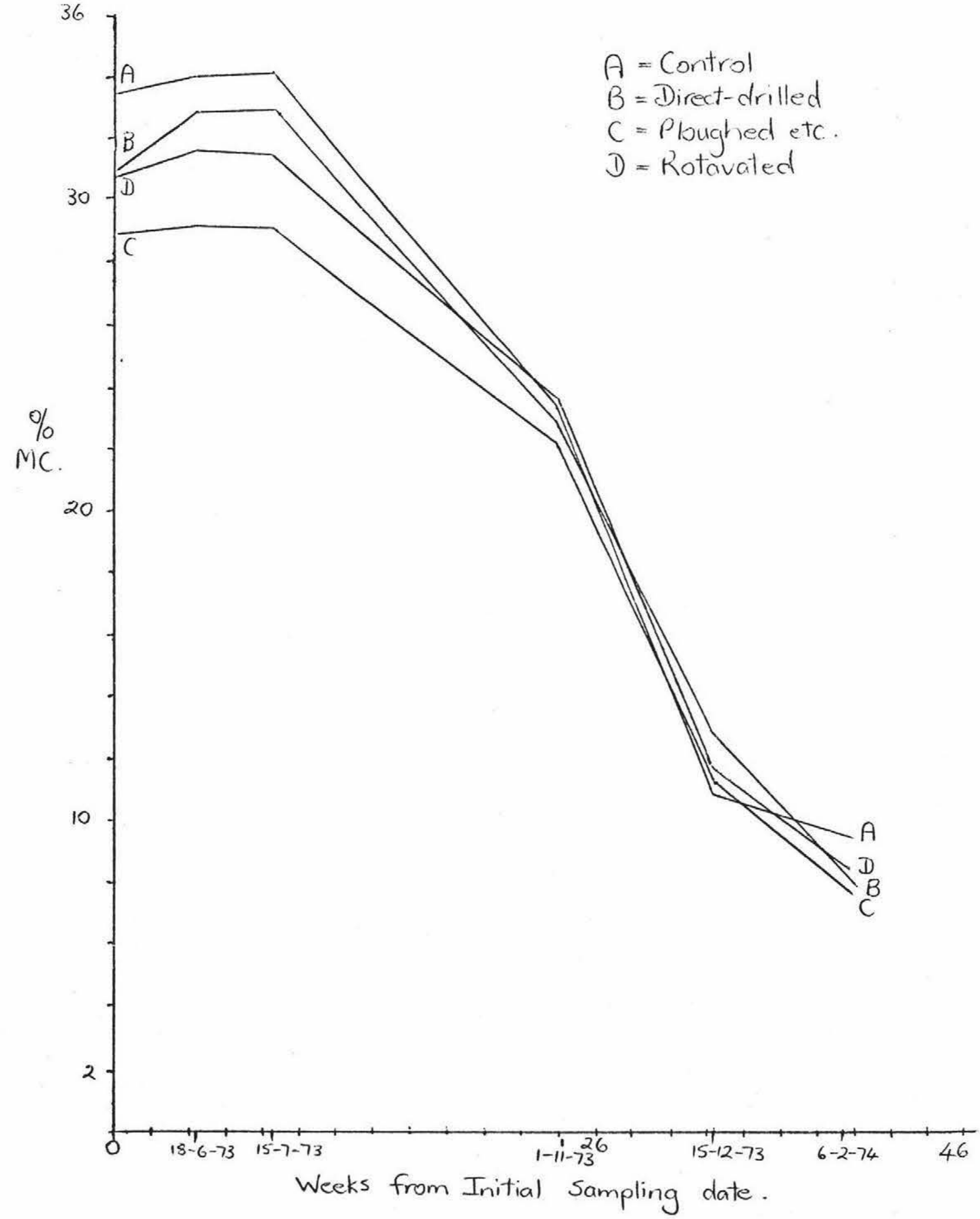


Figure 9 Soil Moisture Content at 75-125mm depth
Fallowed Plots

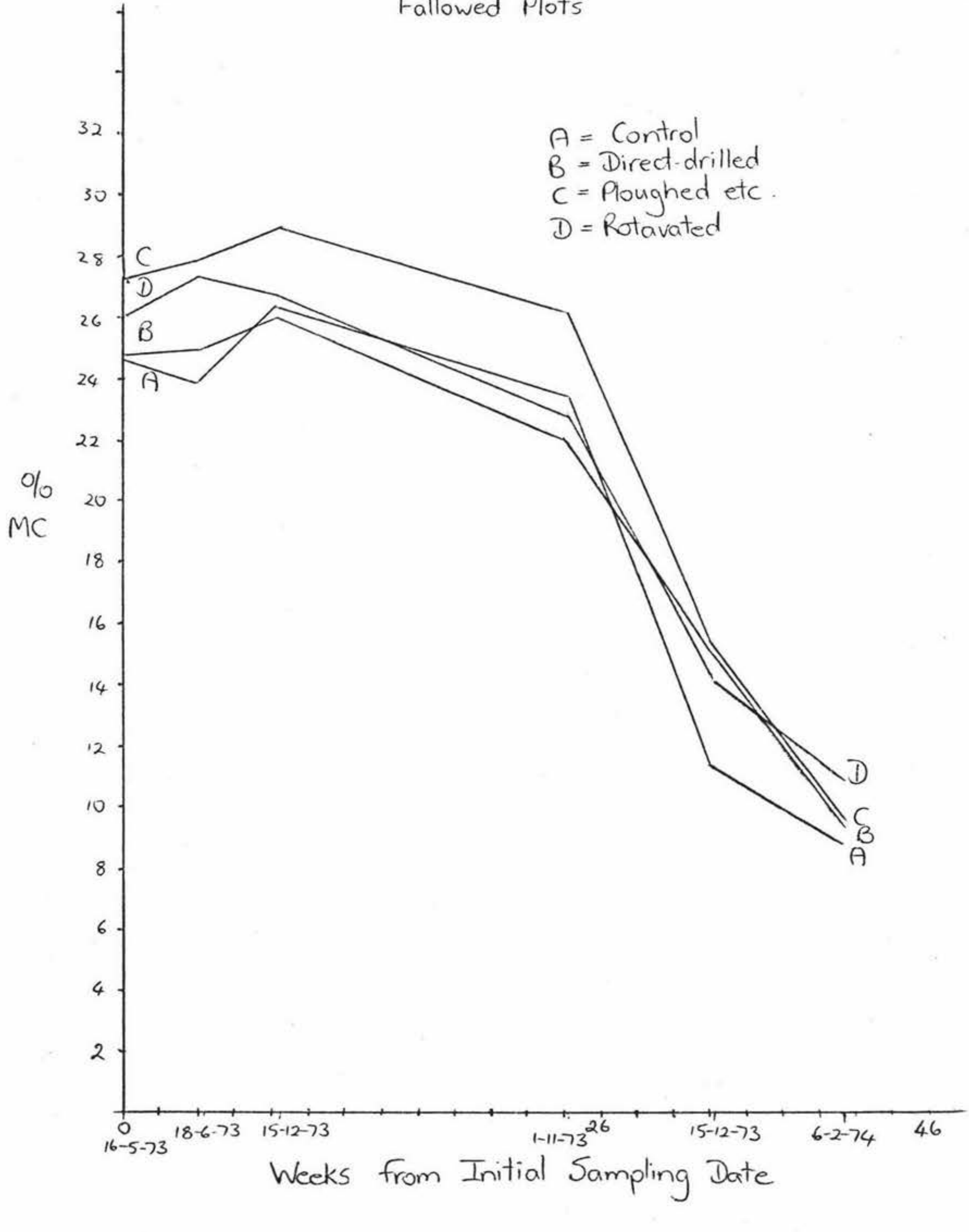
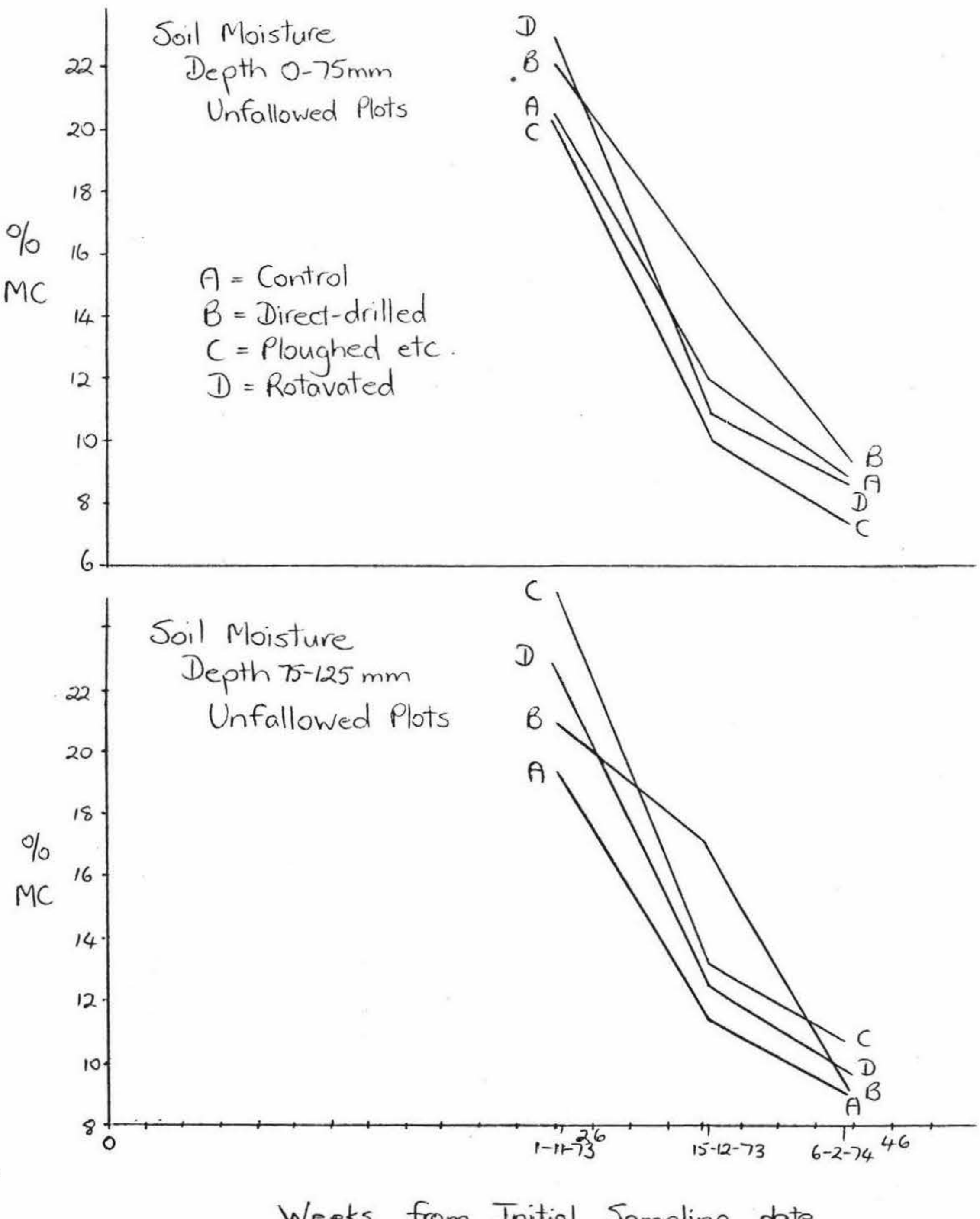


Figure 10 Soil Moisture - Unfallowed Plots



4.4 SURFACE CRUSTING AND ORGANIC MATTER RESULTS

4.4.1 Surface Crusting

The results from the surface crusting experiment can only be used as a suggestive indication of the characteristics of the various treatments. The evaluation was done largely to compare the trial treatments with two other areas of cultivated ground; one of a known poor structure and one of a reasonably good structure. It was neither feasible nor necessary to set up a randomised experimental design to enable statistical comparisons to be made, and this limitation should be taken into consideration. A study of the graphs (figure 11) suggests that treatments reached a maximum penetrometer force at different depths. Some treatments (especially control and direct-drilled plots) do not appear to reach any discernible maxima at all. Although it could be argued that comparison of these effects would be more meaningful if the experimental design had allowed regression lines to be determined, a detailed study of surface crusting was not intended when the experiment was started.

Figures 11.a and 11.b (control and direct-drilled plots) appear to be similar because the soils in these two treatments were undisturbed and consolidated. The slightly steeper lines on figure 11.a (control plot) were probably caused by the presence of grass roots inhibiting the progress of the penetrometer needles through the profile. Increased friction on the sides of the needles may have caused the higher forces recorded in the two non-tilled treaments compared with the two tilled treatments, and the absence of maxima is likely to be caused by a relatively unchanged soil density with depth.

