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**INFLUENCES OF CLIMATE AND FERTILISER APPLICATION
HISTORY ON VARIOUS MEASURES OF SOIL FERTILITY AND
PRODUCTIVITY IN WAIRARAPA HILL COUNTRY**

A thesis presented in partial fulfilment of the requirements for
the degree of Master of Agricultural Science
in Soil Science at Massey University, New Zealand

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1994

ABSTRACT

During the agricultural downturn of the mid 1980's, it became uneconomic for many Wairarapa farmers to apply fertiliser. Those farmers who could afford to apply maintenance fertiliser, often chose to apply diammonium phosphate (DAP). The increasing popularity and apparent effectiveness of fertilisers such as DAP, which has a nitrogen component, prompted further questions of whether traditional P and S fertiliser application (as single superphosphate), applied to stimulate pasture legume growth and biological nitrogen fixation, was the most cost effective fertiliser strategy. A review of literature revealed that soil fertility and pasture production data for different rainfall regimes in the Wairarapa was scarce. No published data was available on how effective single superphosphate (SSP) applications to Wairarapa hill country farms had been in increasing annual N fixation rates and plant-available soil N, and hence increasing pasture production.

It was concluded that it was necessary to conduct a series of pasture field trials on sites varying in soil type, fertiliser history and climate (annual rainfall) in order to provide data applicable to the Wairarapa region. Sites falling within three rainfall regimes were selected, those being Mauriceville (high rainfall), Gladstone (summer dry) and Whareama (low rainfall) sites. Using total soil phosphorus, sulphur and nitrogen analyses, a total of 14 sites were selected for study, with sites ranging in fertility status within each climate zone. The objective has been to characterise the soil types, soil nutrient status, climate and current pasture production of Wairarapa hill country farms, with a view to completing further studies examining in more detail the complex interactions of soil, climate and pasture.

Soil chemical analyses revealed a wide range of soil fertility status across all sites. Soil total phosphorus (P) contents ranged from 430 $\mu\text{gP/g}$ soil (site 4) to 1470 $\mu\text{gP/g}$ (site 1), while total soil sulphur (S) showed less variation, ranging from 345 $\mu\text{gS/g}$ (site 11) to 860 $\mu\text{gS/g}$ (site 9). Soil total nitrogen (N) contents followed a similar pattern to that seen for total S, and ranged from 4280 $\mu\text{gN/g}$ (site 11) to 7950 $\mu\text{gN/g}$ (site 9).

Fertiliser history had a large influence on the accumulation of P, S and N in these hill country soils, where higher rates of accumulation were associated with greater levels of fertiliser

input. However, P accumulated at a far greater rate than S and N in these soils, which is possibly the result of high S and N leaching losses. Measurements of plant-available nutrient levels followed a similar trend to that seen for soil total elemental analyses, where higher levels of nutrient were correlated with higher fertiliser inputs.

Estimates of the efficiency of past fertiliser applications were made for these sites, using the results of various soil analyses. Traditional P and S fertiliser applications and pasture management on Wairarapa hill country appear to have been particularly inefficient in causing soil N to accumulate. The calculations used to derive these estimates have limitations, but do indicate that either product N and leaching losses are high or N fixation rates are low (or both) in these soils.

July 1993 to March 1994 was an average growing season, and total herbage yields harvested from August 1993 to March 1994 ranged from 4 tDM/ha (site 4) to 15.5 tDM/ha (site 1). Soil fertility status (and hence historical SSP applications) was the main factor influencing total herbage yield, where high yields were recorded at high fertility sites, and the reverse for low fertility sites. Climate (soil moisture levels) also influenced total yield but to a lesser extent than soil fertility status.

Pasture growth at Gladstone and Whareama sites stopped when soil volumetric water content in the top 7.5 cm fell below 0.2. At the wetter Mauriceville sites, soil moisture was not limiting until mid-February 1994. Legume growth was particularly sensitive to soil moisture stress.

By converting pasture production to stock units, gross margin analyses were performed. The most profitable options in all three rainfall regimes were sites which had received frequent fertiliser applications. This suggests that historical fertiliser applications are economically effective, which is an important factor in sustainable agricultural enterprises.

Herbage N and P uptake results supported this finding, and showed that pasture N uptake varied widely between high and low fertility sites. Pasture N uptake ranged from 70 kgN/ha at low fertility site 4, to 250 kgN/ha at high fertility site 1 for the period of early August

1993 to early January 1994. This implies that historical superphosphate applications have been effective in providing large increases in annual amounts of plant-available soil N at high fertility sites when compared to unfertilised sites, despite the fact that soil N accumulation was less than expected.

Acetylene reduction activity (ARA) measured at each harvest showed that annual N fixation levels are limited by extended summer dry periods which stop legume growth. The wetter Mauriceville sites fixed more N on an annual basis than Gladstone and Whareama sites. ARA was linearly related to yield. Variations in the data indicated that species and other short-term soil condition changes have a large effect on the relationship between ARA and N fixation rates.

Although soil N accumulation is slow in these pasture systems, annual pasture N uptake is dramatically increased where fertiliser inputs have been high. The results indicate that rapid cycling of soil/plant N is occurring, and that annual leaching and product losses of N may nearly equal N fixation rates. This was exemplified in a simple budget of the nitrogen cycle, taking account of N losses and gains in a low fertility and high fertility system. There was insufficient information to conclude why soil N is not accumulating in these grazing systems. Further research is required to fully explain this N cycle, including the relative quantities of N inputs and losses from the system.

ACKNOWLEDGEMENTS

I would like to express my gratitude to the following people for their contributions to this thesis.

Firstly, to Dr. M.J. Hedley for his supervision, patience and support over the course of this study. Secondly, to Dr. A.D. Mackay for his supervision and constructive suggestions, and Chris Garland for contributing local knowledge and feedback.

Bob Toes for his assistance with laboratory work, and all staff in the Department of Soil Science for their contributions.

Mr A. Hammond for proof-reading and giving useful comment on this script, and Ms N. Collins for valuable assistance in thesis preparation.

Finally, I wish to acknowledge the following Wairarapa farmers on whose farms sites are located, for their assistance and cooperation over the past eighteen months; Messers D Blackwood, B Christensen, A Day, D Dunlop, N Kilmister, D Kinnell, K O'Riley, D Williams.

TABLE OF CONTENTS

ABSTRACT	ii
ACKNOWLEDGEMENTS	v
TABLE OF CONTENTS	vi
LIST OF TABLES	x
LIST OF FIGURES	xv

CHAPTER 1

INTRODUCTION	1
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CHAPTER 2

LITERATURE REVIEW

2.1	SOILS OF THE WAIRARAPA HILL COUNTRY	4
	2.1.1 Introduction	4
	2.1.2 Yellow-Grey Earths of the Wairarapa	4
	2.1.3 Yellow-Brown Earths of the Wairarapa	5
	2.1.4 Wairarapa Yellow-Grey Earth to Yellow-Brown Earth Intergrades	6
2.2	FACTORS INFLUENCING THE FERTILITY STATUS OF WAIRARAPA	
	SOILS	9
	2.2.1 Sources of Phosphate in Hill Country Rocks of the Wairarapa	9
	2.2.2 Evaluation of Fertility Status	11
	2.2.3 Nutrient Accumulation and Transformations Under Pastoral	
	Grazing Systems	12
	2.2.3.1 Phosphorus	12
	2.2.3.2 Sulphur	20
	2.2.3.3 Carbon/Organic Matter and Nitrogen	21
2.3	NITROGEN FIXATION IN WAIRARAPA HILL COUNTRY	24
2.4	SUMMARY	25

CHAPTER 3
METHODS AND MATERIALS

3.1	INITIAL SOIL SAMPLING	27
3.2	SITE SELECTION	28
3.3	FERTILISER HISTORY	28
3.4	SITE ESTABLISHMENT	31
3.5	HARVESTING AND DISSECTION OF HERBAGE	31
3.6	THE ACETYLENE REDUCTION TECHNIQUE	32
3.7	SOIL MOISTURE CONTENT	33
3.8	SOIL SAMPLING AND PREPARATION	33
3.9	CLIMATE MEASUREMENTS	33
3.10	SOIL ANALYSES	34
3.10.1	Total Phosphorus	34
3.10.2	Sequential Phosphate Extraction	35
3.10.2.1	NaOH Extraction and Digest	35
3.10.2.2	H ₂ SO ₄ Extraction and Residual P Digest	36
3.10.3	Total Nitrogen	37
3.10.4	Total Sulphur	37
3.10.5	Soil pH	37
3.10.6	Total Carbon	38
3.10.7	Plant-Available Nutrients	38
3.10.7.1	Phosphate	38
3.10.7.2	Resin-Exchangeable Phosphate	38
3.10.7.3	Sulphate	38
3.10.7.4	Exchangeable Cations and C.E.C.	39
3.10.7.5	Mineralisable N	39
3.11	HERBAGE ANALYSES	40
3.11.1	Total Phosphorus and Nitrogen	40
3.11.2	Molybdenum	40

CHAPTER 4

CHEMICAL CHARACTERISATION OF SOIL NUTRIENT STATUS

4.1	INTRODUCTION	41
4.2	ASSESSMENT OF PLANT-AVAILABLE NUTRIENT STATUS OF SOILS .	41
	4.2.1 Olsen P	42
	4.2.2 Resin-Extractable P	45
	4.2.3 Extractable Sulphate	45
	4.2.4 Soil pH	48
	4.2.5 Soil N Availability Index	48
	4.2.6 Exchangeable Cations	48
4.3	CATION EXCHANGE CAPACITY	50
4.4	TOTAL ELEMENT CONTENT OF SOILS	51
	4.4.1 Total Soil Carbon (C)	51
	4.4.2 Total Soil Phosphorus (P)	51
	4.4.3 Total Soil Sulphur (S)	54
	4.4.4 Total Soil Nitrogen (N)	54
4.5	PHOSPHATE FRACTIONATION	55
4.6	DISCUSSION	58
	4.6.1 The Relationship Between Total Soil P and Total Soil N	58
	4.6.2 The Relationship Between Mineralisable Soil N and Total Soil P	61
	4.6.3 The Relationship Between Total Soil S and Total Soil P	62
	4.6.4 The Relationship Between Total Soil S and Total Soil N	64
	4.6.5 The Relationship Between Indices of Available Soil P and Total P or Individual P Fractions	64
	4.6.6 The Relationship Between Plant-Available P Extraction Methods	69
4.7	CONCLUSIONS	74

LIST OF TABLES

Table 2.1	Summary of observations of P accumulation and transformation in N.Z. pastoral grazing systems	19
Table 3.1	Site information	30
Table 4.1	N.Z. MAF recommended soil test levels	42
Table 4.2	Soil Olsen P, sulphate S, resin P and mineralisable N values for the 0 - 7.5 cm depth	44
Table 4.3	Soil pH, CEC, total carbon (C) and exchangeable cation values for the 0 - 7.5 cm depth	50
Table 4.4	Total soil phosphorus (P), nitrogen (N) and sulphur (S) content	53
Table 4.5	Sequential fractionation of soil phosphate	57
Table 5.1	Monthly rainfall, maximum/minimum temperature and A.E.T. (October 1993 to January 1994)	77
Table 5.2	Summary of climate, herbage yield and nitrogen fixation levels in the D.I.S.R. national series of N-fixation trials (1979)	118

LIST OF FIGURES

Figure 3.1	Location of Wairarapa trial sites and New Zealand Meteorological Service Climate Stations (A) Mangamutu (B) Castle Point and (C) Taratahi	29
Figure 4.1	Olsen P values for the 0 - 7.5 cm soil depth at all sites	43
Figure 4.2	0.1M Calcium phosphate extractable sulphate values for the 0 - 7.5 cm soil depth at all sites	46
Figure 4.3	Resin-exchangeable phosphate values for the 0 - 7.5 cm depth at all sites	47
Figure 4.4	Mineralisable nitrogen for the 0 -7.5 cm depth at all sites	49
Figure 4.5	Total soil P, S and N content for the 0 - 7.5 cm depth at all sites	52
Figure 4.6	Fractionation of total soil phosphate components for the 0 - 7.5 cm depth at all sites	56
Figure 4.7a	The relationship between total soil N and total soil P contents for the 0 - 7.5 cm depth at all sites	59
Figure 4.7b	The relationship between total soil S and total soil P contents for the 0 - 7.5 cm depth at all sites	63
Figure 4.7c	The relationship between total soil N and total soil S contents for the 0 - 7.5 cm depth at all sites	65

Figure 4.7d	The relationship between total soil N and total soil S contents, excluding the sulphate S fraction, for the 0 - 7.5 cm depth at all sites	66
Figure 4.8a	The relationship between Olsen P and total soil P (Kjeldahl digest) contents for the 0 - 7.5 cm depth at all sites	67
Figure 4.8b	The relationship between Olsen P and total soil P (sum of sequential P extraction) contents for the 0 - 7.5 cm depth at all sites	68
Figure 4.8c	The relationship between soil resin extractable P and Olsen P contents for the 0 - 7.5 cm depth at all sites	70
Figure 4.8d	The relationship between soil Olsen P and 0.1M NaOH extractable inorganic P (P _i) contents for the 0 - 7.5 cm soil depth at all sites	71
Figure 4.8e	The relationship between resin-extractable (less Olsen-extractable) P and H ₂ SO ₄ extractable P fractions for the 0 - 7.5 cm depth at all sites	72
Figure 4.9	The relationship between mineralisable N and total soil P contents for the 0 - 7.5 cm depth at all sites.	73
Figure 5.1a	Seasonal soil volumetric water contents from 24.8.93 (harvest 1) to 18.3.94 for the 0 - 7.5 cm depth at Mauriceville sites	79
Figure 5.1b	Seasonal soil volumetric water contents from 24.8.93 (harvest 1) to 18.3.94 for the 0 - 7.5 cm depth at Gladstone sites	80
Figure 5.1c	Seasonal soil volumetric water contents from 24.8.93 (harvest 1) to 18.3.94 for the 0 - 7.5 cm depth at Whareama sites	81

Figure 5.2a	Total cumulative dry matter yield from the start of trials (5.8.93) to 18.3.94 at Mauriceville sites	83
Figure 5.2b	Total cumulative dry matter yield from the start of trials (5.8.93) to 30.3.94 at Gladstone sites	84
Figure 5.2c	Total cumulative dry matter yield from the start of trials (5.8.93) to 30.3.94 at Whareama sites	85
Figure 5.3a	Cumulative legume dry matter yield from the start of trials (5.8.93) to 18.3.94 at Mauriceville sites	87
Figure 5.3b	Cumulative legume dry matter yield from the start of trials (5.8.93) to 30.3.94 at Gladstone sites	88
Figure 5.3c	Cumulative legume dry matter yield from the start of trials (5.8.93) to 30.3.94 at Whareama sites	89
Figure 5.4a	The botanical composition of swards at Julian Day 278 (harvest 3) . . .	90
Figure 5.4b	The botanical composition of swards at Julian Day 300 (harvest 4) . . .	91
Figure 5.4c	The botanical composition of swards at Julian Day 343 (harvest 6) . . .	92
Figure 5.5a	The relationship between herbage yield from 24.8.93 to 5.10.93 (harvests 2 and 3) and soil Olsen P content	94
Figure 5.5b	The relationship between herbage yield from 16.11.93 to 6.1.94 (harvests 6 and 7) and soil Olsen P content	95
Figure 5.5c	The relationship between dry matter yield from 24.8.93 to 5.10.93 (harvests 2 and 3) and soil sulphate S content	96

Figure 5.5d	The relationship between dry matter yield from 24.8.93 to 5.10.93 (harvests 2 and 3) and soil resin P content	98
Figure 5.5e	The relationship between dry matter yield from day 24.8.93 to 5.10.93 (harvests 2 and 3) and soil mineralisable N content	99
Figure 5.6a	The relationship between legume dry matter yield from day 24.8.93 to 5.10.93 (harvests 2 and 3) and soil Olsen P content	100
Figure 5.6b	The relationship between legume dry matter yield from day 24.8.93 to 5.10.93 (harvests 2 and 3) and soil sulphate S content	101
Figure 5.6c	The relationship between legume dry matter yield from day 24.8.93 to 5.10.93 (harvests 2 and 3) and soil resin P content	102
Figure 5.6d	The relationship between legume dry matter yield from day 24.8.93 to 5.10.93 (harvests 2 and 3) and soil mineralisable N content	103
Figure 5.6e	The relationship between legume dry matter yield from day 16.11.93 to 6.1.94 (harvests 6 and 7) and soil Olsen P content	104
Figure 5.6f	The relationship between legume dry matter yield from day 16.11.93 to 6.1.94 (harvests 6 and 7) and soil sulphate S content	105
Figure 5.6g	The relationship between legume dry matter yield from day 16.11.93 to 6.1.94 (harvests 6 and 7) and soil resin P content	106
Figure 5.6h	The relationship between legume dry matter yield from day 16.11.93 to 6.1.94 (harvests 6 and 7) and soil mineralisable N content	107
Figure 5.7	The relationship between herbage P and N concentrations at Julian days (a) 236 (harvest 1); (b) 257 (harvest 2) and (c) 278 (harvest 3)	109

Figure 5.7	The relationship between herbage P and N concentrations at Julian	
(continued)	days (d) 300 (harvest 4); (e) 320 (harvest 5) and (f) 343	
	(harvest 6)	110
Figure 5.8	The relationship between total harvested P and N over the	
	period 5.8.93 to 9.12.93 (Julian Days 217 to 343)	112
Figure 5.9	The relationship between total N harvested and total soil P	
	over the period 5.8.93 to 9.12.93 (Julian Days 217 to 343)	113
Figure 5.10a	Acetylene reduction activity from 24.8.93 to 6.1.94 at	
	Mauriceville sites	115
Figure 5.10b	Acetylene reduction activity from 24.8.93 to 30.3.94 at	
	Gladstone sites	116
Figure 5.10c	Acetylene reduction activity from 24.8.93 to 30.3.94 at	
	Whareama sites	117
Figure 5.11	The relationship between legume dry matter yield and	
	acetylene reduced for the period 24.8.93 to 30.3.94	120
Figure 6.1	A simplified nitrogen cycle in Wairarapa hill country pastures	127

CHAPTER 1: INTRODUCTION

It is generally accepted that in order to maintain improved legume based pastures in New Zealand, the soil phosphorus and sulphur fertility status must be raised and maintained at a higher level than that in native soils. Consequently, high initial applications (capital dressings), followed by smaller annual applications (maintenance) of fertiliser are recommended to raise and maintain appropriate soil fertility conditions for high yielding legume species. In turn, the legume species (principally clovers) are presumed to fix and supply adequate quantities of nitrogen, required for pasture growth (Ball and Tillman, 1994).

However, determining sustainable soil fertility management strategies for pasture can be a difficult task. In the Wairarapa region, factors such as climate, soil type and fertiliser history will have major influence on soil nutrient supply and the relative performance of legumes fixing nitrogen into the system.

There are a number of problems associated with determining appropriate soil fertility strategies for hill-country pastures of the Wairarapa. Climate is variable across the region, ranging from high rainfall areas, to areas which consistently receive extended periods of drought. Such conditions will influence the extent and seasonality of pasture yield, as well as nutrient availability to pasture.

Climate will also have influenced soil formation, nutrient loss and nutrient retention capacity mechanisms in each soil.

Central YBEs, YGES and YBE/YGE intergrades form a mosaic across large areas, making fertiliser recommendations difficult. These soils have formed from a wide variety of parent rocks under different weathering regimes, and so differ in their physical and chemical properties.

Fertiliser history and stocking rate will also influence nutrient requirements. The form and quantity of past fertiliser applications can determine the present soil fertility status, and so influence present fertiliser needs. For example, farms which have historically applied P above

maintenance levels would be expected to have a high soil P status, and have a soil P reserve. In such situations fertiliser P requirements may be low, unless current stocking rates are very high.

Traditional fertiliser policy in the region has relied upon superphosphate, predominantly to supply elevated soil P and S levels for clover growth. The legume in turn fixes N₂, which is subsequently made available to grasses. However, the nutritional adequacy of clovers has recently been questioned (Ball and Tillman, 1994), and current research is focusing on breeding more P-efficient clover cultivars (Dunlop *et al.*, 1988; Caradus *et al.* 1991). It has been suggested that in some situations clovers are inadequate providers of soil nitrogen, therefore maintaining elevated soil P levels for N₂ fixation by clovers is wasteful (Ball and Tillman, 1994). There is a need to investigate whether strategic N fertiliser inputs (plus minimal P and S) are more efficient than traditional superphosphate policies, and if more P-efficient pasture species are required.

Climate may also influence the efficiency of legumes to supply (input) soil nitrogen. For example, areas which are consistently drought prone would be expected to have shortened growing seasons and less N-fixation on an annual basis. Therefore, under drier climate regimes there may be less "effective" N-fixation days, which would limit the supply of mineralisable N to the soil.

Climate may also influence the efficient use and loss of fixed N. In general, annual dry matter production would be expected to be greater in high rainfall areas when compared with drier regimes, and therefore lead to more grazing days. While N fixation may be extended, the longer grazing period could be seen as a longer period for nutrient loss; a problem which may be compounded by higher stocking rates. If this scenario does exist in high rainfall areas, would the reverse be true for drier climate regimes? i.e. less grazing days, lower stocking rates and less nutrient losses?

In order to determine appropriate sustainable soil fertility management strategies, researchers must have a comprehensive understanding of the influence of climate, soil type and fertiliser history, in addition to plant-soil interactions.

This study examines the soils, climate and fertiliser history of the Wairarapa hill-country, with the purpose of evaluating the efficiency of traditional superphosphate applications to pasture.

CHAPTER TWO: LITERATURE REVIEW

2.1 SOILS OF THE WAIRARAPA HILL COUNTRY

2.1.1 Introduction

Excluding the alluvial Wairarapa basin, the landscape of the Wairarapa region is predominantly steep or easy rolling hill country. Large areas of hill country exist, both on the east coast, and bordering the steep Tararua and Rimutaka Ranges to the west.

Soils in this region are formed from a variety of rocks, mainly mudstone, sandstone, greywacke and limestone. Unlike much of the North Island, these soils are outside the dominant influence of volcanic ash.

Topography has a large influence on climate in the Wairarapa, and hence on soil formation patterns. The mean annual rainfall ranges from 800mm (or less) in some coastal areas, to above 1800mm in some areas near Mauriceville, and near the ranges to the west. Soil groups include central yellow-brown earths (YBE), yellow-grey earths (YGE), and yellow-grey earth/brown earth intergrades.

2.1.2 Yellow-Grey Earths of the Wairarapa

The YGEs occur under a mean annual rainfall of 750-1000mm in the Wairarapa, mid-Hawke's Bay and Manawatu regions. These soils tend to be silt loams which, except on the steeper hills, are inclined to have compacted subsoils and suffer from impeded drainage. Many of these soils are derived from river alluvium.

The YGEs of the Wairarapa are therefore confined to drier, mostly south-western (Martinborough) and coastal areas. It must be noted, however, that the YGEs of this region usually form under mean annual rainfalls of 900-1000mm per annum, with slightly damper and cooler summers than similar soil types in mid-Hawke's Bay.

A typical Wairarapa YGE is the Kokotau silt loam. This soil is found on rolling land in extensive areas around Carterton, Martinborough and Masterton. It is a poorly drained soil formed with shallow deposits of loess which overlies fine sandstone and siltstone. In the past, pasture production on this soil type has been measured by Bircham and Crouchley (1976). Paddocks with a fertiliser history of 250-400 kg/ha/yr superphosphate were top dressed at a rate of 125 kg/ha/yr superphosphate for a five year period. Pasture production was maintained above 90% of maximum DM production at this rate of application.

In spite of their relatively long duration, these trials did not continue for a sufficiently long time to erase the residual effects of past fertiliser history. However, they suggest low maintenance requirements for sulphur (S) (During, 1984c). Pasture growth response to phosphate fertiliser on these soils is estimated to be similar to that on central YGE to YBE intergrades. During (1984c) recommends applying 175 kg/ha/yr superphosphate and 375 kg/ha/yr lime in order to maintain pasture production at 90% of maximum.

2.1.3. Yellow-Brown Earths of the Wairarapa

In the Wairarapa, YBEs are found extensively in the areas of Ekatahuna, Mauriceville, Pahiatua, Alfredton, Pongaroa and within the hill country of the ranges to the west. These soils are developed under an annual rainfall exceeding 1100mm. They are formed from sediments ranging from claystones to conglomerates and from soft bentonitic mudstones to hard greywacke sandstones. In general, the YBEs have been more strongly weathered, have topsoils with higher organic matter contents, and are more free-draining, more friable, and are more phosphate deficient than the YGEs.

In this current study, trial areas were situated on four different yellow-brown earths. The Waimarama (Mauriceville, sites 1, 2 and 3) and Kourarau (Gladstone, site 10) soils are developed on calcareous siltstones and sandstones and are weakly to moderately leached. However, in this particular instance, the Kourarau soil at Gladstone has been classified as a central brown rendzina due presumably to high content of calcareous materials. The Matamau soil (Mauriceville, site 4) is usually classified as a YBE/YBL intergrade, but in this situation is a very strongly leached yellow-brown earth. This soil type is developed from pumiceous

sandstones and mudstones. Lastly, the Kaikouta soil (site 14, near Tararua ranges) is a strongly leached yellow-brown earth, derived from loess and sandstone (greywacke).

Initial P requirements on YBEs are high, but the residual effect of a capital fertiliser dressing is considerable (During, 1984d). This was shown by a rate of P mowing experiment where over a period of six years one initial application of 1920 kg/ha superphosphate led to pasture production approximately equal to that achieved by applying the same total amount evenly in six annual dressings of 320 kg/ha.

On a Mikimiki hill soil which had previously received 280 kg/ha superphosphate fairly regularly, with a Olsen P test of 10 (mgPdm⁻³ soil), Crouchley and Sinclair (1982) observed very small responses to rates higher than 280 kg/ha/yr superphosphate. In the same experiment these authors saw virtually no effect of omitting sulphur (P applied as MCP) application over a three year period. This soil's sulphate retention capacity was high for a YBE, which may have contributed to high extractable sulphate status of the unfertilised treatments. Historically, many farmers on soils developed from greywacke preferred basic slag as a fertiliser, which contains little S compared to superphosphate (During, 1984d).

During (1984d) recommends applying 230 kg/ha/yr superphosphate on these yellow-brown earths, lime at 300 kg/ha/yr (if required), potassium (if required) and molybdenum if a deficiency is apparent.

2.1.4 Wairarapa Yellow-Grey Earth to Yellow-Brown Earth Intergrades

In the Wairarapa, YGE/YBE intergrade soils can be found in large areas along the hilly east coast. These soils are associated with mean annual rainfalls ranging from 1000 to 1400mm, usually in the area of 1150mm.

Most of the YGE/YBE intergrades comprise soils on steep or hilly terrain, so that the effective rainfall is lower than that indicated above. The rejuvenation of soil profiles by sheet and other forms of erosion might be modifying factors in their development. Evidence suggests that many of these soils are only moderately weathered, containing some illite, hydrous micas, and much vermiculite (NZSB, 1968).

The majority of soils in this group, as well as containing exchangeable potassium (K), are expected to have non-exchangeable but plant-available potassium reserves. For this reason, the routine exchangeable K soil test may not be reliable, and the NaTBT test may fulfil a useful function (During, 1984c). Another feature of the YGE/YBE intergrades is that, in general, they have low phosphate retention, and also low sulphur retention, which may lead to higher sulphate leaching than on YBEs.

In this current study, three of the research areas are situated on YGE/YBE intergrade soils. The Atua soils (Gladstone, sites 11 and 12) are moderately leached YGE/YBE intergrades, and are silt loams over clay loams derived from siltstone (NZSB, 1968). They are extensive in Wairarapa hill country, and with light phosphate topdressing maintain excellent pastures for sheep and cattle breeding and fattening. Gibbs *et al.* (1968) showed that higher rates of superphosphate, 250 kg/ha/yr or above, are far more necessary on the Atua soils than on the Wanstead soils (discussed later in this section). In addition, over the common pH range for pasture (5.0-6.2), the pasture vigour for the Atua soils was much more sensitive to pH change than that on the Wanstead soils. This may have been due in part to a molybdenum deficiency on the Atua soil (not deficient on the Wanstead soil). In molybdenum-deficient areas the application of 50-100 g/ha every 4-5 years of sodium molybdate is advised if soil pH remains below 6.2 (During, 1984c).

The Wanstead soils, represented in this study by the Whareama sites 5, 6, 7, 8 and 9, are hill soils found on or very near the east coast. They are sticky clays, and are fertile but unstable. These clays are montmorillonitic, and are derived from bentonitic mudstone (NZSB, 1968). Again, these soils are phosphate deficient, and probably sulphur deficient. Gibbs *et al.* (1968) observed that on this soil type, there appeared to be little benefit from applying superphosphate at rates above 250 kg/ha/yr. According to Gibbs *et al.*, the greatest increase in pasture growth to the high P input as compared with medium P input, occurred at pH 5.0-5.5. This suggests that P requirements for maintenance are higher at low pH than high pH, an observation confirmed by more recent field trials in Wairarapa hill country (During, 1984c).

The final soil in this study (Site 14) is classified as being part of the Kohinui series (Pollok *et al.*, 1994). This soil is not found on sloping hill country, but is a soil present on the alluvial flats of the Wairarapa Plains, in this instance at the Massey University farm "Riverside". This is a stoney soil associated with strongly leached intergrades between yellow-brown loams and yellow-brown earths. The soil consists of a relatively shallow silt cover over deep stoney deposits, which cause excessive drainage. For this reason, and because of the uneven spread of rainfall experienced, this soil tends to be droughty in summer. Parent material is mixed alluvial, loessial and volcanic ash composition, which overlay the gravel beds (below 60-70cm). Phosphate retention is in the medium range (40-60%) for this soil type (Pollok *et al.*, 1994), possibly due to the presence of allophanic material.

Fertiliser requirements for YGE/YBE intergrades of the Wairarapa region are presented by During (1984c). He gives a figure of 140-160 kg/ha/yr superphosphate for sheep farms that are not potassium deficient, with 300-350 kg/ha/yr of lime. At this level of application, a relative dry matter production of 90% (i.e. 90% of maximum yield) could be expected on well farmed properties carrying 11-13 ssu/ha.

For soils such as the Atua set, it is likely that maintenance requirements for phosphate are higher than those mentioned above, and molybdenum may also be a requirement.

However, one important point should be kept in mind when comparing the recommended "maintenance" levels stated by During (1984c) with present-day fertiliser requirements. Many of the fertiliser recommendations of During are based on studies of the 1960s and 70s. Since this time, the responsiveness of pasture production to fertiliser may have changed. Hence if fertiliser and lime have not been applied at maintenance rates, the optimum rates of fertiliser calculated in the 1950s, 60s and 70s may no longer be appropriate.

For example, during the rural economic downturn of the 1980s less fertiliser was applied for 5-10 years, but stock numbers were not decreased in proportion. This may lead to higher fertiliser requirements than those outlined in the 1970s. Likewise, if the maintenance fertiliser rates of the 1970s had been applied for the previous 20 years, but stocking rates had

increased over this time period, we would expect the fertiliser requirements of today to be higher i.e. fertility levels have declined due to greater levels of stock transfer and nutrient loss. Even if the stocking rates and maintenance fertiliser applications of 20-30 years ago have been maintained consistently to present day, this gives no guarantee that the maintenance rates of 20 years ago will match the maintenance rates of today.

Another scenario may also exist, where both stocking rates and applied fertiliser have been increased over the past 20 years. In this situation soil fertility levels may have remained static, or increased over the past 20 years. This may have the effect of increasing plant-available nutrient reserves, subsequently reducing the maintenance fertiliser requirement when compared to that of 20 years ago.

2.2 FACTORS INFLUENCING THE FERTILITY STATUS OF WAIRARAPA SOILS

2.2.1 Sources of Phosphate in Soil Parent Rocks of the Wairarapa

Phosphate (P), like many nutrients required for plant growth, has to be derived from soil parent materials (primary and secondary P minerals) or added fertiliser. The quantities and sources of this phosphate can vary widely.

Until recently, there has been little published work on phosphate levels in New Zealand rocks, and the minerals they are sourced from. Eden and Parfitt (1992) studied this subject in detail, focusing on the hill country of the Wairarapa region. Much of what follows is a summary of their findings.

The aforementioned study reported on the acid-soluble phosphate levels of Wairarapa soils in order to provide information on the reserves of P. This information was thought to be helpful in identifying the parent materials which have the largest amounts of phosphate, and which may be available to plants under regimes of low phosphate fertiliser additions (Eden and Parfitt, 1992).

The general findings of this study were that the highest phosphate concentrations occur in mudstones. These contained 50% more phosphate than fine to medium sandstones, and at least ten times more phosphate than coarse sandstones. Also, most of the phosphate was found in the fine-medium silt fraction (20-2 μ m), and in the clay fraction (<2 μ m).

This phosphate is associated with calcite or apatite mineral grains, which tend to have large reactive surfaces (Eden and Parfitt, 1992). These will dissolve rapidly in this soil environment, due mainly to acid leaching, and will release phosphate into the soil.

This process was noted by Walker and Syers (1976), where they observed that upper soil horizons may be depleted of phosphate as a result of weathering, plant uptake and leaching, and are often acidic as a result of the excess winter rainfall and the influence of indigenous forest. They also observed a relationship between particle size and phosphate content, and they found that sandstones had a lower rate of P loss than mudstones. They identified apatite as the major primary mineral, which had been previously noted in soils by the New Zealand Soil Bureau (Saunders, 1968).

Based on this information, areas where soils are formed on mudstone would be expected to have a high total soil P content. In the current study, this would include sites 5, 6, 7, 8 and 9 (Whareama), and site 10 (Gladstone). Sites 1-3 (Mauriceville) would also be expected to contain relatively high native P, due to the limestone parent material of the soil, which may contain apatite grains (calcium phosphate).

Eden and Parfitt (1992) drew a number of conclusions from their recent study of phosphate minerals in soils of the Wairarapa. They implied, from their results, that soils developed on mudstones are likely to be more productive than those on sandstones for pastoral farming under a regime of limited P input, particularly where deep-rooting grasses are planted (Eden and Parfit, 1992). Deeper rooting plants would also have better access to the soil profile, and hence to soil water. They also suggested that mudstones are more erodible than other soil types, and so it may be wise to plant steeper slopes in forestry.

It must be noted, however, that native supplies of soil phosphorus are considered to be inadequate for improved pastures on these soils (Saunders, 1968).

2.2.2 Evaluation of Fertility Status

At present, there is little published information on the current pasture growth response to fertiliser application on Wairarapa soils. However, one study was conducted in the early 1980s, investigating the response to phosphorus and sulphur fertilisers on Wairarapa hill country soils (Crouchley and Sinclair 1982). The purpose of these experiments was to determine whether current fertiliser practise was providing adequate P and S for pastures on these soils to maintain improved pasture species, and higher stocking rates.

Over a two and a half year period Crouchley and Sinclair looked at the effect of P and S additions to six Wairarapa hill soils. Phosphate was applied at three rates; 25, 50 and 100kgP/ha as monocalcium phosphate (MCP), while sulphur was applied at two rates; 30 and 60kgS/ha as gypsum. All trial sites had been top-dressed annually for at least 10 years prior to the experiments, with about 250kg/ha superphosphate. Lime had also been applied on several occasions within this period.

The results of this study were that pasture on all soils responded to phosphate, but not always to sulphur (Crouchley and Sinclair, 1982). Twenty-five and 50kgP/ha gave very similar responses, but often 100kgP/ha was superior (Crouchley and Sinclair, 1982). Thirty and 60kgS/ha gave similar responses.

Although all of these sites had received 250kg/ha of superphosphate for at least 10 years, they were all still responsive to phosphate. This indicated that this rate had not been excessive but appeared to be adequate since 25kgP/ha (equivalent to 250kg superphosphate) was generally as effective as 50kgP/ha in the subsequent trials (Crouchley and Sinclair, 1982). The higher response from the 100kgP/ha treatment was unexplained.

The authors concluded that annual applications of 250kg/ha superphosphate would provide adequate P and S for maintenance of improved pasture on Wairarapa hill-country soils. They

also commented that applications should preferably be made in spring to avoid leaching of sulphate by winter rainfall (Crouchley and Sinclair, 1982).

In 1992, a detailed survey was conducted investigating fertiliser use (predominantly nitrogen fertiliser) on sheep and beef farms of the East Coast (Mortan *et al.*, 1992). The survey, conducted by MAF, involved locating 78 farms which had used nitrogen fertiliser in some form over the past 4-5 years.

This survey revealed that most fertiliser nitrogen was applied to the survey farms as DAP, Urea, Cropmaster 20, and Ammonium Sulphate (in descending order). Feed demand was rated by farmers as being the most important factor influencing the timing and quantity of fertiliser nitrogen. In addition, the farmers considered the main benefits of fertiliser nitrogen to be the lower susceptibility to drought and greater feed supply during winter and early spring.

This survey also showed that the farmers who were using more nitrogen fertiliser were also applying more phosphorus, sulphur and lime. However, it appeared that where nitrogen fertiliser was being applied in only very small amounts, P and S was applied solely in the form of superphosphate. It should be noted that in this latter case, P and S inputs were only marginally lower than on farms applying large amounts of N, and in fact were considerably higher than those farms applying moderate levels of N fertiliser.

2.2.3 Nutrient Accumulation and Transformations Under Pastoral Grazing Systems

This section reviews literature on the accumulation and transformations of soil nutrients due to fertiliser application and climate, and how this may influence soil fertility status.