The most interesting differences are between the rotary cultivated and ploughed treatments. A comparison of figures 11 c. and 11 d. suggests that many of the lines on both graphs reached definite maxima. This seems to indicate the presence of differences in penetrating force with depth, possibly caused by crusting. It is also reasonably apparent that larger penetrating forces were required with the ploughed treatment than with the rotavated treatment. This may have been caused by differences in the organic matter content of the samples from the two treatments, although this view is not supported by the results from the Walkley-Black titrations on the surface soil. Mean organic matter percentages of treatments ploughed and direct-drilled were 5.24% and 5.16% respectively.

On the other hand, a comparison of figures 11c. and 11.f, which are graphs of known poorly structured and better structured areas respectively, appear to show large differences in the strength of the respective crusts. The poorly structured plot appeared to be highly crusted, and the percentage of organic matter of the poor and better plots were 2.46% and 4.56% respectively. The relatively high strength crust on the poorly structured area is thought to have been caused largely by inorganic cementing compounds baked hard by the drying action of the sun on the surface soil. The content of organic matter in the 75-125mm profile on the poorly structured area (4.75%) was not particularly low, and the decreased level on the surface may have been caused by deeper than usual ploughing, which may have brought soil up from a profile which was high in inorganic cementing agents. This, however, is speculative only.

Although few explanations can be offered on these results of crusting experiments, apparent differences in the incidence of crusting have been illustrated in the figures. Possible reasons for the relatively high incidence of crusting are:-

1. A low level of organic matter in the surface soil.
2. A higher level of inorganic cementing agents in the surface soil.

3. Variation in the extent of decomposition of organic matter in the surface soil, resulting in weaker bonding together of soil aggregates.
4. Slight differences in soil moisture levels in the surface soil, perhaps in part related to the differences in organic matter composition.
5. Greater breakdown of structural aggregates by machinery, resulting in easier formation of crusts by a given amount of raindrop impact.

4.4.2 Organic Matter Results

The organic matter evaluation results can also by used only to roughly indicate this characteristic, since a scund experimental design was not possible. Results of the Walkley-Black titrations are summarized in table 19.

TABLE 19 Soil organic matter percentages

Treatment Time	Depth (mm)	Control	Direct-Drilled	Ploughed	Rotavated
		FALLOWED TRIAL			
After autumn) 1973) Tillage)	0-75mm	7.65	8.04	6.05	7.12
	75-125	5.56	5.84	6.13	7.14
After spring) 1973) Tillage)	0-75	6.82	5.96	5.34	6.38
	75-125	3.44	5.25	5.01	3.81
After autumn) 1974) Tillage)	0-75	6.16	6.26	5.24	5.16
	75-125	3.81	3.26	4.86	4.40
		NON-FALLOWED TRIAL			
After spring) 1973) Tillage)	0-75	6.23	6.26	4.26	5.76
	75-125	4.92	4.71	5.52	5.89
After autumn) 1974) Tillage)	0-75	6.70	5.65	3.98	4.58
	75-125	5.21	5.27	4.30	3.99

Supplementary Data

Poorly structured area	0-75mm	2.46
	75-125	4.75
Well structured area	0-75	4.56
	75-125	2.73

Few trends can be seen in the organic matter results, other than an apparent higher percentage or organic matter present in the 0-75mm layer in the non-tilled treatments compared to the tilled treatments. Notable also is the low organic matter content in the surface soil of the poorly structured area outside the trials.

Fig. 11 Penetrometer Force Requirements - cultivated and uncultivated soil (29-4-74)

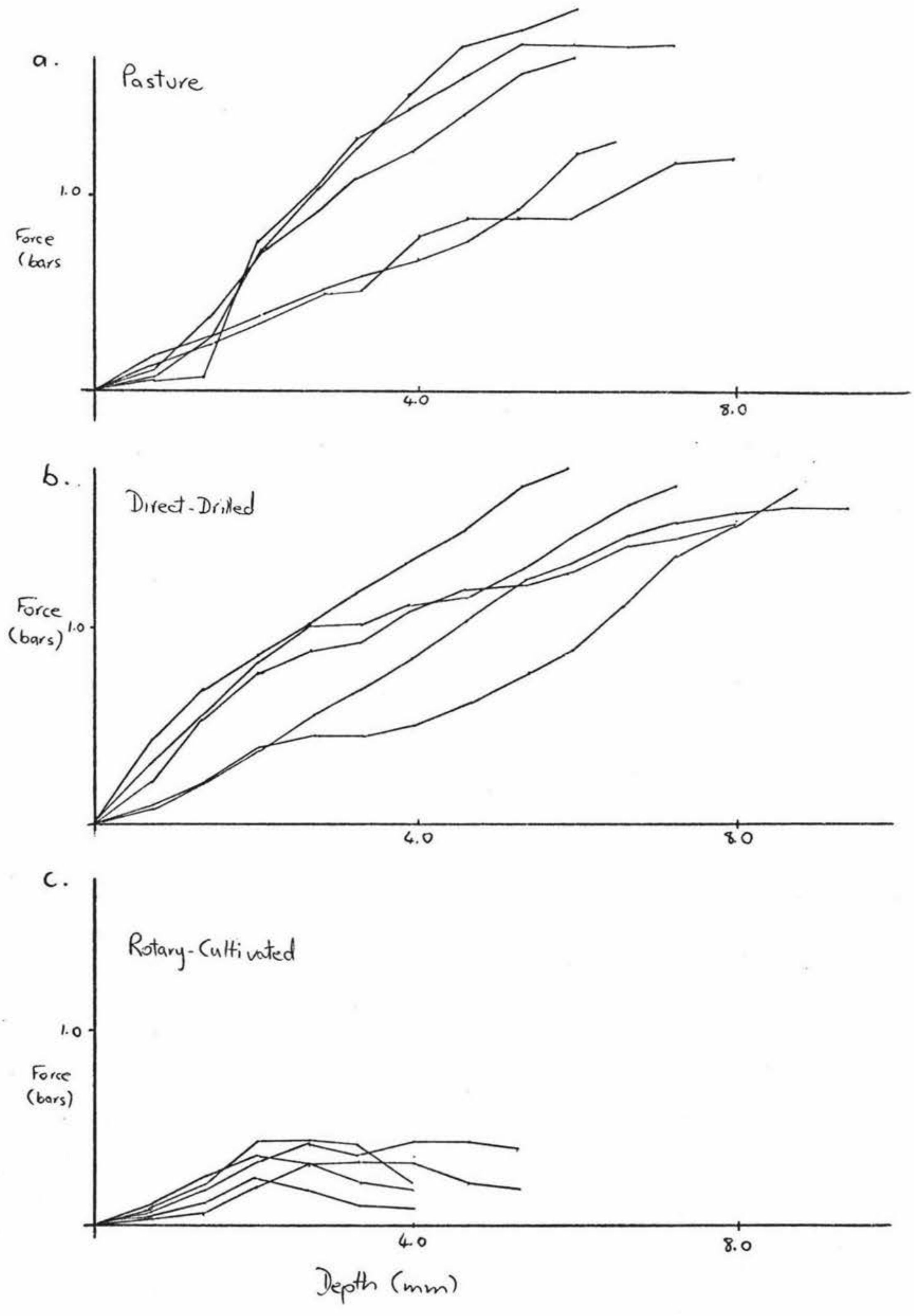
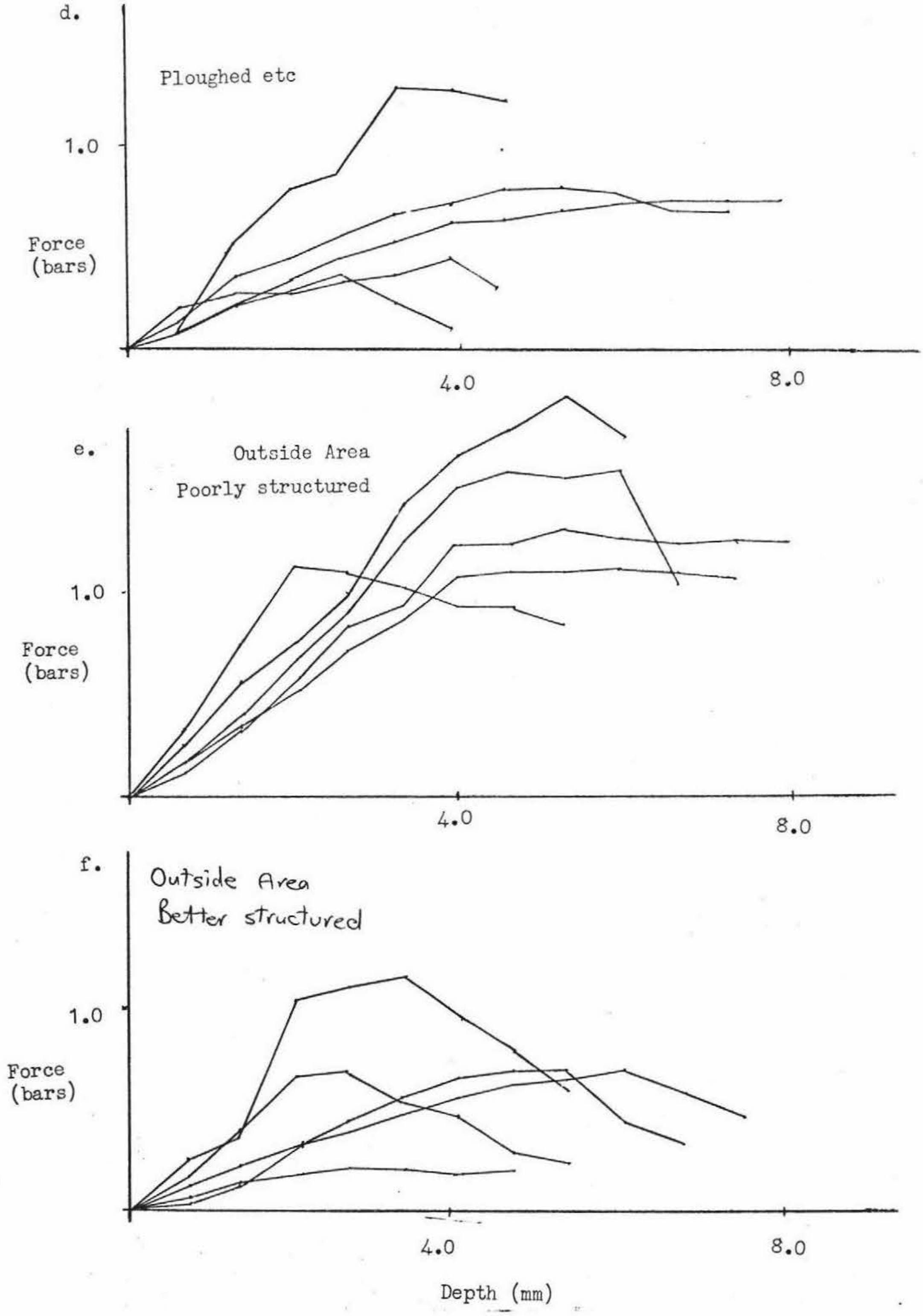


Figure 11 (cont'd)



4.5 DRY SIEVING RESULTS

The dry sieving of soil samples from ploughed and rotary cultivated treatments showed up several differences between the two tillage methods. The results are illustrated in figures 12 and 13.

The results were subjected to analysis of variance. Treatment means and the results of the analyses are shown in table 20.

TABLE 20 Dry sieving of cultivated soil. (arc-sin transformations in parenthesis)

MWD[x] (Fallowed) cm			LSD	
Date of Sampling	Ploughed etc.	Rotavated	0.05	0.01
21-5-73	1.92	1.86	5.8	10.8
5-11-73	1.32	1.15	0.6	-1.1
28-3-74	1.42	0.52	0.3	0.60
8-5-74	0.87	0.51	0.2	0.3
MWD (Non-fallowed) cm				
5-11-73	1.37	1.35	0.3	0.6
28-3-74	1.32	0.67	0.2	0.4
8-5-74	0.92	0.75	0.2	0.3
Fraction 3[+] (Fallowed) %				
21-5-73	2.6	4.7		
	(2.14)	(3.30)	(2.61	(4.79)
5-11-73	15.4	21.8		
	(8.86)	(12.64)	(10.9)	(18.53)
28-3-74	15.8	43.6		
	(9.08)	(26.08)	(7.78)	(14.28)
8-5-74	28.1	36.8		
	(16.42)	(21.7)	(9.01)	(16.54)
Fraction 3 (Non-fallowed) %				
5-11-73	13.5 (7.78)	16.0 (9.20)	(8.24)	(15.13)
28-3-74	19.6 (8.30)	36.5 (21.43)	(5.18)	(9.52)
8-5-74	25.9 (15.03)	32.5 (18.96)	(2.24)	(4.12)

+, < 1.8 mm diameter.

x Mean-weight diameter

On all sampling occasions clods on the rotary cultivated seedbed appeared to be relatively more broken down than on the ploughed seedbeds. However, the differences did not become statistically significant until 28-3-74 which was the time at which samples were taken during tillage operations.

Figure 12 shows how the MWD of the rotary cultivated plots increased with time until they were sampled again on 8-5-74, whereas MWD of clods on the ploughed plots decreased as a result of tillage operations. It is probable that the clods on the ploughed plots would have reached their lowest MWD value immediately after tillage operations were completed in early April. It is also probable that after completion of cultivation, the MWD would increase under the influence of soil wetting and natural soil aggregation mechanisms. Thus the values shown on 8 May may reflect the nett effect of concurrent processes breaking down and building up soil structure, and the values do not necessarily represent the lowest absolute value of MWD that was reached. The clods on the non-fallowed treatments tended to be consistently larger than on the fallowed treatments. This was probably caused by the fact that the non-fallowed treatment had less time out of pasture, and the binding action of pasture plant residues (e.g. roots), and perhaps the influence of microbiological fauna, was higher where there was a larger proportion of non-decomposed or decomposing organic matter.

The marked decrease in MWD with time, and the increasing difference between the rotary cultivated and ploughed treatments may illustrate a deterioration of structure with the length of time out of pasture, with the effect being more pronounced in the rotary cultivated plots. However, the general level of clod breakdown could also possibly be closely correlated with soil moisture levels at the time of tillage. The drier soil was more easily disrupted than the moist soil by tillage machinery, (soil moisture steadily decreased over the experimental period; see Chapter 4.3). This reinforces the importance of relating tillage operations to weather conditions so that the least amount of work has to be done to create a seedbed. The graphs of MWD on both the non-fallowed and fallowed trials closely resemble each other. This suggests that the effect of soil moisture or season at the time of tillage operations may have had more influence on the breakdown of aggregates and clods than the effect of time out of pasture. However, it can be noted that there was a tendency to use more fuel during tillage of the non-winter-fallowed trial, probably due to the presence of a larger content of fibrous plant residues. On the 8-5-74, the respective MWD's of the two tilled plots were significantly different at the 5% level of probability on the winter fallowed plots only. (Table 20).

A measure of the efficiency of conversion of energy into soil clod breaking might be given by dividing MWD by the appropriate fuel use figures. Thus an expression of MWD/petrol used could be established for all treatments which were cultivated. At the time differences were significant on 28-3-74, (i.e. MWD/petrol used) for a given quantity of fuel used, the clods on the rotary cultivated plots were, on the average, 42.5% smaller than the clods on the ploughed plots (fallowed treatments) and 52.0% smaller than those on the ploughed plots (non-fallowed treatments). The efficiency of soil clod breakdown by the rotary cultivater per gram of fuel burned appears, therefore, to be relatively greater than the traditional tillage implements. Also, at the time os sampling in March the rotary-cultivated plots appeared to have a good seedbed tilth, whereas the ploughed plots had further to be disced (twice), and dutch harrowed (and levelled) before they were in a suitable seedbed form.

EROSION AND SOIL TILLAGE

Although the MWD values for the two tilled treatments do not generally differ greatly (except on 28-3-74), there was a tendency for the decrease in the size of clods with time out of pasture to be greater with the rotary cultivated treatments than with the ploughed treatments. This is illustrated by the presence of a significant difference in MWDs on 8-5-74, and also in the graphs of the dry sieving results in figure 13 . The evidence suggests that the proportion of soil clods less than 1.8mm in diameter is likely to be higher in the rotary cultivated plots, especially as the length of time out of pasture increases, as shown by the difference in the proportions of soil in fraction 3+ on 8-5-74 (which were all significant at 5% level of probability).

In addition, although statistical analyses were not done, a study of the graphs suggests that there was a tendency for a relatively larger percentage of soil to be in the size range greater than 9.5mm in the ploughed treatments. The tendency became more marked as time progressed, and the rotary cultivated plots became less resistant to breakdown by vigorous machine tillage as the binding action of pasture residues disappeared.

The conclusion can be reached that erosion and possibly soil drainage problems would tend to be greater on this rotary tilled soil because of the higher percentages of soil in the small clod size fractions. It was thought that a continuation of the trials for a longer period of time may have determined whether or not any serious breakdown of soil structure under a continuous rotary tillage treatment would occur.

+ i.e. soil clods less than 1.8 mm. diameter.

Figure 12 Dry Sieve Analysis - Cultivated Soil

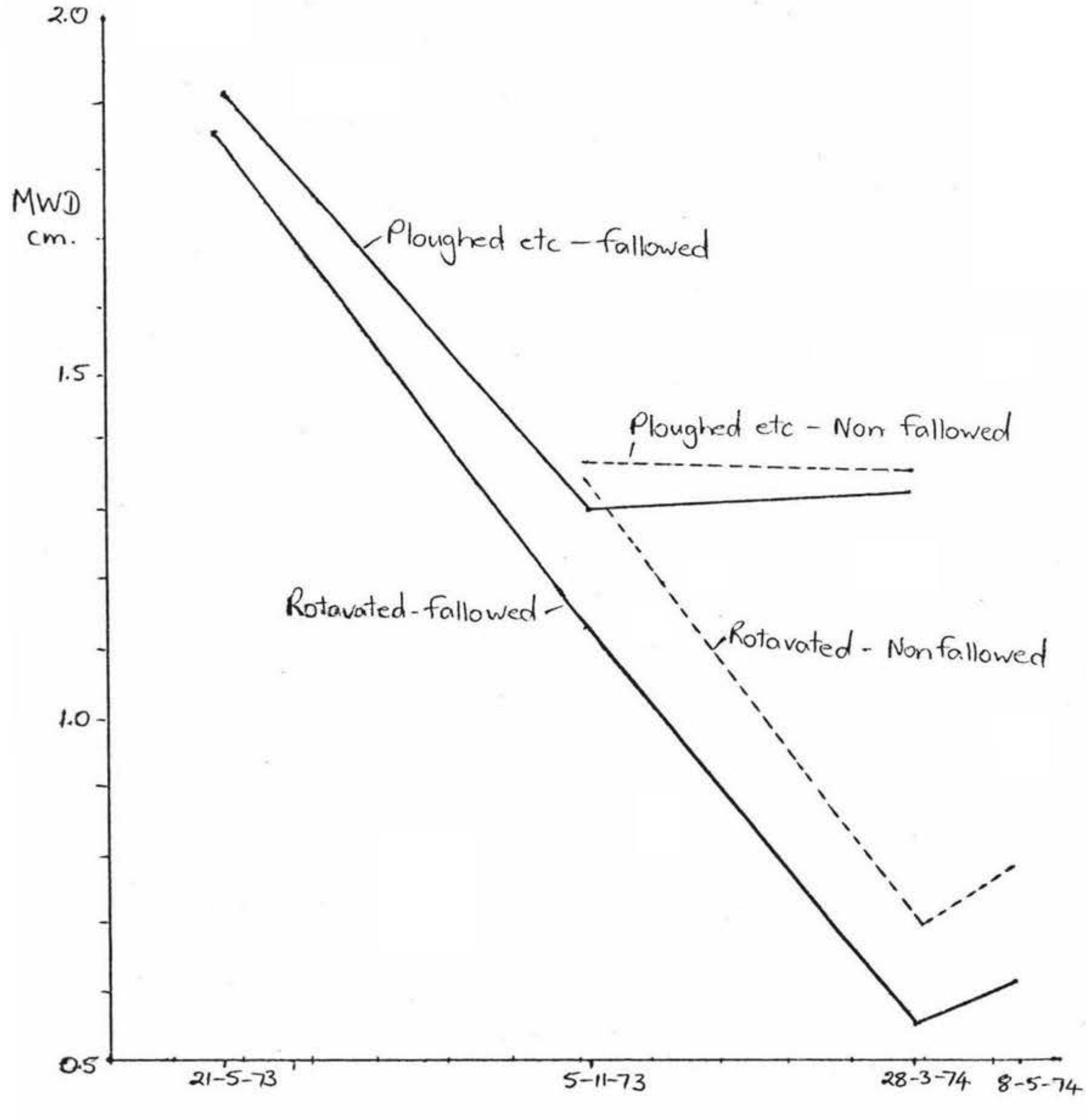
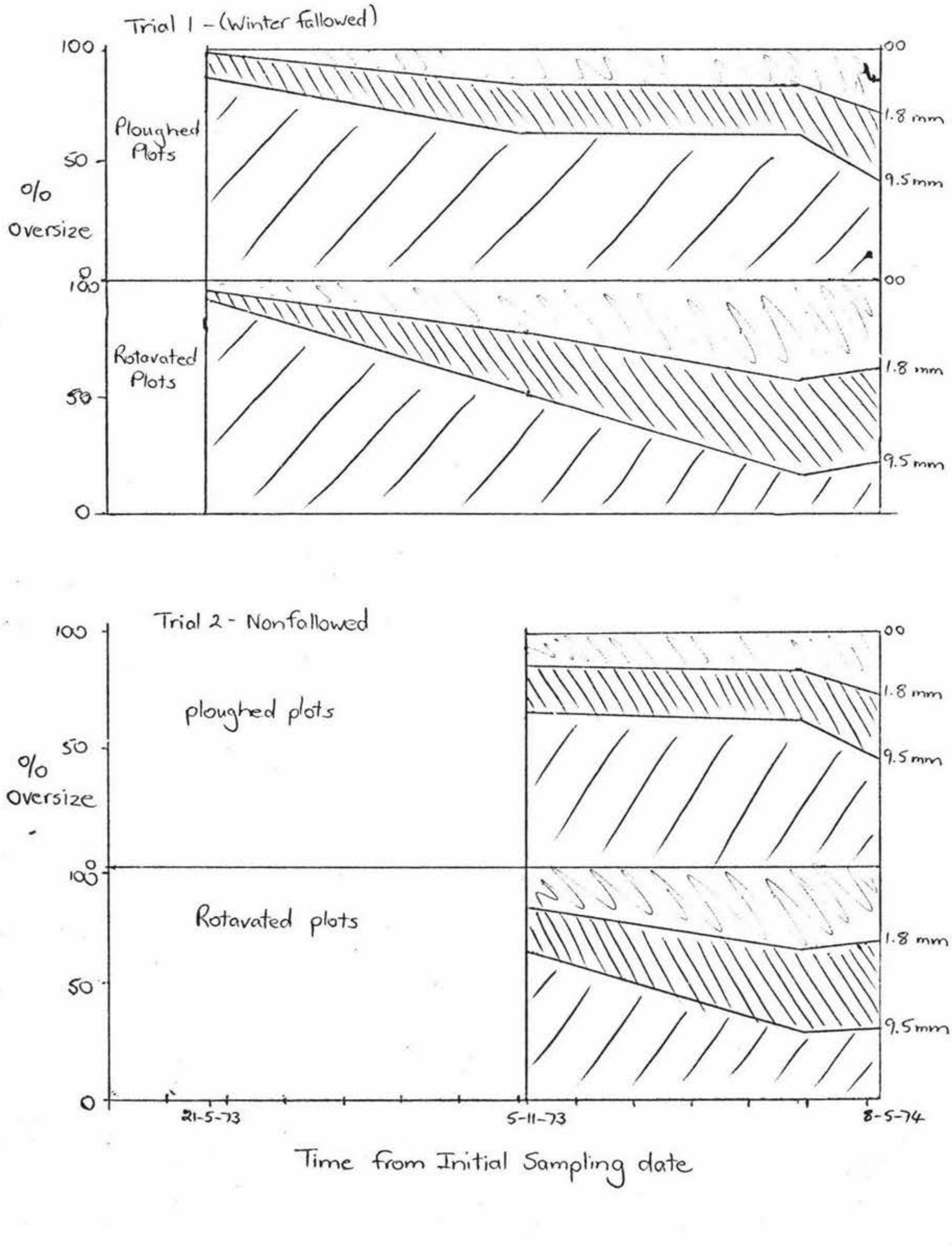


Figure 13 Dry Sieving Analysis - Cultivated Soil



4.6 WET SIEVING RESULTS

Wet sieving of soil samples from the tillage treatments appeared to be a satisfactory method of examing some of the physical characteristics of the soil, and some differences in the characteristics of soil from the treatments did show up. The results are illustrated in figures 14 and 15.