2.2.3.1 *Phosphorus*

P Nutrition of Pasture Species

Processes involved in pedogenesis cause phosphorus to be lost from the soil by leaching and erosion (Saunders, 1968). Since the only significant source of P for soils is the parent rock,

all soils will gradually become P deficient over time. New Zealand soils are no exception, and it was identified as early as the late 1800's that pasture production in New Zealand was P limited. In order to compensate for this P loss, and higher demand for soil P, the farmer applied fertiliser (predominantly single superphosphate).

Phosphorus plays important roles in pasture; being a component of the photosynthetic process as a key element involved in the synthesis and transfer of chemical energy to plants (Hedley *et al.*, 1993), and as a requirement of legumes for nitrogen fixation. High levels of available P in soils are required in order to maintain the presence and N₂-fixing activity of the clovers in the pasture, and hence maintain the N input into the grass/legume sward (Haynes and Ludecke, 1981). Clovers in the pasture environment are said to be "nutritionally fragile", i.e. are less able to compete with grasses for growth-limiting nutrients, and therefore continuing inputs of P and S are needed to maintain active clovers (Ball and Tillman, 1994). Since pasture production in New Zealand has been traditionally dependant on the clover component of the sward to supply soil nitrogen (rather than N fertilisers), the application of superphosphate has played a very important role.

Ball and Tillman (1994) reviewed the topic of efficiency of nutrient use by pastures in New Zealand. They argued that nutrients applied in fertiliser (especially P) were wasted in order to provide elevated soil nutrient levels for clover growth and N fixation. This was based on the assumption that excessive P uptake by grasses leads to greater animal transfer loss of P. The authors commented that Hart (1989) had found that P levels were about twice as high in root nodules than in young mature leaves of white clover, and that high levels of inorganic P had to be present in nodules for symbiotic N₂ fixation to occur. Using this information, Ball and Tillman then inferred that clovers may have nutritional P inefficiencies, and that providing elevated soil P levels (via fertiliser) for clover N₂ fixation would therefore be wasteful (Ball and Tillman, 1994). The authors then suggested that nutrients directed at clovers were instead being taken up in luxury quantities by grasses. Since grasses are the main component of the sward, it was suggested that nutrients (P, S) could be used more efficiently if new grass species could be bred which were largely incapable of luxury nutrient uptake (Ball and Tillman, 1994).

Soil P Status

The ability of a soil to supply phosphorus to the plant is related to the total amount of P present in the soil, and also to the forms in which it exists. The following review looks at the accumulation (from fertiliser application), and transformations of phosphorus in New Zealand based pastoral grazing systems. This accumulation of P, and its subsequent availability to pasture, will, to a certain extent, dictate the relative importance and efficiency of providing P fertiliser.

Soils under permanent pasture in New Zealand develop high organic matter contents because of the continual supply of plant debris and animal dung returning to the soil surface. Since organic compounds containing phosphorus are present in soil organic matter, it would be expected that such soils would have high levels of organic phosphorus, in part derived from applied phosphate fertiliser (Jackman, 1954a).

During the mid-1950s Jackman (1954a) investigated the relationship between the conversion of applied phosphorus into organic forms, and the subsequent availability of this phosphorus. He commented that soils carrying pastures responsive to additional phosphate often contain high levels of organic phosphorus, and that it was presumed that this form is only slowly available to pasture plants (Jackman, 1954a). If this theory held true, then the change of fertiliser phosphorus into organic form is significant, since it implies a reduction in phosphorus availability.

Jackman examined the increases in total and organic phosphorus on a variety of soil types, where either superphosphate, animal manure or lime were applied. It was found that on soils with high organic phosphorus contents (e.g. Yellow-brown loams), applied phosphorus was largely converted into organic forms (Jackman, 1954a). In comparison, on soils with low natural organic phosphorus levels (e.g. Manawatu silt loam), phosphorus applied as fertiliser tended to remain in inorganic forms.

From these results Jackman suggested that pastures on soil groups such as yellow brown loam and yellow brown pumice soils, which commonly respond to topdressed phosphate, may be

responding to a nutrient deficiency rather than the physical nature of the soil limiting plant growth. He further suggested that if the phosphate were not immobilised to the same extent, the level of fertility would be higher on these soils (Jackman, 1954a).

In a further study, Jackman (1954b) investigated the relationship between the organic phosphorus content of soil, and various soil characteristics. Results showed that the organic phosphorus was highly correlated to the organic carbon and phosphate-fixing capacity of the soils used.

He concluded from these findings that based on very high levels of organic carbon and phosphate fixing capacity, that allophane was probably responsible for the stabilisation of carbon and organic phosphorus in yellow-brown loams and pumice soils (Jackman, 1954a, and b; 1960). Other clay minerals were said to play a similar but less dominant role.

Many years later, Perrott and Mansell (1989) studied the effect of fertiliser phosphorus and liming on different soil phosphorus fractions. In this study the authors described the accumulation of inorganic and organic phosphate levels in New Zealand soils, which have built up as a result of pasture establishment and topdressing with phosphatic fertilisers (Perrott and Mansell, 1989).

This trial was conducted on a Kokotau silt loam near Masterton, where MCP was applied at 0, 20, 40, 60 and 80 kgP/ha, and lime applied at 0, 2.5 and 5 t/ha. Herbage was harvested on a regular basis from stock exclusion areas, and at the conclusion of the trial (5 years) a detailed fractionation of soil phosphorus was undertaken.

The results from this experiment showed that where fertiliser P was applied, P accumulated as adsorbed inorganic P, and as occluded inorganic P (Perrott and Mansell, 1989). Also, fertiliser did not cause an accumulation of organic P, but it did increase the more labile forms and decrease the more stable forms of organic P. Changes observed in P fractions were attributed to the increase in nutrient cycling when fertiliser and/or lime was applied (Perrott and Mansell, 1989).

Perrott *et al.* (1989) also investigated the accumulation of phosphorus on yellow-brown pumice soils. On this occasion the author sampled a variety of YBP soils in the Taupo region, ranging from undeveloped land to high producing dairy farms. Again, a sequential P fractionation was used, this time to compare total soil P with microbial P and Olsen P.

It was shown that most of the inorganic P in these pumice soils originates from fertiliser application, as the inorganic P levels in samples from virgin sites were very low (Perrott *et al.*, 1989). Total soil P was used as a basis for comparing accumulation patterns i.e. fertiliser history. The more labile P fractions increased curvilinearly with total P, as did total organic P (Perrott *et al.*, 1989). All the other P fractions increased linearly with total P. The results suggested that at high levels of P application, when bioproductivity is no longer responsive to P, organic P ceases to accumulate with increased P addition, and the extra P accumulates as inorganic soil P forms.

Nguyen *et al.* (1989) re-emphasised that superphosphate application over several years can build up P and S reserves to a level where only a maintenance rate of superphosphate is required to offset losses from the soil-plant-animal systems. These authors demonstrated this using data accumulated over a 34 year period from a grazing experiment on a Lismore stoney silt loam in mid Canterbury.

The grazing experiment mentioned was conducted at Winchmore Irrigation Research Station from 1952 to 1985. Detailed measurements of soil fertility and pasture production were made over the duration of the trials. This allowed Nguyen *et al.* (1989) to examine the influence of long-term superphosphate applications to irrigated pastures on dry matter production, and the accumulation of S and P reserves which may effect the residual value of superphosphate (Nguyen *et al.*, 1989). After detailed examination of this historical data, Nguyen and co-workers drew a number of conclusions. Firstly, they concluded that in the initial stage of pasture development, the absence of P or S fertiliser inputs can lead to a severe reduction in pasture production, and a major deterioration of pasture quality i.e. towards weed species. It was concluded that superphosphate applied at 21-24 kgP/ha/yr was sufficient to satisfy phosphate maintenance requirements, and excess sulphur requirements for irrigated pastures (Nguyen *et al.*, 1989). Superphosphate applied at above maintenance rates for six years did

not safeguard against a yield reduction in the first season after discontinuation of fertiliser (Nguyen *et al.*, 1989). However, superphosphate applications over several years built up soil P and S reserves that may contribute significantly to plant uptake. Under this situation, the residual P may be able to maintain pasture production and improved pasture species without any yield reduction for a longer period than that observed under short-term P applications (Nguyen *et al.*, 1989). These authors also suggested that because soil organic S, and organic and inorganic P can accumulate in pastoral soils, especially from superphosphate application, these reserves should be taken account of in conjunction with standard soil tests when assessing pasture requirements (Nguyen *et al.*, 1989).

Phosphorus and sulphur accumulation resulting from long-term superphosphate applications was studied by Lambert *et al.* (1988). The accumulation of these nutrients was monitored over an eleven year period at Balantrae Hill Country Research Station. Research farmlets received applications of either 125 or 490 kg/ha/yr of superphosphate. Results showed that 50% of the extra P applied (above the lower rate of application) was present in the top 75mm of the soil at the trial completion (Lambert *et al.*, 1988). In contrast, these workers found that only 14% of the extra S applied accumulated in the topsoil. This rate of accumulation was said to be similar to the rate of accumulation of organic P (Lambert *et al.*, 1988).

Furthermore, the authors concluded that hill soils with a significant history of superphosphate application could be expected to have much larger available P than available S reserves (Lambert *et al.*, 1988). Also, when the direct effects of slope on superphosphate application rate were taken into account, it was found that slope did not affect the rate of P or S accumulation in the top 75mm of the soil (Lambert *et al.*, 1988).

Perrott and Sarathchandra (1989) studied phosphorus in the microbial biomass of New Zealand soils under established pasture. This is significant as soil microbes play a central role in the mineralisation and immobilisation of plant nutrients, and hence soil nutrient cycling. Soil samples were collected from sites on the major soil groups, and an extraction method was used to determine the P content of the microbial biomass.

The resulting data showed that the microbial P in the top 7.5cm of the soils ranged from 10.5 to 57.4 kgP/ha (mean 31.8 kgP/ha), which could amount to several times that in the standing crop of the above-ground pasture (Perrott and Sarathchandra, 1989). The extracting solutions used were found to extract a labile fraction of organic P from soils. Perrott and Sarathchandra (1989) concluded that the P status of New Zealand soils under pasture could be one factor influencing the amount of P in the soil microbial biomass.

A further study by these authors (Perrott *et al.*, 1990) looked at the subject of soil organic phosphorus in greater depth. An experiment was established on a yellow-brown loam near Matamata, under grazed dairy pasture. Various seasonal and fertiliser effects were monitored over a two year period, including soil microbial properties, forms of soil P and organic matter in the soil.

It was found that topdressing with potassic superphosphate increased total inorganic phosphorus, NaHCO₃-extractable inorganic phosphorus, but did not affect organic forms of phosphorus, microbial biomass phosphorus or organic debris (Perrott *et al.*, 1990). However, the amounts of phosphorus released from labile organic and microbial phosphorus during spring were large (29 kgP/ha) which could contribute substantially to plant P requirements (Perrott *et al.*, 1990).

Finally, the authors concluded that a number of seasonal mechanisms were responsible for changing the forms of biomass P in the soil at any one time. These included changes in fungal and bacterial populations during winter, mineralisation of labile inorganic P (P_i) in spring due to increased bacterial growth (promoted by plant growth), and the subsequent release of P from the microbial biomass as a result of bacterial "grazing" by protozoa (Perrott *et al.*, 1990).

In conclusion, all of the studies mentioned have shown an increase in total soil P with the application of P fertiliser. A summary of the observations made in this section can be seen in Table 2.1. Measurement of total soil P in this current study could therefore be useful in determining levels of historical P fertiliser application. The accumulation of soil P could be used to gauge the efficiency of historical fertiliser use when compared with current pasture yields.

Table 2.1 Summary : Observations of P Accumulation and Transformation in N.Z. Pastoral Grazing Systems.

Location	Treatment	P _T ↑	P _o ↑	P _i ↑	Reference
North Island	Tokomaru SL, +P	Yes	Yes	N/A	Jackman 1954a and b
	YBL Soils, +P	Yes	No	N/A	
Masterton	Kokotau SL, + 20-80 kgP+/ha	Yes	No	Yes	Perrott & Mansell 1989
Taupo	YBP Soils, Fertilised Undeveloped	Yes Low	Yes Low	Yes Low	Perrott <i>et al.</i> 1989
Canterbury	Lismore SL, 0 17 34 kgP/ha/y	?	Yes	No	Nguyen <i>et al.</i> 1989
		Yes	Yes	Yes	
		Yes	Yes	Yes	
Various Soils	Major Soil Groups (developed)	N/A	Yes	N/A	Perrott & Sarathchandra 1989
Matamata	YBL, +P	Yes	No	Yes	Perrott <i>et al.</i> 1990
Balantrae	YBE, +P	Yes	Yes	Yes	Lambert <i>et al.</i> 1988
Various Soils	Observed ↑ Organic Matter	No	Yes	No	Jackman 1964 a and b

P_T = total P, P_i = inorganic P, P_o = organic P, ↑ = increased

Many of these studies reviewed above have shown that the proportion of organic P (P_o) and P_i fractions in the soil vary widely, depending on the degree of soil development (fertiliser history, etc), soil type, and climatic conditions. In light of this review, techniques involving fractionating P forms in soils would appear to provide a useful index of soil P status relative to past fertiliser history and soil productivity. Greater increases in soil P_o relative to soil P_i would indicate that P application had stimulated the organic cycle i.e. more plant growth, more soil humus, more P_o.

In addition, it appears that Olsen P measurements could also be used as an index of fertiliser history, and could provide useful information for predicting pasture yield and the likely response to fertiliser P application.

These soil P measurements, plus others such as resin-extractable phosphate (Saggar *et al.*, 1992a), could therefore be used as a measure of plant P availability, and as an index of the efficiency of use of P applied as fertiliser in the hill country soils of the Wairarapa.

2.2.3.2 *Sulphur*

Sulphur (S), like phosphorus, is a key element for plant growth and plays an important role in forming plant proteins. Because the New Zealand farmer has historically applied superphosphate to overcome soil nutrient deficiencies, sulphur as a major component of superphosphate, was applied to pastures on a regular basis. As discussed in the previous section, such long-term applications of fertilisers can cause a subsequent build-up of soil / plant nutrient reserves.

Nguyen and Goh (1990) examined the accumulation of soil sulphur fractions in grazed pastures receiving long-term superphosphate applications. Once again, this study looked at the long-term trials conducted at the Winchmore research station since 1952 (see previous section, 2.2.3.1).

In this study grazed and irrigated pastures were fertilised annually at 0, 188 and 376 kg/ha superphosphate. This provided an annual S input of 0, 21 and 42 kgS/ha/yr respectively (Nguyen and Goh, 1990). Top soil samples were taken at the beginning of each growing season over a 35 year period, and were analysed for changes in different forms of S, organic nitrogen and total carbon.

The results obtained showed that over 95% of soil S was organic sulphur (S_o), with the remainder being adsorbed and readily-soluble S (Nguyen and Goh, 1990). Applications of superphosphate substantially enhanced the accumulation of S_o , but there was no further increase in S_o when S inputs were increased from 21 to 42 kgS/ha. This was attributed, in

part, to high sulphate leaching, as the Lismore stoney silt loam has a low capacity to adsorb S.

In addition, the accumulation of S_o reached a steady state after 25-27 years, whereas N and C reached this steady state some 3-4 and 9-12 years earlier, respectively (Nguyen and Goh, 1990). The authors suggested that S, N and C were being stabilised independently in organic matter. Therefore the accumulation of S_o was not directly related to the accumulation of N and C in soil organic matter (Nguyen and Goh, 1990).

Carbon bonded and HI-reducible made up the majority of S in the soil, with a greater proportion of carbon bonded S near the soil surface (Nguyen and Goh, 1990). This would be expected, as most plant litter, roots, dung and urine are deposited or situated near the soil surface. Microbial sulphur was not affected by superphosphate applications, and accounted for less than 3% of total soil S in all treatments (Nguyen and Goh, 1990).

In conclusion, these studies have generally shown an increase in total soil S with increased inputs of S fertiliser (superphosphate), mostly in the form of organic S (S_o). Therefore, in this study of Wairarapa soils it may be useful to measure total soil S, because this may reflect the past productivity of the soils as organic S has accumulated over time.

2.2.3.3 *Carbon/Organic Matter and Nitrogen*

In New Zealand, both climate and the soil environment combine to allow vigorous pasture growth. Consequently, organic matter tends to cycle and accumulate in pastoral based systems, and nutrient demand is high (Jackman, 1964a). The rate at which the organic matter accumulates and cycles will be highly dependant on climate and soil nutrient status i.e. relating to pasture yield. At the forefront of nutrient demand is soil nitrogen.

Although clovers are capable of adding very large amounts of symbiotic fixed N to the soil, many pastures suffer from chronic or near chronic N stress (Ball *et al.*, 1982). The main reason for this is poor distribution of the cycled nitrogen in dung and urine, which often makes nitrogen the key limiting nutrient in pastoral systems (During, 1984a). It can therefore

be concluded that at times of rapid pasture growth, nitrogen stress may be considerable (Ball *et al.*, 1982). In this current study, herbage N and P analyses were made in order to identify these periods of N and P stress at the Wairarapa sites.

The majority of soil N (95%) is present in soil organic matter and is unavailable to plants (McLaren and Cameron, 1990). Therefore the organic compounds in soil must first be broken down biologically in order to produce plant available N i.e. NO_3^- and NH_4^+ .

When the C:N ratio of plant material is low (i.e. narrow), N quantities will be surplus to microbe energy requirements, and hence plant available N may be released into the soil (McLaren and Cameron, 1990). In contrast organic matter (OM) with a high C:N (i.e. wide) ratio will break down very slowly in the soil, unless N from other soil sources can be utilised. An appropriate C:N ratio for mature clover would be 20:1, while straw may be 80:1, and soil humus/microbes 10:1 or less (McLaren and Cameron, 1990). For net mineralisation to occur in agricultural soils, it is usually necessary for the C:N ratio of the organic matter to be less than 25:1 (McLaren and Cameron, 1990).

Jackman (1964a) investigated the accumulation of organic matter in pastoral soils in some detail. He reinforced the point that soil organic matter contains organic carbon (C_o), sulphur and organic phosphorus in relatively constant proportions (Jackman, 1964a). Further, Jackman suggested that since these forms are unavailable to plants, increasing amounts of OM must lead to immobilisation of these nutrients, and a consequent reduction in the supply of inorganic forms of N, S and P (Jackman, 1964a). In his study samples were collected from several New Zealand soil types in pasture, then analysed for C_o , S_o , P_o and organic nitrogen (N_o). The first finding of this study was that in general, organic matter had accumulated in the top 75mm, and consequently N, S and P were being immobilised (Jackman, 1964a). In contrast, net mineralisation was occurring in the 75-150mm horizon. Also, in most of the soils studied, immobilisation of N, S and P exceeded mineralisation (Jackman, 1964a), i.e. soil available nutrient status was declining, constituting a maintenance fertiliser requirement. Further, it was observed that organic carbon, nitrogen and sulphur were present in constant proportions, but organic phosphorus was more variable (Jackman, 1964a). In a subsequent study of these soils, Jackman (1964b) looked at rates of OM mineralisation. He concluded

that annual rates of immobilisation of N, S and P in organic forms may be important when compared with the amounts needed to maintain good pasture growth (Jackman, 1964b).

Haynes and Williams (1992) also examined the accumulation of soil organic matter, and organic sulphur, under pasture and the decline with cultivation. These authors used the soils and data set from the previously mentioned long-term grazing trial at Winchmore Research Station. In this study the amounts of C_o, N_o and S_o in the soil were compared between pasture trials receiving 0, 188 and 376 kg/ha/yr superphosphate treatments. These treatments were also compared with a wilderness site not used for agriculture, and an arable site which had been cultivated for eleven consecutive years. Results showed that levels of organic C, S and total N in the 0-4 cm soil layer followed the order of 376 = 188 > control ≥ wilderness >> arable (Haynes and Williams, 1992). Compared with the control, accumulation of total N and organic S in the 188 and 376 treatments were proportionally greater than that of C, reflecting the inputs of sulphate S and increased clover growth and N₂ fixation in superphosphate-treated plots (Haynes and Williams, 1992). Mineralisation of S was also measured on these soils (0-4 cm) in an incubation study. The amounts of mineralised S followed the order of 376 > 188 > wilderness > arable > control (Haynes and Williams, 1992). Also, Sakadevan *et al.* (1993a) found that the amounts of N and S mineralised were greater in soils from pastures which had received fertiliser continuously, compared with those hill pastures that had not received superphosphate in the previous seven years. In both the above studies, more mineralisation was associated with smaller soil carbon : nutrient ratios.

Perrott *et al.* (1992) investigated the effects of season and fertiliser inputs on the organic cycle in a hill country soil (Te Kuiti) under pasture. This included examining changes in soil phosphorus, as well as seasonal and superphosphate effects on soil microbial phosphorus and sulphur, Olsen P and sulphate S.

It was found that although pasture production declined, there was no effects of withholding superphosphate on the soil biological cycle i.e. on soil microbial P and S, total P_o and Olsen P (Perrott *et al.*, 1992). However, seasonal variations occurred indicating storage and release of phosphorus by the soil organic matter and microbial biomass (Perrott *et al.*, 1992).

In conclusion, it is apparent from this review that soil N and S will tend to accumulate with organic carbon in pastoral soils, and that this accumulation will be greater where fertiliser has been applied. Therefore, soil total N and C measurements could be useful in determining past soil productivity and fertiliser history, and in the case of N may indicate the level of historical N accumulation resulting from N fixed by pasture legumes.

2.3 NITROGEN FIXATION IN WAIRARAPA HILL COUNTRY

Over the past 60-70 years New Zealand farmers and agriculturists have developed pastoral systems based on grasses and clovers. This is unique when compared to other temperate countries, as New Zealand agriculture is almost completely dependant on clovers to supply large inputs of nitrogen required to sustain pasture production. Until relatively recent times, very little nitrogen fertiliser has been used.

However, this complete dependence on the legume component of the sward to supply nitrogen has limitations. For example, in areas with a high frequency of summer drought, clover N fixation and hence sward N supply may be confined to a short growing season, and therefore soil N may be severely limited on an annual basis. In order to determine the quantity and period of nitrogen fixation in the sward, it is important to measure rates of N fixation.

As with fertiliser response trials, studies measuring N fixation rates in the Wairarapa are virtually non-existent. However, a national series of trials were conducted by the MAF and the DSIR in the mid-late 1970s. These trials investigated the role of clovers in the N cycle of grazed pastures, and focused on nitrogen fixation. A total of nine sites were established, ranging from Kaikohe in the far north, to Gore in the far south. At most of these sites, measurements continued for 2 or more years, beginning in 1974.

One of the sites included in this national series of trials was situated on the Wairarapa plains (Crouchley, 1979). This was the Masterton site, which was established on a Kokotau silt loam (see section 2.1.2). Superphosphate (@ 250kg/ha/yr) had been applied on a regular basis at this site, which had also received lime. Over the duration of this study, a flock of sheep were

rotationally grazed over the trial area, and dry matter yields and N fixation rates were measured.

The results from this study showed that the pasture yielded 9.4 -12.2 t/DM/ha/yr, with N fixation, estimated by the acetylene reduction technique, varying from 90 to 241 kgN/ha/yr over two consecutive years (Crouchley, 1979). The author attributed the lower levels of N fixation and clover growth to soil moisture deficits, clover root cyst nematodes, and possibly clover flowering. On sub-plots receiving N fertiliser, there was a large growth response to a winter N fertiliser treatment over the first two years of the trial, but no response in the third winter, after a season of exceptionally high N fixing activity (Crouchley, 1979).

In general, the rate of N fixation reflected soil moisture patterns, with very high rates where summer rainfall occurred. The exception to this rule was in spring, where N fixation declined due to the increased activity of clover root cyst nematodes. Nitrogen fixation rates also decreased with the onset of clover flowering (Crouchley, 1979).

The author concluded that in the Wairarapa region soil moisture seemed to be a critical factor governing clover growth and N fixation rates (Crouchley, 1979).

2.4 SUMMARY

The climate regime (primarily rainfall) and nutrient reserves (soil nutrient status) will determine the productivity of a soil. Soil nutrient status may be a product of both the origin of soil parent materials, and the accumulation of soil nutrients from fertiliser applications. This review of literature has indicated that such variations in climate and fertiliser history impact greatly on soil nutrient reserves, particularly P, N and S.

Traditional fertiliser policy in the region has relied upon superphosphate, predominantly to create elevated soil P and S levels suited to improved legume growth, which in turn supplies nitrogen. In order to obtain an accurate description of soil fertility status, both nutrient reserves and nutrient plant-availability must be measured. The difference between soil P and S contents at fertilised and unfertilised sites should reflect the fertiliser history of the site, whereas soil N accumulation in the same soil per unit of accumulated P and S may serve as a useful P and S fertiliser efficiency index.

The productivity of the soil under pasture will be determined by the pasture growth and/or animal production. Therefore, one measure of the efficiency of fertiliser use would be a comparison of measured soil fertility status with measured pasture yield.

Alternatively, because nitrogen availability appears to be the key factor limiting growth in legume-based pastures, a measure of soil fertility status compared to amounts of N fixed by the legume component of the sward would also be a useful measure of the effectiveness of traditional P and S fertiliser strategies.

CHAPTER 3: METHODS AND MATERIALS

3.1 INITIAL SOIL SAMPLING

The objective of the initial soil sampling strategy was to identify hill pasture sites in three distinct climate (rainfall) zones with similar soil type and aspect, but with contrasting fertiliser histories.

Prior to the selection of specific sites for experimental purposes, a total of 28 sites were sampled, covering three general climatic zones. The following rainfall categories were used for the trial areas:

- (i) Mauriceville and Riverside sites; high rainfall, 1600mm⁺ per year, with an even annual distribution and no summer-dry period.
- (ii) Gladstone sites; intermediate rainfall, 950 to 1200mm per year, "average" distribution, slight summer dry period.
- (iii) Whareama sites; low rainfall, 800 to 900mm per year, uneven distribution (winter dominant), reliable and extended summer dry conditions.

The initial soil samples were taken in May of 1993. Approximately thirty, 25mm diameter cores were taken at the proposed sites, from a relatively small area within a paddock. These cores were taken to a total depth of 150mm, and cut accurately to give two different zones i.e. 0 to 75mm and 75 to 150mm. The usual precautions were taken to avoid areas where stock congregate, dung/urine patches, stock tracks, camp sites, gateways etc.

Each soil sample was then prepared for analysis in the laboratory by air drying at room temperature, then sieving through a 2mm mesh to remove unwanted plant material and stones. The sample was then thoroughly mixed and sub-sampled. One sub-sample was dried for over 24 hours at 105°C, and then ring-ground for two minutes to produce a dry, fine-particle sample to be used for total nitrogen (N), phosphorus (P) and sulphur (S) analysis. The methodology for total N, P and S analysis of soil is outlined in section 3.10.

3.2 SITE SELECTION

Results from the initial soil analyses provided information on the total N, P and S contents of both the top soil and subsoil at the proposed sites, and therefore gave some indication of fertiliser history and fertility levels. Using this information and climate and soil characteristics, a total of fourteen sites were selected for this study. These sites covered the three climate regimes outlined previously, and also attempted to cover three distinct fertiliser histories (fertility regimes) i.e. "high", "medium" or "low" fertiliser inputs (see section 3.3, Fertiliser History). The location of the trial areas are shown in Figure 3.1.

In addition to climate and soil fertility levels, other criteria were used in the site selection process. These included the aspect, and the slope of the site. The soil types present were identified using available soil maps, and Land Resource Inventory Worksheets. Most sites were also chosen to represent "typical" hill country pastureland, with a slope of 25° or less.

Aspect was the final consideration. The majority of sites selected had a north, north-west, or westerly aspect, with one or two exceptions e.g. sites 5 and 6 had opposing NE and S aspects. Hence the effect of aspect could be examined, using sites of very similar fertility levels, soil type, climate and slope etc. The location, aspect, soil type and fertiliser history of each site are summarised in Table 3.1.

3.3 FERTILISER HISTORY

As mentioned in the previous section, sites within a climate zone were selected on the basis of contrasting fertiliser history. The fertiliser histories of all 14 sites are summarised in Table 3.1, along with location, soil and aspect data.

At Mauriceville, sites 1 and 2 had received "high" rates of fertiliser (200+kg superphosphate/ha/yr) over many years, while site 3 is thought to have received superphosphate at a lower rate, and less frequently. The Mauriceville site 4 however has a contrasting fertility status, having little or no fertiliser applied over the past 20-25 years.



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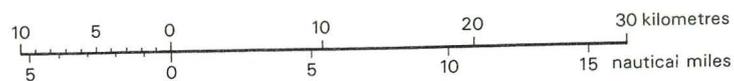


Figure 3.1 Location of Wairarapa trial sites and New Zealand Meteorological Service Climate Stations (A) Mangamutu (B) Castle Point and (C) Taratahi

At Wharerama, sites 5, 6 and 7 represent sites that have received medium rates of fertiliser on a fairly regular basis. Site 8 is a high fertility site, having received 250 kg/ha/yr superphosphate for many years, while site 9 has had little or no fertiliser applied over the past 12 years.

Table 3.1 Site Information

Location	Site No	Aspect	Soil Group, Parent Material	Fertilizer History
Mauriceville	1	W	Central YBE, Limestone	200-kg/ha/yr Superphosphate (20 years +)
	2	W		
	3	NW		
	4	W	Loess and Siltstone	No fertilizer past 20 - 25 years
Whareama	5	NE	Central YGE/YBE Intergrade, Mudstone and Argillite	1069-83 250 kg/ha/yr Super, 1983 to 1993 10 kgP/ha/yr
	6	S		
	7	N		
	8	NW		250 kg/ha/yr Superphosphate (20+ years)
	9	N		No Fertilizer (12 years)
Gladstone	10	N	Central Brown Redzina, Mudstone	200-kg/ha/yr Superphosphate (15-20 yrs)
	11	WNW	Central YGE/YBE Intergrade, loess & sand /siltstone	No Fertilizer 20 + years
	12	W		No Fertilizer 8 years
Masterton	13	No Aspect	Central YBE/YGE Intergrade, Gravels	180 kg/ha/yr Superphosphate (10-15 years)
	14	NE	Central YBE, Greywacke	

Gladstone sites also have a range of fertiliser histories. Site 10 is a high fertility site, and has received 200kg +/-ha/yr superphosphate for the last 15-20 years, while site 11 is a low fertility site having received no fertiliser over the same period. Site 12 received fertiliser some 8-10 years ago, but has had little since. The final two sites 13 and 14 (near Masterton), are both high fertility sites, and have good fertiliser histories.

3.4 SITE ESTABLISHMENT

The selected trial sites were established in mid-August, 1993. Each site consisted of a 4m x 4m square plot, which was first prepared by mowing pasture to a height of approximately 2cm, and removing cut herbage. A total of four 0.5m² stock exclusion cages were then placed in each plot, and were secured to the ground with steel pegs. This gave a combined total of 56 cages on the 14 trial areas. For added protection from stock damage, an electric fence was erected around each plot.

3.5 HARVESTING AND DISSECTION OF HERBAGE

All trial sites in this study were harvested for pasture dry-matter yield every 20 to 28 days. Pasture was cut at ground level in all four stock exclusion cages using a domestic hedge trimmer. Samples were then stored in plastic bags and chilled until botanical separations could be completed. When the cages were harvested, the remainder of the plot was also trimmed and cleared of debris, so as to create a bench mark for the following period of pasture growth. In addition, all exclusion cages were moved onto a "fresh" area of the site once they were harvested.

In the laboratory, herbage samples were thoroughly mixed, then a grab sample was taken from each for a botanical separation. The botanical separation entailed separating and drying the grass species, legume species and dead matter in each sample. Samples were then oven dried at 65° to 70°C, and weighed to provide a value for grass and legume dry matter, and dead matter content. Dried grass and legume samples were milled and stored in a desiccator for later use in chemical analyses.

Total dry matter yield of each sample was also measured. After the grab sample had been removed, the fresh-weight of the remaining herbage was expressed as a proportion of the initial total fresh-weight, and was then oven dried as described above. The dry-weight of the residual herbage was then measured, and the total dry-matter yield calculated for each stock exclusion cage. Using an area conversion factor, a mean pasture growth rate was then calculated for each site, and expressed as kgDM/ha for every harvest/growth period.

3.6 THE ACETYLENE-REDUCTION TECHNIQUE

In clover root nodules, atmospheric nitrogen gas is reduced to ammonia by the nitrogenase enzyme complex of rhizobium bacteria. The nitrogenase enzyme is not specific in action to nitrogen, but preferentially reduces acetylene gas to ethylene gas if clover roots are placed in an acetylene atmosphere. A relative rate of symbiotic nitrogen fixation was assessed in the field at each harvest (until early January) by a modified version of the acetylene-reduction assay of Hardy *et al.* (1968), see also Hoglund and Brock (1978).

The clover roots were incubated in 10% acetylene-in-air mixture for about one hour. Acetylene is first "scrubbed" i.e. passed through vessels of concentrated sulphuric acid and distilled water to remove contaminants. The acetylene is then collected in a Buctiner flask stoppered with a "Suba seal", with a yellow rugby bladder attached to the side arm. This then acts as the acetylene storage apparatus for transport to the field sites.

Seven soil core samples (25mm diameter) were taken from the harvested exclusion cages in the field, and cut to a length of 75mm. These were then placed in 600ml glass preserving jars, then "Perfect Seal" lids, fitted with a red "Vacutainer" tube stopper, were screwed down tight. Using a syringe, 30mls of air was then removed from the jar, and 30mls of acetylene gas injected into the sample. All samples were then incubated in a insulated food container for one hour, at a temperature close to 50mm soil temperature. Control jars (gas blanks) were prepared by injecting 30ml of acetylene into jars containing no soil.

During the incubation, the clover root nodules convert some of the acetylene to ethylene gas, which is released into the preserving jar. After the one hour incubation period, double-ended

needles are used with red stoppered "Vacutainer" tubes to take 10ml samples of gas from the sample jars. These gas samples were then analysed for ethylene by gas chromatography, at AgResearch Grasslands, Palmerston North.

After analysis of gas mixtures for ethylene, incubation time, acetylene levels in gas blanks were subtracted from jars containing soil and jar volume factors were used to calculate acetylene reduction rates. These were then converted to N fixation rates, expressed as kgN/ha/day.

3.7 SOIL MOISTURE CONTENT

The soil moisture content at each site was monitored over the duration of the trial. At each harvest, soil cores, taken to measure nitrogen fixation rates, were oven dried at 105°C for 40 hours to measure soil moisture levels, the results of which were expressed as gravimetric and volumetric water contents.

3.8 SOIL SAMPLING AND PREPARATION

In addition to the initial soil sampling, further soil samples were taken for analysis in late winter/early spring. A total of fifteen, 25mm diameter cores were taken and cut accurately to two depths, 0-75mm and 75-150mm from within each trial plot. Topsoil (0-75mm) samples were taken in replicate. These samples were then prepared as described previously (see section 2.1), to produce both 2mm sieved air-dry soil, and fine oven-dried ring-ground soil samples. The prepared soil samples were then used for various elemental analyses, as outlined below.

3.9 CLIMATE MEASUREMENTS

In order to interpret relationships between yield and soil /nutrient data it was necessary to collect climate data.

Measurements were taken in each of the three climate zones i.e. Mauriceville, Gladstone and Wharerama. These included daily rainfall, and daily temperature (maximum / minimum). In addition to this on-site data, climate data was obtained from near-by N.Z. Meteorological stations. This included measurements from Mangamutu, Castle Point and Taratahi Meteorological Stations. The location of these stations are shown in Figure 3.1.

In addition to rainfall and wind information, the Tauherenikau station also recorded daily sunshine hours for the region. This was particularly useful, as this measurement was used (incorporated with the other climate data) to model the influence of climate on evapotranspiration and hence predict soil moisture content and soil limited evapotranspiration in the three climate zones selected (see later sections).

Soil temperature was also measured to a depth of 10cm, and was recorded at each site when herbage was harvested.

3.10 SOIL ANALYSES

3.10.1 Total Phosphorus

Total soil phosphorus was measured using the Kjeldahl digestion of soil (McKenzie and Wallace, 1954), followed by analysis with a "Technicon II" Auto-analyser.

One gram \pm 0.001g of finely ring-ground, oven-dry (105°C) soil was weighed into a Kjeldahl digest tube, and 4ml of digest mixture added (250g K_2SO_4 : 2.5g selenium powder : 2.5L conc. H_2SO_4). Standard soil samples containing a known quantity of P, and digest tubes containing no soil (digest blanks) were also included. The digest tubes were then placed in an aluminium block and heated to 360°C for four hours.

When cool, the digests were diluted to 50ml with distilled water, and mixed thoroughly on a vortex mixer. Silicates in this solution were allowed 24hrs to settle before aliquots from the supernatant were analysed. Total phosphorus content of the digest was then measured using a "Technicon II" Auto-analyser configuration.

3.10.2 Sequential Phosphate Extraction

In order to characterise the P accumulation in the topsoil samples (resulting from fertiliser application), a sequential analysis of soil phosphorus was undertaken. The method used was a simplified version of that used by Perrott *et al.* (1989), involving alkali and acid extractions.

3.10.2.1 *NaOH Extraction and Digest*

Top soil ($0.5 \pm 0.001\text{g}$) which had been finely ground and oven-dried (105°C) was weighed into a 50ml polypropylene centrifuge tube. Thirty ml of 0.1M NaOH was added to each tube, which was then shaken on an end-over-end shaker for 16 hours. These were centrifuged at 8000 rpm for 10 minutes, then the supernatant filtered through Whatman No. 42 filter paper, taking care to leave no liquid in the tube.

The NaOH P_i and NaOH P_T contained in the supernatant were then analysed using the following procedures.

NaOH P_i

A 4ml aliquot of extractant was pipetted into a 50ml volumetric flask, and 10ml of Murphy and Riley reagent added. This was made to volume with distilled water, and the colour development at 712nm was measured after 30 minutes, using a spectrophotometer (Murphy and Riley, 1962).