Analyses of variance were made to determine whether MWD (mean-weight-diameter) and the proportions of soil in fractions 3 (00-1.676mm aggregate size) were statistically different between treatments. It was expected that there would be some large differences occurring because of the widely differing soil structures present between the two non-tilled and the two tilled treatments. Results are summarized in table 21.

As expected, treatments left in pasture and direct drilled were consistently more stable against wet sieving than ploughed rotavated treatments. On no occasion was there found to be a significant difference between the control and the direct-drilled treatments, either between their MWD values or the percentages of soil in fraction 3.

The most interesting comparisons occur between the two tilled treatments. It could reasonably be expected that the non-tilled treatments would be more resistent to erosion and structural instability than the tilled treatments (Bakerman, 1970) There was a tendency for a larger percentage of soil to be in the smallest size fraction with the rotary cultivated treatment after dry sieving. The same is not the case after wet-sieving, however. On the sampling occasions of 11-6-73 and of 2-12-73 the ploughed treatments tended to be less stable to wet sieving than the rotary culti-vated plots, although the differences on these two occasions were not statistically significant in the proportions of soil in fraction 3 (of size less than 1.676mm diameter).

TABLE 21

WET SIEVING OF SOIL UNDER CULTIVATION
(arc-sin transformations in parenthesis)

Treatment Means:	Control	Direct-drilled	Ploughed etc	Rotary cultivated	LSD 0.05	LSD 0.01
Fallowed Plots MWD+ (mm)						
Date: 11-6-73	5.1	4.9	3.9	3.8	1.0	1.4
2-12-73	5.4	5.8	3.7	4.6	1.2	1.8
26-4-74	5.5	5.6	3.3	2.7	0.5	0.8
Fraction 3x (%)						
11-6-73	3.2 (15.09)	4.0 (19.12)	9.6 (25.80)	9.3 (23.30)	(10.21)	(14.67)
2-12-73	11.5 (6.60	6.3 (3.76)	39.9 (23.76)	27.6 (16.11)	(8.87)	(12.74)
26-4-74	19.2 (11.07)	15.6 (8.28)	47.5 (28.28)	56.2 (34.16)	(7.51)	(10.79)
Non-fallowed plots MWD (mm)						
2-12-74	5.7	5.3	3.7	4.4	1.0	1.4
26-4-74	5.8	5.7	3.5	3.0	0.3	0.4
Fraction 3 (%)						
2-12-74	8.7 (4.98)	8.9 (5.11)	40.0 (23.71)	31.9 (18.65)	(7.99)	(11.49)
26-4-74	15.2 (8.77)	15.7 (9.33)	44.8 (26.72)	50.0 (30.03)	(3.35)	(4.82)

+ Mean-weight-diameter

x i.e. clods less than 1.676 mm diameter.

It is suggested, from visual evidence, that this was caused by a lower proportion of turf and pasture fibres (e.g. roots) binding the soil of the ploughed surface-clods together. Inversion of the pasture profile by the plough had resulted in the turf being buried and the exposure of a deeper soil layer on the surface which contained relatively little fibrous matter. The fibrous matter in the rotary cultivated plots had been mixed throughout the tilled profile and continued to hold small pieces of turf together making them more stable during wetting and sieving, especially at this early date before much decomposition had taken place.

The MWD values for the ploughed and rotavated treatments largely support the suggestion that the rotary cultivated soil was slightly more stable.

The results on 26-4-74 seem to indicate that the relative characteristics of the soils had changed, and that the stability of the rotary cultivated soil had started to deteriorate to a more marked extent than the ploughed soil. At this time it can be seen (table 21) that in both the non-fallowed and fallowed trials the ploughed plots have relatively less soil in fraction 3 and a relatively larger MWD than rotary cultivated plots, and that the differences are all significant at the 5% probability level.

The sharp drop in the stability of the rotary cultivated soil may be associated in some way with the dry summer period in which the binding action of the fibrous matter from pasture residues was lost. The phenomenom cannot be explained fully as simply a drop in binding action with time due to decomposition or number of cultivations, since there was a marked similarity in the results from both the non-fallowed and fallowed treatments. Page et al (1947) noted that differences in the response of soil to tillage were found with time and that generalizations were difficult.

However, it seems reasonable that the relative differences between treatments at the sampling period on 26-4-74 (in the trials reported herein) indicate that rotary cultivated soil may drop sharply in structural stability once the initial binding action of the turf disappears.

Figure 14 Wet Sieving of Cultivated and Non-cultivated Soil (Trial 1 - Fallowed Plots)

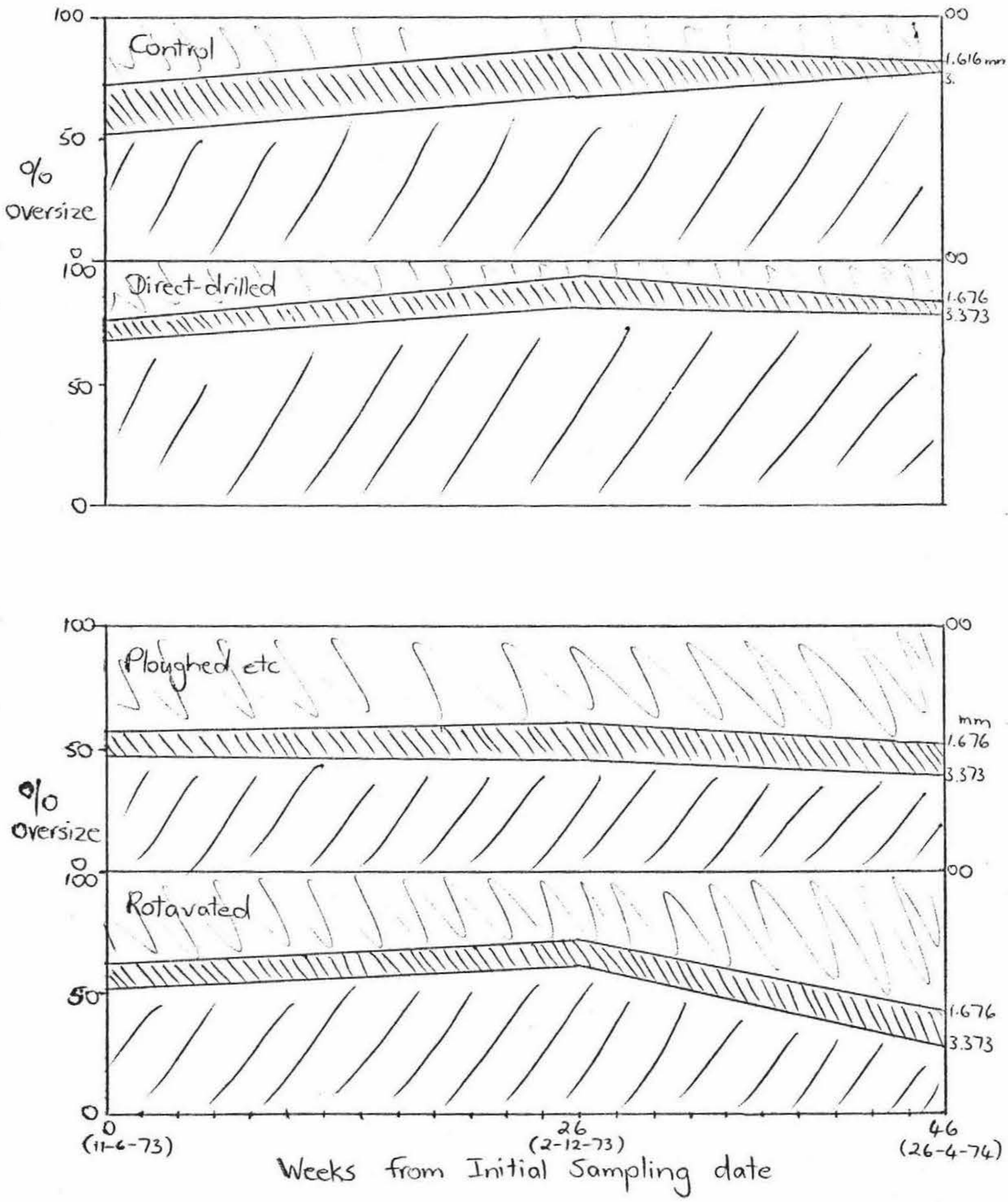
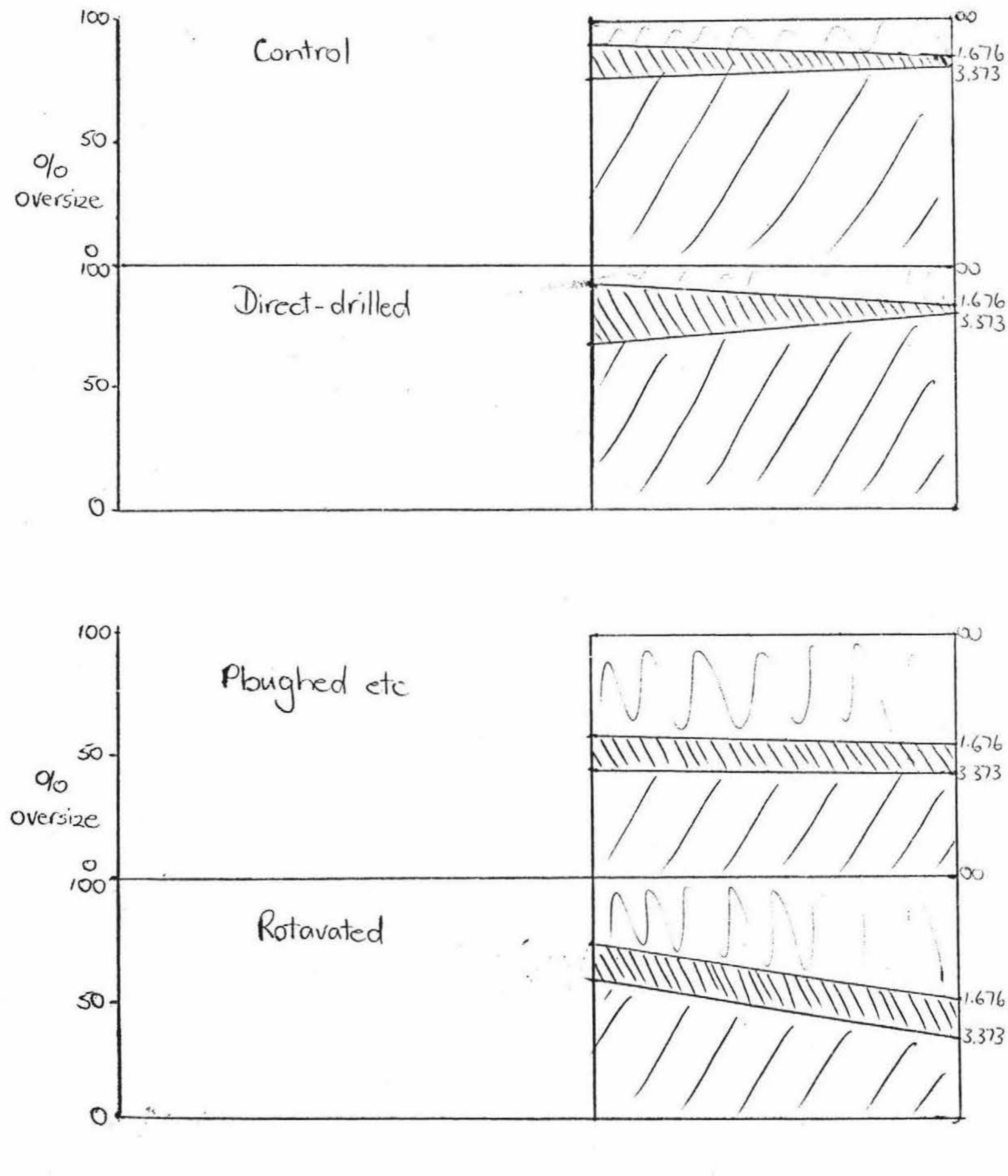


Figure 15 Wet Sieving of Cultivated and Non-cultivated Soil. (Trial 2 - Nonfallowed Plots)



4.7 CROPPING RESULTS

The 1973-74 growing season was generally unfavourable because of the dry weather conditions. No irrigation was arranged as it was felt that this may have had the effect of reducing some of the differences between treatments. Unfortunately, the barley portion of the crops could not be harvested, but photographs were taken at 8 weeks to enable visual comparisons to be made.

Plate 6 shows the barley crops on a ploughed and a rotary cultivated plot (the divisions between the two plots are in the centre of the photograph).

Plate 6 Barley establishment - fallowed plots 1973-74. (on the left ploughed, on the right rotavated).