The colour development of each soil sample was also corrected for the colour of the NaOH extract. This was done by adding Murphy and Riley reagent which contained no ascorbic acid. The spectrophotometer reading for extract colour, and also blank extracts were then subtracted from the sample reading to give a corrected value for P concentration calculation.

NaOH P_T

Another 4ml aliquot of NaOH extractant was taken, pipetted into a 50ml conical flask, and 2ml of conc. H₂SO₄ added. This was heated on a hot plate at 300°C for over 1 hour, until the digest had charred black. Samples were then cooled, and 0.5ml of 30% H₂O₂ added. The digests were then reheated for 30 minutes until clear.

P-nitrophenol indicator, 4M NaOH and 0.5M H₂SO₄ were then used to neutralise the acid digest, and the contents of the flask transferred to a 50ml volumetric flask. Again, 10ml of Murphy and Riley reagent was added to all samples, which were made to volume with distilled water, and colour development measured as for NaOH P_i.

3.10.2.2 H₂SO₄ Extraction and Residual P Digest

H₂SO₄ P

Thirty ml of 0.5 M H₂SO₄ was added to the original soil pellet, which was then shaken, centrifuged and supernatant collected in the same manner as for NaOH. A 5ml aliquot of this extract was added to a 50ml volumetric flask, and was neutralised using p-nitrophenol indicator, 4M NaOH and 0.5M H₂SO₄. Once again, Murphy and Riley reagent was used for P analysis, as described earlier.

Residual P

The remaining soil pellet was then transferred to a 125ml conical flask, which was carefully washed from the centrifuge tube with 25ml of distilled water, and 4ml of conc. H₂SO₄ added. This was placed on the hot plate (300°C) until the soil had charred black, then cooled. Flasks were rotated on the hot plate to ensure even heating. Then, 0.5ml of 30% H₂O₂ was added to each sample, and was reheated. This cooling, adding 0.5ml H₂O₂, reheating process was continued until the soil residue had turned white or blue-grey i.e. until the soil was fully digested.

The digest solution was then cooled, transferred to a 50ml volumetric flask and made to volume with distilled water. This was mixed and allowed to settle before a 5ml aliquot was taken and transferred to another 50 ml volumetric flask. This was then neutralised and P concentration determined as outlined in the previous sections.

3.10.3 Total Nitrogen

The total nitrogen content of soil samples was determined by the Kjeldahl digest method (McKenzie and Wallace, 1954), followed by analysis on a Technicon II Auto-analyser, as outlined above for total phosphorus.

3.10.4 Total Sulphur

The total S content of the soil was determined by using a modification of the dry oxidation procedure, described by Landers *et al.* (1983). The oven-dried, fine-ground soil (0.250g) was weighed into a small pyrex test-tube and was mixed thoroughly in a vortex mixer with about 0.50g of mixed oxidant (12.5g NaHCO₃ : 1g Ag₂O). About 0.5g of NaHCO₃ was then layered on top of the sample as a trap for SO₂ gas.

The samples were then placed in small aluminium blocks and were heated in a cold muffle furnace to a temperature of 550°C for a period of 3 hours. After cooling, the dry mixture was dissolved carefully in 10ml of 5M HCl. The samples were then diluted to 50ml with distilled water, mixed thoroughly, and left to settle for 24 hours before being analysed.

Sulphur concentration of the oxidised solution was again determined using a Technicon Auto-analyser (Sakadevan *et al.*, 1993a).

3.10.5 Soil pH

Soil pH was determined by adding 25ml of distilled water to 5g of air-dry 2.0mm sieved soil, mixing thoroughly, then leaving to settle for over night. Samples were then mixed again in the morning, allowed to settle for one hour, then the pH of the supernatant solution measured

using a glass continuation electrode pH meter. Care was taken not to disturb soil sediment while taking pH readings.

3.10.6 Total Carbon

Soil total carbon content of samples was determined by the Leco combustion method, as described by Bremner and Tabatabai (1971).

3.10.7 Plant-Available Nutrients.

3.10.7.1. *Phosphate*

Soil plant-available phosphate was measured by the method of Olsen *et al.*, 1954.

3.10.7.2 *Resin-Exchangeable Phosphate*

In addition to Olsen P, resin P measurements were made on soil samples. Resin P is a procedure for determining the amount of phosphate extracted from soils by ion exchange resin membranes. This method uses strips of both anion and cation exchange strips, so that in soils of variable charge, extraction of soil P may be more effective i.e. when cations contributing to surface positive charge are removed. The resin P technique used was that reported by Saggar *et al.* 1990.

3.10.7.3 *Sulphate.*

Extractable sulphur (sulphate) was determined by the method described by Landers *et al.* (1983). Air-dry 2mm sieved soil samples (5.00 g) are weighed into a 50 ml centrifuge tube and 25 ml of 0.01M calcium tetrahydrogen di-orthophosphate [$\text{Ca}(\text{H}_2\text{PO}_4)_2 \cdot \text{H}_2\text{O}$] added. Samples are then shaken on an end-over-end shaker for thirty minutes, followed by centrifugation at 8000 rpm for 10 minutes, and then filtered through Whatman No. 42 filter paper.

The amount of extractable S in the supernatant solution is then measured using a Technicon Auto-analyser, as outlined for the measurement of total soil sulphur.

3.10.7.4 *Exchangeable Cations and Cation Exchange Capacity*

Exchangeable cations (K, Mg, Na, Ca) were measured using 1.00 ± 0.01 g air-dry 2mm sieved soil. The soil sample is mixed with 3g of acid washed sand and placed in a leaching tube, preblocked with damp Whatman No. 41 filter paper. Fifty ml of ammonium acetate (64ml NH_4OH , 57ml glacial acetic acid / L, pH 7.0) containing either 1.26g/L CsCl (measuring K, Na) or 2.41g/L $\text{Sr}(\text{NO}_3)_2$ (measuring Ca, Mg) is then leached through the soil.

The leachate is collected and diluted 9:1 with the appropriate ammonium acetate solution, which is then analysed for the presence of cations using an atomic absorption spectrometer. The cation exchange capacity was measured by summing amounts of H^+ , Ca^{2+} , Mg^{2+} , K^+ and Na^{2+} ions displaced. The quantity of H^+ ions were calculated using pH depression of the leachate compared to an initial ammonium acetate solution.

3.10.7.5 *Mineralisable N*

Soil mineralisable N was measured by a modification of the method used by Craighead and Clark (1989).

Air-dry, 2mm soil (5.00g) was weighed into a 50ml centrifuge tube, and 20mls of distilled water added. This was then capped and incubated at 30°C for a period of 15 days. All samples were replicated. Soil in solution was suspended on a daily basis throughout the duration of the incubation.

At the completion of the incubation, mineralisable N was extracted by adding 10ml of 3M KCl to each tube, shaking on an end-over-end shaker for 20 minutes, followed by centrifugation at 8000 rpm for 5 minutes. The extracted solution was then filtered through Whatman No. 42 filter paper, and analysed for NH_4^+ concentration using a Technicon II Auto-analyser, as outlined in the measurement of total soil nitrogen (Section 3.10.3).

3.11 HERBAGE ANALYSES

3.11.1 Total Phosphorus and Nitrogen

The total P and N content of both grass and legume sward components were measured at each harvest. This was determined using the Kjeldahl digest method, followed by analysis with a Technicon II Auto-analyser, as described for measurement of total soil N and P.

Like soil, the herbage was dried (65°C) then finely ground. However, unlike the soil digest, only $0.1\text{g} \pm 0.001\text{g}$ of herbage is digested, due to the higher N and P content of herbage compared to soil. Otherwise, the methods for soil and herbage digestion are identical.

3.11.2 Molybdenum

During the mid-spring period of rapid pasture growth, the molybdenum content of legume samples was measured to determine if this trace element was deficient. The analyses involved here were undertaken by R.J. Hill laboratories of Hamilton, where the zinc-dithiol colourimetric method is the procedure used for determination of molybdenum.

CHAPTER 4: CHEMICAL CHARACTERISATION OF SOIL NUTRIENT STATUS

4.1 INTRODUCTION

The objective of this section of study was to confirm that the 3 - 5 pasture production sites chosen for field study within each climate zone (Mauriceville, Gladstone and Whareama) did indeed contrast in soil nutrient status. A suite of soil chemical analyses designed to provide indices of soil plant-available and total soil nutrient status were undertaken with secondary objectives of:

1. Determining the soil fertility status of each site by using chemical extraction indices of plant-available nutrient content, including Olsen-extractable P, resin-extractable P, extractable sulphate, exchangeable cations, CEC and soil pH;
2. Analysing samples for total P, S and N content to determine the extent of P, S and N accumulation resulting from fertiliser application, and
3. Obtaining a measurable index of mineralisable soil N was also measured, in order to estimate levels of "readily-available" N accumulated through legume management.

Efficiency of fertiliser use is examined by considering a number of relationships between the relative accumulation of P, S and N in the soil across a range of sites.

In addition to total P measurements, a soil P fractionation was undertaken to investigate methods for better characterising the influence of fertiliser history.

4.2 ASSESSMENT OF PLANT-AVAILABLE NUTRIENT STATUS OF SOILS

Soil test levels referred to in this section for plant-available nutrient status are those recommended by the New Zealand Ministry of Agriculture and Fisheries, MAF (Cornforth and Sinclair, 1984), now known as Agriculture New Zealand. This data was used as no

known P and S soil test / pasture growth response calibrations for the Wairarapa region were available in published literature.

4.2.1 Olsen P

Olsen P levels ($\mu\text{g/g}$) varied considerably across all sites, ranging from 8 to 62 $\mu\text{gP/g}$ soil (or 10 to 82 $\mu\text{gP/ml}$ soil reflecting bulk density, Figure 4.1). Using the MAF recommended soil Olsen P values as standards (Table 4.1), sites 1, 2, 3, 7, 8 and 10 had Olsen P values above 20 $\mu\text{gP/g}$ soil, which would suggest high levels of plant available P (for legume-based pastures). Sites 5, 6, 9, 11, 13 and 14 had medium Olsen values, ranging between 12-18 $\mu\text{gP/g}$ soil. The remaining sites 4 and 12 had low Olsen values (below 12 $\mu\text{gP/g}$), with site 4 having a very low P level of 8 $\mu\text{gP/g}$ soil.

Table 4.1 N.Z. MAF Recommended Soil Test Levels

	Very Low	Low	Medium	High
Olsen P ($\mu\text{g P/g}$)				
Rainfall > 1000 mm				
Autumn	0 - 10	11 - 20	21 - 30	> 30
Spring	-	-	0 - 20	> 20
Rainfall < 1000 mm				
Autumn	-	-	0 - 20	> 20
Spring	-	-	0 - 10	> 10
Sulphate S ($\mu\text{g S/g}$)	0 - 4	5 - 10	11 - 15	> 15
Cations (meq/100g)				
K	0 - 0.33	0.34 - 0.46	0.47 - 0.56	> 0.56
Mg	-	0 - 0.16	0.17 - 0.48	> 0.48
Ca	-	0 - 5	6 - 10	> 10
P-Retention	-	0 - 30	31 - 85	86 - 100

Adapted from Cornforth and Sinclair (1984).

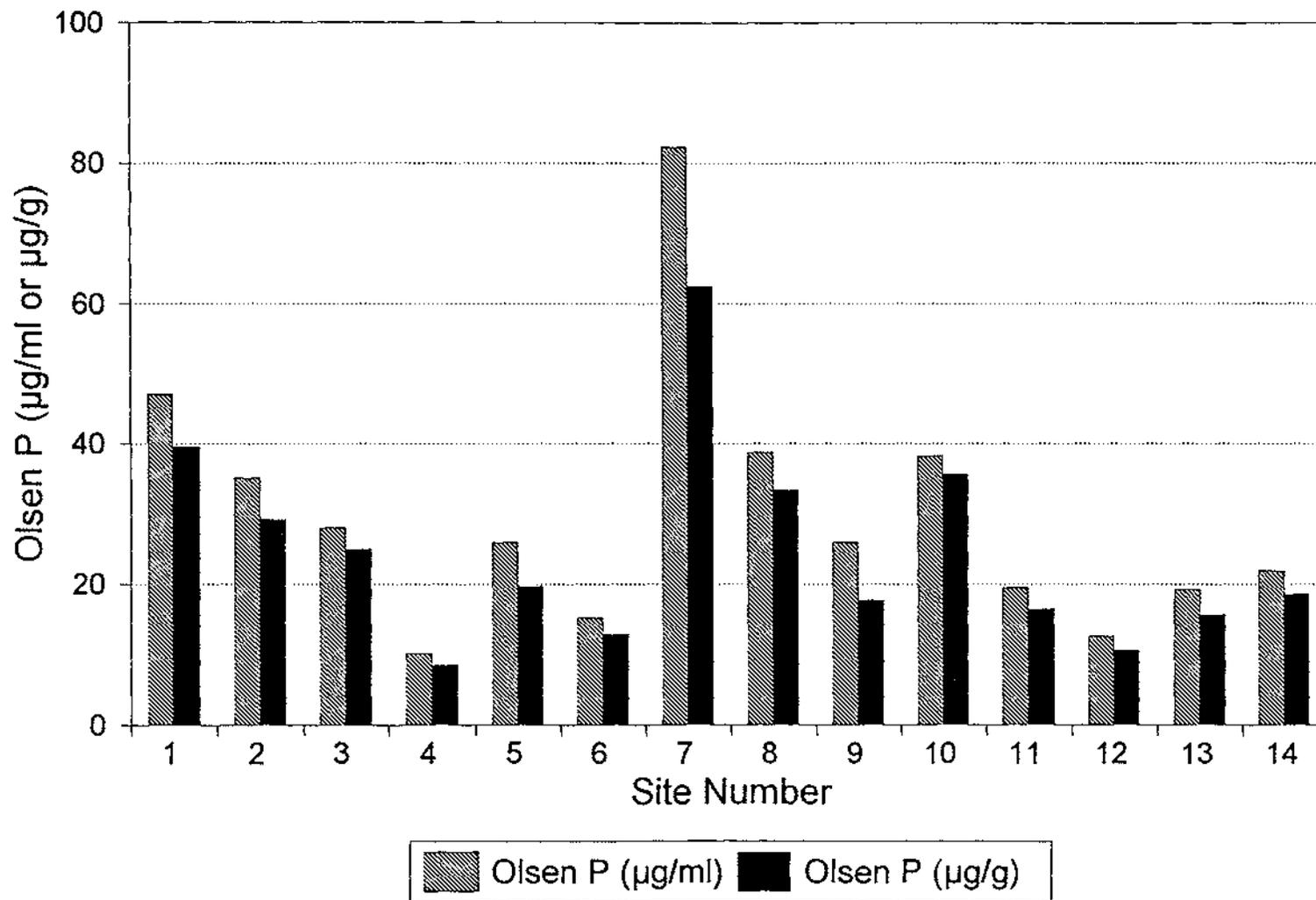


Figure 4.1

Olsen P values for the 0 - 7.5 cm soil depth at all sites

Table 4.2 Soil Olsen P, Sulphate S, Resin P and Mineralisable N Values for the 0 - 7.5 cm Depth

Site No	Olsen P		Resin P $\mu\text{g/g}$	Sulphate S		Mineralisable N	
	$\mu\text{g/ml}$	$\mu\text{g/g}$		$\mu\text{g/ml}$	$\mu\text{g/g}$	$\mu\text{g/g}$	kg/ha
1	47±6	40±5	89±7	12±1	10±1	471±45	300
2	35±5	29±4	93±3	11±0	9±0	417±49	266
3	28±3	25±3	30±1	17±1	15±1	395±7	252
4	10±2	9±1	13±1	10±1	8±0	172±18	110
5	26±2	20±2	86±3	11±2	9±1	372±54	237
6	15±1	13±1	60±4	9±1	7±0	310±9	198
7	82±9	63±7	119±15	18±4	13±3	247±39	158
8	33±2	33±2	118±1	19±2	16±2	414±32	264
9	26±5	18±3	73±0	12±3	8±2	255±54	163
10	38±11	36±10	118±1	12±2	11±2	395±16	252
11	20±1	16±1	60±4	8±1	7±1	291±29	185
12	13±0	11±0	83±3	7±2	6±1	219±51	140
13	19±2	16±2	22±3	15±1	12±1	287±5	183
14	22±1	19±1	56±1	10±0	9±0	292±43	186

In general, soil Olsen P values reflected fertiliser history (Table 4.2). Those areas with good fertiliser history, such as sites 1, 2, 3, 8 and 10, all recorded high Olsen P levels, whereas sites historically receiving little or no fertiliser (sites 4 and 12) had very low Olsen values. As would be expected, those sites which had received fertiliser infrequently or at lower rates, inherently fell into the "medium" Olsen P category. However, this was not so for sites 7 and 11, which had high Olsen P values relative to fertiliser history. Other soil analyses (resin P, SO_4^{2-} , K^+) also had high values at site 7, which would suggest that this site is a stock camp area.

4.2.2 Resin-Extractable P

Soil resin-extractable P levels were higher than Olsen P values across all sites. Values ranged from 13 to 120 $\mu\text{gP/g}$ soil (Figure 4.3), with sites 1, 2, 5, 7, 8 and 10 having high resin P values when compared with those of Saggar *et al.* (1992b). However, sites 3, 4 and 13 had relatively low values.

Over most sites, resin P values reflected fertiliser history, where those sites receiving more fertiliser had higher levels of resin-extractable P. However, the resin P values for sites 3 and 13, sites which had moderately high past fertiliser applications, were lower than expected when compared to their Olsen values and with resin values for other sites. Also, site 12 had a substantially higher resin P value than site 11, whereas the reverse was true for Olsen P and sulphate S levels. The reason for this is not apparent, but will reflect the different pools of soil phosphate extracted by the Olsen bicarbonate extract and the non-alkaline simple exchange process involved in resin extraction of P from soil.

4.2.3 Extractable Sulphate

Soil sulphate (SO_4^{2-}) S values varied from 6 to 16 $\mu\text{gS/g}$ soil (Figure 4.2). Again, using MAF standard recommendations (Table 4.1), sites 1, 3, 7, 8, 10 and 13 had higher sulphate levels (above 9 $\mu\text{gS/g}$ soil), while most other sites fell into the medium bracket i.e. 6-9 $\mu\text{gS/g}$ soil. Sites 11 and 12 had low sulphate values of around 6 $\mu\text{gS/g}$ soil.

As with Olsen P, sulphate S values did, to a certain degree, reflect fertiliser history. Sites receiving high fertiliser inputs, such as sites 1, 3, 8, 10 and 7 (suspected camp site) had high levels of sulphate S, while most other sites fell into the medium category, and so would be expected to be marginally or variably S deficient. Sites 11 and 12, which have received little or no fertiliser over an extended period had low soil sulphate levels, and hence are likely to be sulphur deficient.

In a number of cases (e.g. site 2 verses site 4), however the difference in sulphate levels did not reflect the large difference in fertiliser history. This may in part be explained by the very

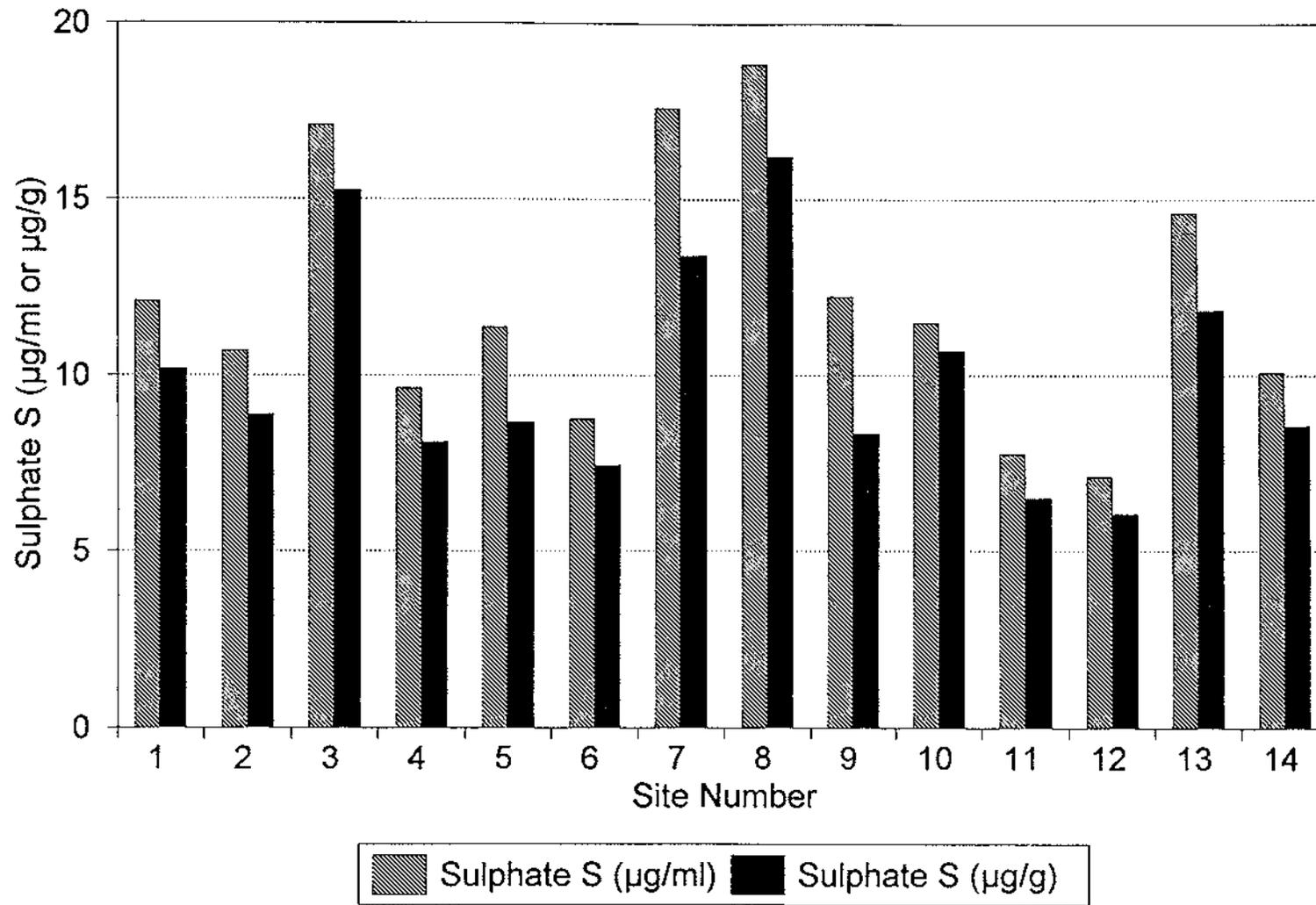


Figure 4.2

0.1M Calcium phosphate extractable sulphate values for the 0 - 7.5 cm soil depth at all sites

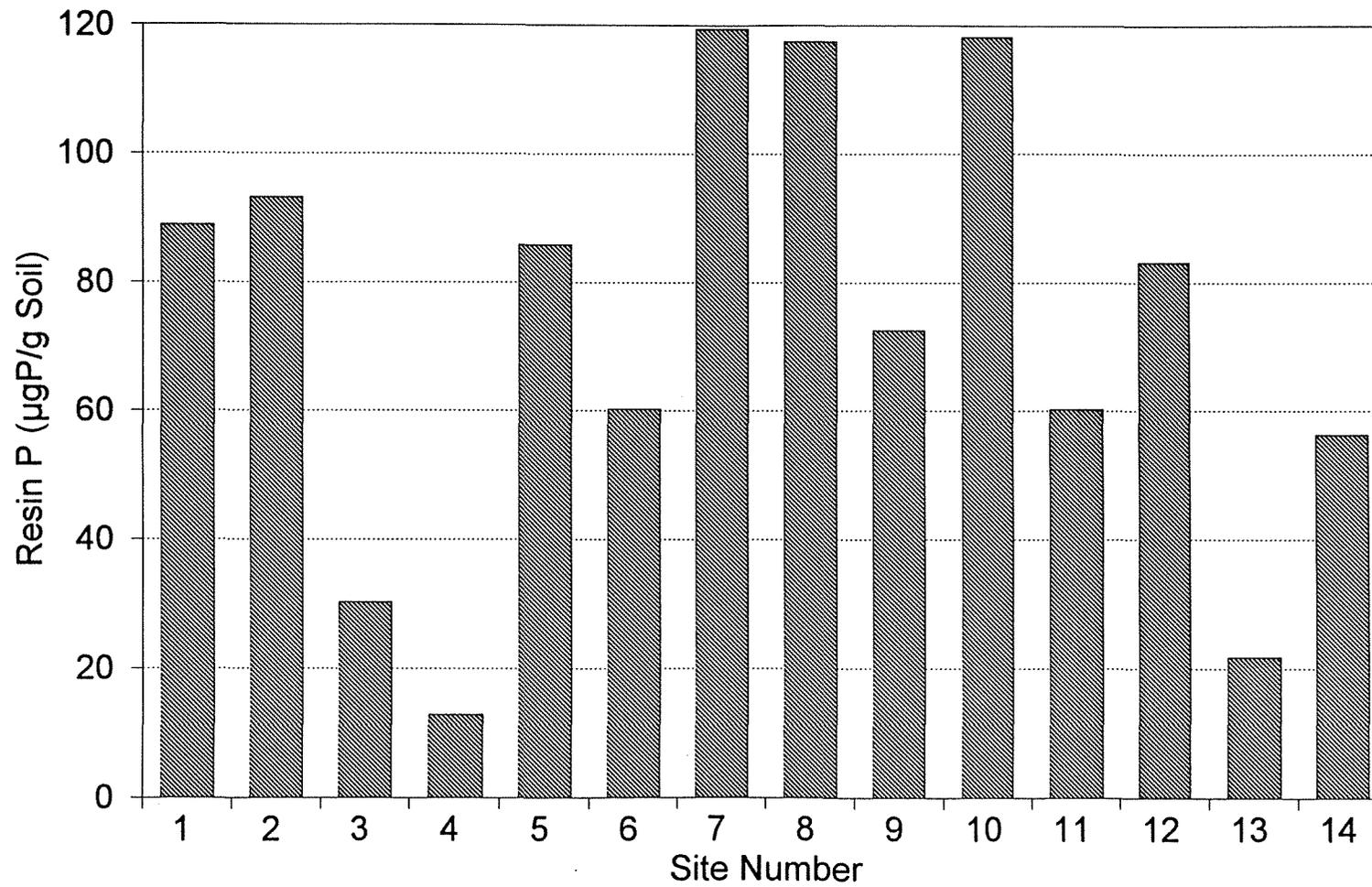


Figure 4.3

Resin-exchangeable phosphate values for the 0 - 7.5 cm depth at all sites

mobile nature of SO_4^{2-} in soil, where SO_4^{2-} applied as fertiliser (superphosphate), returned in urine and mineralised from soil organic reserves (Sakadevan *et al.* 1993a and b), is prone to leaching losses (Saggar *et al.* 1990).

4.2.4 Soil pH

Soil pH ranged from 4.8 to 5.9 (Table 4.3). Sites 8, 10, 12 and 14 had pH values between 5.5 and 6.0. In contrast, sites 1-7, 11 and 13 all had pH values below 5.5, while site 9 had a low value of 4.8. The N.Z Ministry of Agriculture and Fisheries recommend an optimum pH range of 5.5 to 6.5 for grass/legume pasture (McLaren and Cameron, 1990), and hence many of these Wairarapa sites are slightly more acidic and lay outside this range. Site 9 is excessively acidic for pasture growth, and at the pH of 4.8, aluminium toxicity may be a growth limiting factor.

4.2.5 Soil N Availability Index

Soil mineralisable N levels ranged from 172 to 470 $\mu\text{gN/g}$ soil (Figure 4.4), or 110 to 300 kgN/ha to 7.5 cm (bulk density = 0.85). Sites 1, 2, 3, 5, 8 and 10 had very high levels of mineral N (350-470 kgN/ha), while most other sites contained approximately 250 kgN/ha . As a comparison, Jackman (1964a) made estimates of mineralised N in pasture (topsoil) ranging from 194 to 492 kgN/ha . Further, Walker *et al.* (1958) estimated by calculations that on a volcanic Taupo soil in pasture, additions of nitrogen to the soil organic pool from clover ranged from 140 to 280 kgN/ha/yr , although not all of this would remain easily minealisable.

The soil mineralisable N levels appear to be linked with fertiliser history. The values increase with increased fertiliser inputs. This is evident at sites 4, 9 and 12, where low or nil fertiliser inputs are reflected by low mineralisable N levels in the topsoil when compared to other sites.

4.2.6 Exchangeable Cations

Potassium values ranged from 0.5 to 1.5 meK/100g soil (Table 4.3). At this level, all sites would fall into the high or medium-high category for soil potassium using MAF K quick-test levels given in Table 4.1.

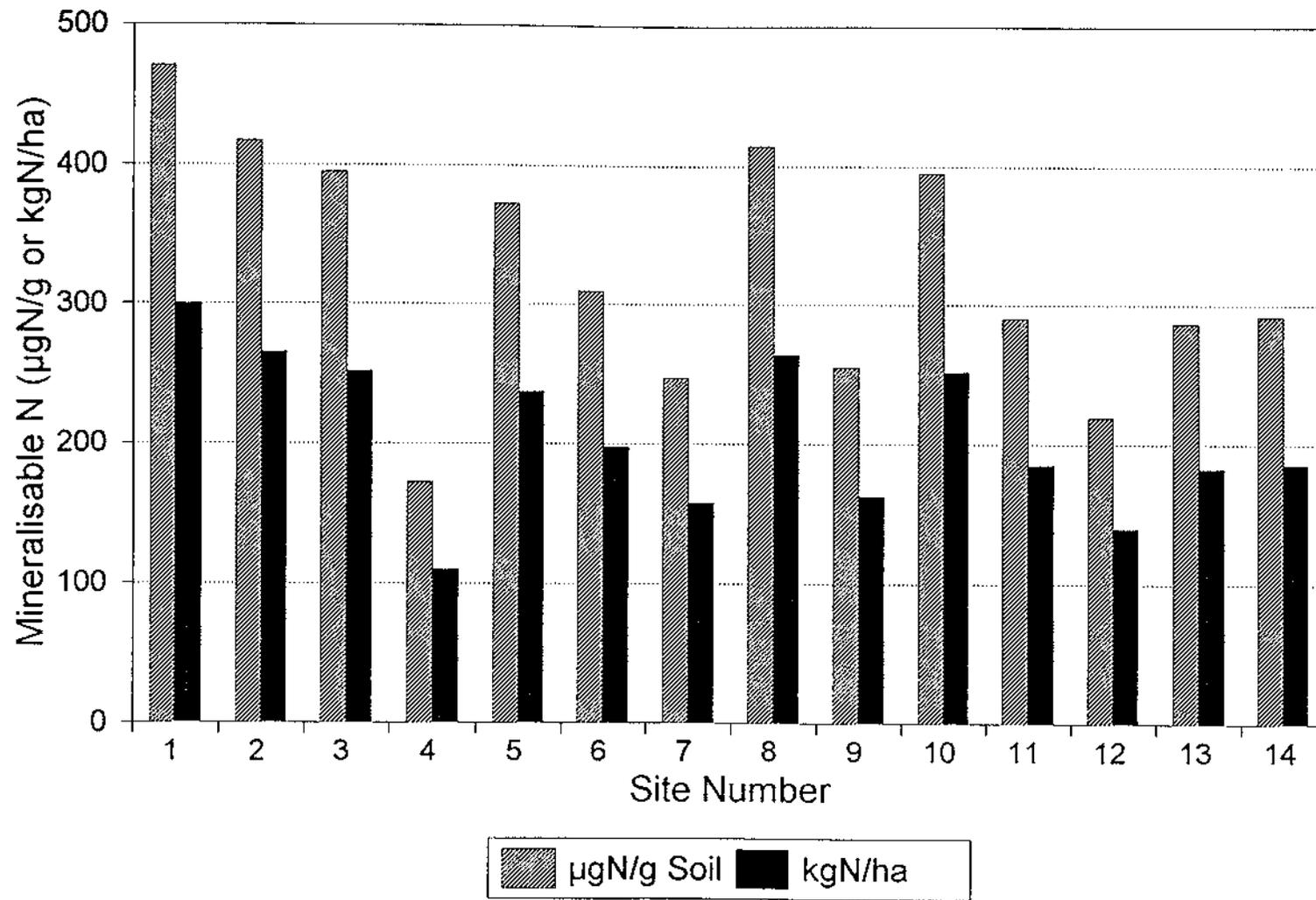


Figure 4.4

Mineralisable nitrogen for the 0 -7.5 cm depth at all sites

Again using MAF recommendations (Table 4.1), Ca and Mg levels would be regarded as medium to high at all sites. Calcium and magnesium levels ranged from 5.4 to 15.8 meCa/100g and 0.9 to 6.0 meMg/100g respectively. Sodium levels ranged from 0.18 to 0.83 meNa/100g, which should not be limiting pasture growth.

Table 4.3 Soil pH, CEC, Total C and Exchangeable Cation values for the 0 - 7.5 cm Depth

Site No	pH	Total C %	CE C	Exchangeable Cations			
				Mg	Na	Ca	K
1	5.5±0.1	5.8±0.2	26	1.4±0.2	0.3±0.1	9.4±0.5	1.0±0.3
2	5.4±0.1	5.6±0.3	23	1.6±0.2	0.3±0.1	9.9±0.7	0.7±0.1
3	5.4±0	6.0±0	24	1.1±0	0.3±0.1	8.2±0.4	0.8±0.4
4	5.0±0.1	6.4±0.1	25	1.7±0.1	0.2±0.1	5.4±0.1	0.5±0
5	5.4±0	6.7±0.1	32	6.0±0.1	0.8±0.1	11.3±0.3	1.5±0.2
6	5.4±0.1	5.3±0.3	27	2.0±0.2	0.7±0.1	8.7±0.7	0.9±0.1
7	5.0±0.1	5.6±0.3	25	2.7±0.2	0.5±0	6.7±0.1	0.9±0.1
8	5.7±0.1	6.2±0.2	32	5.2±0.1	0.8±0.1	15.8±0.1	0.9±0.1
9	4.8±0	8.9±0.6	34	4.3±0.1	0.8±0.2	6.1±0	1.2±0.1
10	5.7±0.1	5.4±0.6	20	1.5±0.2	0.3±0	10.3±0.3	0.7±0
11	5.4±0.1	5.8±0.3	20	2.3±0.4	0.5±0	5.9±0.8	0.9±0.4
12	5.9±0.1	5.4±0.2	22	2.2±0.1	0.2±0.1	12.2±0.6	0.8±0
13	5.3±0.1	7.2±0	29	0.9±0.1	0.6±0.1	8.9±0.1	0.5±0.1
14	5.6±0.2	5.9±0.1	26	1.1±0.1	0.4±0.2	12.6±0.1	0.5±0.1

Exchangeable cations and CEC are expressed as meq/100g soil.

4.3 CATION EXCHANGE CAPACITY

Cation exchange capacity (CEC) and total carbon levels are shown in Table 4.3. Soil CEC ranged from 20 to 32 me/100g, with sites 11 and 12 having the lowest values (20 me/100g),

and sites 8, 9 and 13 having higher values (32, 34 and 29 me/100g respectively).

This range of CEC values is typical of central yellow-brown earth and yellow-grey earth soils (New Zealand Soil Bureau, 1968), showing a moderate ability to retain cations in the surface soil.

4.4 TOTAL ELEMENT CONTENT OF SOILS

4.4.1 Total Soil Carbon (C)

Soil carbon levels ranged from 5.3 to 8.9% C, while most sites ranged from 5.5 to 6.5 %C (Table 4.3). These values lay in the range expected for hill country soils in pasture (McLaren and Cameron, 1990), and agree with values noted by other workers (Haynes and Williams, 1992). Sites 9 and 13 had higher C contents (8.9% and 7.2% respectively) than other locations, which may be due to C accumulation from pasture senescence i.e. the slow decomposition of organic matter due to an N, P or S deficiency, providing "poor quality" substrates for soil organism growth.

4.4.2 Total Soil Phosphorus (P)

Results of total P, S and N soil analyses are shown in Table 4.4.

Total phosphorus content varied significantly across all sites, ranging from 430 to 1460 $\mu\text{gP/g}$ soil (Figure 4.5). Those sites with relatively high total P content (above 800 $\mu\text{gP/g}$) included sites 1, 2, 8, 10, 13 and 14. At the low end of the spectrum, sites 4 and 11 had total P levels below 500 $\mu\text{gP/g}$. Other sites ranged from 500 to 800 $\mu\text{g/g}$ soil.

The key factor influencing total soil P levels appeared to be fertiliser history. Sites which had very little or no past fertiliser additions (sites 4, 11, 12) contained low total P when compared with the high total P levels of sites receiving large amounts of fertiliser (sites 1, 8 and 10 respectively). This would suggest that long-term application of P based fertiliser (superphosphate) has resulted in the accumulation of phosphate in the 0 - 7.5 cm topsoil horizon. This is supported by the findings of other workers (Jackman, 1954a; Lambert *et al.*, 1988; Perrott, 1989; Perrott and Mansell, 1989; Nguyen *et al.*, 1989; Perrott *et al.* 1990).

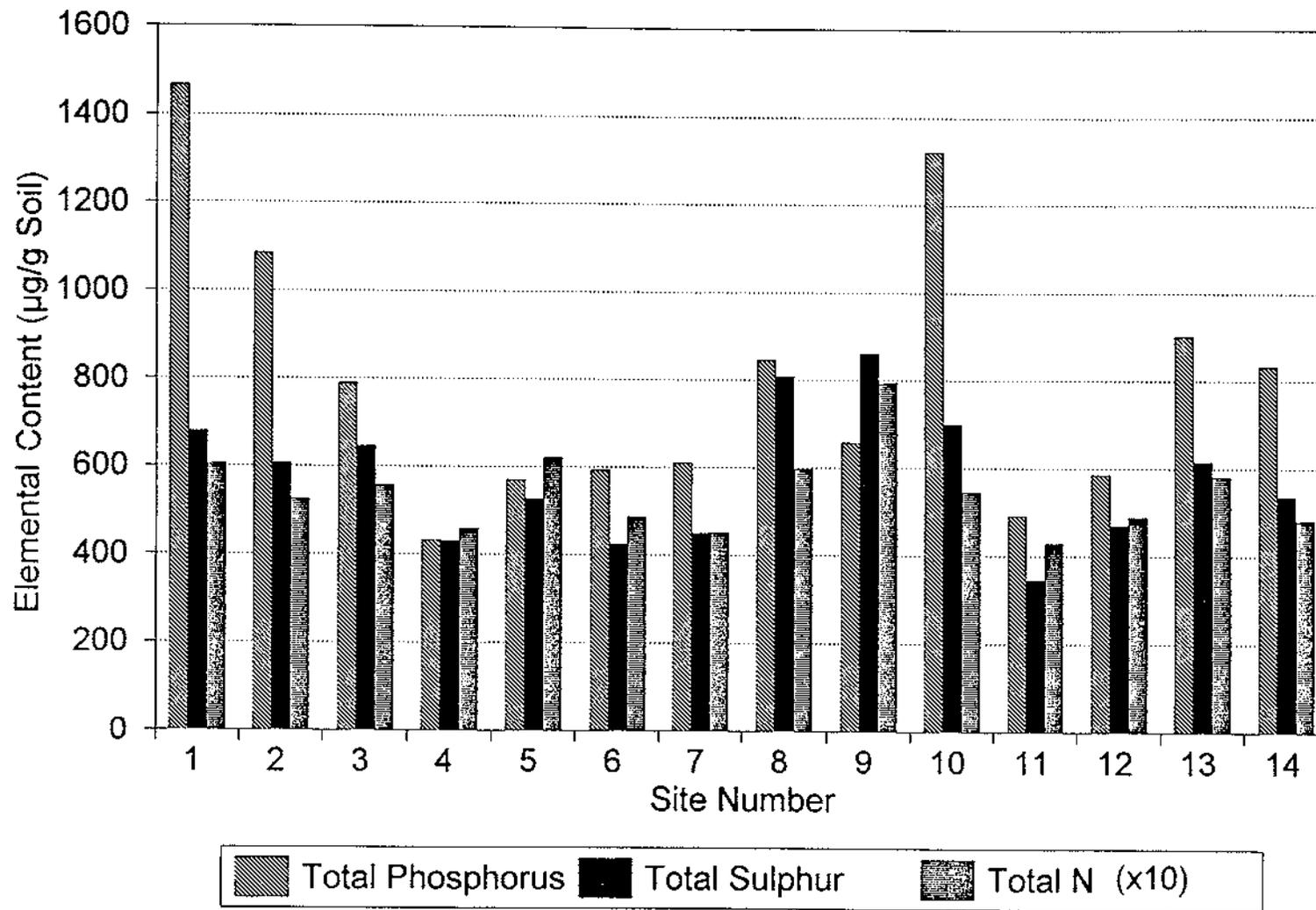


Figure 4.5

Total soil P, S and N content for the 0 - 7.5 cm depth at all sites

Soil parent material may also have influenced the total P content. Those sites with soils derived from limestone would be expected to show higher levels of

Table 4.4 Total Soil Phosphorus (P), Nitrogen (N) and Sulphur (S) Content ($\mu\text{g/g}$)

Site No	Total P		Total N		Total S	
	0 - 7.5	7.5 - 15	0 - 7.5	7.5 - 15	0 - 7.5	7.5 - 15
1	1466 \pm 84	1133	6057 \pm 102	3727	679 \pm 38	470
2	1084 \pm 93	880	5235 \pm 203	3598	607 \pm 27	453
3	790 \pm 5	609	5555 \pm 112	4027	646 \pm 90	430
4	433 \pm 8	386	4591 \pm 28	3687	430 \pm 69	312
5	571 \pm 5	398	6204 \pm 90	3834	526	332
6	594 \pm 42	492	4866 \pm 176	3630	424 \pm 37	353
7	610 \pm 54	572	4520 \pm 113	4600	451 \pm 21	259
8	846 \pm 54	548	5959 \pm 144	4237	808 \pm 61	401
9	658 \pm 83		7948 \pm 575		860 \pm 125	
10	1321 \pm 118	1089	5449 \pm 326	4102	701 \pm 63	399
11	493 \pm 29	390	4281 \pm 148	2800	345 \pm 50	466
12	586 \pm 5	474	4889 \pm 153	3590	469 \pm 63	359
13	902 \pm 8	700	5810 \pm 90	4501	615 \pm 42	403
14	834 \pm 36	673	4818 \pm 32	3442	536 \pm 79	291

Note : all values are $\mu\text{g/g}$ soil for the 0 - 7.5cm or 7.5 - 15cm soil depths.

native P (Eden and Parfitt, 1992), which may have influenced the high total P levels of Mauriceville sites 1, 2 and 3, and Gladstone site 10. It is likely, however, that fertiliser history was the overriding factor. In addition, most of the Whareama sites (sites 5-9) showed medium to low total P levels compared with other sites, suggesting that native total P levels were not high. This does not agree with the findings of Eden and Parfit (1992), who found high total P levels in soils formed on similar parent materials (mudstone) to those found at sites 5-9.

4.4.3 Total Soil Sulphur (S)

Across sites, total soil S varied less than total P (Figure 4.5). Values ranged from 345 (site 11) to 860 $\mu\text{gS/g}$ (site 9), with many sites containing 500-600 $\mu\text{gS/g}$. Sites 4, 6, 7 and 11 had the lowest total S levels (around 400-470 $\mu\text{gS/g}$), while sites 8 and 9 contained twice this level of S.

As with total P, total S content appeared to be influenced by fertiliser history. Sites with regular or high past fertiliser applications, sites 1, 2, 3, 8 and 10, all had higher total S levels compared with the other sites, with the reverse being true for the low fertility sites 4 and 11. This is in part due to the accumulation of organic soil S from fertiliser additions, as reported by previous workers (Nguyen and Goh, 1990; Lambert *et al.* 1988; Haynes and Williams, 1992). However, site 9, which had received little fertiliser in recent years, had a high total S value of 860 $\mu\text{gS/g}$. It is possible that this site has accumulated S_o primarily from dung and low fertility plant litter, as the total carbon level (8.9%) at this site is high when compared to other sites in this study.

In addition, climate may have influenced soil S accumulation. For example, when comparing sites with good fertiliser history, it appears that those sites in higher rainfall areas (sites 1, 2, 3, 13 and 14) had accumulated less S than comparative sites in drier areas (sites 8 and 10). This may in part be explained by the mobile nature of S in soil, and its subsequent susceptibility to leaching loss (Nguyen and Goh, 1990; Lambert *et al.*, 1988; Sakadevan *et al.*, 1993b) in areas of high rainfall.

4.4.4 Total Soil Nitrogen (N)

Total soil N values ranged from 4300 to 8000 $\mu\text{gN/g}$ (Figure 4.5). Sites 1, 2, 3, 5, 8, 9, 10 and 13 contained high N levels (above 5200 $\mu\text{gN/g}$), while in comparison sites 4, 7 and 11 had much lower levels (below 4600 $\mu\text{gN/g}$). Other sites ranged from 4600-5200 $\mu\text{gN/g}$.

Total nitrogen levels followed a pattern very similar to that seen for total sulphur. A number of sites with good fertiliser histories (sites 1, 2, 3, 8, 10 and 13) also had high total N

contents, while some sites with low fertiliser additions (sites 4 and 11) had low total N levels. Site 9, considered to be a low fertility site, contained the highest level of soil N. Like total sulphur, this may be related to the high total carbon levels at this site, as the majority of soil N is present in soil organic matter (McLaren and Cameron, 1990).

4.5 PHOSPHATE FRACTIONATION

Results of the soil phosphate fractionation are presented in Table 4.5, and Figure 4.6.

Sodium hydroxide extractable P_i was the major P fraction at all sites. The quantity of P extracted in this fraction varied from 200 to 700 $\mu\text{gP/g}$. Sites 1, 2, 3, 8, 10, 13 and 14, which have extensive fertiliser histories, all had high levels of NaOH extractable P_i when compared to sites of low fertiliser input. This suggests that the soil P_i fraction has increased markedly where fertiliser P has been applied, a finding supported by other workers (Lambert *et al.*, 1988; Perrott and Mansell, 1989; Perrott 1989; Nguyen *et al.*, 1989; Perrott *et al.*, 1990).

Organic P, extracted by NaOH, was a smaller P fraction and less variable than NaOH P_i . NaOH P_o values ranged from 170 to 420 $\mu\text{gP/g}$. At most sites NaOH P_o ranged from 200 to 300 $\mu\text{gP/g}$, with no significant difference between fertilised and unfertilised sites. Similar observations were made by Jackman (1954a), Perrott and Mansell (1989) and Perrott *et al.* (1990).

Acid-extractable P (H_2SO_4) varied considerably across sites, ranging from 22 to 260 $\mu\text{gP/g}$. This P fraction appeared to reflect fertiliser history, where high levels of H_2SO_4 extractable P indicated high fertiliser inputs. This was apparent at high fertility sites 1, 2, 8, 10, 13 and 14, where H_2SO_4 levels were markedly higher than other sites.

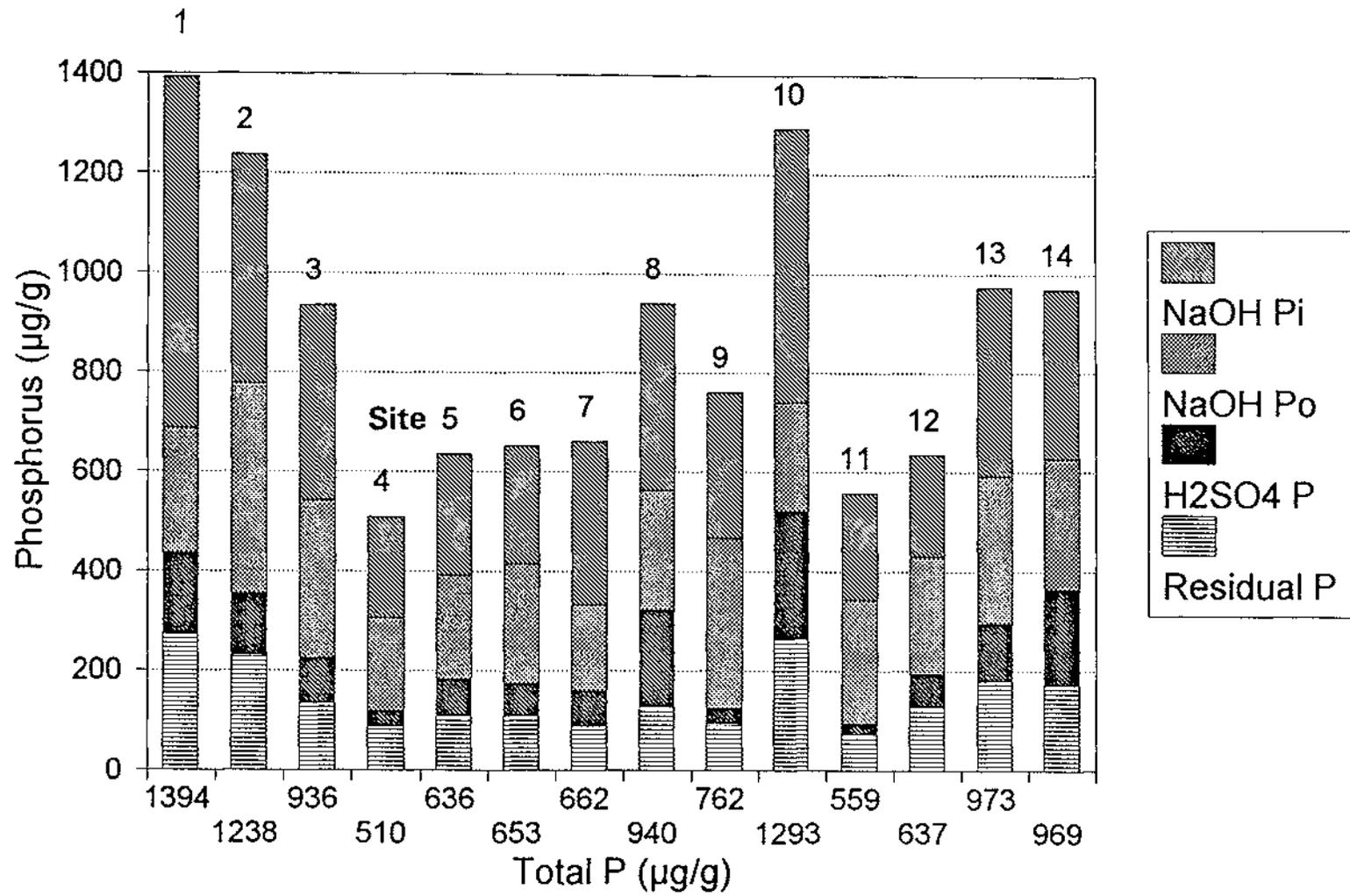


Figure 4.6

Fractionation of total soil phosphate components for the 0 - 7.5 cm depth at all sites

Table 4.5 Sequential Fractionation of Soil Phosphate

Site No	NaOH P _i	NaOH P _o	H ₂ SO ₄ P	Residual P	Total P
1	707±52	252±0	162±1	274±2	1394±51
2	461±42	425±82	123±12	230±13	1238±15
3	393±12	319±72	90±3	134±4	936±67
4	205±9	186±3	30±3	89±5	510±3
5	245±13	209±4	73±4	110±0	636±5
6	238±32	240±4	64±8	110±5	653±49
7	330±33	172±9	72±16	88±10	662±49
8	377±19	242±28	192±15	130±6	940±68
9	295±6	341±67	31±5	94±6	762±84
10	553±83	218±182	257±18	265±6	1293±289
11	217±9	248±26	22±3	73±7	559±45
12	207±1	236±19	65±5	129±6	637±21
13	381±6	298±6	116±3	179±5	973±9
14	342±12	263±24	193±21	172±7	969±64

All values are expressed as $\mu\text{gP/g}$ soil.

The residual P fraction ranged from 70 to 270 $\mu\text{gP/g}$. Although a number of high fertility sites had higher residual P levels than other sites, the relationship between residual P and fertiliser history is unclear.

Overall, sites 1, 2, 3, 8, 10, 13 and 14 showed high total P content, sites 4, 11 and 12 had low total P, while other sites had intermediate total P levels. This would suggest that total P is a useful indicator of fertiliser history and soil P fertility status at these sites.

It should also be noted that on a number of occasions the total P fractionation extracted more or less P than the Kjeldahl total P digest. This was attributed to the documented failure of the Kjeldahl method to digest 100% of soil P (McKenzie and Wallace, 1954), and also in part to the margin of error which is associated with summing the extracted P values in the soil P fractionation procedure to calculate total P.

4.6 DISCUSSION

It has been established that in order to maintain legume based pastures, native soil P levels must be raised and maintained at an elevated level (During 1984a and e; Langer, 1990; Ball and Tillman, 1994). Given this fertiliser strategy for pastures, one would expect levels of soil N to increase with increasing P.

4.6.1 The Relationship Between Total Soil P and Total Soil N

A regression analysis was carried out to determine the relationship between total soil N and total soil P (Figure 4.7a). A poor correlation ($R^2=0.06$) was found between soil total P and total N contents across all sites. This means that only 6% of the variation in the N data was explained by the variation in total P. However, sites with good fertiliser history (e.g. sites 1, 2, 8 and 10) tended to have both higher total N and total P levels than those sites with poor fertiliser history, such as sites 4, 11 and 12. Site 9, a suspected stock camp area, had a very high soil N level, which may be explained by the higher C content (8.9%) at this site, and the associated accumulation of N and S.

If we assume that the only primary source of soil nitrogen is pasture legumes, and that nitrogen availability is the key factor limiting pasture production, then efficiency of superphosphate applications would be dependent on the units of N provided by legumes versus the units of P and S applied. An important question is, how does this level of efficiency vary across sites of varying fertiliser history and soil type? If it is assumed that the increase in P in Wairarapa soils is mainly due to fertiliser P impact, then the slope of the regression in Figure 4.7a represents the gain in soil N due to P inputs. The limitations of these assumptions are explained below.

Although the relationship between total P and total N is poor, the slope of the line indicates that soil N content increases by 0.763 units (e.g. 7.6 ppm) of total N for every 1 unit (e.g. 10 ppm) increase in total P. Therefore to increase the 0 - 7.5 cm soil horizon by 7.6 ppm total N (equivalent to 10 ppm total P), you would require 71 kg superphosphate per ha (6.38 kgP/ha). These values are obtained using an average topsoil bulk density of 0.85, which is

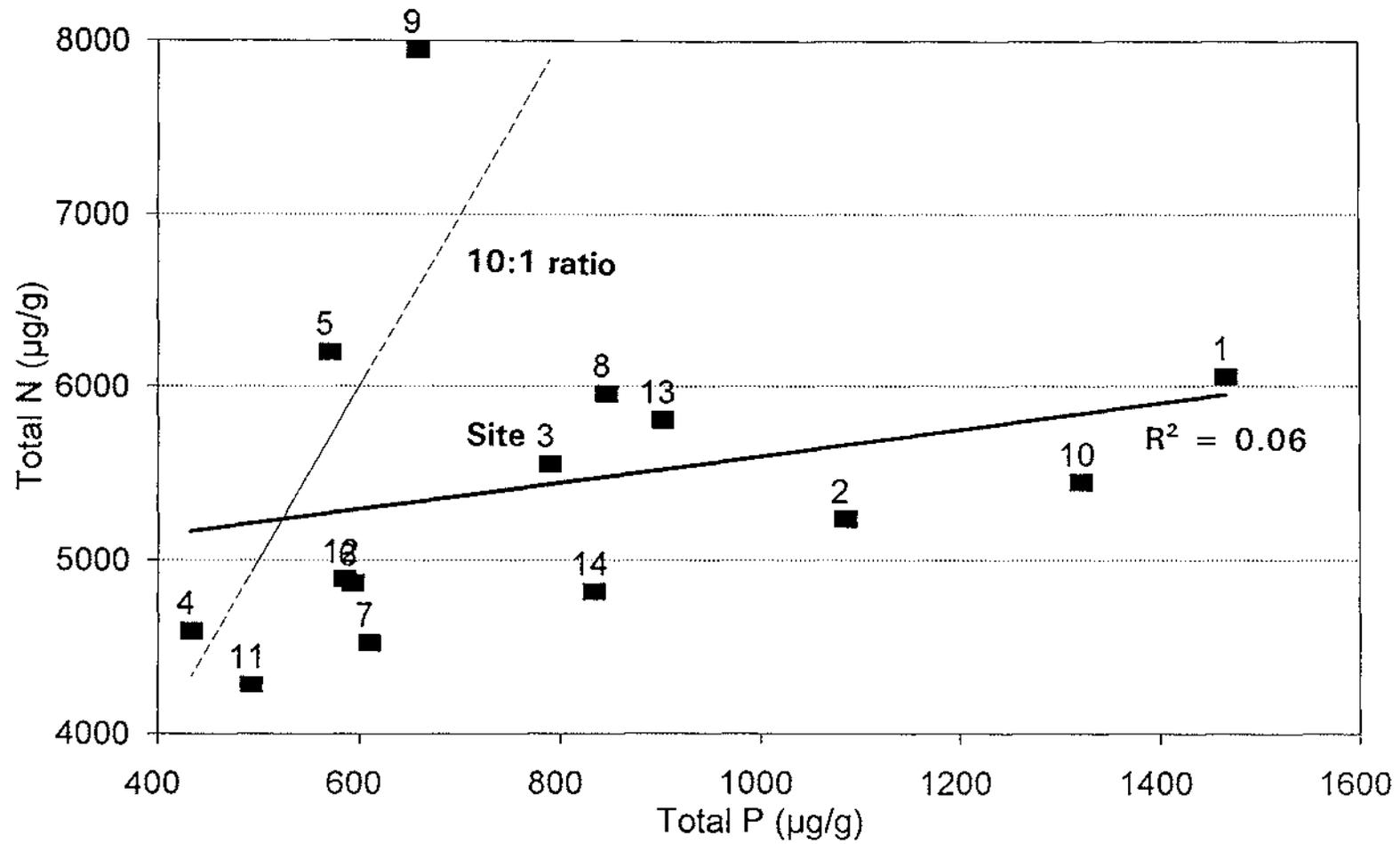


Figure 4.7a

The relationship between total soil N and total soil P contents for the 0 - 7.5 cm depth at all sites

a mean pb value across all sites.

Assuming that mineralisable N is 6% of total soil N (mean value measured across all sites), then every 71 kg of superphosphate /ha would produce 0.29 kg/ha of mineralisable N from legumes, or the equivalent of 0.64 kg of urea. Since P fertiliser is used as a tool to increase N fixation and the N content of soils, the data suggests that this process is particularly inefficient at these Wairarapa sites. A common soil total N:P ratio is 10:1, which is similar to that seen at the low fertility sites. However, the high fertility sites have a much narrower N:P ratio (e.g. 4:1), suggesting that P is accumulating from fertiliser much quicker than N is accumulating from biological fixation.

There are some limitations in using the increase in soil total P as an index of fertiliser P inputs, and likewise increases in total soil N as an index of N inputs. The most obvious factor is the P content of soil parent materials, which of course does not result from the accumulation of fertiliser residues, and is known to influence native soil N levels (Walker and Adams, 1958). Native P levels in these soils are unknown, but a fair estimate can be made using these soil analyses. For example site 4, which has received very little if any fertiliser since being developed for pastoral grazing, recorded a total soil P level of 430 ppm in the 0 - 7.5 cm horizon and 380 ppm in the 7.5 - 15 cm horizon. This would suggest that soil parent materials contained between 300 and 500 ppm P. Similar total soil P levels were observed at low fertility sites 5 (Whareama) and 11 (Gladstone). Therefore it appears that regardless of differing parent material, native total P levels at these sites are low, as observed at the low fertility sites within each climate zone. Consequently, major increases in total soil P are highly likely to be the result of fertiliser addition or stock camping behaviour.

In theory, the total P content of a pastoral topsoil would equal native P plus fertiliser P additions, minus any P losses from stock transfer. Therefore, an estimate of present total soil P can be achieved by summing an estimate of native soil P (unfertilised site) and the estimated fertiliser P inputs and subtracting an estimate of P lost.

A simple calculation of this nature was carried out to compare total soil P levels at sites 6 and 8 (Whareama), the only two sites where we had documented fertiliser history for at least 30

years (see Appendix 1). The soils at these sites are similar, but the written fertiliser history for each differs. For example, since 1960 approximately 580 kgP/ha has been applied as fertiliser to site 6, while site 8 has received 460 kgP/ha over the same period. Stock transfer loss was estimated to be 6 kgP/ha at site 6, and 4 kg/ha/yr at site 8, based on the values of Saggar *et al.* (1990) and During (1984e). A higher stock transfer loss was estimated for site 6, as it is a much steeper site than site 8, and so would be expected to have greater P losses.

Assuming that the native P levels were around 400 ppm (0-7.5 cm depth) at both sites, and that little fertiliser was applied pre-1960, then site 6 would be expected to have accumulated about 100 ppm P more than site 8 in the topsoil horizon, resulting in a total P content of 1000 ppmP for site 6 and 900 ppmP for site 8 (assuming pb of 0.85). However, this estimate does not agree with soil total P analyses, which showed that site 8 did indeed have a total P content of 850-900 ppmP (0-7.5cm), but site 6 had 600 ppmP in the same horizon. Therefore using fertiliser history, this calculation over-estimated total P at site 6 by 400 ppmP.

This calculation has obvious limitations, but does show the real difficulty in reconciling soil analyses with documented fertiliser history. We have shown that these sites are not camp sites, therefore nutrient transfer would be expected to some extent. However, nutrient loss/transfer is often difficult to quantify, and when combined with the inaccuracies of fertiliser history (i.e. no knowledge of developmental and early fertiliser applications), it seems that soil analyses may in certain circumstances provide a better estimate of nutrient accumulation in soil due to fertiliser application.

4.6.2 The Relationship Between Mineralisable N and Total Soil P

Following a similar argument to that proposed in the previous section, a regression analysis was made to determine the relationship between mineralisable soil N and total soil P (Figure 4.9). A higher correlation ($R^2=0.57$) existed when compared to that of total N against total P. It was also apparent that those sites with good fertiliser history tended to have higher levels of mineralisable N, while the reverse was true for low fertility sites. The slope of this line indicated that for every 1 kg/ha increase in total P, mineralisable N increased by 0.214 kgN/ha. Using the same calculation as used for total P against total N, an application rate of

71 kg superphosphate /ha (6.38 kgP/ha) would increase mineralisable N by 1.37 kgN/ha, equivalent to 3 kg urea/ha. Although the value of 1.37 kgN/ha is over four times greater (and probably more reliable) than that calculated for total P against total N, it still shows a large inefficiency of units of P applied in order to obtain units of N sourced from legumes. These calculations suggest that either N fixation rates are low or that annual losses of fixed N from pastures are large in these soils (i.e. N inputs are mostly equalled by N losses).

However, more research is required in order to explain these results. It is clear that many sites are accumulating soil N at low rates compared to the rate of P accumulation from fertiliser inputs. The reasons for this could be : the pasture legumes are grossly inefficient at fixing N, only supplying small quantities of mineral soil N; leaching losses high; nutrient transfer losses are large.

4.6.3 The Relationship Between Total Soil S and Total Soil P

A further regression analysis was made in order to determine the relationship between soil total S and total P (Figure 4.7b). A weak linear relationship was found between these P and S levels ($R^2=0.29$). Once again, those sites with a consistent fertiliser history had higher levels of both total S and P, while unfertilised sites were low in P and S. Sites 8 and 9 contained high levels of S when compared to other sites, which probably prevented a close linear fit across sites.

A common ratio of total P to total S in soil is 1:1. However, only site 8 had such a ratio, with most sites containing far more total P than total S. Also, the slope of the line indicates that there is a gain of only 2.7 ppmS/ha for every 10ppmP/ha increase. Given that the traditional fertiliser is superphosphate, with a P:S ratio of 1:1.22, these results indicate that over 55% of the S applied has been lost probably by leaching from the pasture soil relative to P. This level of leaching is of the same order (40 - 70%) of applied superphosphate S that Sagger *et al.* (1990) measured on sheep pastures on YGE/YBE intergrades.

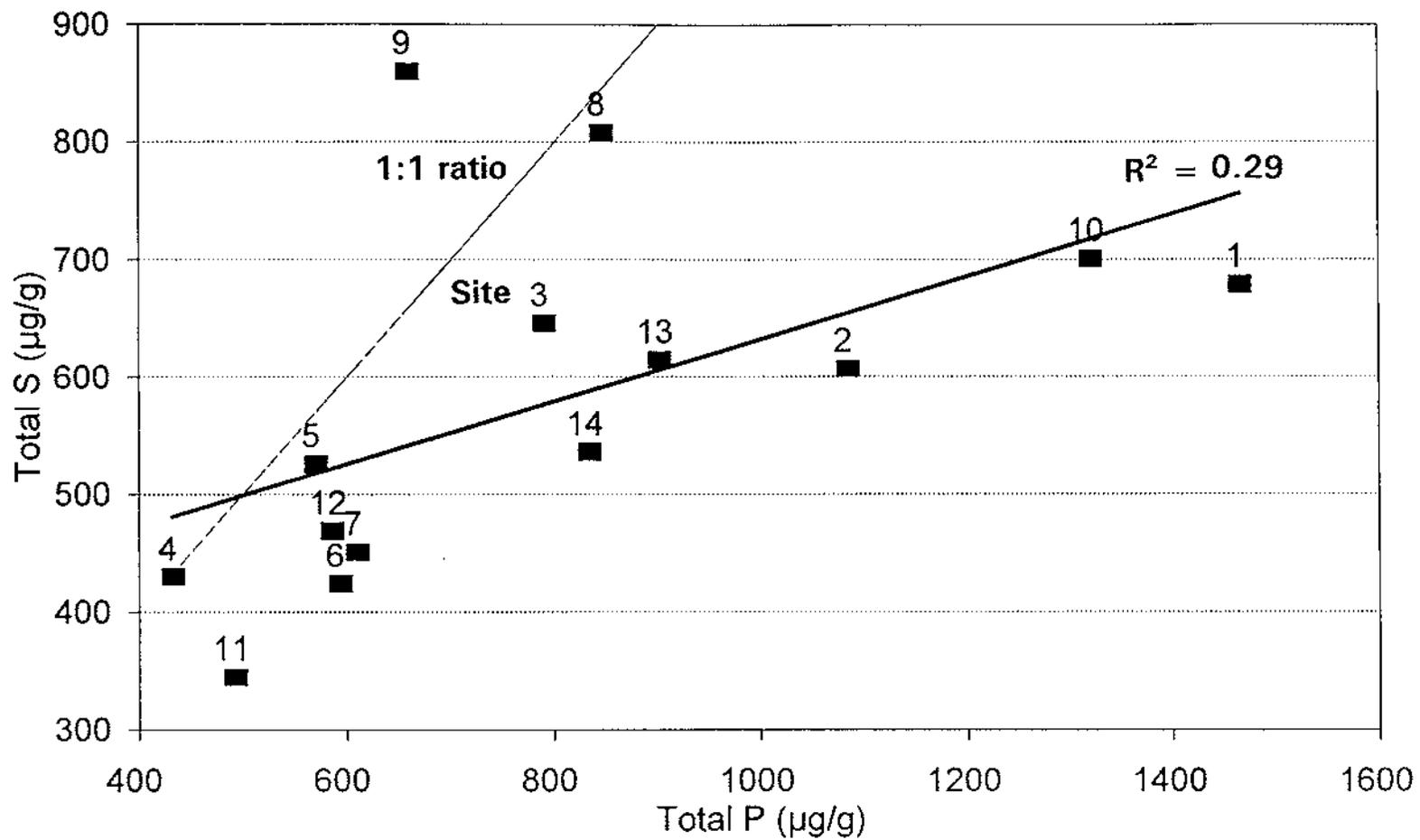


Figure 4.7b

The relationship between total soil S and total soil P contents for the 0 - 7.5 cm depth at all sites

Phosphate applied as fertiliser can be adsorbed strongly by soil minerals, and incorporated into soil organic matter. However, most S can only be retained in fertilised YGE and YBE topsoils in the organic fraction. The results from these trials indicate that lack of synthesis of organic S has prevented the accumulation of S in these soils, relative to the accumulation of P. Sulphate sorption may be expected to be higher in subsoils where more anion exchange sites are available. Lack of nitrogen may be one factor constraining plant growth and therefore the formation of organic soil S.

4.6.4 The Relationship Between Total Soil S and Total Soil N

Total soil N was found to have a good linear correlation with total S content ($R^2=0.70$, Figure 4.7 c & d). Once again, sites receiving fertiliser had higher levels of both total N and Total S, while the opposite held true for non-fertilised sites. The higher correlation probably results from both N and S being retained in soil organic matter. However, most sites do not have the 10:1 N:S ratio common in soils. The reason for this could be that in low fertility sites N-fixation is S or P limited (reflecting S deficiency), and that in high fertility sites inputs of fertiliser S do not stimulate 10:1 increases in N fixation (see Figures 4.7a and b). In general, the sites with poor fertiliser history show N:S ratios of 10:1 and greater, whereas those with a better fertiliser history show N:S ratios less than 10:1.

4.6.5 The Relationship Between Indices of Available Soil P and Total P or Individual P Fractions

As discussed in sections 4.4 and 4.5, total soil P levels appeared to be strongly related to fertiliser history. However, the extent to which increased total P levels had increased plant available P was uncertain. In order to determine the relationship between Olsen P and total P, a regression analysis was carried out (Figures 4.8a and 4.8b). A strong linear relationship ($R^2=0.76$, and 0.75) existed between Olsen P and both Kjeldahl and sequentially-extracted total P respectively. The suspected camp site (site 7), was excluded from this regression as this site had very high Olsen P in comparison to total P. In general, those sites with high Olsen P values also had high levels of total P, with the reverse being true for low fertility sites.