Plate 7 , shows the barley establishment on the corresponding treatments in the non-fallowed trial.

Plate 7 Barley establishment, non-fallowed plots. (on the left ploughed, on the right rotavated).

From the photographs, there appears to be little difference between the two tilled treatments in crop growth. Cattle broke into the second trial and lightly grazed the tops of some plants.

Plates 8 and 9 show the non-fallowed and fallowed direct drilled plots, each after fifty-six days. Contrast between the two crops is obvious. Decreased establishment of plants in the non-fallowed trial is especially marked.

Plate 8 Non-fallowed direct-drilled plant establishment.

Plate 9 Fallowed direct-drilled establishment.

Plates 10, 11 and 12 show, respectively, the weediness in the rotary cultivated chou moellier crop, apparent low number of plants in the direct-drilled crop, and the freedom from weeds in the ploughed crop (fallowed trial). Plate 13 shows the poor establishment of plants on the non-fallowed direct-drilled plots.

Results of the herbage yield analysis are shown in Table 22. Yields are given as kilograms of dry matter chou moellier per m^2. and number of plants per m^2.

PLATES 10-13 Crop growth (refer to text p. 114)

Plate 10

Plate 11

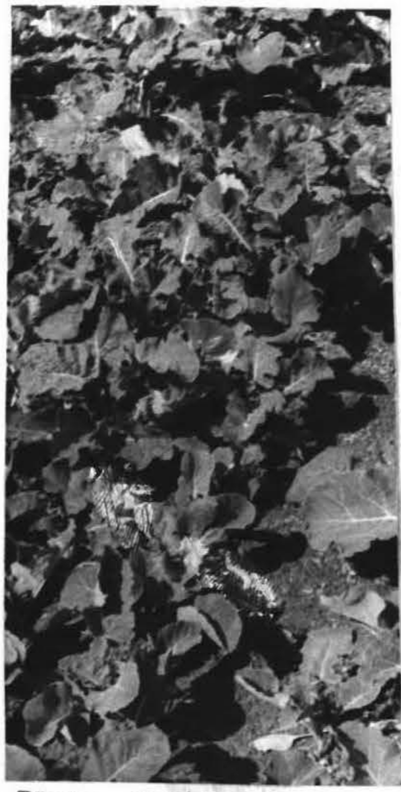


Plate 12

Plate 13

Table 22 RESULTS OF HERBAGE YIELD ANALYSIS

Treatment

Fallowed trial	Direct-drill	Plough etc.	Rotavated	LSD (P=0.05)
kg/m	0.19	0.22	0.22	0.76
No. of plants/m^2	23.0	23.0	17.5	7.00
Non-fallowed trial				
kg/m^2	0.16	0.13	0.10	0.02
No. of plants/m^2	10.6	28.0	26.0	7.8

The results of the herbage analysis show several differences between treatments. Visually, there appeared to be fewer plants on the fallowed direct-drilled plots than the rotary cultivated plots. This proved to be an optical illusion caused by the presence of weeds on the rotary cultivated plots. The yields and numbers of plants The yields and numb ers of plants were not significantly. different on the fallowed plots.

The results of the analysis on the non-fallowed plots were more interesting. The number of crop plants which established on the direct-drilled plots was significantly lower than the other two treatments ($P= 0.05$), but the former plots had a significantly higher yield. The rotary cultivated treatment had a significantly lower yield than the ploughed treatment.

The differences in the incidence of weeds between the rotary cultivated and ploughed treatments can probably be explained by the deep burying of weed seeds in the ploughed plots, compared with the mixing of weed seeds throughout the topsoil by the rotary cultivator. This apparently allowed a proportion of weed seeds to germinate and establish. These weeds apparently influenced the yield of crop on the rotary cultivated plots, and this appeared to be more marked on the non-fallowed trial.

DECREASED PLANT ESTABLISHMENT:

Six samples of a direct-drilled row were taken about two weeks after sowing, from both the chou moellier and barley crops in the non-fallowed plots, using a U_shaped shovel. Each sample was 0.3m in length. No chou moellier seeds could be found presumably because of their small size. The more easily identified barley seeds, however, allowed realistic counting from dissections in the laboratory (Withers et al 1974).

Many of the barley seeds were found to be rooted into the sides and bottom of the coulter slits, but had not reached the surface. This suggests that shoots were either destroyed by soil fauna (e.g. slugs) or were physically prevented from emerging by closure of the coulter slit as suggested by Dixon (1972).

Fourteen seeds (or plants) were found in the samples. Of these 3 were established plants (21.4%), 9 were rooted but dead seeds (64.3%), and 2 were non-germinated seeds (14.3%).

Several insects were found, and one of these was identified as the larva of a species of beetle (Elateridae sp.) (K.S. Milne pers. comm.) and commonly knows as a wireworm. It is frequently noticed in the first year of a crop planted out of pasture and seems to thrive in heavy, poorly drained soils rather than light soils.

This study was very brief, but it is possible that wireworms were the cause of the low apparent establishment of plants in the non-fallowed direct-drilled crop.

Fallowing of the direct-drilled plots over winter may have served to rid the soil of many insect pests by destroying the pasture vegetation with herbicides and depriving them of food.

4.8 VISUAL APPRAISALS AND GENERAL DISCUSSION OF TRIALS

Various aspects of the cultivated trials were considered of interest but could not easily be quantified. Low (1972) described many features of his study on long-term cultivation effects in general and objective discussions. He also described visual appraisals of various situations with the result that a much clearer picture of the experiments was gained.

Photography is one method of recording important features of a system of soil management when experiments to qualify or quantify the points of interest are not practicable. One disadvantage of photography is that it often requires considerable experience and perhaps expensive equipment in order to illustrate a particular feature of the soil, especially when microscopic or detailed difference in soil characteristics are of interest. However, important characteristics of treatments were able to be recorded by photographs in these trials which help to describe some aspects.

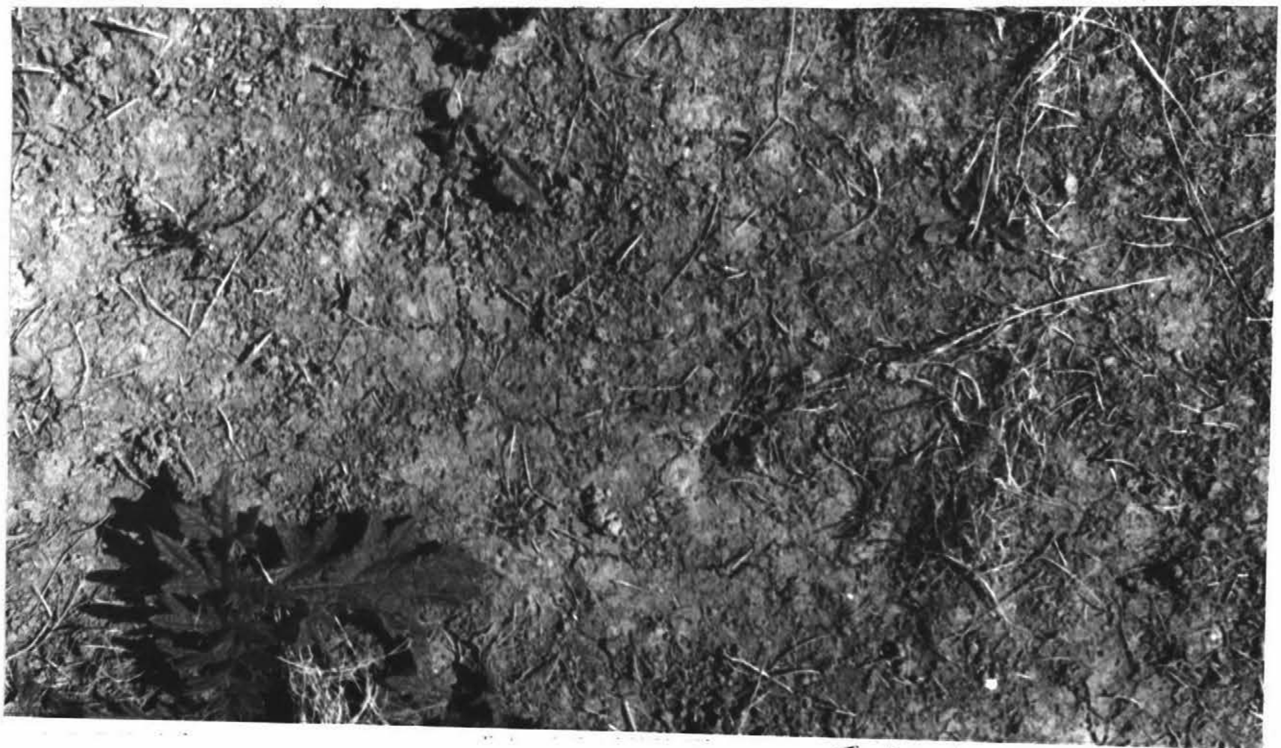
The Winter Fallow

Plates 14 , 15 and 16 show vertical photographs of examples of the three fallowed treatments before tillage was commenced in the spring of 1973.

Features which could be noted are the undisturbed and relatively bare surface on the direct-drilled plot, the weediness in the rotavated plot, and the characteristic water damaged appearance of the ploughed plot.

Over the winter fallow period rain falling on the trial area tended to infiltrate quickly into the surface of the rotary cultivated plots which were covered with small pieces of turf held together by pasture roots and fibres. As the winter progressed, many of the turf pieces sprouted shoots and took root with the eventual result shown

Plate 14. Surface of fallowed direct-drilled plot



Scale 1:3.33

Plate 15. Weediness in rotavated fallowed plot

Scale 1:3.33

in plate 15 . Rotary cultivation is thought to be of little use in helping to control weeds in a subsequent crop because of that machine's inability to deeply bury pasture residues and weed seeds present on the soil surface.

There is little doubt that the plough is very effective in burying pasture residues and weeds. However, as is clear from the photograph, rainfall and water runoff during high intensity rain storms during the winter have resulted in a rilled and crusted soil surface. The trial was situated on flat ground which prevented much erosion taking place, and water merely flowed across the soil surface until a point of entry into the profile was found. One of these points of water entry can be clearly seen in plate 16 as a hole in the soil surface which leads down to the bottom of the plough furrow. Presumably water pooled in cavities on the furrow bottoms until it percolated deeper into the non-tilled soil horizons. Many similar holes were present on the ploughed plots, at distances of approximately 2 to 3 metres apart. When the rains had stopped and the soil surface dried, crusting and cracking of the soil surface occurred as shown in the photograph.

I t is a reasonable assumption that if the fallowed plots were on sloping ground and water was not forced to find entry points into the soil at weak points between plough furrows, rilling erosion could have occurred. Heavy rainfall was likely to be responsible for forming seals on the surface of the upturned soil which was relatively low in organic matter which reduced water infiltration at the points of raindrop impact. I t can be concluded that fallowing of soil after ploughing runs the risk of rilling and possibly tunnel erosion, with slumping of soil in the tilled profile a possibility in some soils.

In the case of the rotary cultivated plots, the paraquat and dicamba herbicides effectively kept practically all herbage growth in check, although a few very sparse weeds e.g. Scotch thistles, appeared on the plots. The cropping results show what is probably a significant beneficialy effect on the chou moellier crop resulting from the winter fallow on the direct-drilled plots. It is possible that the greater establishment of plants on fallowed direct-drilled plots reflects a large reduction of insect pests in the soil which would normally have lived in the pasture (both above and below the soil surface).

Rotary Cultivation and Ploughing

Plate 17 shows a comparison of the ploughed and rotavated plots during cultivation of the non-fallowed plots in the spring of 1973. Both plots were in pasture over the winter. The photograph shows a ploughed plot (on the left) after ploughing and discing, and rotavated plot after one pass over with the rotary cultivator. The difference in the ability of the two tillage systems to bury pasture vegetation can be seen in the photographs.

The order of aggregate breakdown in the rotavated plots with time can be seen on comparison of plates 18 and 19 . Plate 18 shows the surface of a fallowed rotavated plot on 5-11-73, plate 19 shows the same surface on 28-3-74.

Plate 20 is a ploughed surface on 28-3-74 and several operations were needed before it was broken down enough to form a seedbed. Pulverization of of soil clods during a dry season by the rotary cultivator was, if anything, difficult to prevent, whereas it was found difficult to break down clods sufficiently to form a seedbed under the traditional plough/disc/harrow system.