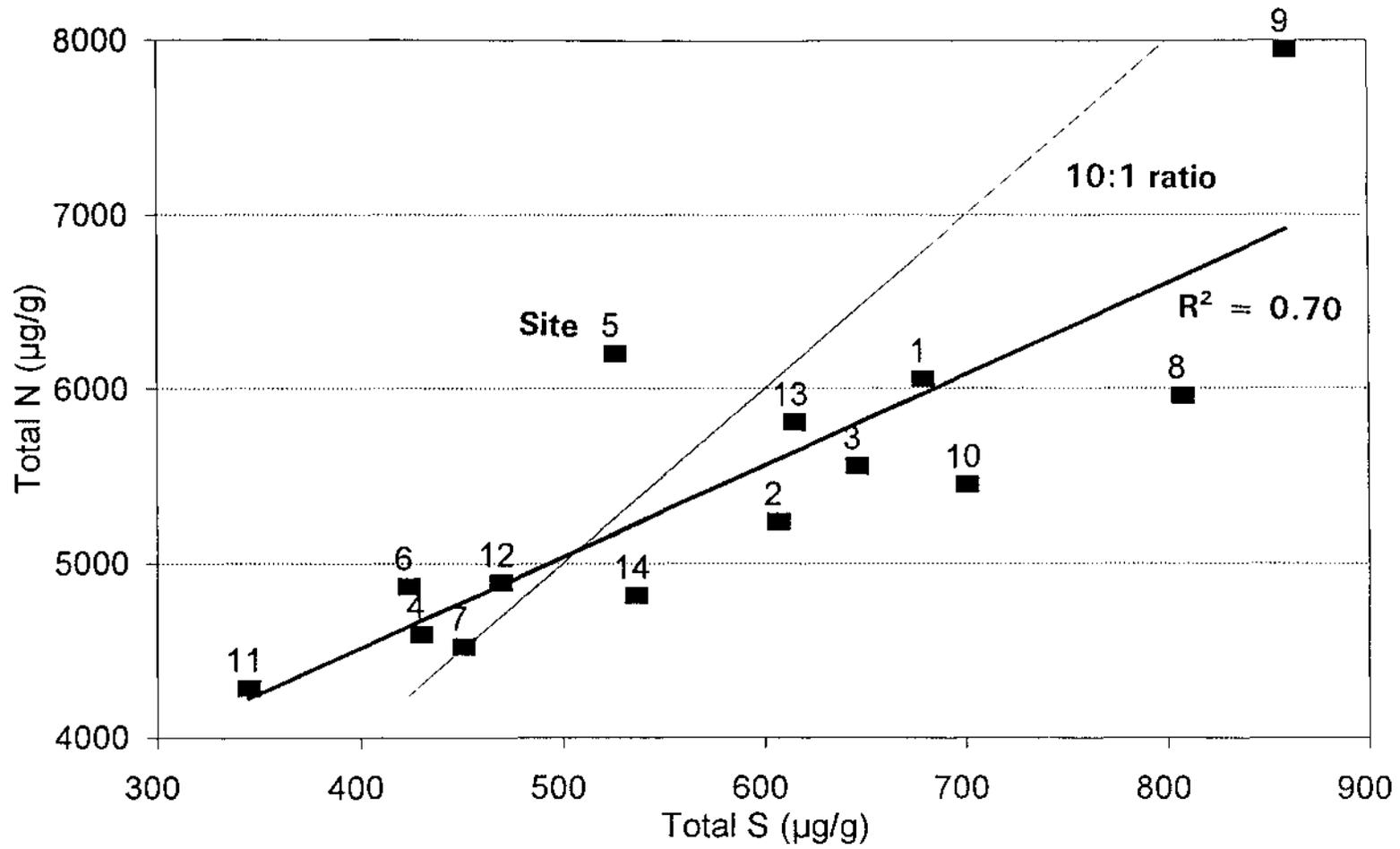


Figure 4.7c The relationship between total soil N and total soil S contents for the 0 - 7.5 cm depth at all sites

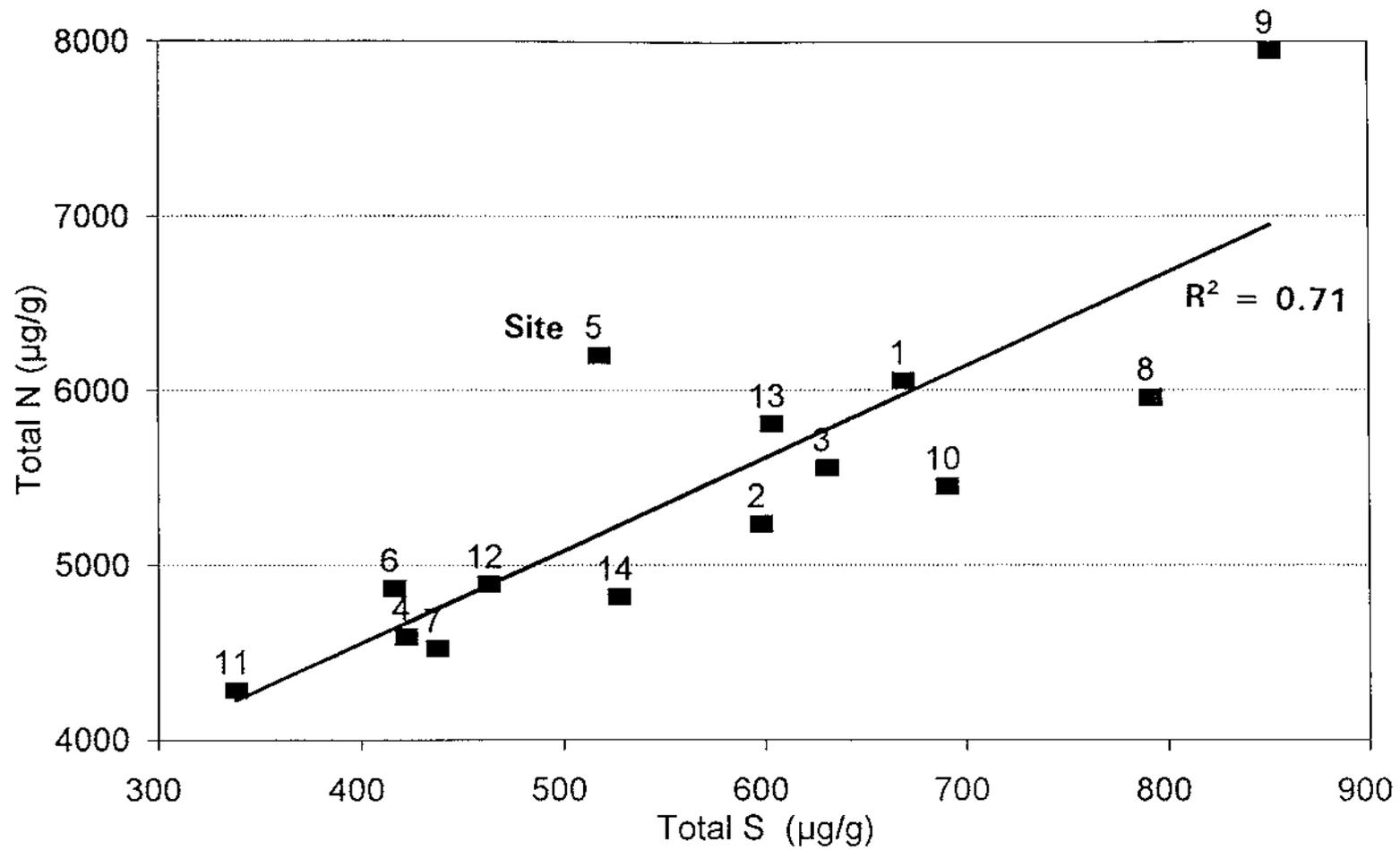


Figure 4.7d The relationship between total soil N and total soil S contents, excluding the sulphate S fraction, for the 0 - 7.5 cm depth at all sites

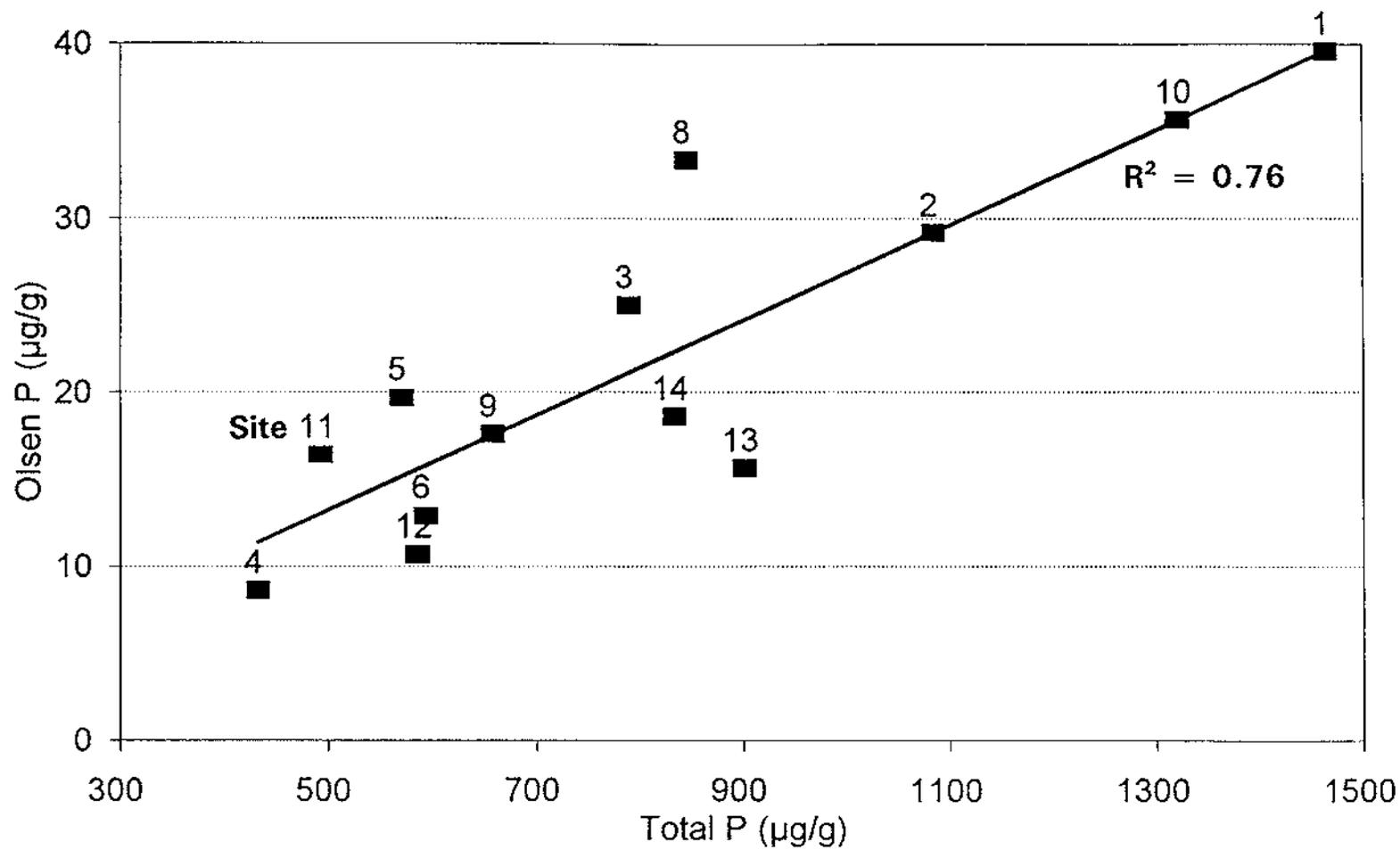


Figure 4.8a The relationship between Olsen P and total soil P (Kjeldahl digest) contents for the 0 - 7.5 cm depth at all sites

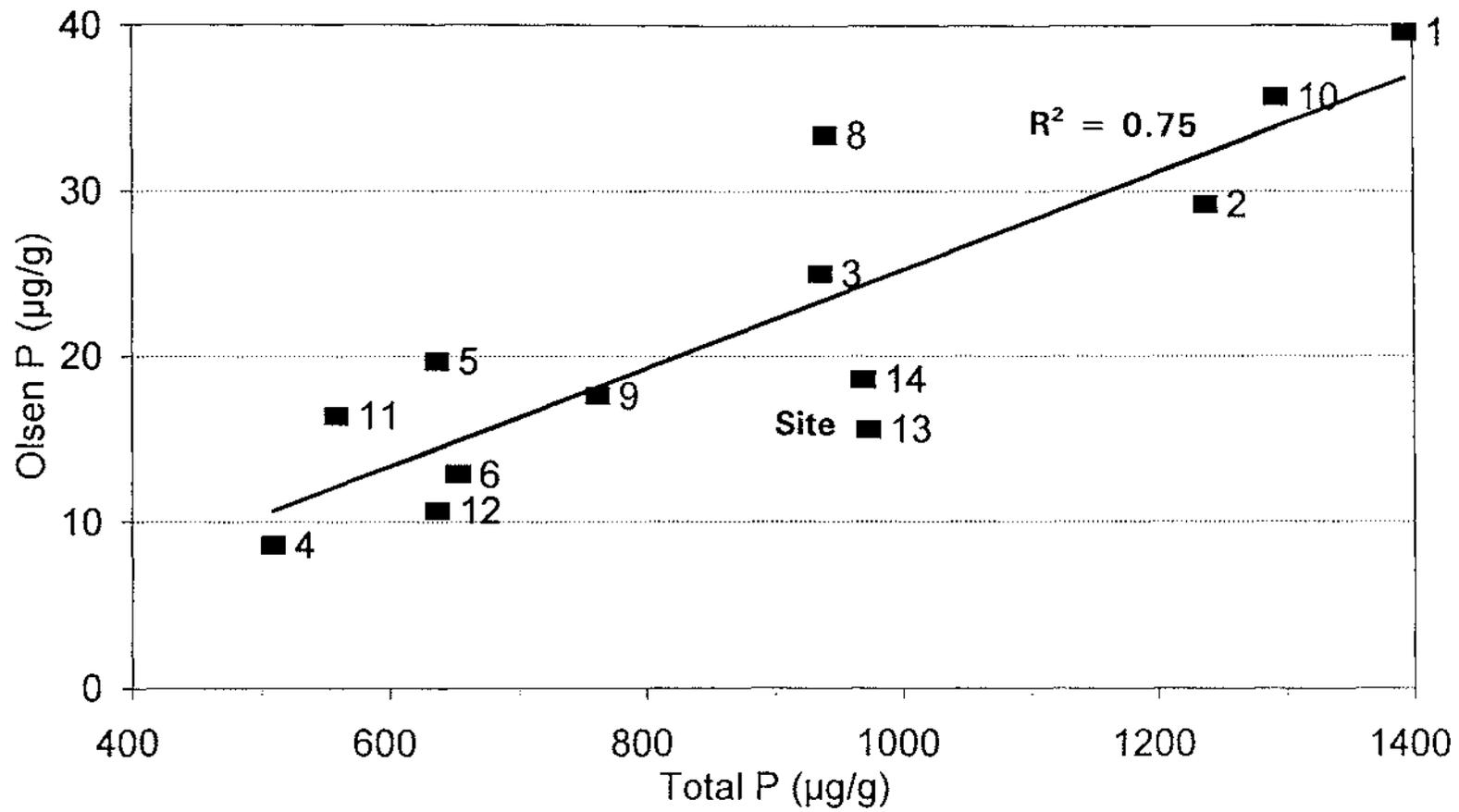


Figure 4.8b The relationship between Olsen P and total soil P (sum of sequential P extraction) contents for the 0 - 7.5 cm depth at all sites

Given the limitations explained earlier in section 4.6.1, the slope of this regression line gives a good indication of how much P must be applied as fertiliser in order to increase plant available P (Olsen P) levels. Using the mean slope of Figures 3a and 3b, an application of 100 $\mu\text{gP/g}$ soil would raise the Olsen P level by 2.9 $\mu\text{gP/g}$. This means that in order to raise the Olsen P status by 2.9 units, 708 kg/ha of superphosphate would need to be applied, or 247 kg/ha of superphosphate to raise the Olsen P by 1 unit. This calculation does not take account of stocking rate and nutrient loss/transfer, but it does give a general view of the large quantities of P fertiliser required to maintain elevated Olsen P levels in order to support legume based pastures. The efficiency of such large P fertiliser applications is questionable, given the apparent low levels of mineralisable N supplied by pasture legumes on Wairarapa hill country soils.

4.6.6 The Relationship Between Plant-Available P Extraction Methods

In order to compare the amounts of P exacted by Olsen and resin-membrane techniques, a regression analysis was carried out (Figure 4.8c). No strong linear relationship existed between Olsen P and Resin extractable P ($R^2=0.45$). The resin P test extracted more than twice as much P as the Olsen test for most soils, which agrees with the findings of Saggar *et al.* (1992b). A number of high fertility sites did show both high resin P and Olsen P levels, but the effect of fertiliser history seemed inconsistent. Because ion-exchange resins dissolve some acid-soluble P (Saggar *et al.*, 1992a), which the Olsen test would not extract, a plot and regression analysis was made of resin P minus Olsen P against H_2SO_4 extractable P (Figure 4.8e). H_2SO_4 P is a measure of acid-soluble P residues (not extracted by Olsen), but showed only a weak correlation with resin P minus Olsen P ($R^2=0.16$).

However, a relatively strong linear relationship did exist between Olsen P and NaOH extractable P_i (Figure 4.8d, $R^2=0.80$), where site 7 (camp site) was excluded. This agrees with results of Perrott *et al.* (1989). Extractable P reflected fertiliser history, where extractable soil P increased linearly with increased fertiliser inputs.

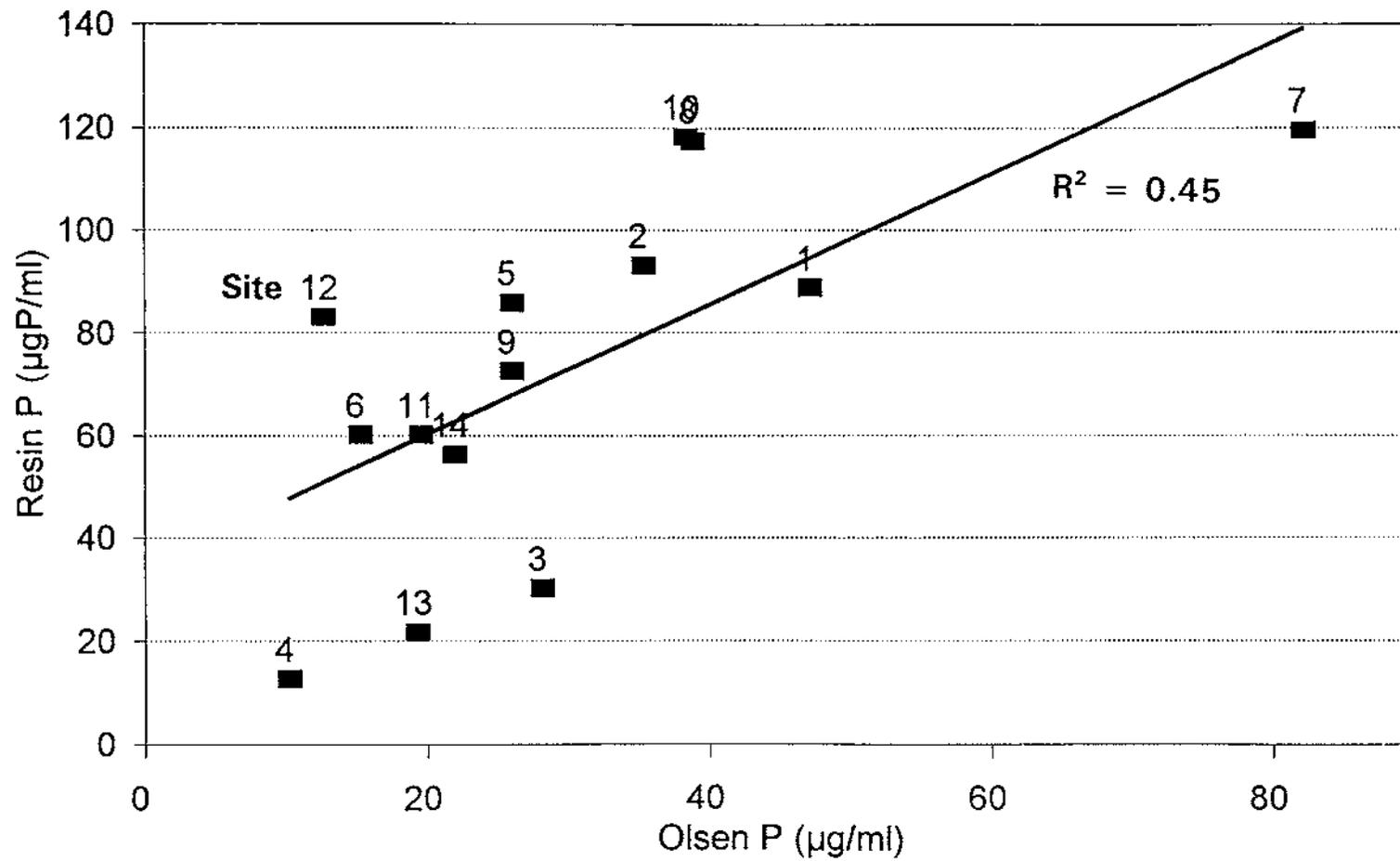


Figure 4.8c The relationship between soil resin extractable P and Olsen P contents for the 0 - 7.5 cm depth at all sites

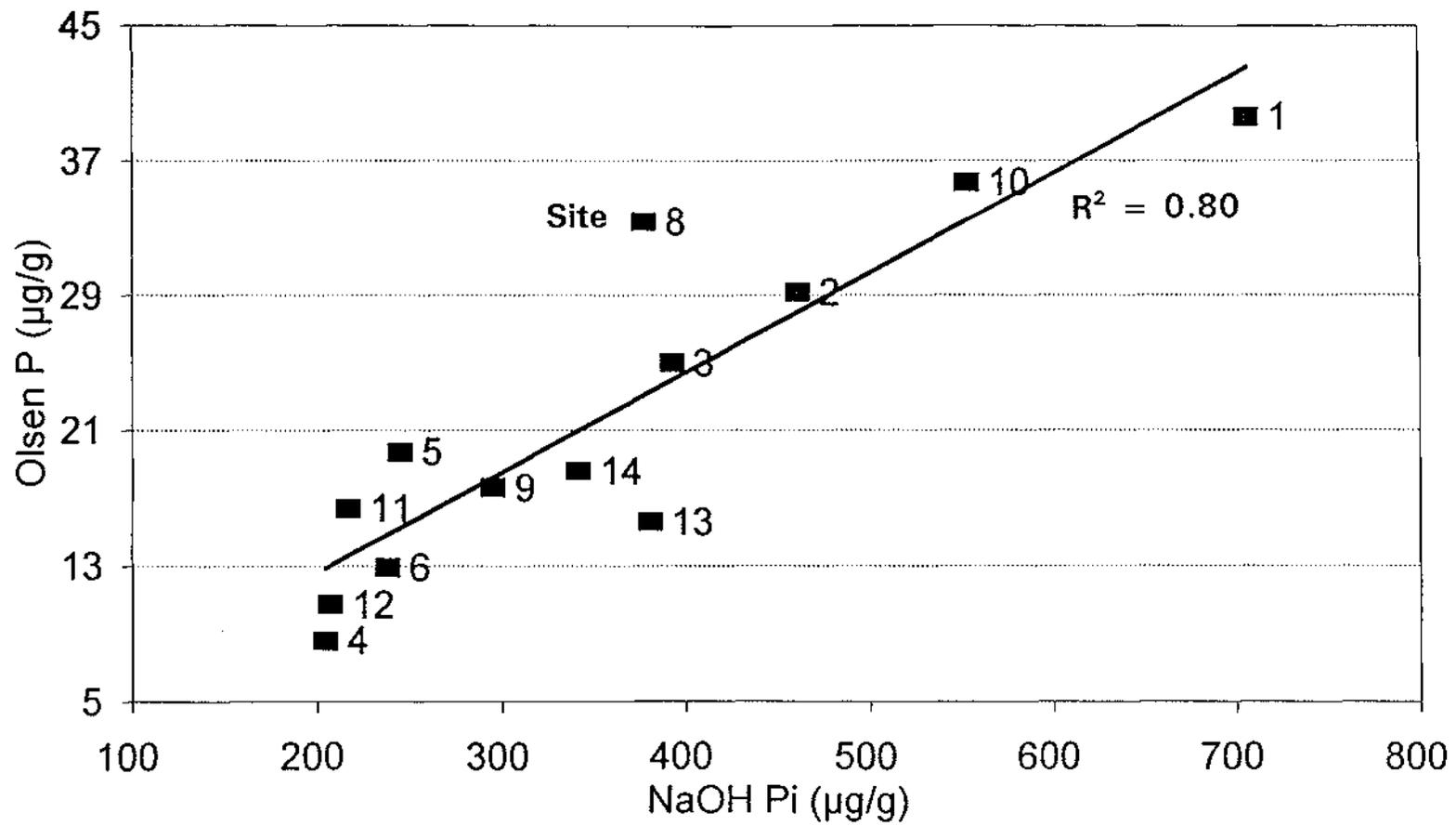


Figure 4.8d

The relationship between soil Olsen P and 0.1M NaOH extractable inorganic P (P_i) contents for the 0 - 7.5 cm soil depth at all sites

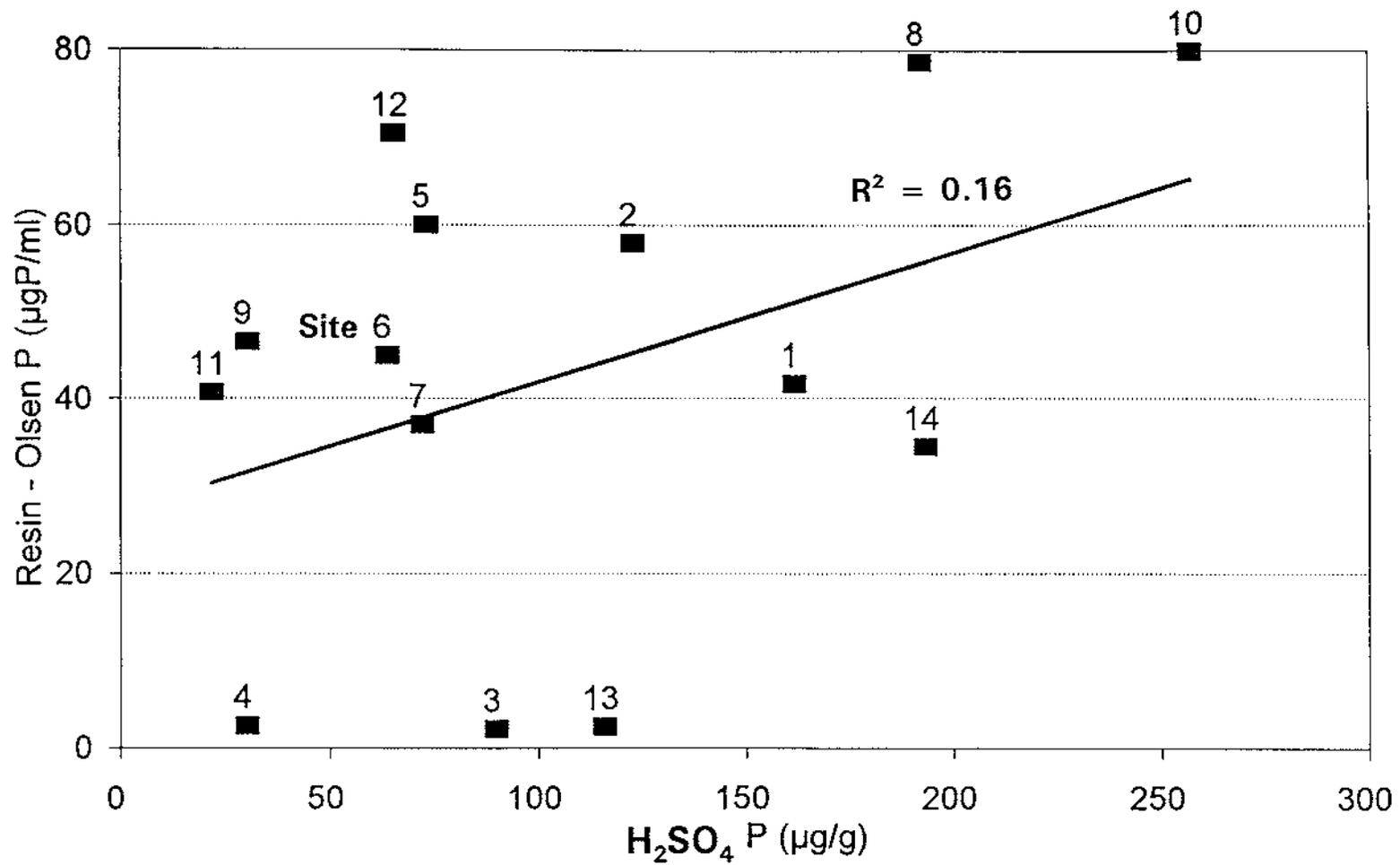


Figure 4.8e

The relationship between resin-extractable (less Olsen-extractable) P and H₂SO₄ extractable P fractions for the 0 - 7.5 cm depth at all sites

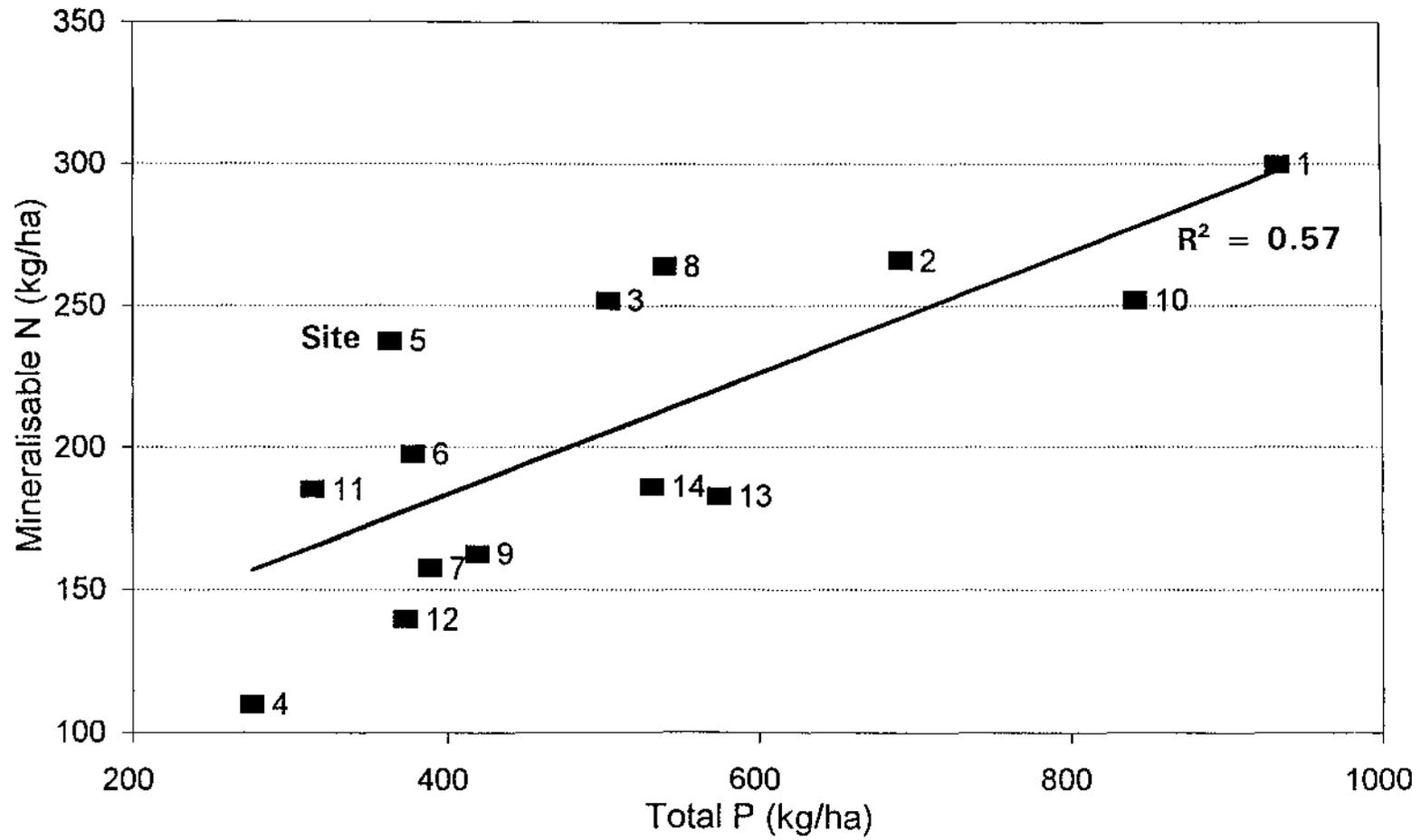


Figure 4.9 The relationship between mineralisable N and total soil P contents for the 0 - 7.5 cm depth at all sites.

4.7 CONCLUSIONS

Both plant-available and total soil nutrient analyses have confirmed that sites within each climate zone (Mauriceville, Gladstone, Whareama) have contrasting soil nutrient status.

When taking all soil nutrient indices into consideration, sites 1, 2, 8 and 10 were classified as being high fertility sites, while sites 3, 13 and 14 have similar but somewhat lower nutrient levels. Low fertility sites include sites 4, 11 and 12, while other sites fall into the intermediate fertility range. Site 7 was classified as a stock camp area.

It is apparent across all sites that P, S and N are accumulating in these soils as a direct result of fertiliser history. Consequently, sites with consistently high fertiliser inputs had higher levels of total P, S and N in the topsoil horizon when compared to those sites historically receiving little or no fertiliser. However, less total S had accumulated across sites than total P, suggesting that the mobile nature of S in soil had caused large S losses. Soil total N levels followed a very similar pattern to that seen for total S, which was explained by the majority of soil S and N being present in soil organic matter.

The fractionation of soil P showed a marked increase in the P_i fraction with increased fertiliser inputs, as reported by other workers (Perrott, 1989; Perrott *et al.*, 1990; Nguyen *et al.*, 1989). Total P levels measured by this method agreed with those obtained using the Kjeldahl method. Calculations attempting to reconcile soil total P analyses with documented fertiliser history (Appendix 1) were unsuccessful and inaccurate. Inaccuracy probably resulted from variables such as stock transfer, anomalies in fertiliser history and unknown native soil P levels. Soil analyses were thought to be a more reliable method of estimating fertility status and fertiliser history.

Using a plot of total P against total N at all sites, and also a plot of total P against mineralisable N (measured by soil incubation), a calculation was made to determine the quantity of mineralisable N produced per unit of P input. This was used as an estimate of fertiliser efficiency in the legume-based pasture system, and showed that approximately 0.3-1.4 kg mineralisable N/ha was being produced by legumes for every 6.4 kgP/ha applied as

fertiliser. It was concluded that the application of P fertiliser in order to provide N sourced from legumes was particularly inefficient in Wairarapa hill-country pasture. The limitations of this exercise were explained.

In addition, these calculations suggested that either N fixation rates are low, or the losses of fixed N are large in these soils. Further research is required to fully explain these results. It was also suggested that N fixation may be S limited at low fertility sites, and that at high fertility sites inputs of fertiliser S have not stimulated 10:1 increases in N fixation.

CHAPTER 5: SEASONAL CLIMATE AND PASTURE PRODUCTION

5.1 INTRODUCTION

This section of study examines the influence of climate and soil fertility on pasture yield, and nitrogen fixation.

5.2 SEASONAL CLIMATE

The growing season can be divided into three distinct periods; early (early August) to mid-spring (October), mid-spring to mid-summer (early January) and mid-summer to Autumn (late March). Monthly temperature and rainfall data for the three sites in different rainfall zones (Mauriceville, Gladstone and Whareama) are shown in Table 5.1, along with predicted values of soil limited (actual), evapotranspiration (A.E.T.) calculated using a water balance computer model developed by Leng, L., Hedley, M.J. and Sakadevan, K (pers. com.). In addition, historical climate data from New Zealand Meteorological Service weather stations are presented for each location, using Castle Point (Whareama), Taratahi (Gladstone) and Mangamutu (Mauriceville) weather stations. This historical data is assumed to represent "average" climatic conditions within each climate zone.

The Mangamutu weather station is some 35 km north of the Mauriceville sites, but was selected to be the weather station most likely to represent climatic conditions in Mauriceville, because it lies on the same annual rainfall isohyet (N.Z. Meteorological Service map - North Island, 1941-1970).

Spring temperatures were about average across all sites, with the exception of a warmer than average October at Whareama. Likewise, early to mid summer temperatures were average at most sites, except for a much warmer than average December at Mauriceville, and slightly warmer than average temperatures at Whareama.

Again using past weather records, Mauriceville received less than average early-spring rainfall, but then received average rainfall up until early summer, when rainfall fell below

average. Gladstone sites received a much drier than average spring, which was followed by a much wetter than average early summer. Whareama sites also had a drier than average spring, but then received more than twice the average rainfall for November, followed by a much drier than average early summer.

Table 5.1 Monthly Rainfall, Maximum/Minimum Temperature and A.E.T., October 1993 to January 1994

Month	Aug	Sept	Oct	Nov	Dec	Jan
Mauriceville						
Rainfall (mm)	61	144	120	164	81	54
A.E.T. (mm)	37	59	85	115	91	81
Temperature (oC)						
Mean Daily Max	13.0	13.3	19.9	19.1	25.4	19.8
Mean Daily Min	0.4	3.9	7.7	6.7	10.0	8.3
N.Z.M.S. Data, 13 yr Mean						
Rainfall (mm)	118	110	129	106	115	94
Temperature (oC)						
Mean Daily Max	12.6	14.3	16.2	18.1	20.4	21.7
Mean Daily Min	3.8	5.7	7.4	9.0	10.7	11.8
Gladstone						
Rainfall (mm)	45	130	40	123	99	
A.E.T. (mm)	40	62	52	96	93	
Temperature (oC)						
Mean Daily Max	9.8	11.0	17.3	17.1	22.2	
Mean Daily Min	2.4	3.9	7.4	6.1	7.4	
N.Z.M.S. Data, 13 yr Mean						
Rainfall (mm)	89	89	65	57	55	51
Temperature (oC)						
Mean Daily Max	12.5	14.5	16.9	18.8	21.0	23.1
Mean Daily Min	3.8	5.4	6.5	8.1	9.4	11.1
Whareama						
Rainfall (mm)	58	97	45	138	33	
A.E.T. (mm)	44	62	54	107	64	
Temperature (oC)						
Mean Daily Max	13.3	15.0	21.0	18.4	18.5	
Mean Daily Min	2.8	5.0	7.2	7.8	11.9	
N.Z.M.S. Data, 13 yr Mean						
Rainfall (mm)	94	69	67	56	64	61
Temperature (oC)						
Mean Daily Max	12.9	14.9	16.5	18.4	20.1	21.7
Mean Daily Min	7.5	9.1	10.0	11.4	13.3	14.4

5.3 SOIL VOLUMETRIC WATER CONTENT

The dominantly high winter rainfall and low evaporation rates, combined with low summer rainfall and high evaporation caused a marked general reduction in measured soil moisture content as the growing season progressed at all sites (Figures 5.1a - 5.1c). Within each climate zone, soil volumetric water content did not vary substantially across sites. However, there was a constant decline in soil moisture levels from spring (late August) to late summer (mid March).

At Mauriceville sites, volumetric water content was 0.7 in spring which fell to 0.47 by early January, then declined rapidly to 0.22 by late March. However, the decline in soil moisture levels from spring to late summer was much slower than at Gladstone and Whareama, and reflects the higher rainfall at Mauriceville.

Gladstone sites dried out much quicker than Mauriceville sites, falling from 0.67 in spring to 0.25 in late October, which resulted from the lower rainfall and higher evaporation at Gladstone. However, moisture levels at Gladstone sites rose to 0.45 in early December, reflecting the high November rainfall, before falling to a very low level of 0.15 in late March.

Whareama sites followed a very similar soil moisture pattern to that observed at Gladstone. Volumetric water content declined rapidly from 0.65 in late August to 0.22 in late October, then rising to 0.48 in December before falling to a consistently low level from January to March. As with the Gladstone sites, above average November rainfall, followed by low summer rainfall and high evaporation rates are responsible for these fluctuations in soil moisture levels.

Overall, Whareama sites were driest, but followed a very similar soil moisture pattern to that observed at Gladstone sites. The Mauriceville sites had the highest soil moisture levels, and did not dry out rapidly when compared to soil moisture levels at the Whareama and Gladstone sites, which is explained by higher rainfall and lower evaporation at Mauriceville.

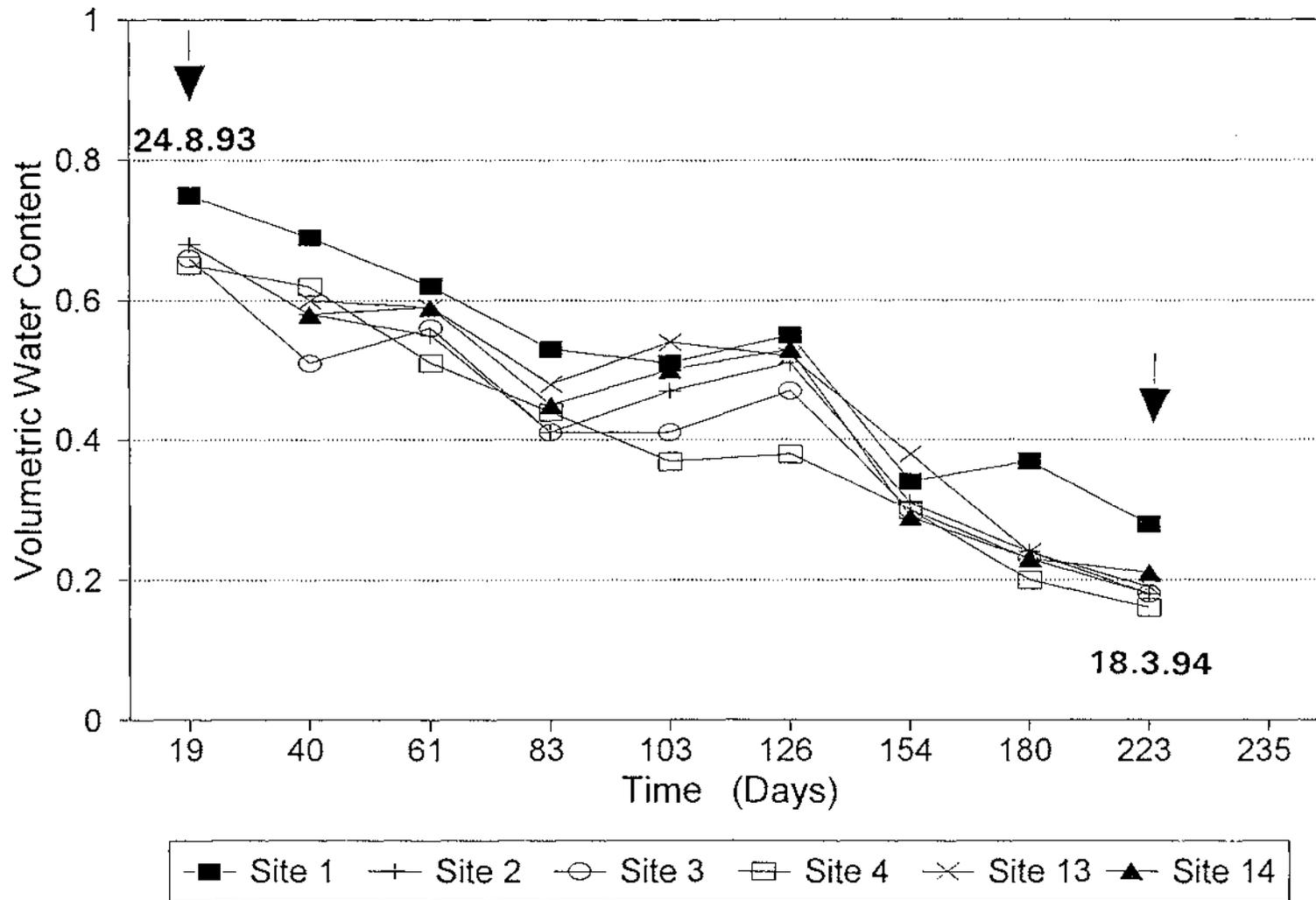


Figure 5.1a Seasonal soil volumetric water contents from 24.8.93 to 18.3.94 for the 0 - 7.5 cm depth at Mauriceville sites

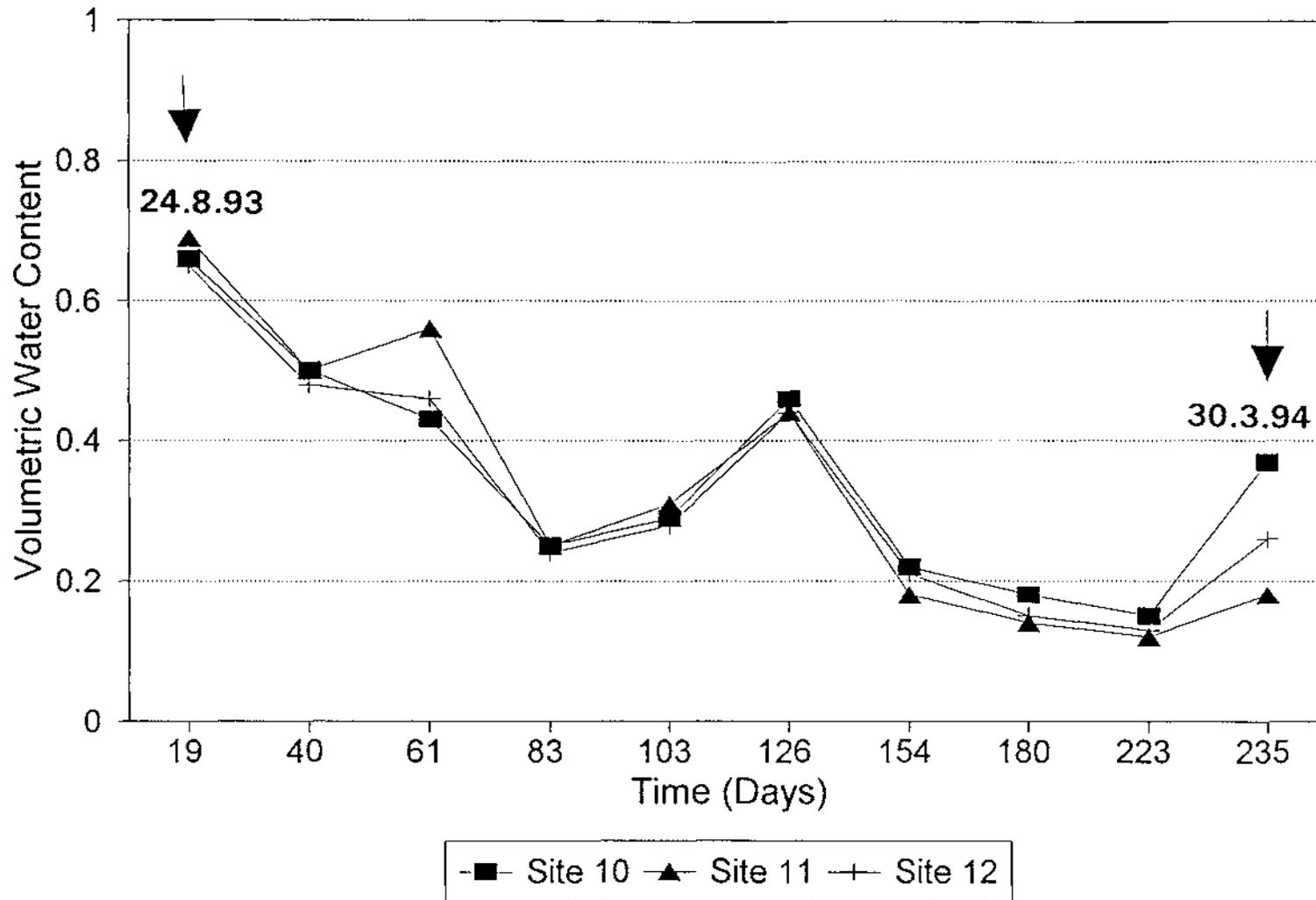


Figure 5.1b

Seasonal soil volumetric water contents from 24.8.93 to 18.3.94 for the 0 - 7.5 cm depth at Gladstone sites

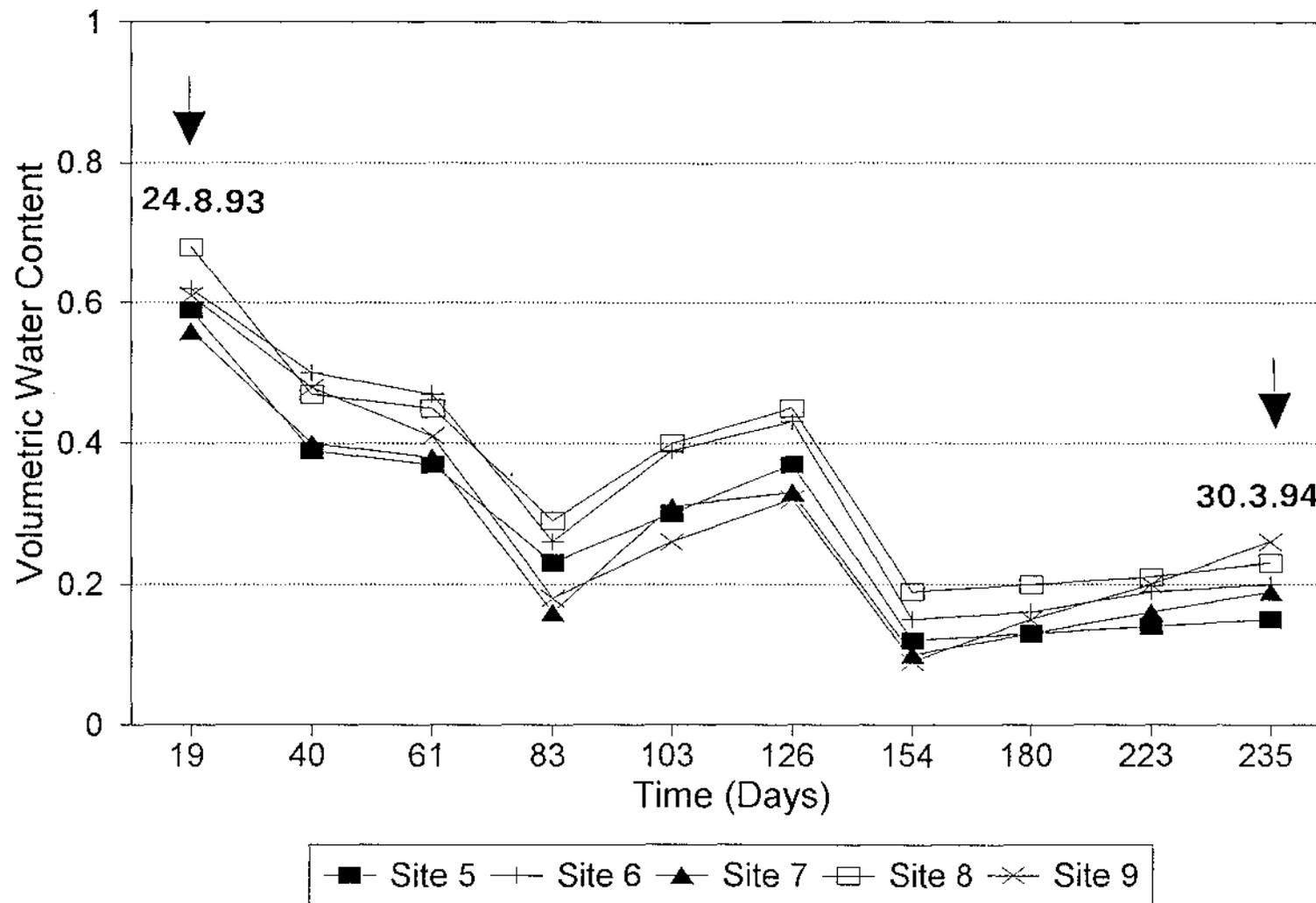


Figure 5.1c

Seasonal soil volumetric water contents from 24.8.93 to 18.3.94 for the 0 - 7.5 cm depth at Whareama sites

In general, the climate data supports the selection of the three groups of sites as areas with different rainfall regimes, but the differences between Whareama and Gladstone were small.

5.4 HERBAGE YIELD

5.4.1. Total Herbage Yield

Total herbage yields from early August 1993 to late March 1994 are shown in Figures 5.2a to 5.2c.

Total herbage yield ranged from 15.5t DM/ha at (site 1) to below 4t DM/ha (site 4) from early August 1993 to March 1994. The highest yielding sites were sites 1 (15.5t DM/ha), 2 (9.5t DM/ha), 3 (9.8t DM/ha), 13 (8.8 t DM/ha), 14, 10 (10.1t DM/ha) and 8 (8.1t DM/ha). Low yielding sites included sites 4 (3.9t DM/ha), 6 (4.8t DM/ha), 9 (5.5t DM/ha) 11 (6.4t DM/ha), and 12 (5t DM/ha). Sites 5 and 7 had intermediate yields.

Total herbage yield reflected the influence of both climate and soil fertility status. High fertility sites (1, 2, 3, 13, 14, 10 and 8) had high yields, although sites of comparable fertility e.g. site 1, site 10 and site 8 had a wide variation in yield. This in part is attributed to climate, where the drier Whareama and Gladstone sites yielded less than Mauriceville sites of comparable fertility levels. However, site 4 (Mauriceville) was the lowest yielding site, and showed the large influence of fertiliser history, when compared to site 1. This suggests that soil fertility status influenced yield to a much greater extent than the climate differences.

A sharp decline in growth rate was noted at Gladstone and Whareama sites from early January onwards. This is attributed to low soil moisture levels from mid to late summer, which would have severely limited pasture growth. This same decline in growth rate was also apparent at Mauriceville, but only from mid-March, and not as marked as at other sites. Pasture growth rates at all sites appeared to decline rapidly when soil volumetric water content fell to 0.2. This value agrees with the findings of Scotter *et al.* (1979), who noted minimal or nil pasture growth at similar soil moisture levels on the Tokomaru silt loam soil, near Palmerston North.

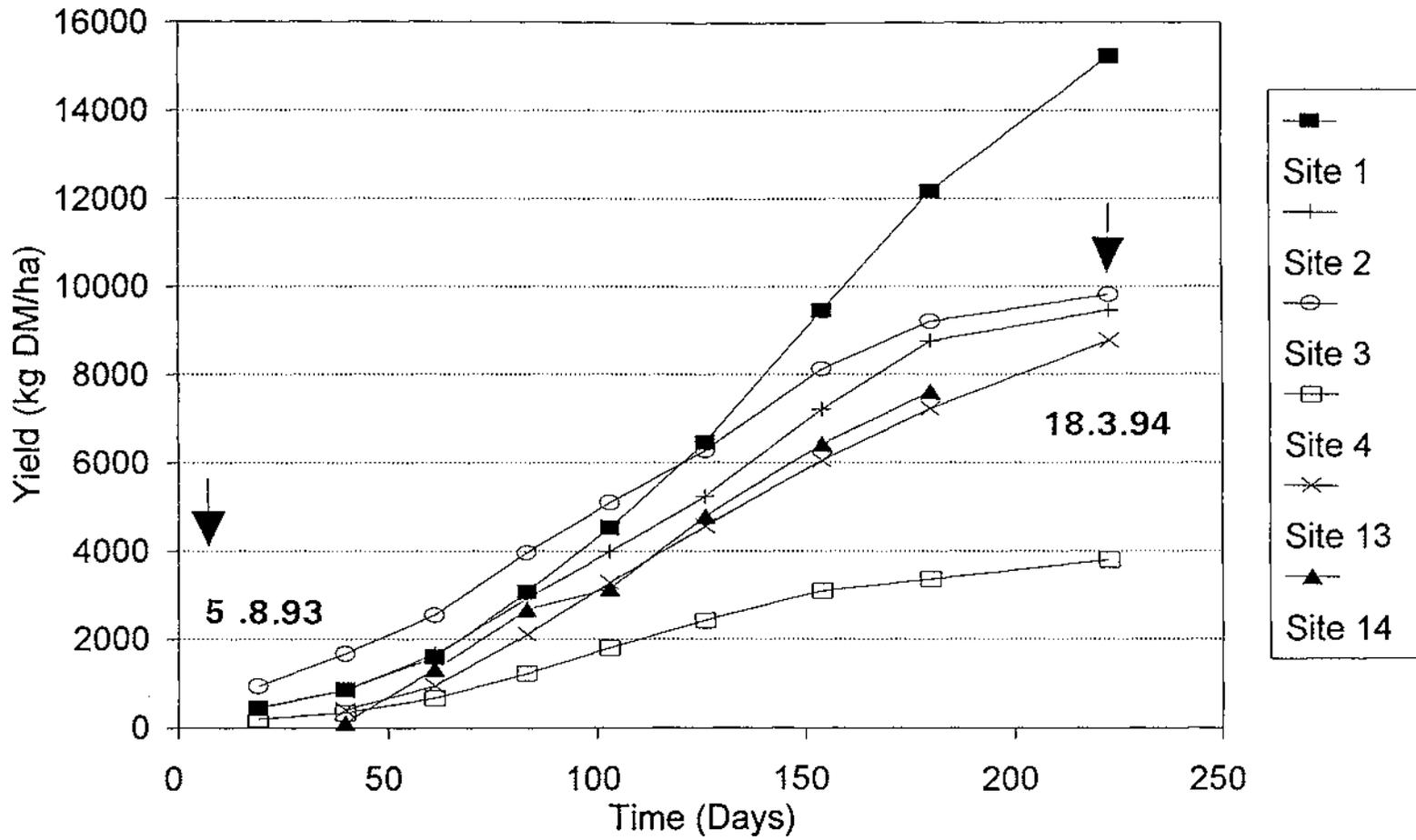


Figure 5.2a

Total cumulative dry matter yield from the start of trials (5.8.93) to 18.3.94 at Mauriceville sites

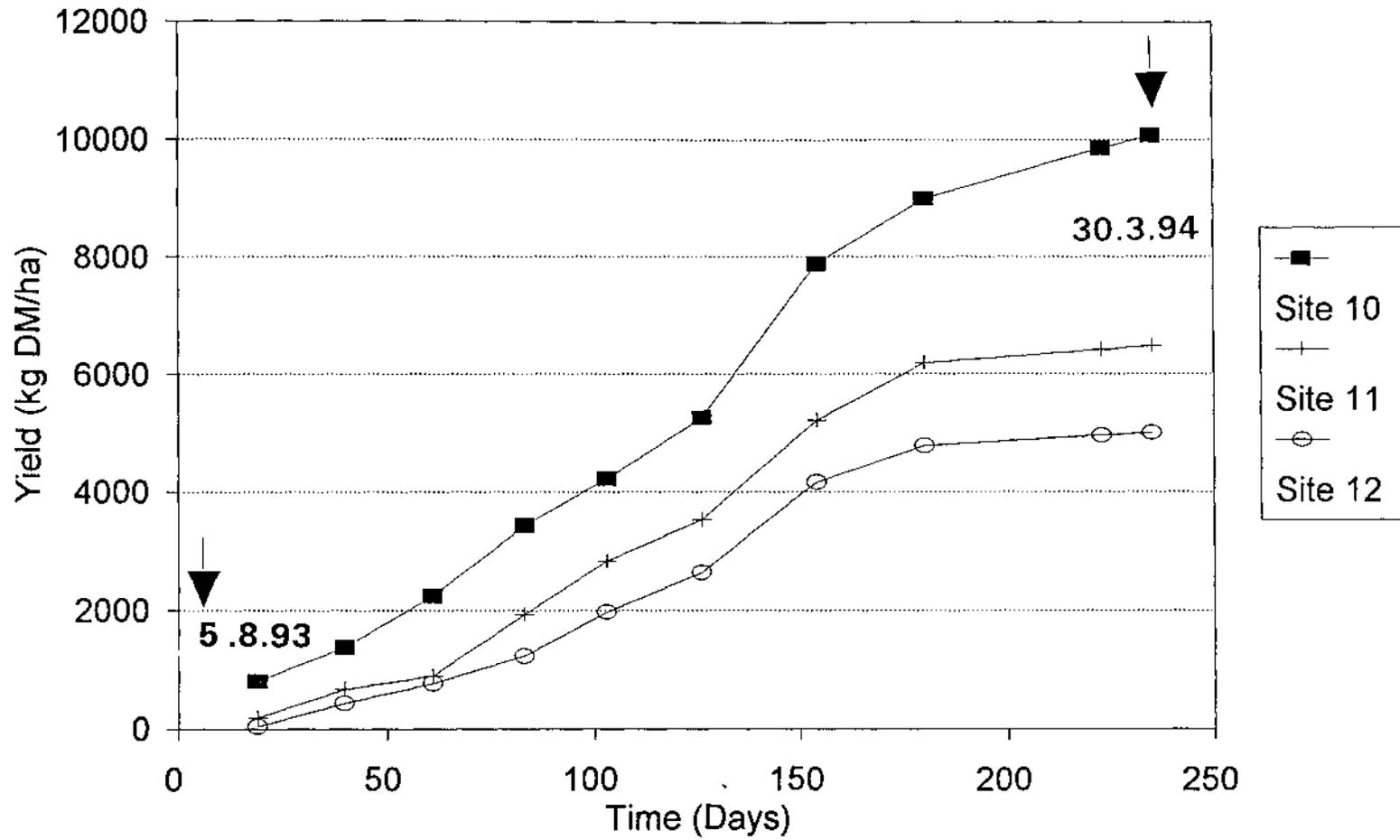


Figure 5.2b

Total cumulative dry matter yield from the start of trials (5.8.93) to 30.3.94 at Gladstone sites

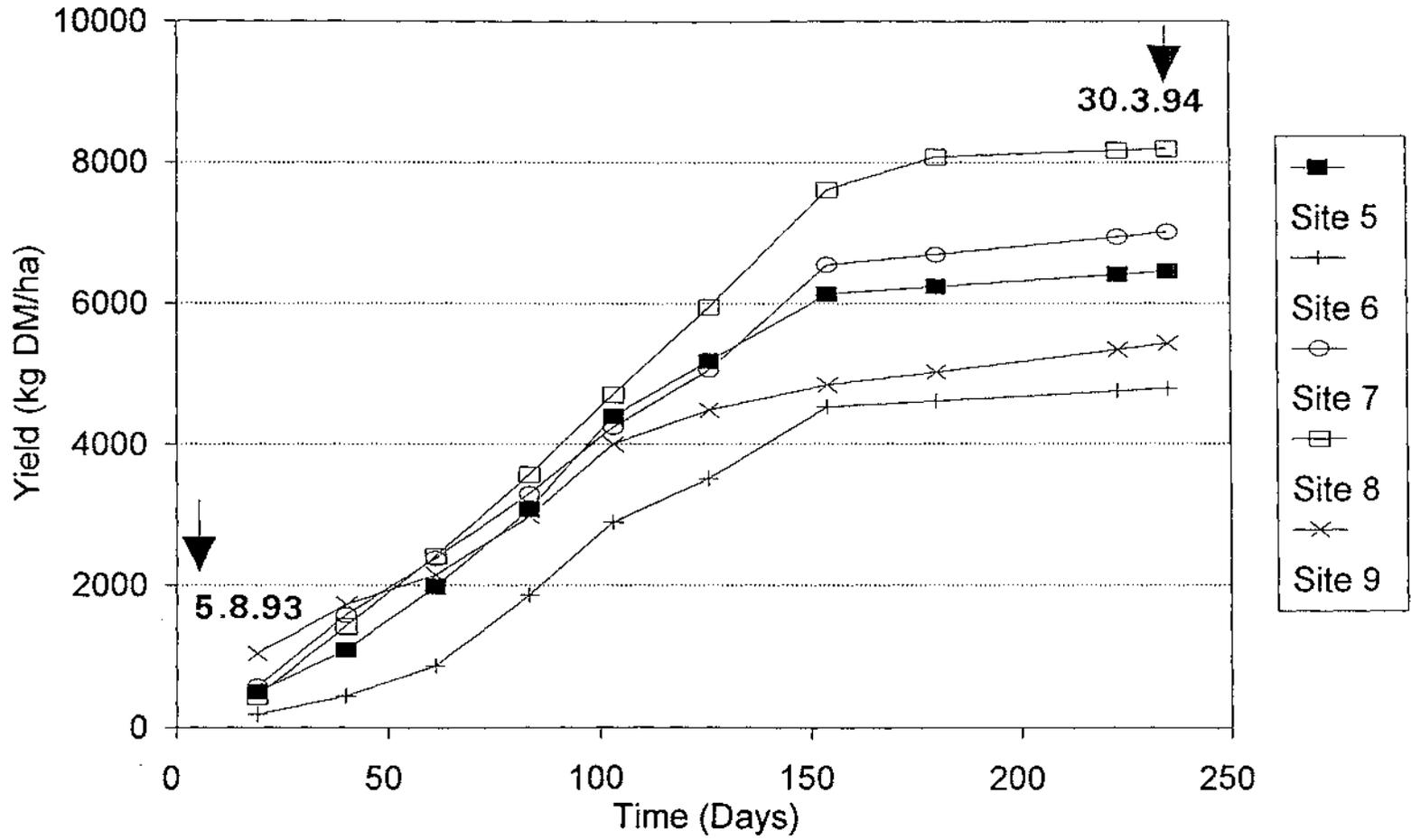


Figure 5.2c Total cumulative dry matter yield from the start of trials (5.8.93) to 30.3.94 at Whareama sites

5.4.2. Legume Herbage Yield.

Total legume yields for the spring - summer growth period are shown in figures 5.3a to 5.3c.

Legume herbage yield ranged from 0.02t DM/ha (site 7) to 2.7t DM/ha (site 10). Sites with high legume yield included sites 3 (1.5t DM/ha), 13 (1.45t DM/ha), 10 (2.7t DM/ha), 12 (1.48t DM/ha) and 8 (1.32t DM/ha). Low yielding sites included sites 4 (0.18t DM/ha), 5 (0.18t DM/ha) and 7 (0.02t DM/ha).

Unlike total herbage yield, legume herbage yield did not appear to be linked with soil fertility status/fertiliser history (see section 5.5.1).

Clover DM yield appeared to be influenced by the composition of the sward (see Figures 5.4a to 5.4c), where a higher proportion of legumes in the sward gave higher legume DM yield, exemplified by sites 3, 8, 10 and 13.

Clover growth appeared to be more sensitive to moisture stress than total yield. Legume growth rates declined sharply (to zero growth levels), and at an earlier date than total herbage growth rates. This is exemplified at Whareama sites, where no clover growth occurred from late December to late March. There is a shortage of published data that directly compares legume and grass yield under soil moisture regimes. Marriott (1988) reported a marked decline in white clover growth and nitrogen fixation when soil moisture content fell to less than 15% of dry soil weight. In a previous study (Engin and Sprent, 1973), white clover growth and nitrogen fixation levels were also depressed with the onset of soil water stress.

One possible explanation for the perseverance of grass growth under moisture stress (when compared to that of clover) is the presence of low fertility summer grasses in the sward. This is apparent at low fertility sites 4, 11 and 12 where low fertility grass species dominate. Such species would be expected to allow the sward some drought tolerance. It is important to note however that over all sites the major factor contributing to increased dry-matter yield from pasture was soil fertility status, not the presence of drought-tolerant low fertility grass species.

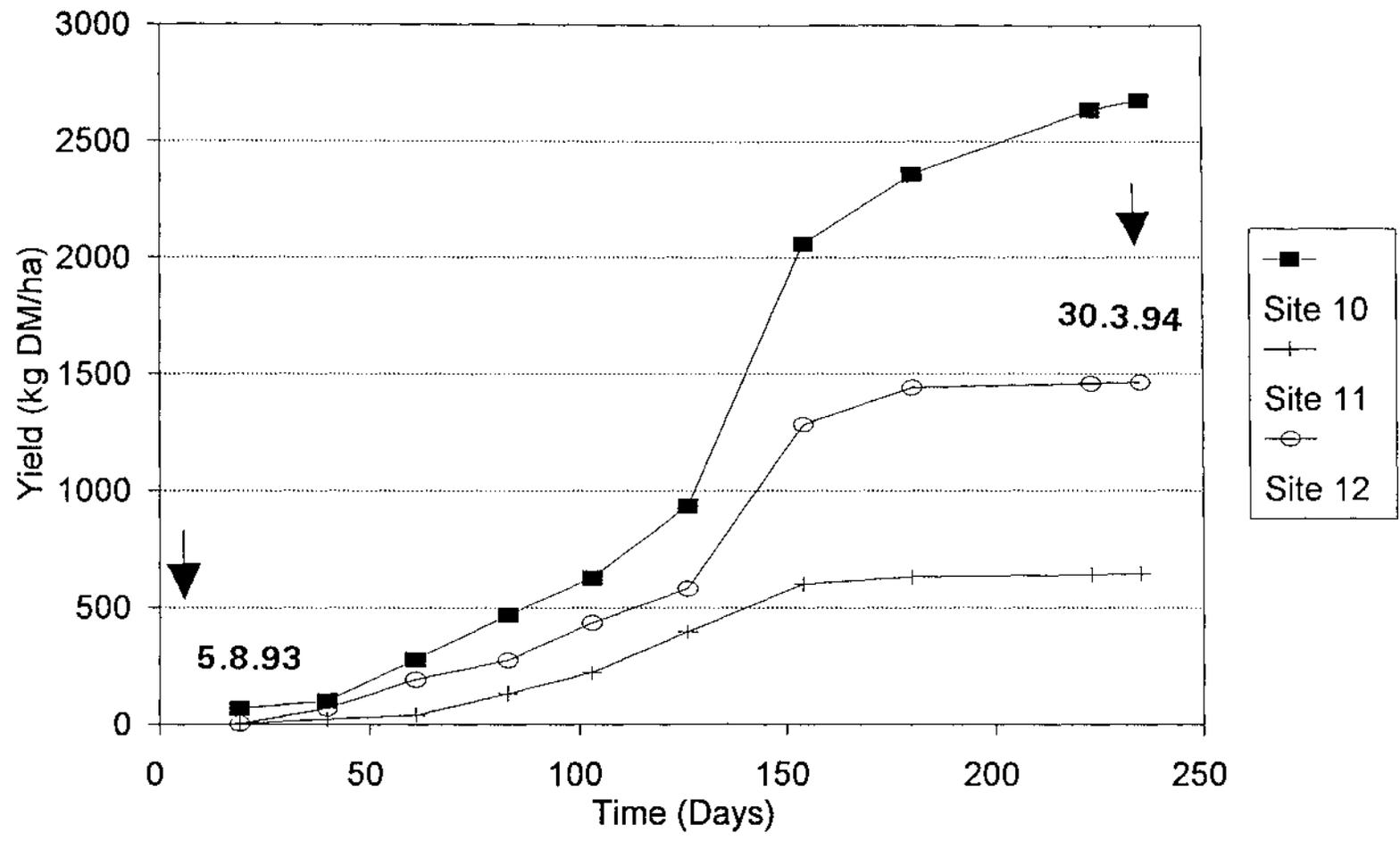


Figure 5.3b Cumulative legume dry matter yield from the start of trials (5.8.93) to 30.3.94 at Gladstone sites

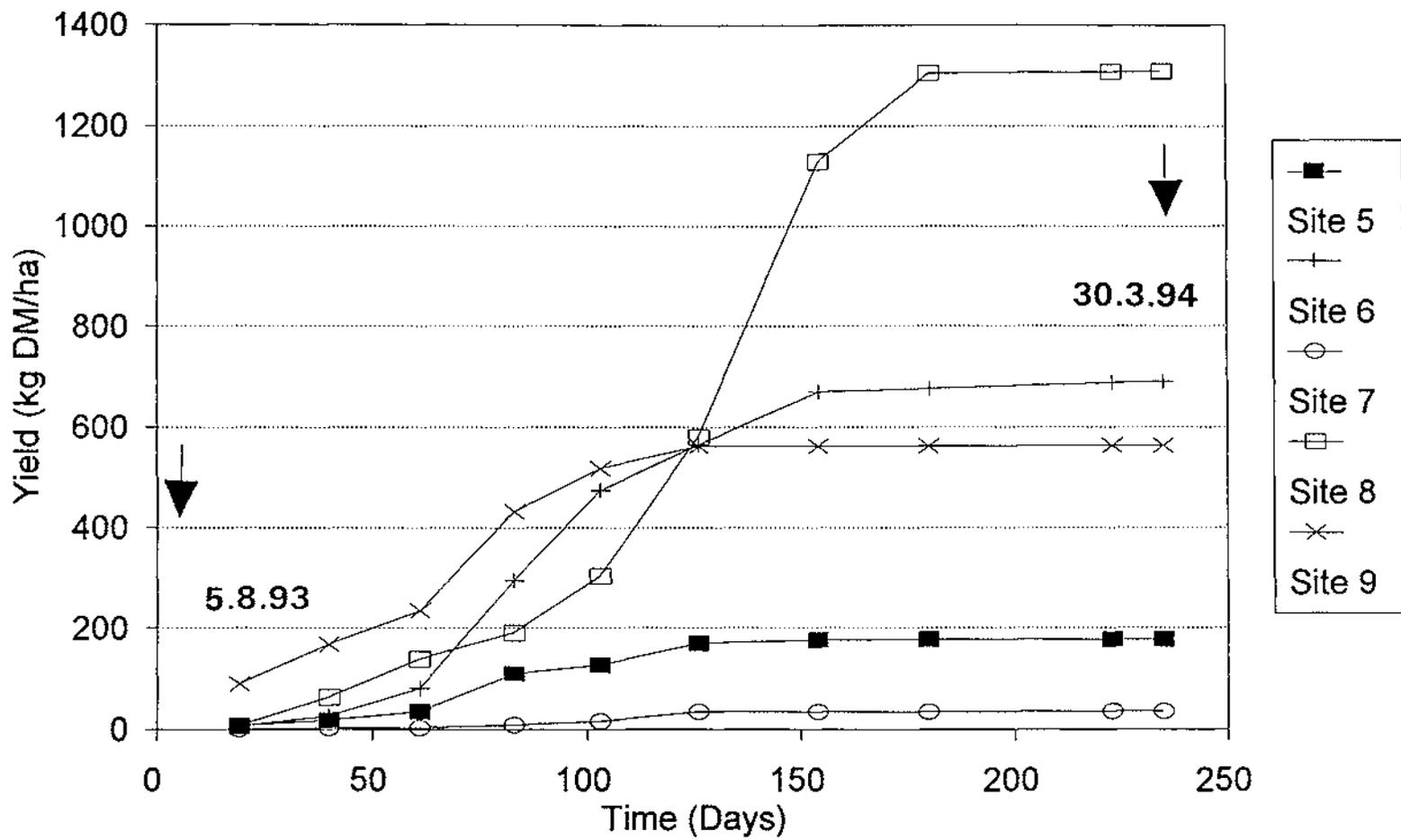


Figure 5.3c Cumulative legume dry matter yield from the start of trials (5.8.93) to 30.3.94 at Whareama sites

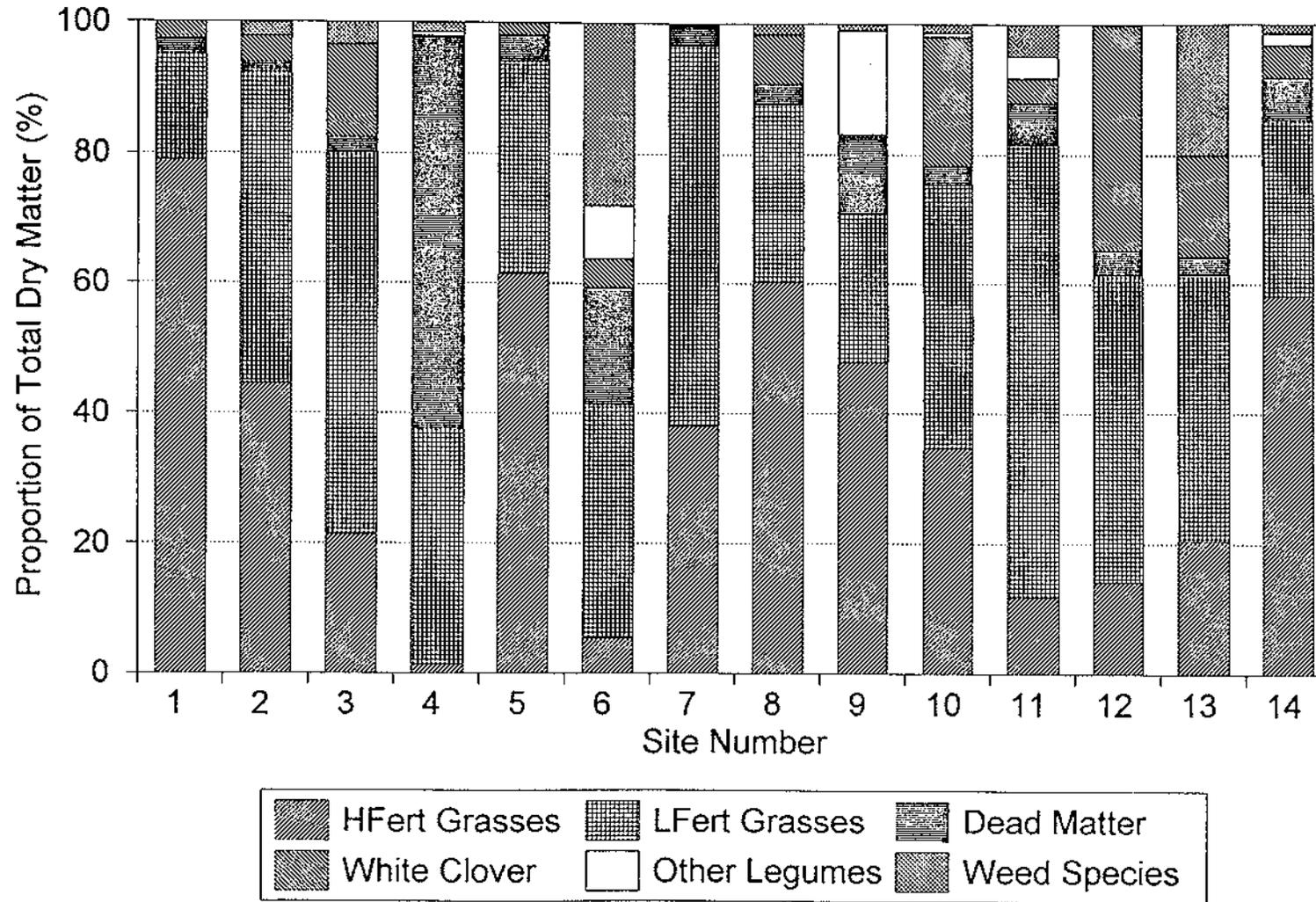


Figure 5.4a The botanical composition of swards at Julian Day 278 (harvest 3)