Plate 16. Water damage on ploughed fallowed plot

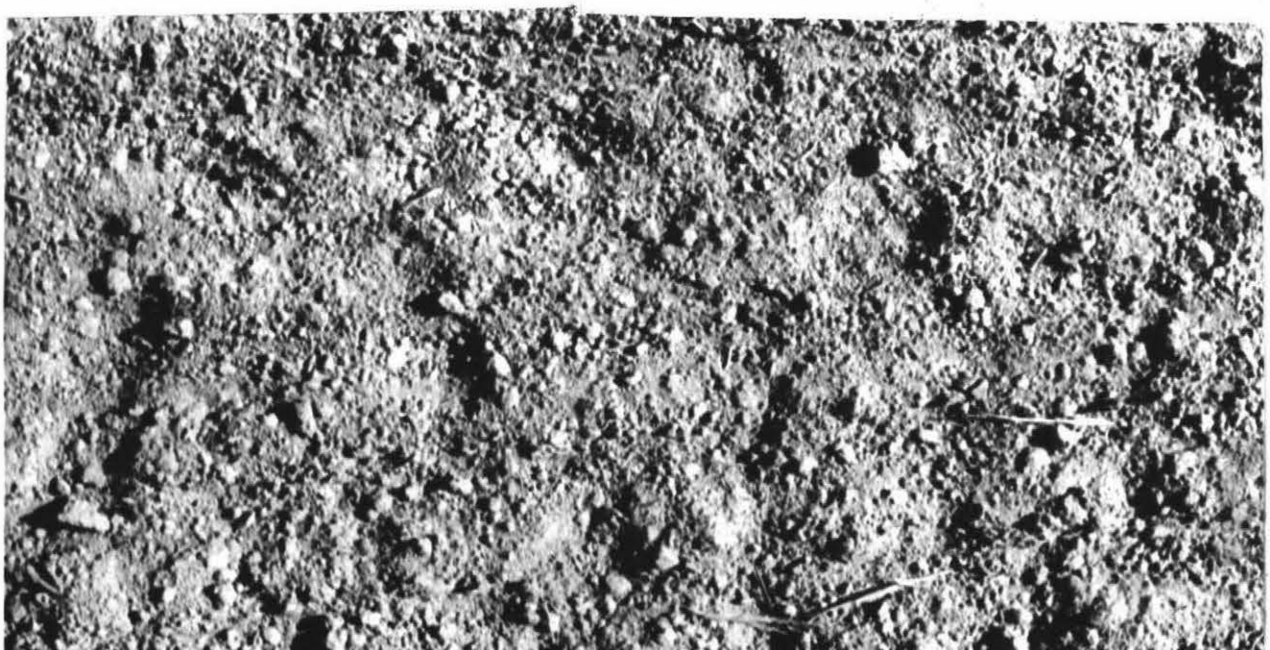
Scale 1:3.33

Plate 17. Ploughed and rotavated plot (Spring 1973)
(left) (right)

Plate 18. Surface of fallowed rotavated plot on 5-11-73

Scale 1:3.33

Plate 19. Surface of fallowed rotavated plot on 28-3-74



Scale 1:3.33

It was observed that once tilled soil had become wet, on redrying it tended to settle into a massive structure as aggregates became cemented together. The aggregates were able to be relatively easily separated by the action of the rotary cultivator. However, it is not known whether this was predominantly due to the action of the implement or to the thorough mixing of organic matter throughout the soil, decreasing the strength of aggregate cements.

Plate 20. Ploughed surface on 28-3-74

Scale 1:3.33

Chapter 5 SUMMARY AND CONCLUSIONS

Three methods of soil-tillage were investigated. These were:-

1. traditional plough/disc/harrow.
2. direct-drilling or chemical tillage
3. rotary cultivation.

Methods 1 and 3 also involved rolling and levelling operations.

Two trials were conducted. One was tilled and left fallow over winter 1973 and the other was left in pasture until spring 1973.

Crop Yields

Two crops, chou moellier and barley were sown in spring 1973. The chou moellier showed a significantly lower number of established plants in the non-fallowed direct-drilled treatment. However, in terms of dry matter, the direct-drilled crop had a significantly higher yield than the ploughed treatment, which itself was significantly better than the rotavated treatment.

Dry weather yields of chou moellier, in the winter fallowed trial, tended to be greater than on the non-fallowed trial, but there were no significant differences between treatments in these fallowed plots either in terms of plant establishment or yield.

Photographic and visual appraisal of the barley was made in the absence of yield data. In general, it appeared that this crop was probably less sensitive to the tillage treatments than was chou moellier.

Soil Erosion and Drainage

Wet sieving of soil from the tillage treatments showed a substantial and significantly different response to wetting and sieving, between the non-tilled treatments (direct-drilled) and the mechanically tilled treatments (plough etc. and rotavated). There may have been a tendency for a larger percentage of soil to be in the smallest aggregate size fraction with the rotary cultivated treatment compared with the ploughed treatment, early in the experiments but this was not significant. Surface soil from the ploughed treatment may also have been less stable to wet-sieving at that time.

As the length of time out of pasture increased, the rotary cultivated soil appeared to decrease in stability, to a greater extent than the ploughed soil. At the termination of the experiments the rotavated soil from both the fallowed and non-fallowedtrials contained a significantly greater proportion of soil in the smallest aggregate size fraction than did the ploughed soil after wet-sieving.

Since soil aggregates in the smallest size fractions could be expected to be the most sensitive to the forces of erosive and slumping, it might be reasonable to expect continuous rotary cultivation to be more detrimental to soil structure (and therefore more prone to erosion) in the long-term, than ploughing.

Fuel Use

Total petrol used by various tillage mechanisms differed greatly. On an arbitrary scale where petrol used in conventional (plough etc.) cultivation equals 100, the relative amounts of petrol used on the rotavated and direct-drilled treatments were 53.9, and 10.6 respectively. All differences between treatments in amounts of fuel used, on both the fallowed and non-fallowed trials, were highly significant.

The number of operations required in order to establish a seedbed by each of the treatments in the three tillage periods, also appeared to differ. For example, an average of 6.2 tractor operations were required on the ploughed plots, compared to 3.6 on the rotary cultivated plots, and 0.8 on the direct-drilled plots. This did not include spraying but did include the drilling operation.

Soil Resistance to Penetration

In general, the undisturbed profiles, which were left in pasture, and which were direct-drilled, required a higher penetrating force than the two mechanically tilled treatments. Little difference was apparent between the ploughed and rotary cultivated treatments.

The average increase in penetrating force at 1cm depth, caused by localized wheel tracking on the plots appeared to be 7.4% (direct-drilled) 84% (ploughed) and 87% (rotary cultivated), although no attempt was made to statistically analyse these comparisons.

Soil Mositure

Although manystatistically significant differences occurred between treatments at a depth (0-75mm) few clear treands appeared. The fact that various densities of growing plants were present on the plots (including the control plots, under pasture), complicated interpretation of these results. It is difficult to be conclusive about the manner in which moisture contents were influenced by the actual soil tillage operations.

Clearly, the technique of direct-drilling seemed to be the most economical in terms of fuel use, and least destructive soil aggregate size and stability. However, fallowing for a time before sowing appeared to be necessary to ensure a satisfactory plant establishment. Compensatory individual growth of plants partly offset the decreased plant establishment count on the non-fallowed direct-drilled plots with a chou moellier crop, but this may not occur with all crops. Chou moellier dry matter yields on the ploughed treatments were greater than yields on rotary-cultivated treatments in both the fallowed and non-fallowed treatments. Photographic and visual appraisal of the barley crop suggested that this crop was less sensitive than chou moellier.

In the short-term, surface soil from the ploughed treatments may have been slightly less stable to wet-sieving compared to rotavated treatments, possibly because of less organic matter present in the soil surface due to inversion of the profile by the plough.

In the long-term, damage to soil structure in the rotary-cultivated treatments was more severe than in ploughed treatments.

Dry-sieving of soil samples from the ploughed and rotavated treatments showed that the rotary cultivator broke up soil clods and aggregates to a greater extent than the implements used on the ploughed treatments. However, ploughing was observed to be superior to rotary cultivation in terms of weed control.

Fallowing appeared to be beneficial to crop dry matter yields in all treatments, although it must be remembered that there is a loss of pasture production associated with fallowing.

The direct-drilled treatment appeared to be markedly more resistant to wheel compaction than the two mechanically tilled treatments, possibly due to a more rigid soil structure. Measurements of soil resistance to a penetrometer probe showed that the two tilled profiles were signigicantly less dense or rigid than the direct-drilled and control (pasture) profiles.

This thesis has illustrated some characteristics of three tillage systems, and each system appears to have both advantages and disadvantages. Final conclusions must ultimately be left to the soil manager who can make decisions with regard to the various aspects (e.g. soil type, fuel costs etc.) which are important to his particular situation.

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Appendix 1 PETROL MEASUREMENT RESULTS

Autumn 1973

(gram petrol per plot)

Control Plots - None

Direct-drilled plots No drilling.

Ploughed etc. plots N.B. Plots 1-4 are 'fallowed' plots over winter 1973.

Plots 5-8 are 'non-fallowed' plots

	1	2	3	4	Tractor
ploughing	271.2	201.5	237.1	162.8	83.8
2 X Tandem disc	71.7	13.3	24.9	19.1	54.4
leveller/Dutch harrow	44.8	53.8	47.5	41.4	20.2
power harrow	29.6	26.8	24.9	22.4	45.4
2 X roller	28.9	36.4	14.9	26.2	61.0
Corrected total	446.2	331.9	349.3	271.9	264.9

(Rolling unnecessary because of rain on rotavated plots)

Rotavated Plots	1	2	3	4	Tractor
1st Rotovation	37.6	30.8	29.2	33.4	55.5
2nd & 3rd	69.0	80.6	82.7	84.4	49.2
Corrected Total	106.6	111.4	111.9	117.6	104.7

SPRING 1973

Control Plots   Nil

Direct-drilled plots - Drilling 44.8

Ploughed Plots	1	2	3	4
Ploughing	181.9	188.9	178.7	158.0
Rolling	58.2	67.9	62.8	62.9
1st Disc	17.9	19.8	17.5	12.2
2nd Disc	21.9	30.1	21.9	44.1
Levelling	12.1	10.4	21.4	17.2
Rolling	25.6	29.7	13.8	17.9
Total	317.6	346.8	316.1	312.3

	5	6	7	8	Tractor
Ploughing	190.2	189.6	189.9	226.1	83.8
Rolling	57.8	60.5	49.9	56.3	30.5
1st Disc	12.2	15.9	17.9	29.0	
2nd Disc	28.9	17.9	26.0	49.3	29.0
Levelling	14.5	26.9	8.5	17.0	18.6
Rolling	15.5	16.2	17.1	21.3	30.5
Total	319.1	327.0	309.3	390.4	221.4

Rotary Cultivated Plots

	1	2	3	4
1st Rotav.				
2nd "	37.7	35.3	45.5	40.0
Roller	14.3	15.6	6.0	5.1
Leveller	14.7	7.3	9.5	32.0
3rd Rotov.	42.9	51.5	55.9	58.4
Roller	32.2	44.7	18.5	39.5
Totals	141.8	154.4	135.4	175.0

	5	6	7	8	Tractor	
1st. Rotav.	111.8	119.1	115.6	124.9	55.5	
2nd "	44.6	44.8	50.6	15.4	55.5	
Roller	9.7	9.7	9.9	20.3	30.5	
Leveller	4.8	3.3	16.4	6.9	18.6	
3rd Rotav.	50.6	65.4	53.8	60.2	55.5	
Roller	23.2	29.5	37.7	36.7	30.5	
	244.7	271.8	284.0	264.4	190.6	1–4
					246.1	5–8

Autumn Cultivation 1974

Control plots Nil

Direct-drilled Plots Drilling 11.8

Ploughed etc. plots	1	2	3	4	
Ploughing	132.5	117.2	97.9	86.2	
1st & 2nd Disc	47.3	43.9	38.8	49.4	
1st & 2nd Dutch harrow/leveller	50.1	51.7	55.4	48.2	
Roller	35.9	35.1	24.9	52.8	
Total	265.8	247.7	217.0	236.6	
	5	6	7	8	Tractor
Ploughing	125.4	102.7	122.4	114.3	83.8
1st & 2nd Disc	37.7	54.2	51.2	70.3	83.5
1st & 2nd Dutch harrow/leveller	48.4	57.2	95.8	51.4	40.3
Roller	58.1	53.9	58.6	55.8	30.5
Total	269.6	268.0	328.0	291.8	238.1

Rotavated Plots	1	2	3	4	
Rotavated	105.1	93.2	113.4	106.0	
Roller	18.2	9.7	16.1	2.6	
Total	123.3	102.9	129.5	108.6	
	5	6	7	8	Tractor
Rotav.	105.8	98.3	104.7	96.9	55.5
Roller	21.7	22.4	2.1	8.3	30.5
Total	127.5	120.7	106.8	105.2	86.0

Rolling Resist. etc.

Petrol used (g)	3rd gear	2nd gear	1st gear
1.	11.8	18.5	28.7
2.	11.7	19.1	26.8
3.	9.9	24.5	28.3
4.	14.1	20.7	23.7
5.	12.0	28.7	26.7
	11.9	22.3	26.8

Duncan Seedliner	Pasture		Cultivated
1.	85.1	1.	82.2
2.	92.6	2.	75.6
3.	99.1	3.	85.7
4.	80.7	4.	86.1
	89.4		82.4
Less Tractor:	44.8	Less Tractor:	37.8

Appendix II PENETROMETER ANALYSIS RESULTS

Newtons Force Mean of 8 Readings 16-7-73

Depth:	1cm	2cm	4cm	6cm	8cm	10cm	12cm
Plot A_1 *	90	163	207	247	288	300	305
A_2	107	173	210	243	274	304	319
A_3	123	220	258	275	288	300	325
A_4	100	141	171	193	216	230	261
B_1	933	165	212	227	257	275	292
B_2	101	139	237	264	267	297	300
B_3	62	138	193	202	220	217	285
B_4	97	138	218	240	250	260	272
C_1	60	105	145	157	143	188	192
C_2	68	100	133	175	207	223	228
C_3	73	88	113	135	157	178	188
C_4	68	99	123	150	171	173	183
D_1	80	128	165	188	210	272	292
D_2	75	128	165	182	218	265	278
D_3	67	102	143	190	252	282	298
D_4	53	88	136	156	187	220	249

* Numbers 1 - 4 correspond to the blocks on trial 1 fallowed over winter 1973.

A = Control

B = Direct-drilled

C = Ploughed etc.

D = Rotavated.

Mean of 8 readings 4-1-74

Tracked		1cm	2cm	4cm	6cm	8cm	10cm	12cm
(Non tracked)	A_1)	430						
	A_2)	324						
	A_3)	394						
	A_4)	296	434					
	B_1	366						
	B_2	397						
	B_3	323						
	B_4	339	430					
	C_1	411						
	C_2	385						
	C_3	441						
	C_4	398						
	D_1	311						
	D_2	268						
	D_3	323						
	D_4	292						
Non-tracked								
	B_1	355						
	B_2	296	398					
	B_3	358						
	B_4	364						
	C_1	254	326					
	C_2	194	208	355				
	C_3	415						
	C_4	229	331					
	D_1	206	320	399				
	D_2	223	349					
	D_3	84	117	163	260	396		
	D_4	161	253	407				

Mean of 8 readings 4-1-74

Tracked		1cm	2cm	4cm	6cm	8cm	10cm	12cm
(Non tracked)	A_5*	307						
	A_6	206	349					
	A_7	239	328					
	A_8	181	319					
	B_5	323						
	B_6	258	390					
	B_7	252	349					
	B_8	289	418					
	C_6	258						
	C_6	259						
	C_7	424	258					
	C_8	328						
	D_5	306						
	D_6	307	402					
	D_7	407						
	D_8	152	243					
Non-tracked								
	B_5	353	412					
	B_6	232	360					
	B_7	220	367					
	B_8	191	281	415				
	C_5	178	241					
	C_6	101	173	316	400			
	C_7	149	220	330	354	418		
	C_8	276						
	D_5	141	194	351				
	D_6	67	84	156	294			
	D_7	131	208	293				
	D_8	86	159	320				

* Numbers 5 - 8 correspond to the blocks on trial 2 (Non-fallowed over winter 1973)

Mean of 8 readings 15-11-73

	1cm	2cm	4cm	6cm	8cm	10cm	12cm
A_1	119	155	174	182	199	228	248
A_2	155	191	163	187	210	244	261
A_3	138	163	171	185	209	236	264
A_4	144	168	169	180	203	227	248
B_1	133	149	166	192	211	236	252
B_2	133	154	204	220	250	289	317
B_3	132	157	177	206	224	257	284
B_4	157	179	196	216	244	278	297
C_1	93	103	143	165	184	201	214
C_2	53	105	136	154	171	189	199
C_3	77	104	111	147	166	181	181
C_4	73	108	132	184	208	234	259
D_1	97	116	134	208	209	235	278
D_2	91	124	160	208	233	284	301
D_3	93	112	134	167	196	228	251
D_4	57	97	112	154	193	234	275
A_5	127	150	162	180	202	229	260
A_6	144	166	179	202	232	260	290
A_7	150	171	193	221	231	257	286
A_8	139	169	192	222	260	289	318
B_5	102	131	153	181	197	213	226
B_6	113	142	171	195	223	249	279
B_7	143	156	175	195	232	248	265
B_8	104	141	164	194	214	240	267
C_5	53	77	125	131	159	171	214
C_6	82	119	144	171	186	197	208
C_7	78	120	148	163	170	180	191
C_8	106	136	172	192	205	218	236
D_5	69	100	107	143	171	204	234
D_6	100	103	133	151	177	225	259
D_7	86	119	131	176	221	243	276
D_8	91	120	147	163	198	241	276

Means: 15-11-73

	1cm	2cm	4cm	6cm	8cm	10cm	12cm
Fallowed							
A	139	169	169	183	205	234	255
B	139	159	186	208	232	263	287
C	73	105	130	162	182	201	213
D	84	112	135	184	208	245	276
Non-fallowed							
A	140	164	181	206	231	259	288
B	115	142	166	191	216	237	259
C	79	113	147	164	180	191	212
D	86	110	129	158	192	228	261

Appendix III SOIL MOISTURE RESULTS

Soil Moisture Content 16-5-73

Depth 3-5"

Plots Rep:	Control	Direct-drilled	Ploughed etc.	Rotavated
1	25.1%	24.0	31.0	24.9
2	24.2	24.2	25.4	25.3
3	24.5	26.1	26.7	25.8
4	25.3	25.0	26.8	28.1

Depth 0-3"

1	32.1	27.2	28.8	27.2
2	30.6	30.6	28.1	20.1
3	30.4	33.1	28.4	33.9
4	40.2	31.9	29.7	31.7

Soil Moisture Content 18-6-73

Depth 3-5"

Rep:	Control	Direct-drilled	Ploughed	Rotavated
1	21.9	25.8	27.1	26.8
2	25 5	25.3	29.7	26.4
3	12.6	26.6	27.1	28.3
4	35.6	26.1	27.7	29.0

Depth 0-3"

1	38.4	32.5	30.7	31.9
2	32.1	32.1	28.8	30.8
3	31.9	33.6	28.8	31.5
4	34.1	33.2	28.6	33.0

Soil Mositure Content 15-7-73

Depth 3-5"

Rep:	Control	Direct-drilled	Ploughed	Rotavated
1	26.2	25.0	29.6	25.2
2	25.7	25.4	28.9	27.7
3	26.5	25.9	27.8	26.0
4	27.2	28.1	28.9	27.4

Soil Moisture Content 15-7-73 (cont'd)

Depth 0-3"

Rep:	Control	Direct drilled	Ploughed etc	Rotavated
1	33.9	31.7	28.5	31.4
2	33.8	32.1	29.7	31.4
3	33.7	33.0	29.4	31.6
4	35.1	34.8	29.0	32.0

Soil Moisture Content 1-11-73

Depth 0-3"

Rep:	Control	Direct-drilled	Ploughed etc.	Rotavated
1	23.9	23.1	23.3	23.6
2	24.4	23.6	22.5	23.6
3	22.4	22.5	22.8	22.8
4	23.0	22.4	20.5	24.9
5	21.4	22.3	20.9	23.1
6	19.8	20.7	19.3	22.9
7	19.3	22.6	20.4	21.9
8	21.2	22.6	20.1	23.3

Depth 3-5"

Rep:	Control	Direct-drilled	Ploughed etc.	Rotavated
1	30.7	24.1	26.4	22.3
2	21.5	21.4	26.0	21.4
3	20.0	21.6	27.4	22.5
4	21.4	21.0	25.0	24.3
5	19.7	21.1	24.8	22.7
6	19.7	20.0	23.7	22.9
7	18.7	21.5	26.1	22.6
8	19.8	21.5	25.9	22.6

Soil Moisture Content 15-12-73 (Very dry weather)

Depth 0-3"

Rep:	Control	Direct-drilled	Ploughed etc	Rotavated
1	8.1	16.6	10.6	14.2
2	12.2	9.4	13.1	11.8
3	12.5	13.4	11.0	9.8
4	11.3	12.3	11.9	11.4

Soil Moisture Content 15-12-73 (cont'd) (Very dry weather)

Depth 0-3"

	Control	Direct-drilled	Ploughed etc	Rotavated
5	14.0	15.0	10.5	10.7
6	11.7	13.7	10.4	10.2
7	11.1	15.5	9.8	11.1
8	10.9	17.2	9.9	11.2
Depth 3-5"				
1	10.3	19.3	15.3	17.1
2	12.2	12.7	17.7	15.0
3	11.7	15.1	13.7	12.2
4	11.7	13.8	15.0	13.1
5	11.5	16.4	14.0	12.0
6	11.8	14.9	11.6	12.1
7	11.2	17.7	12.4	12.0
8	11.7	18.3	14.7	14.0

Soil Moisture Content 6-2-74

Depth 0-3"

Rep:	Control	Direct-drilled	Ploughed etc	Rotavated
1	8.96	7.31	10.04	6.52
2	9.16	8.09	8.72	10.06
3	9.94	7.94	5.90	6.46
4	9.90	8.85	6.37	10.50
5	9.84	10.34	7.97	9.22
6	8.22	6.81	6.91	8.74
7	9.39	9.51	5.89	7.56
8	7.68	10.91	8.30	9.27

Soil Moisture Content 6-2-74 (cont'd)

Depth 3-5"

	Control	Direct-drilled	Plough etc.	Rotavated
1	8.26	11.14	8.80	11.30
2	9.81	8.26	11.14	10.84
3	8.53	9.81	9.85	10.85
4	9.53	8.53	8.73	9.97
5	9.42	9.53	10.93	9.55
6	9.52	9.42	11.20	9.89
7	9.20	9.52	11.09	10.21
8	8.80	9.20	9.69	9.13

Depth 5-8"

	Control	Direct-drilled	Plough etc.	Rotavated
1	7.69	10.19	9.27	10.37
2	9.32	11.46	9.93	9.10
3	8.77	9.16	9.48	11.02
4	9.35	10.10	9.01	9.70
5	9.71	10.47	10.49	7.39
6	9.36	11.40	9.18	9.61
7	8.90	10.83	10.58	10.00
8	8.43	10.50	9.31	11.34

Appendix IV PERCENTAGE ORGANIC MATTER

(Results of Walkley-Black Titration)

	After Aut. 1973 Tillage		After Spring 1973 Tillage		After Aut. 1974 Tillage	
	0-75mm	75-125mm	0-75mm	75-125mm	0-75mm	75-125mm
Fallowed:						
A	7.65	5.51	6.89	3.62	6.01	3.93
	7.64	5.61	6.76	3.49	6.31	3.70
B	8.00	5.84	5.95	5.42	6.26	3.49
	8.09	5.84	5.97	5.08	6.26	3.05
C	5.99	6.26	5.86	4.94	5.23	4.92
	6.02	6.00	4.82	5.08	5.25	4.80
D	7.12	7.23	6.43	4.14	5.07	4.48
	7.12	7.06	6.34	3.49	5.25	4.33
Non-fallowed:						
A			6.22	4.89	6.89	5.89
			6.24	4.94	6.51	4.54
B			6.30	4.71	5.55	6.26
			6.22	4.71	5.76	4.28
C			3.95	5.42	3.99	4.45
			4.58	5.63	3.98	4.16
D			5.63	5.00	5.32	3.11
			5.90	6.79	3.84	4.87
Poorly structured area					2.50	4.95
					2.42	4.54
Well structured area					4.42	3.09
					4.71	2.48

A = Control

B = Direct-drilled

C = Ploughed etc.

D = Rotavated

Appendix V WET SIEVING RESULTS

Wet Sieving 11-6-73 (percent)

Fraction:	1 *	2	3	MWD (mm)
Plot: A_1	65 %	2.7	32.3	4.730
A_2	62.8	5.6	31.6	4.637
A_3	80.0	2.5	17.5	5.659
A_4	75.5	1.9	22.6	5.371
B_1	71.0	4.0	25.0	5.122
B_2	78.0	5.2	16.8	5.574
B_3	67	2.6	30.4	4.854
B_4	50	4.1	56.9	3.900
C_1	36.0	12.3	51.7	3.071
C_2	66.0	8.8	25.2	4.882
C_3	49.6	8.6	41.8	3.861
C_4	37.0	8.8	54.2	3.081
D_1	58.0	7.1	34.9	4.360
D_2	54.6	12.3	33.1	4.226
D_3	55.6	7.7	36.7	4.220
D_4	37.0	10.1	52.9	3.101

* Fraction 1 - retained on 3.353 sieve
Fraction 2 - retained on 1.676 sieve
Fraction 3 - retained in bucket.