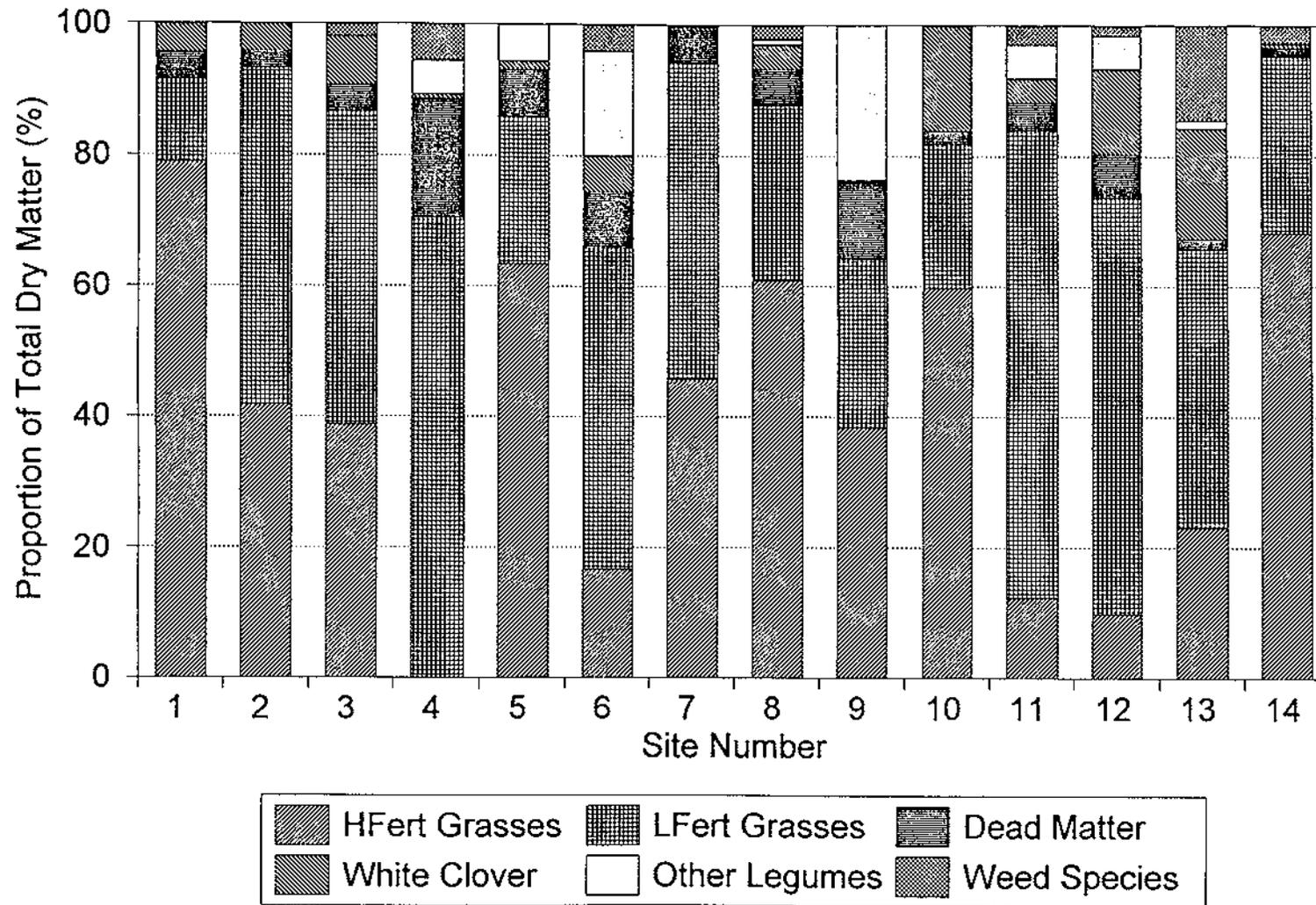


Figure 5.4b

The botanical composition of swards at Julian Day 300 (harvest 4)

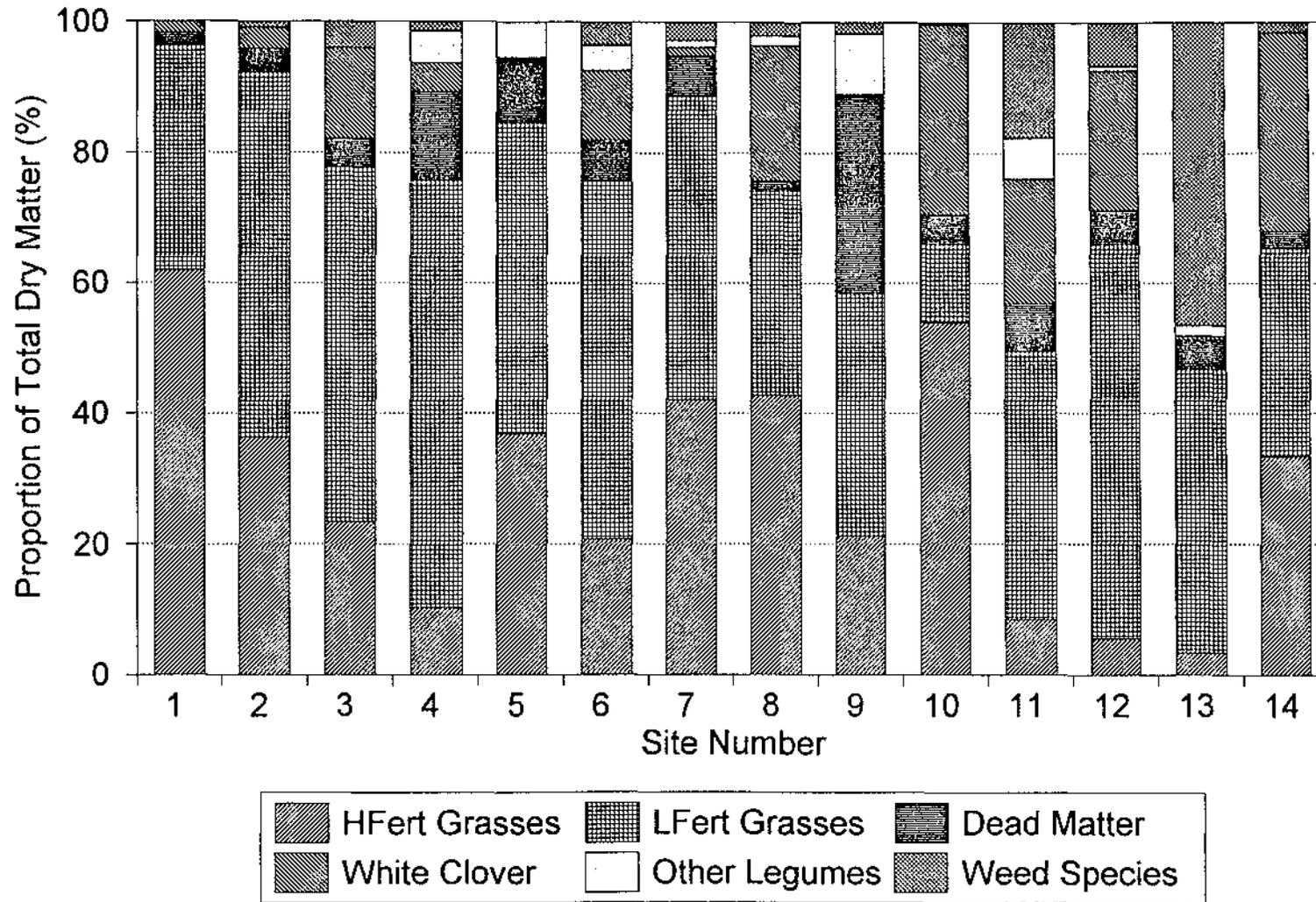


Figure 5.4c The botanical composition of swards at Julian Day 343 (harvest 6)

5.5 THE RELATIONSHIP BETWEEN PASTURE YIELD AND SOIL NUTRIENT STATUS

In order to examine the influence of soil fertility status on total and legume dry matter yields, a number of regressions were carried out. The total accumulated yields for harvests 2 and 3 at Julian days 257 and 278 (September 14 and October 5, 1993) were used for this analysis, as this was the growth period where soil moisture levels were not limiting pasture growth i.e. where soil volumetric water contents were above 60% of field capacity levels.

As a comparison, soil Olsen P, sulphate S, resin P and mineralisable N levels were plotted against legume yield for harvest 7 (growth period from 16.11.93 to 6.1.94), a period where maximum legume growth was occurring, and also for harvests 2 and 3.

5.5.1 The Relationship Between Accumulated Herbage Yield and Soil Nutrient Status

Approximately 52% of the variation observed in accumulated herbage yield could be explained by the variation in Olsen P values ($R^2=0.52$), indicating that increased Olsen P levels provide a index of herbage yield (Figure 5.5a). The slope of this line indicated that an increase of 10 Olsen P units ($\mu\text{g/g}$) would increase DM yield by about 210kg DM/ha for the August to early October growth period. On further examination these results, it was decided that a curvilinear fit would better describe the spread of data. Figure 4.11a also shows the curvilinear fit (Mitscherlich equation) for this data, which gave an improved fit of $R^2=0.64$. This suggests that pasture yield is in fact P limited at many of these sites, as a relatively high P_{max} (Olsen P level required for 95% maximum pasture yield) of 35 $\mu\text{gP/g}$ was observed. Olsen P levels equal to this value or higher were only measured at sites 1, 10 and 7 confirming that at many of these sites pasture growth (yield) is in fact P limited.

In comparison, accumulated DM yield appeared to have a strong linear correlation with sulphate S levels ($R^2=0.64$, Figure 5.5c). This regression indicated that an increase of 10 $\mu\text{g/g}$ sulphate S would increase pasture yield by 1100kg DM/ha for the August-September growth period. This may suggest that pasture yield at many of these sites is also S limited. There is a close relationship (Figure 4.7c) between total soil N and total soil S, because both

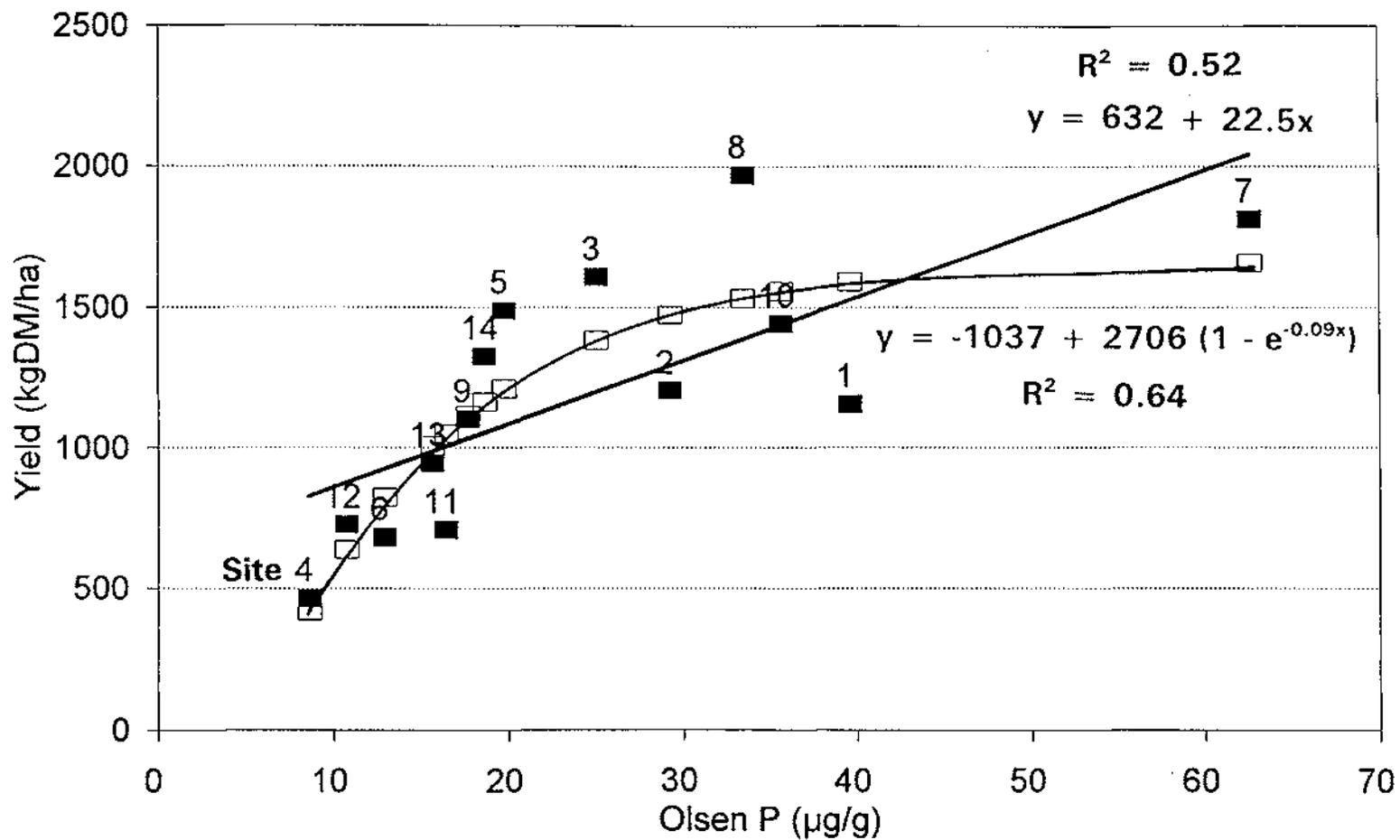


Figure 5.5a The relationship between herbage yield from 24.8.93 to 5.10.93 (harvests 2 and 3) and soil Olsen P content

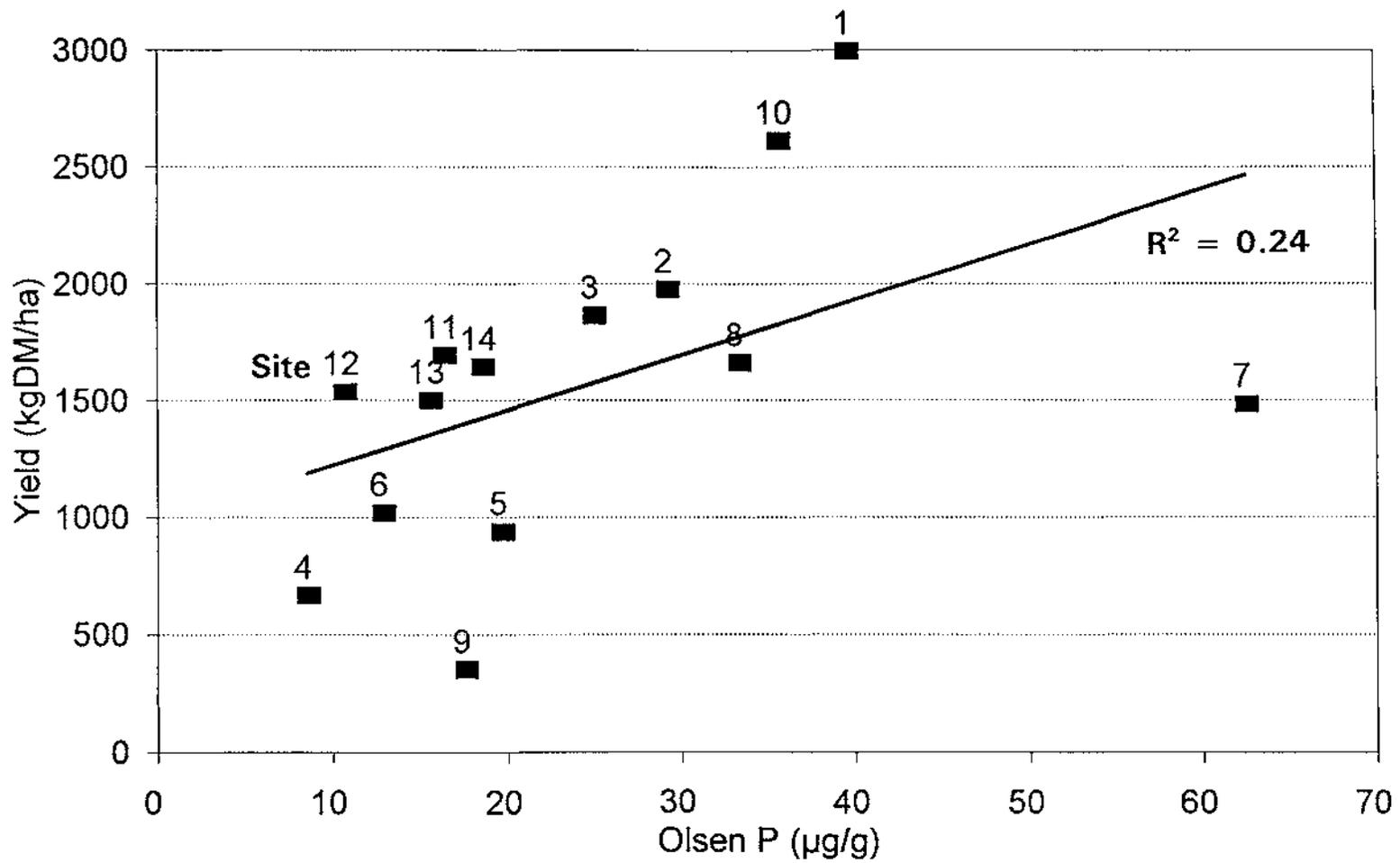


Figure 5.5b

The relationship between herbage yield from 16.11.93 to 6.1.94 (harvests 6 and 7) and soil Olsen P content

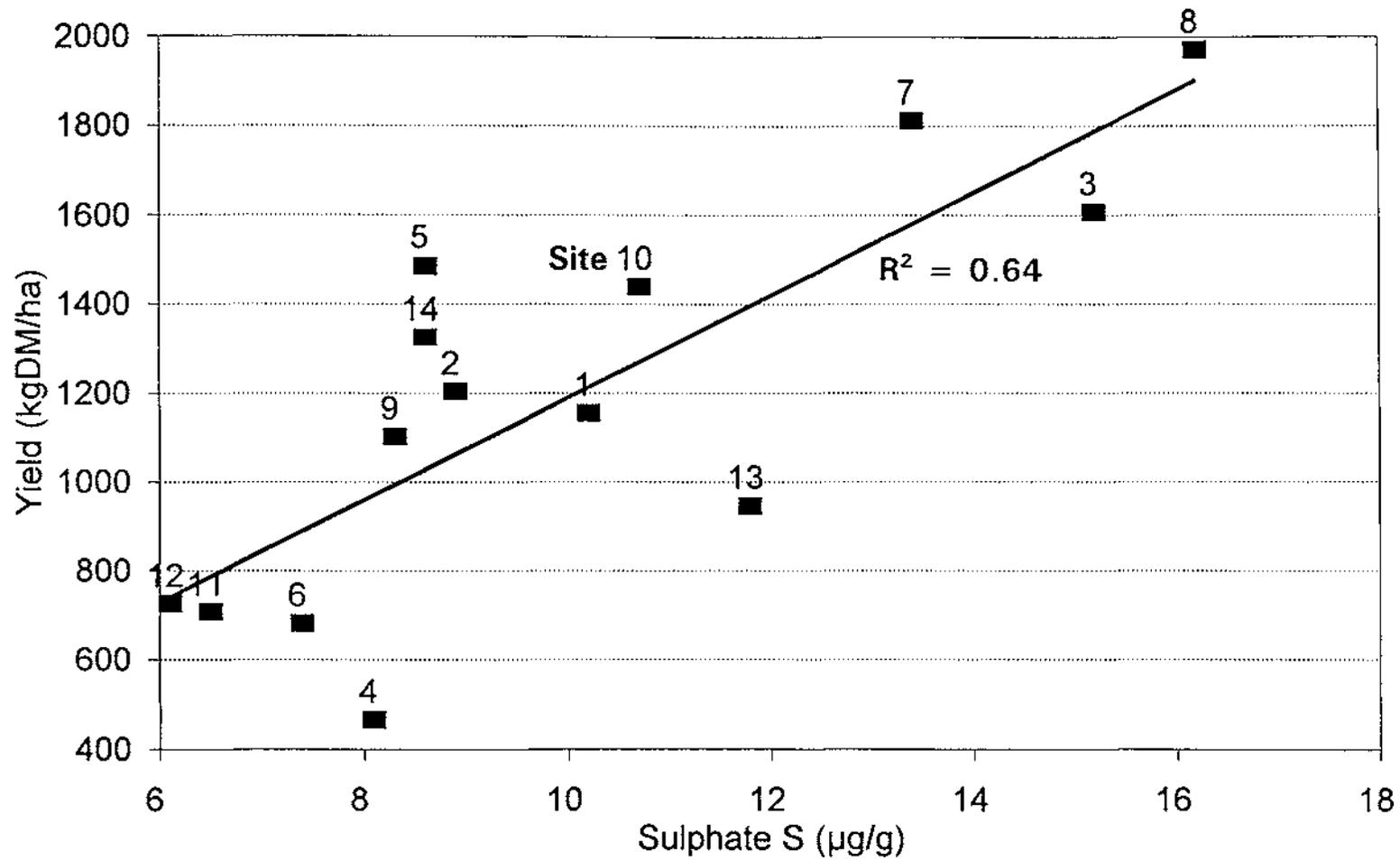


Figure 5.5c The relationship between dry matter yield from 24.8.93 to 5.10.93 (harvests 2 and 3) and soil sulphate S content

S and N are mostly stored in soil organic matter. Therefore it is possible that soil sulphate S values could be acting as a "surrogate" index of available soil N.

Soil resin P levels ($R^2=0.36$) and mineralisable N levels ($R^2=0.33$) showed only weak linear relationships with total yield for the same growth period (Figures 5.5d and 5.5e).

A simple gross margin calculation was carried out to compare the economics of past fertiliser applications with regards to present pasture yields (Appendix 2). The results indicated that in all three climate zones, the frequent application of fertiliser had been the most profitable option.

5.5.2 The Relationship Between Legume Yield and Soil Nutrient Status

Legume DM yield for harvests 2 and 3 were found to have no correlation with Olsen P ($R^2=0.036$, Figure 5.6a), sulphate S ($R^2=0.047$, Figure 5.6b), resin P ($R^2=0.002$, Figure 5.6c) and mineralisable N ($R^2=0.004$, Figure 5.6d).

A further regression, using legume yield from later harvests (harvests 6 and 7) gave very similar results. Once again, legume yield was shown to have no correlation with Olsen P ($R^2=0.001$, Figure 5.6e), sulphate S ($R^2=0.07$, Figure 5.6f), resin P ($R^2=0.06$, Figure 5.6g) and mineralisable N ($R^2=0.07$, Figure 5.6h) levels at harvest 7. This is an unexpected result, because legume growth rates peaked at this harvest, and hence this would be the most likely period for nutrient stress/deficiency to be apparent.

This suggests that legume DM yield, and possibly levels of N fixation, are influenced more strongly by climate and historical pasture management (e.g. oversowing of improved clovers, and grazing management), rather than soil fertility status. Unfortunately, the historical pasture management at each site is practically unknown.

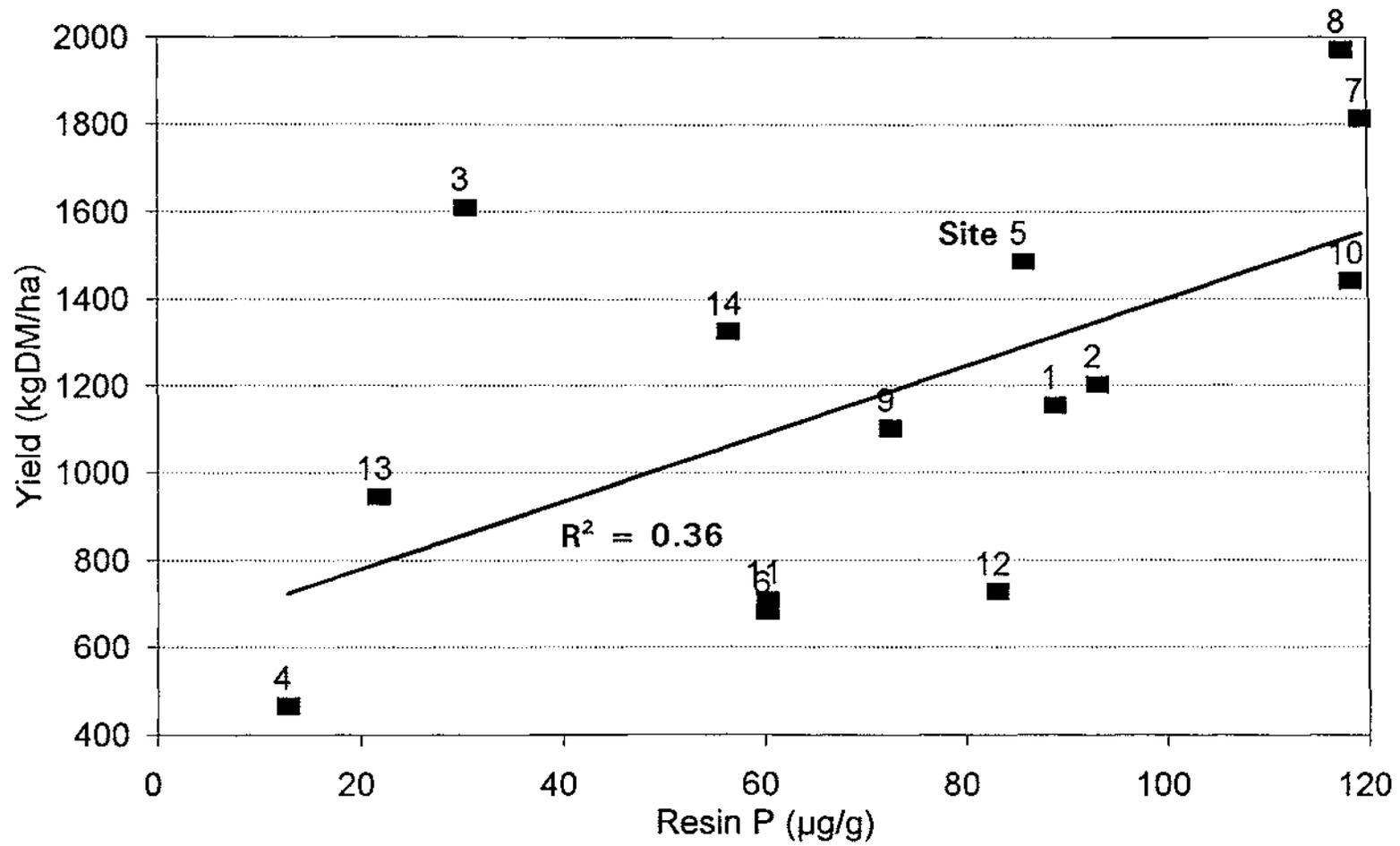


Figure 5.5d The relationship between dry matter yield from 24.8.93 to 5.10.93 (harvests 2 and 3) and soil resin P content

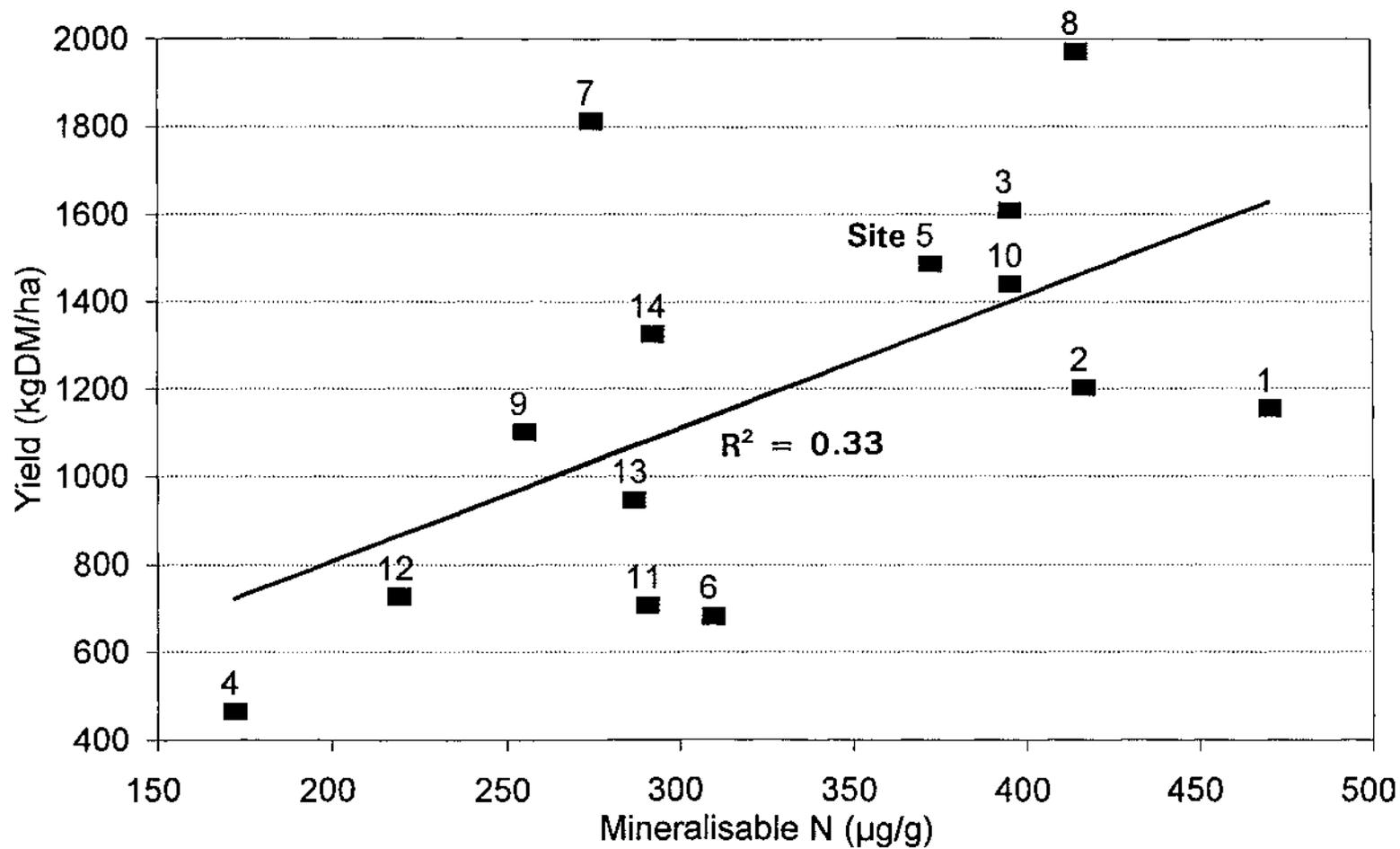


Figure 5.5e The relationship between dry matter yield from 24.8.93 to 5.10.93 (harvests 2 and 3) and soil mineralisable N content

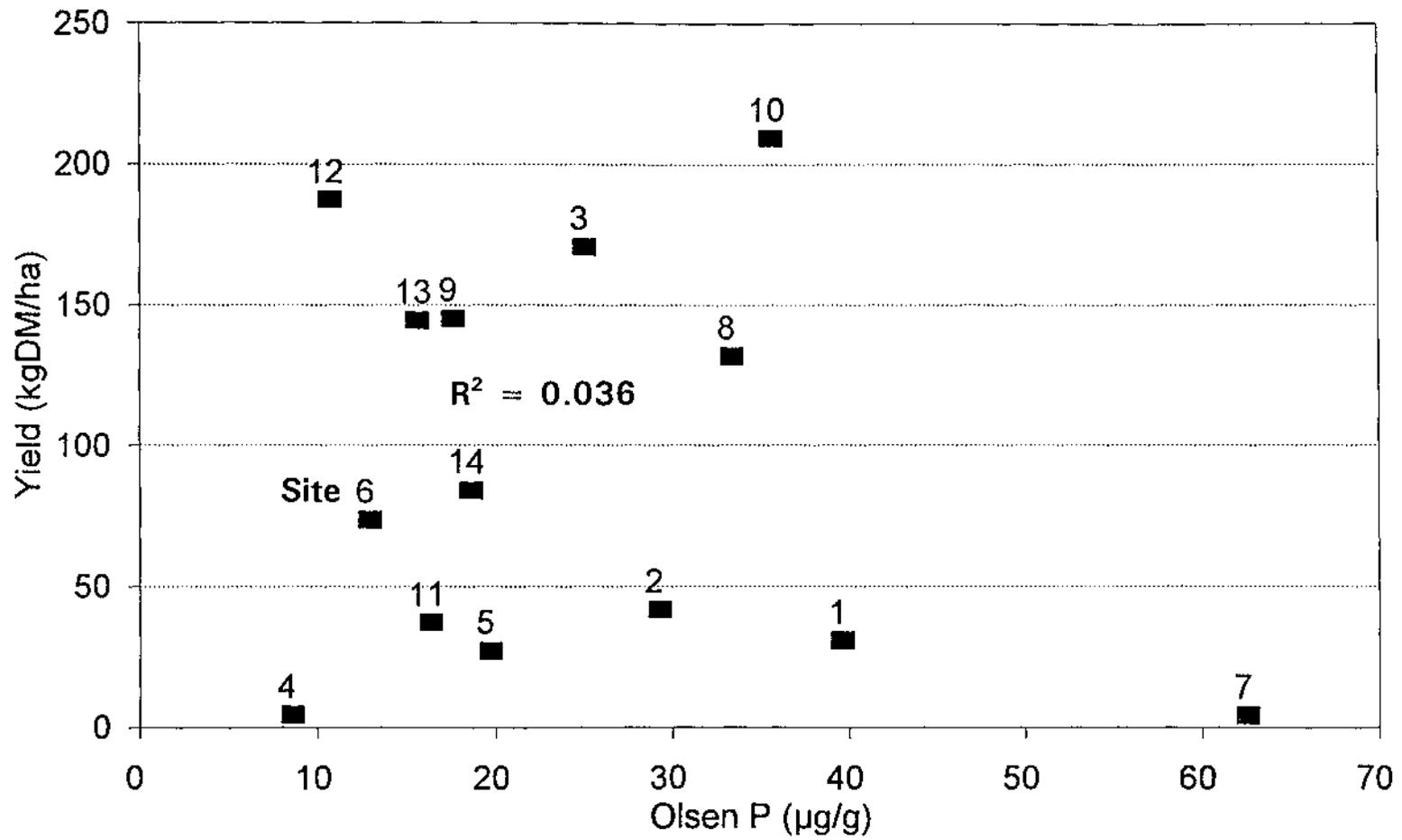


Figure 5.6a The relationship between legume dry matter yield from 24.8.93 to 5.10.93 (harvests 2 and 3) and soil Olsen P content

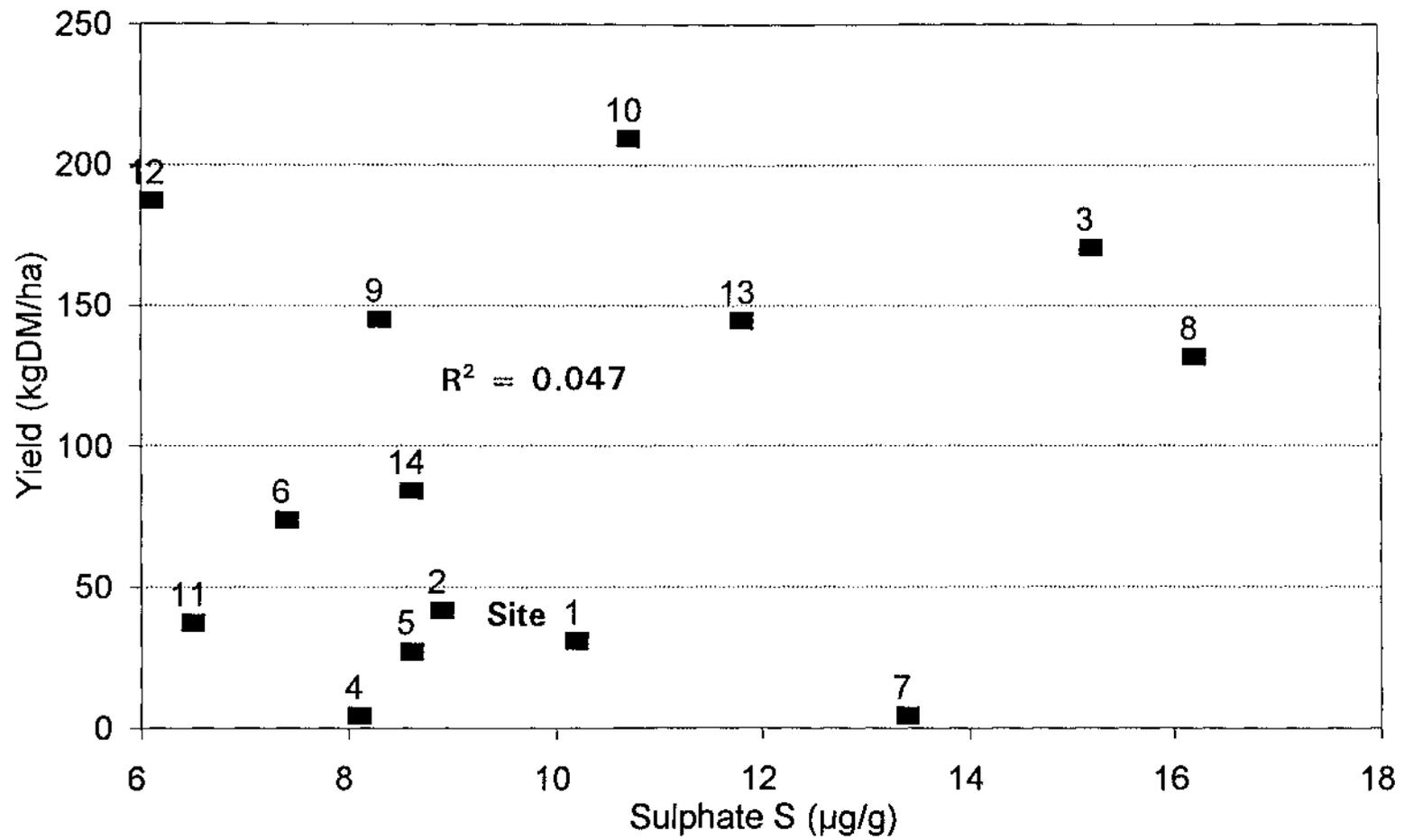


Figure 5.6b

The relationship between legume dry matter yield from 24.8.93 to 5.10.93 (harvests 2 and 3) and soil sulphate S content