A = Control
B = Direct-drilled
C = Plough etc.
D = Rotavated.

Wet Sieving 2-12-73

Fraction:	1	2	3	MWD (mm)
Plot: A_1	52.0 %	32.5	15.4	4.36
A_2	79.2	12.8	7.9	5.76
A_3	69.4	19.9	10.4	5.25
A_4	68.6	19.0	12.3	5.19
A_5	80.2	12.7	7.1	6.29
A_6	81.4	10.9	7.7	5.86
A_7	74.3	17.1	8.6	5.52
A_8	67.7	20.9	11.4	5.16
B_1	78.9	14.6	6.5	5.76
B_2	78.7	14.5	6.8	5.75
B_3	84.4	10.6	6.0	6.05
B_4	79.0	14.0	7.0	5.76
B_5	61.1	30.8	8.0	4.90
B_6	78.5	14.4	7.1	5.74
B_7	61.9	26.1	12.0	4.88
B_8	76.4	15.0	8.6	5.61
C_1	63.2	10.8	26.2	4.73
C_2	55.4	11.7	32.9	4.26
C_3	26.5	15.3	57.7	2.53
C_4	37.2	20.8	42.0	3.27
C_5	37.1	17.4	45.3	3.21
C_6	31.8	16.8	51.2	2.87
C_7	45.7	13.6	40.7	3.69
C_8	69.2	8.1	22.7	5.07

Wet Sieving 2-12-73 (cont'd)

	1	2	3	MWD (mm)
Plot: D_1	59.4%	10.5	30.1	4.49
D_2	73.4	6.4	20.2	5.38
D_3	66.9	13.5	19.6	5.00
D_4	44.0	15.3	40.7	3.61
D_5	65.6	8.0	26.4	4.84
D_6	49.5	10.1	40.4	3.89
D_7	55.5	11.9	32.6	4.27
D_8	61.5	10.1	28.4	4.62

Wet Sieving 26-4-74

Fraction:	1	2	3	MWD (mm)
Plot: A_1	62.2	5.7	32.0	4.60
A_2	84.2	1.7	14.0	5.92
A_3	80.4	2.5	17.0	5.68
A_4	82.4	3.1	13.6	5.81
A_5	78.6	3.9	17.4	5.92
A_6	86.5	2.3	11.0	6.11
A_7	77.2	3.5	19.1	5.49
A_8	83.2	3.1	13.5	5.86
B_1	73.7	6.1	20.1	5.32
B_2	80.7	4.2	15.0	5.72
B_3	85.3	2.8	11.8	5.99
B_4	78.8	5.4	15.7	5.62
B_5	79.5	3.4	17.0	5.64
B_6	80.3	4.5	15.1	5.70
B_7	78.6	2.9	18.4	5.54
B_8	82.8	2.7	14.4	5.83
C_1	38.8	11.8	49.3	3.23
C_2	38.3	13.3	48.2	3.22
C_3	41.9	14.0	44.0	3.46
C_4	37.2	14.6	48.0	3.17

Wet Sieving 26-4-74 (cont'd)

Fraction:	1	2	3	MWD (mm)
Plot: C_5	48.2	14.3	37.3	3.85
C_6	44.5	10.0	45.3	3.56
C_7	33.0	13.5	53.4	2.90
C_8	41.5	14.9	43.5	3.45
D_1	32.9	15.6	51.4	2.92
D_2	26.4	17.5	56.0	2.55
D_3	33.3	12.8	53.8	2.91
D_4	20.1	16.7	63.1	2.30
D_5	34.9	18.0	46.9	3.08
D_6	41.2	12.4	46.3	3.39
D_7	28.0	15.5	56.4	2.62
D_8	34.5	15.0	50.4	3.02
Agron. Plots:				
Good 1.	62.2	9.5	28.1	4.65
2.	56.5	12.4	30.9	4.34
Poor 1.	57.2	10.1	32.5	4.35
2.	49.6	12.3	38.0	3.99

Appendix VI DRY SIEVING RESULTS

Dry Sieving 21-5-73 (Percent)

Fraction:		1 *	2	3	MWD (cm)
Plot:	C_1	87	10.4	2.6	1.75
	C_2	83	13.9	3.1	1.68
	C_3	75	19.9	5.1	1.54
	C_4	76.5	19.3	4.2	1.57
	D_1	68.7	23.2	8.1	1.43
	D_2	83.5	12.3	4.2	1.69
	D_3	82.0	14.2	3.8	1.67
	D_4	73.0	20.0	7.0	1.58

* Fraction 1 - retained on 9.5mm sieve

Fraction 2 - retained on 1.8mm sieve

Fraction 3 - passed through both sieves.

Dry Sieving 5-11-73

Fraction:		1	2	3	MWD (cm)
Plot:	C_1	54.8	26.1	19.0	1.16
	C_2	68.7	17.4	13.8	1.41
	C_3	50.5	19.1	19.9	1.09
	C_4	75.8	15.1	8.9	1.55
	C_5	61.1	24.1	14.7	1.28
	C_6	79.1	10.6	10.2	1.60
	C_7	54.6	28.3	17.1	1.17
	C_8	69.0	18.9	12.1	1.42
	D_1	64.4	17.6	17.8	1.33
	D_2	53.6	24.8	21.6	1.14
	D_3	60.8	19.0	20.0	1.26
	D_4	44.1	27.7	28.1	0.96

Dry Sieving 5-11-73 (cont'd)

Fraction:		1	2	3	MWD (cm)
Plot:	D_5	68.6	18.5	12.8	1.41
	D_6	57.0	24.8	18.0	1.28
	D_7	66.7	19.0	14.2	1.38
	D_8	61.9	19.0	19.0	1.28

Dry Sieving After Rolling 28-3-74

Fraction:		1	2	3	MWD (cm)
Plot:	C_1	63.2	19.7	17.1	1.31
	C_2	55.4	26.2	18.4	1.18
	C_3	66.2	19.7	14.1	1.37
	C_4	66.7	19.7	13.6	1.38
	C_5	65.7	19.2	15.1	1.30
	C_6	69.9	18.4	11.7	1.44
	C_7	64.0	20.0	16.0	1.33
	C_8	63.7	21.2	15.0	1.32
	D_1	21.4	37.5	41.1	0.70
	D_2	17.2	32.1	50.7	0.44
	D_3	18.5	38.5	43.0	0.48
	D_4	21.2	37.9	40.9	0.53
	D_5	28.9	34.4	36.7	0.68
	D_6	24.7	36.1	39.2	0.60
	D_7	38.2	30.9	30.9	0.85
	D_8	26.2	34.4	39.3	0.62

Dry Sieving 8-5-74

C_1	44.5	29.6	25.9	0.97
C_2	41.2	29.4	29.4	0.90
C_3	43.7	29.7	26.5	0.95
C_4	37.5	31.2	31.3	0.84

Dry Sieving 8-5-74 (cont'd)

Plot	Fraction: 1	2	3	MWD (cm)
C_5	43.5	29.0	27.4	
C_6	44.6	28.6	26.8	0.97
C_7	47.7	27.7	24.6	1.03
C_8	45.6	29.4	25.0	0.99
D_1	23.3	36.7	40.0	0.57
D_2	25.4	36.5	38.1	0.61
D_3	23.8	41.3	34.9	0.60
D_4	27.0	38.1	34.9	0.65
D_5	37.1	32.3	30.6	0.83
D_6	31.5	33.9	33.9	0.74
D_7	31.5	35.2	33.3	0.73
D_8	33.9	33.9	32.2	0.77

C = Ploughed etc.

D = Rotavated.

Appendix VII CROP YIELD

No of Plants/M^2

Plot Rep:	1	2	3	4
B_1	19	18	21	15
B_2	32	20	30	28
B_3	25	17	24	28
B_4	26	29	19	15
B_5	14	5	14	15
B_6	23	23	14	15
B_7	7	7	11	8
B_8	7	5	6	3
C_1	15	26	25	17
C_2	26	31	17	17
C_3	27	18	23	18
C_4	30	27	30	19
C_5	26	24	31	27
C_6	24	24	23	30
C_7	35	16	37	36
C_8	32	33	32	17
D_1	10	18	18	15
D_2	14	14	13	17
D_3	23	24	26	23
D_4	16	19	18	13
D_5	26	36	25	25
D_6	21	22	30	26
D_7	30	17	32	18
D_8	20	34	33	20

B = Direct-drilled

C = Ploughed etc.

D = Rotavated

Herbage Yield Kg/m^2

	DM%	1	2	3	4	Mean dW/m^2
B_1	8.00	3.17	2.81	2.67	2.63	0.226
B_2	8.05	1.81	2.81	1.36	2.63	0.173
B_3	7.74	3.17	2.08	2.90	1.81	0.166
B_4	7.91	2.67	3.22	2.63	2.31	0.214
B_5	8.08	3.22	1.72	3.62	2.13	0.216
B_6	7.79	1.95	1.90	2.81	1.54	0.159
B_7	7.81	2.31	1.90	1.45	1.63	0.142
B_8	8.25	1.85	1.17	2.31	0.31	0.116
C_1	7.75	2.31	2.85	2.90	3.53	0.224
C_2	7.39	1.99	3.17	3.22	3.26	0.215
C_3	7.65	3.58	2.85	3.44	2.54	0.237
C_4	7.93	2.31	2.72	2.35	2.26	0.191
C_5	7.76	1.90	2.22	2.99	1.81	0.173
C_6	7.87	1.63	1.58	1.63	2.13	0.137
C_7	7.55	1.40	0.99	1.67	1.13	0.098
C_8	7.65	1.63	1.90	1.76	1.58	0.131
D_1	7.30	2.08	2.58	2.22	1.90	0.160
D_2	8.05	2.17	6.90	2.72	3.17	0.301
D_3	8.00	2.26	1.90	2.90	1.85	0.178
D_4	8.20	2.31	2.17	2.44	2.35	0.190
D_5	7.65	1.72	1.58	1.04	0.86	0.099
D_6	7.77	0.90	0.86	1.27	2.81	0.113
D_7	7.68	0.90	1.04	1.17	1.17	0.082
D_8	7.60	0.90	1.81	1.45	1.31	0.104

B = Direct-drilled

C = Ploughed etc.

D = Rotavated

Appendix VIII SURFACE CRUST AN LYSIS RESULTS

'Fallowed' Plots only: Reading on dial after 2 second interval.

	Rep	
A	a.	0 10 23 42 52 60 94 110 115 112 127 138 140
	b.	0 2 14 40 90 120 155 171 190 210 211 208 210
	c.	0 15 45 80 120 150 178 210 220 230 240
	d.	0 12 36 80 115 130 145 170 190 210
	e.	0 20 35 45 57 65 80 90 110 145 150
B	a.	0 50 80 100 120 122 130 135 150 170 180 210
	b.	0 25 63 90 110 115 121 138 142 152 167 171 180
	c.	0 35 65 96 120 138 158 177 202 220
	d.	0 10 25 43 64 80 100 120 144 155 171 180 184 190 190
	e.	0 10 25 45 52 52 60 74 90 110 130 160 178 200
C	a.	0 20 31 30 35 40 50 30
	b.	0 10 25 32 40 25 12
	c.	10 60 90 110 150 140 (Maybe pressing into a stone)
	d.	0 10 25 37 50 61 75 78 82 85 87 86 85
	e.	0 15 40 51 63 75 82 90 91 87 80 78
D	a.	0 10 25 49 37 30 23
	b.	0 5 15 29 22 15 14
c	c.	12 30 45 39 30 29
	d.	0 9 22 38 51 44 52 52 45
	e.	0 4 10 24 39 40 38 26 23

A = Control

B = Direct-drilled

C = Ploughed etc.

D = Rotavated

Agron Plots (Poor Structured)

a. 0 20 40 60 85 110 126 132 133 133 128 125

B 30 70 90 120 170 200 215 230 210

c. 0 20 50 80 110 150 180 190 182 190 100

d. 0 15 40 70 100 120 145 145 155 148 147 146 147

e. 0 40 90 135 130 120 110 110 100

Agron Plots (Better Structured)

a. 0 15 25 35 46 57 64 70 70 74 80 65 55

b. 0 5 15 35 50 65 75 80 75 50 35

c. 20 45 75 80 60 55 31 28

d. 0 10 15 20 25 22 20 20

e. 30 45 120 130 135 110 90 70