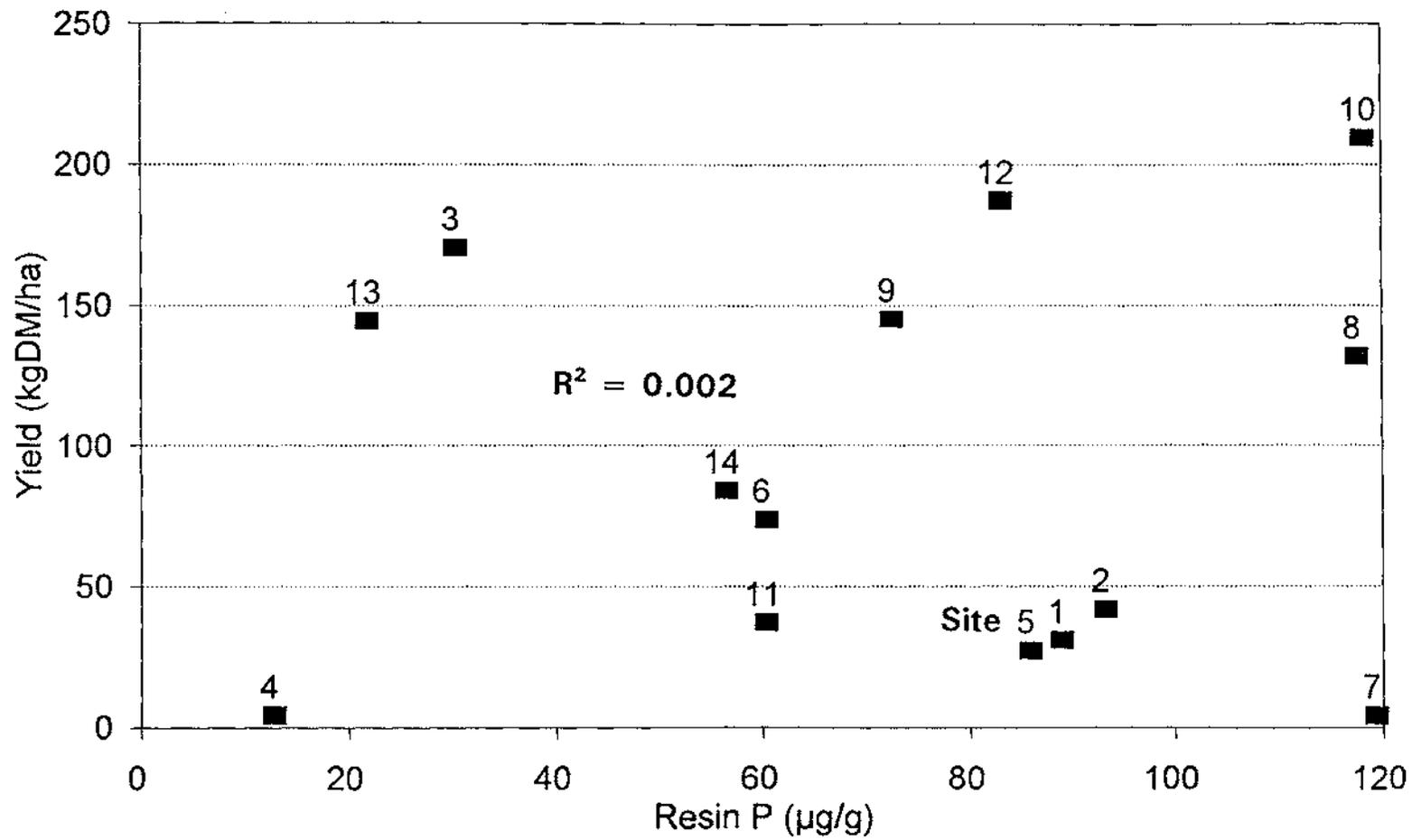


Figure 5.6c The relationship between legume dry matter yield from 24.8.93 to 5.10.93 (harvests 2 and 3) and soil resin P content

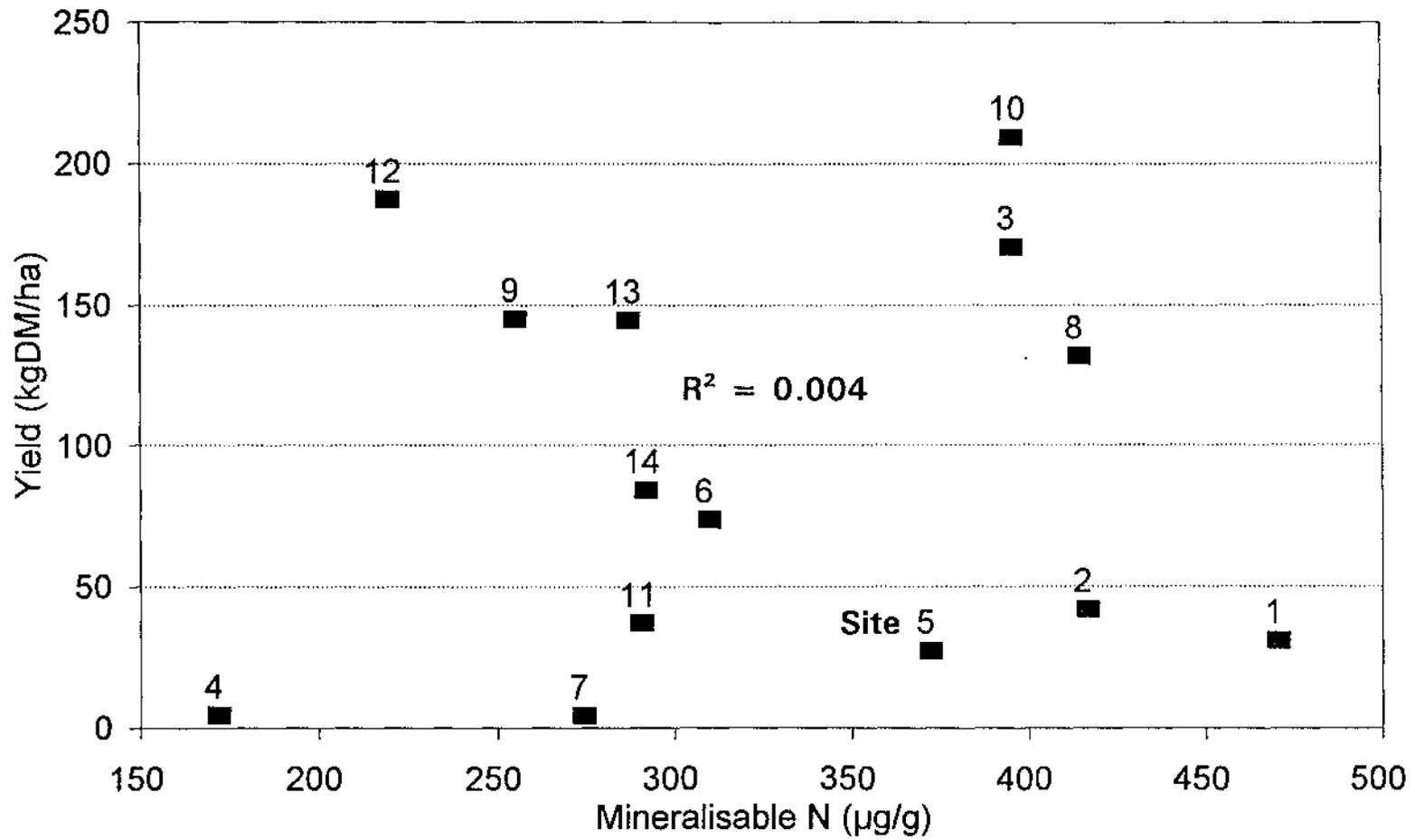


Figure 5.6d The relationship between legume dry matter yield from 24.8.93 to 5.10.93 (harvests 2 and 3) and soil mineralisable N content

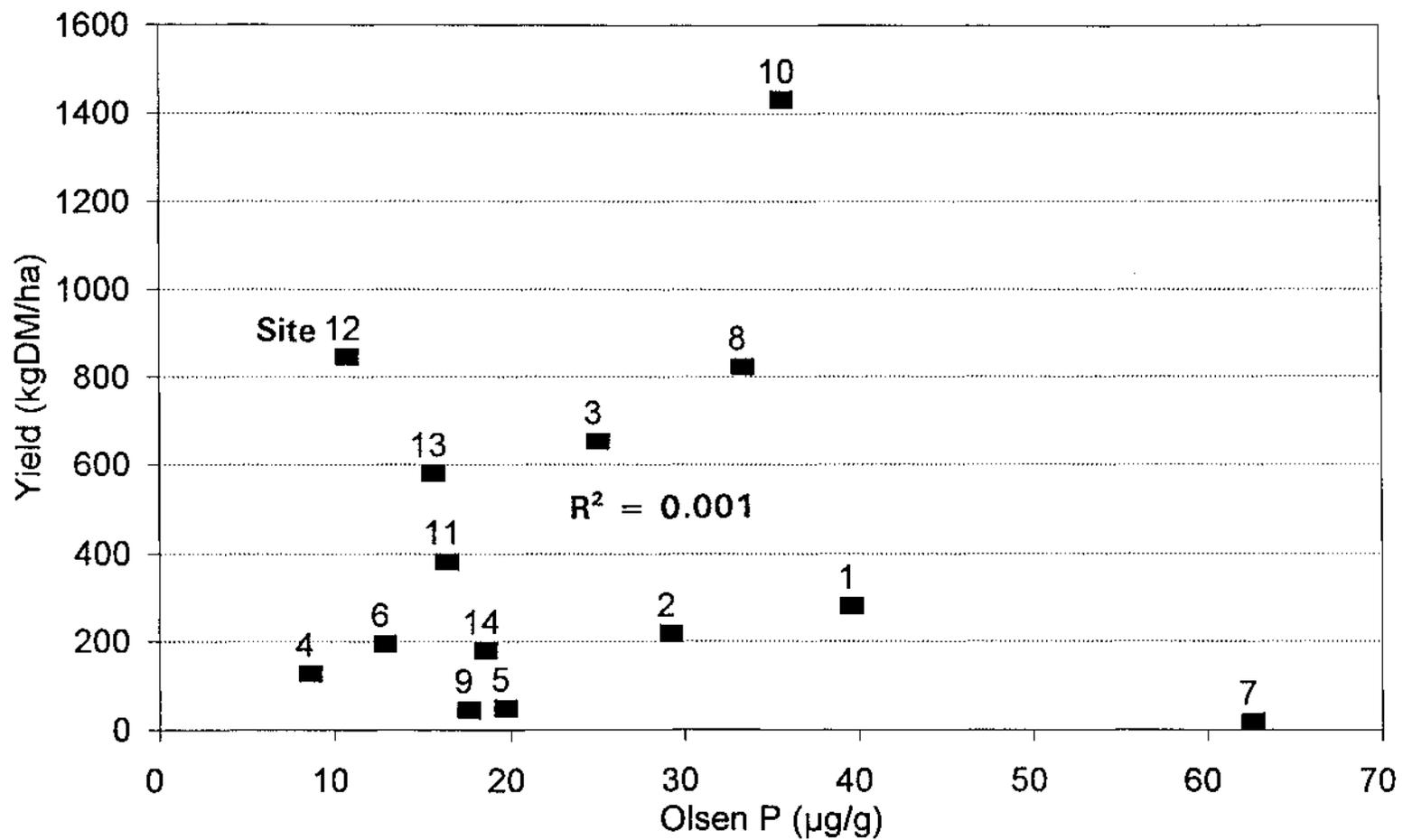


Figure 5.6e The relationship between legume dry matter yield from 16.11.93 to 6.1.94 (harvests 6 and 7) and soil Olsen P content

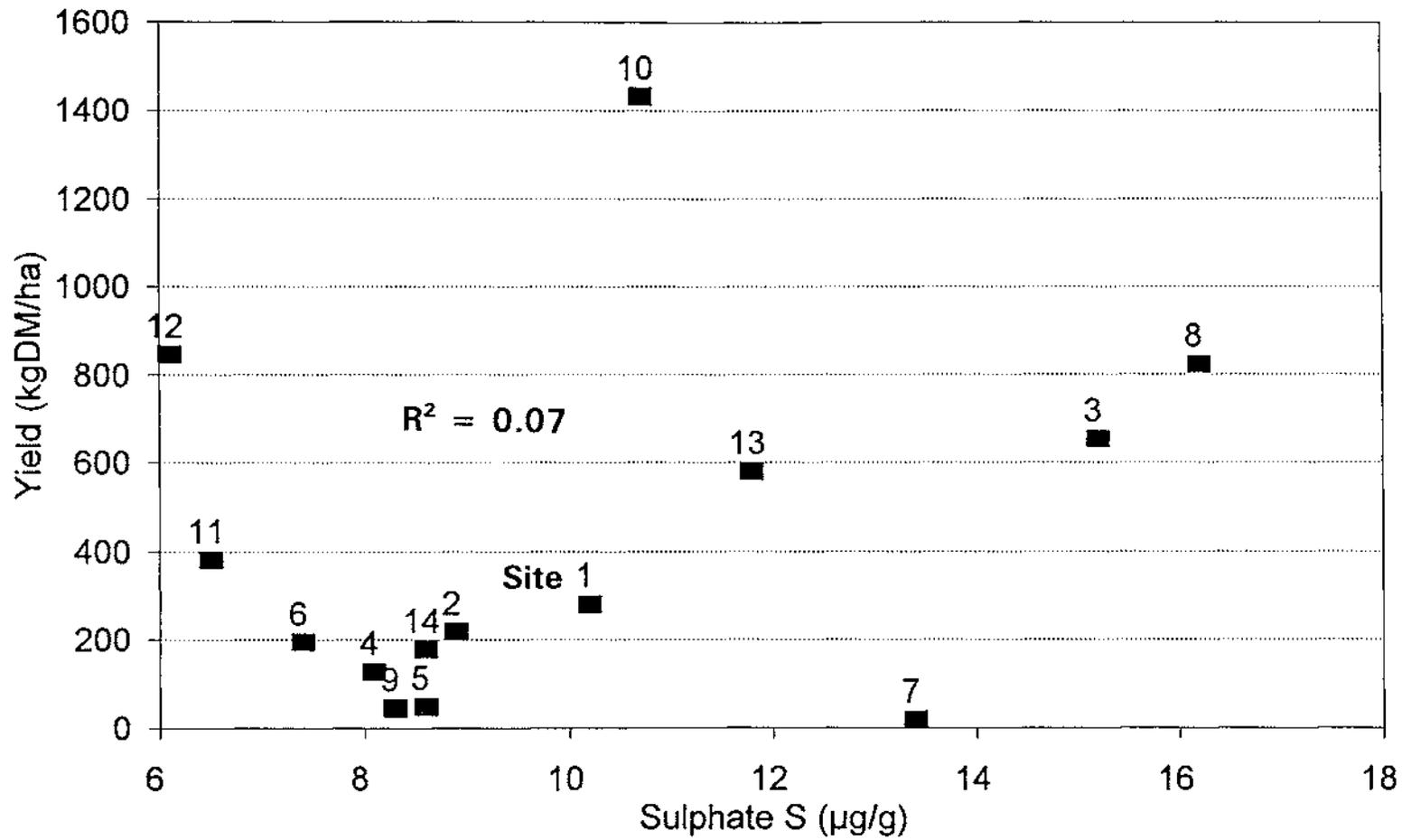


Figure 5.6f The relationship between legume dry matter yield from 16.11.93 to 6.1.94 (harvests 6 and 7) and soil sulphate S content

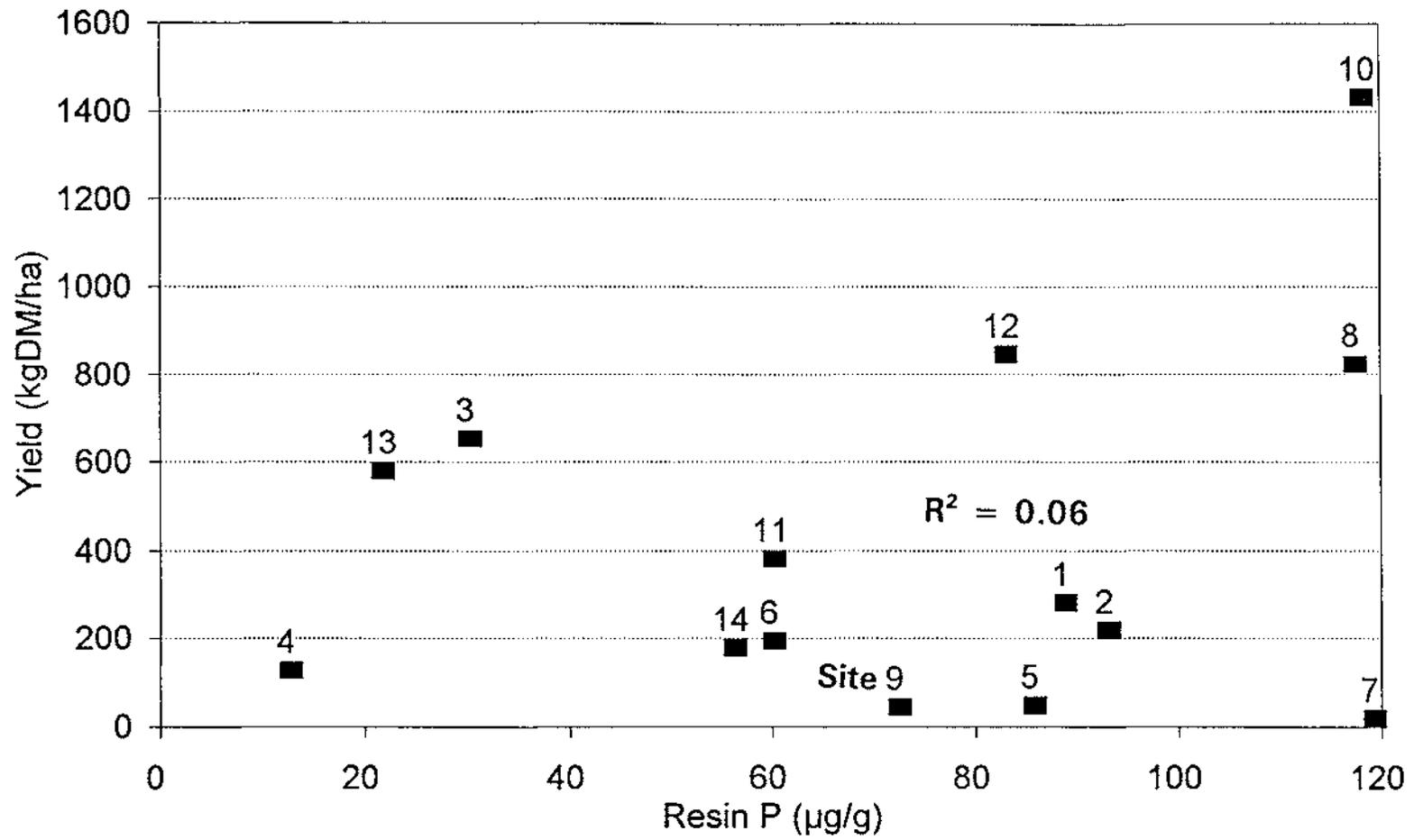


Figure 5.6g The relationship between legume dry matter yield from 16.11.93 to 6.1.94 (harvests 6 and 7) and soil resin P content

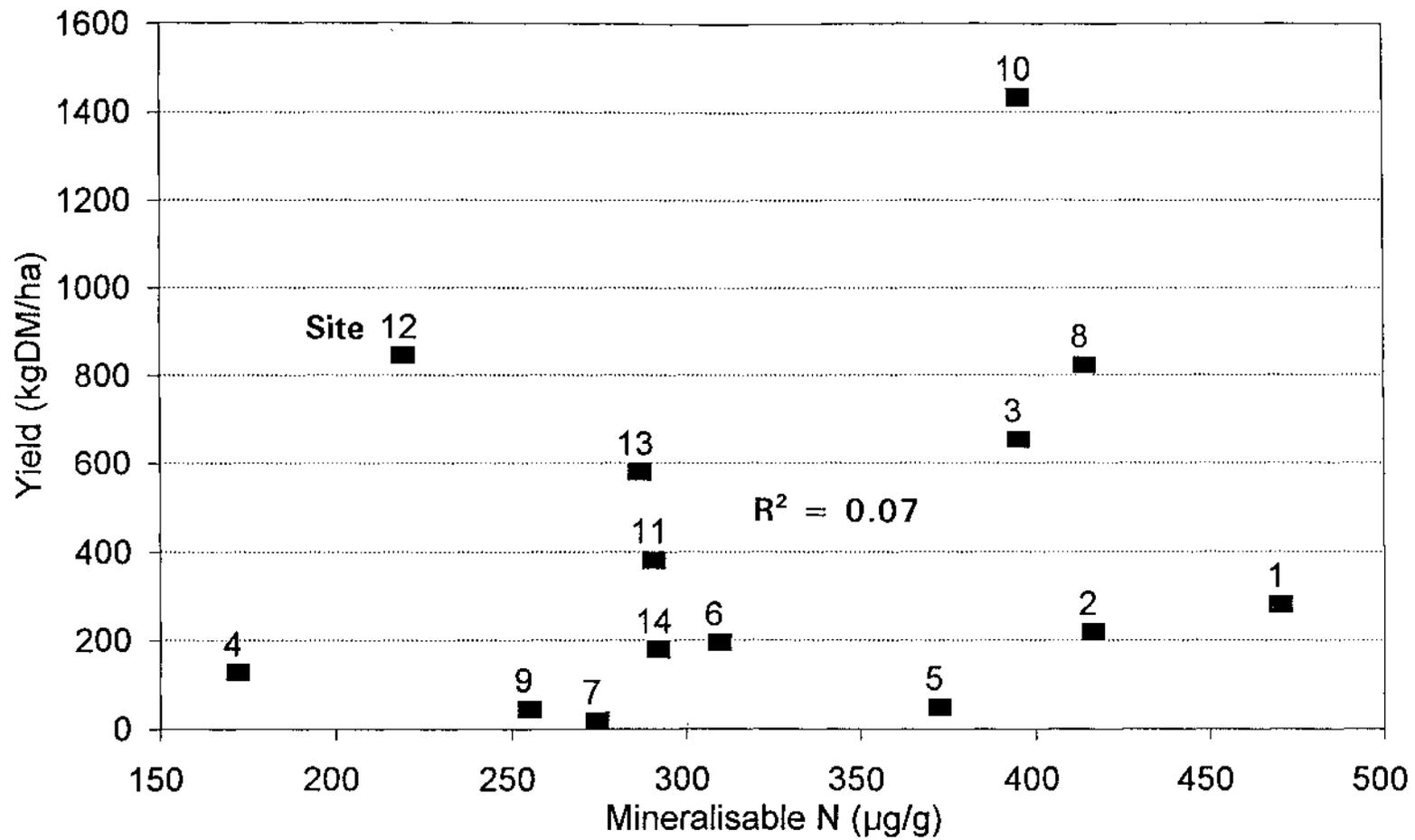


Figure 5.6h The relationship between legume dry matter yield from 16.11.93 to 6.1.94 (harvests 6 and 7) and soil mineralisable N content

5.6 HERBAGE N AND P UPTAKE

5.6.1 Herbage N and P Concentration

Both grass and legume sward components were analysed for N and P content for harvests 1 to 6 (Julian day 217 to 243). To investigate a herbage index for determining the fertility of a site a regression analysis was then carried out for each harvest, plotting herbage N concentration against herbage P concentration. The linear fit of data ranged from $R^2=0.12$ to $R^2=0.91$. Results of these analyses are presented in Figure 5.7a to 5.7f.

Low fertility sites (4, 11 and 12) had consistently low herbage N and P concentrations for harvests 1 - 6, with the reverse being true for high fertility sites (1, 2, 8 and 10). This suggests that the relationship between herbage N and P concentrations may be a useful fertility index. For all 6 harvests, legume species had a higher N concentration than grass species. This difference appeared to be narrow at harvest 1, with the difference between grass and legume N content becoming wider with successive harvests. The slopes of the regression lines are also changing with time. Both grass and legume N and P concentrations increased from harvest 1 to harvest 3, then declined at harvests 4 and 5, before rising slightly at harvest 6. The fall in herbage N and P concentration at harvests 4 and 5 could possibly be due to soil moisture stress. At all sites, especially Gladstone and Whareama sites, soil moisture contents declined rapidly between harvests 3 and 4, rising slightly by harvest 5 (Figures 5.1a to 5.1c). During this period of soil moisture stress plant P uptake has been limited, as P is very immobile in soil, and so relies on soil moisture as a transfer mechanism to plants. The increase in soil moisture levels from harvest 5 may therefore be responsible for increased herbage N and P concentrations at harvest 6.

It is possible that ratios of herbage N and P concentrations could be developed further as a fertility index, showing nutrient deficiencies and the likely response to fertiliser in different growing seasons. The development of such a fertility index will require fertiliser response trials to be conducted at each of the sites. This is beyond the scope of this project.

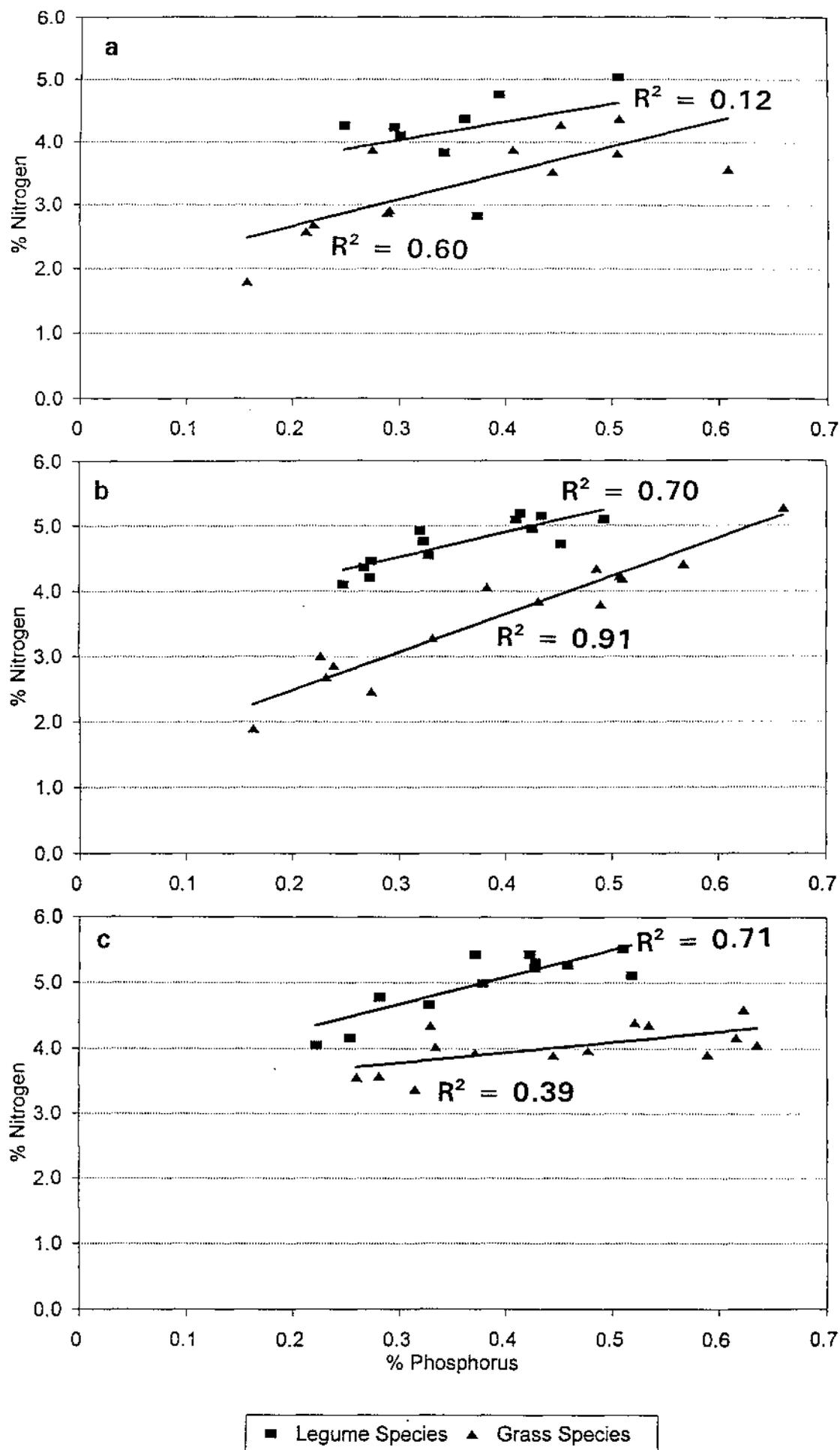


Figure 5.7 The relationship between herbage P and N concentrations at Julian days (a) 236 (harvest 1); (b) 257 (harvest 2) and (c) 278 (harvest 3)

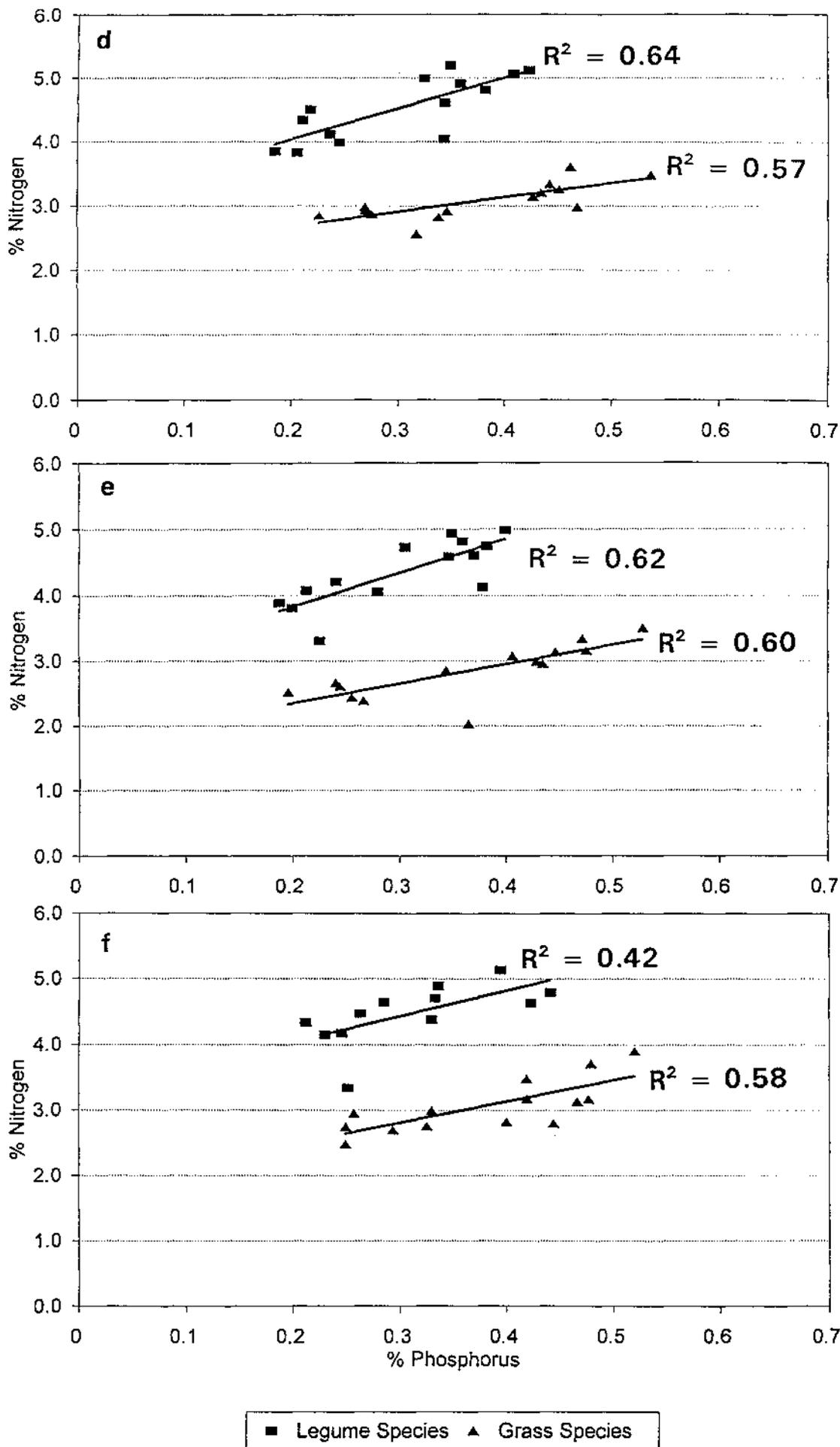


Figure 5.7
(continued)

The relationship between herbage P and N concentrations at Julian days:
(d) 300 (harvest 4); (e) 320 (harvest 5) and (f) 343 (harvest 6)

5.6.2 Total Harvested N and P

The relationship between total harvested N and total harvested P is shown in Figure 5.8.

Harvested N showed a strong linear correlation with harvested P ($R^2=0.97$). These results showed a very large range of N and P uptake, with 70 kgN and 5 kg P/ha uptake at site 4, and 250 kgN and 34 kgP/ha uptake at site 1. The slope of this line indicated that for every 1 kg of P taken up, 6.1 kgN/ha was taken up by pasture. This ratio suggests that N may be limiting because the ratio of N to P uptake in high fertility pastures commonly exceeds 8:1 (McLaren and Cameron, 1990). It was also interesting to note that total N uptake for the period from early August to late January ranged from 70 to 250 kgN/ha. Assuming that most of the mineralisable soil N is utilised by pasture over this main growth period, this range of mineralisable N agrees closely with the levels which were measured in the laboratory incubation study i.e. 100-300 kgN/ha (Figure 5.8).

Walker and Adams (1957) proposed that soil P additions from fertiliser caused a net increase in plant N levels. The increased plant N uptake was said to result from higher levels of total soil N, which in turn had resulted from higher legume growth and N fixation levels induced by fertiliser P inputs. In order to compare the effect of fertiliser P on pasture N uptake, a plot and regression of total harvested N against total soil P was completed. Like the plot of soil mineralisable N (Chapter 4), harvested N had a good linear relationship with total soil P ($R^2=0.52$, Figure 5.9), suggesting that fertiliser P inputs had increased plant-available N levels in the soil. High fertility sites once again had high levels of N uptake compared to low fertility sites. Also, the slope of the line indicated that for every 1 kgP/ha increase in soil total P (e.g. applied as fertiliser), pasture N uptake increased by 0.13 kgN/ha. Once again, it would appear that this is an inefficient use of P fertiliser.

5.7 NITROGEN FIXATION

Acetylene reduction activity (ARA) measurements were made from the initiation of these trial sites in early August 1993 to early January 1994. Following this, acetylene reduction sampling began again in mid-March.

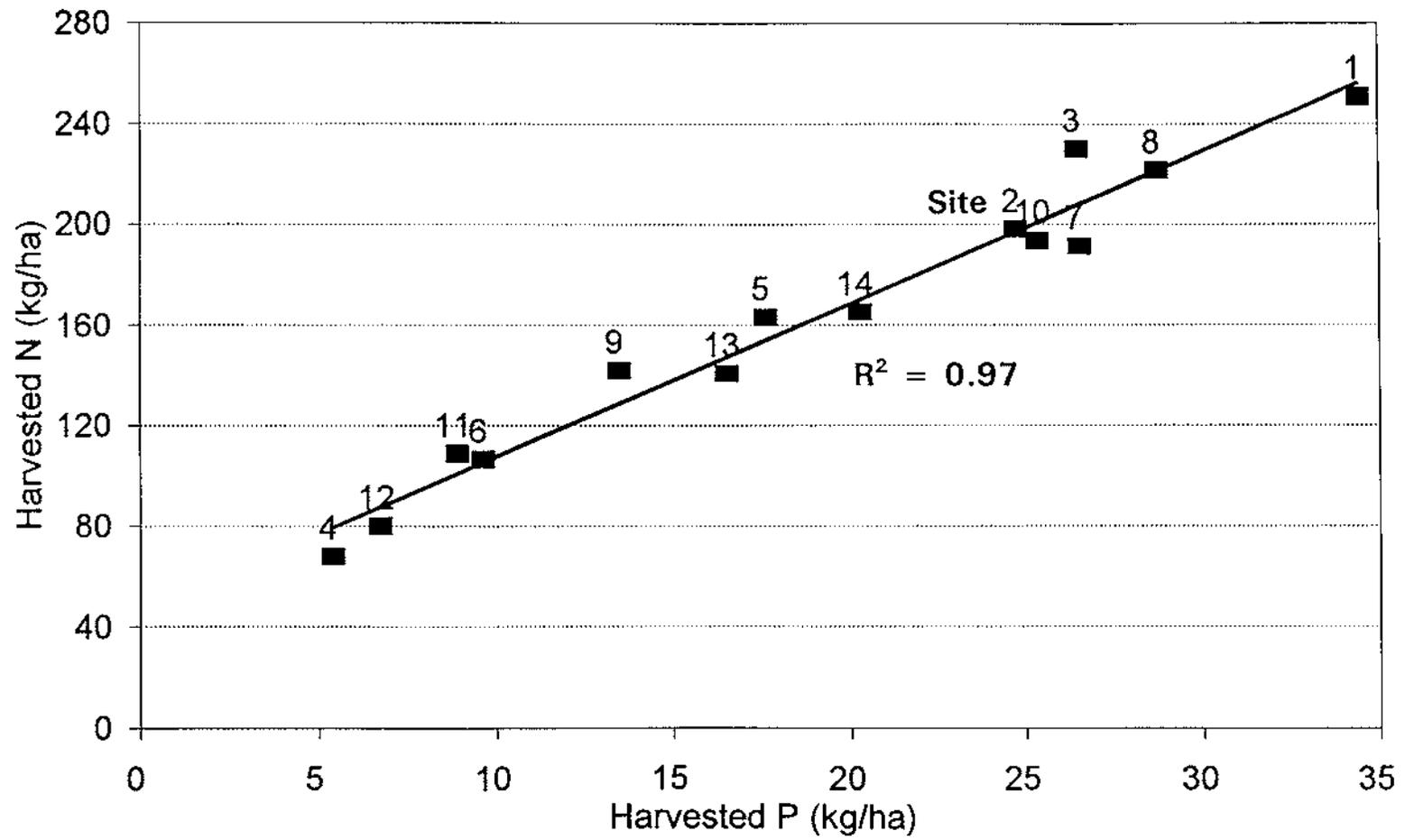


Figure 5.8

The relationship between total harvested P and N over the period 5.8.93 to 9.12.93 (Julian Days 217 to 343)

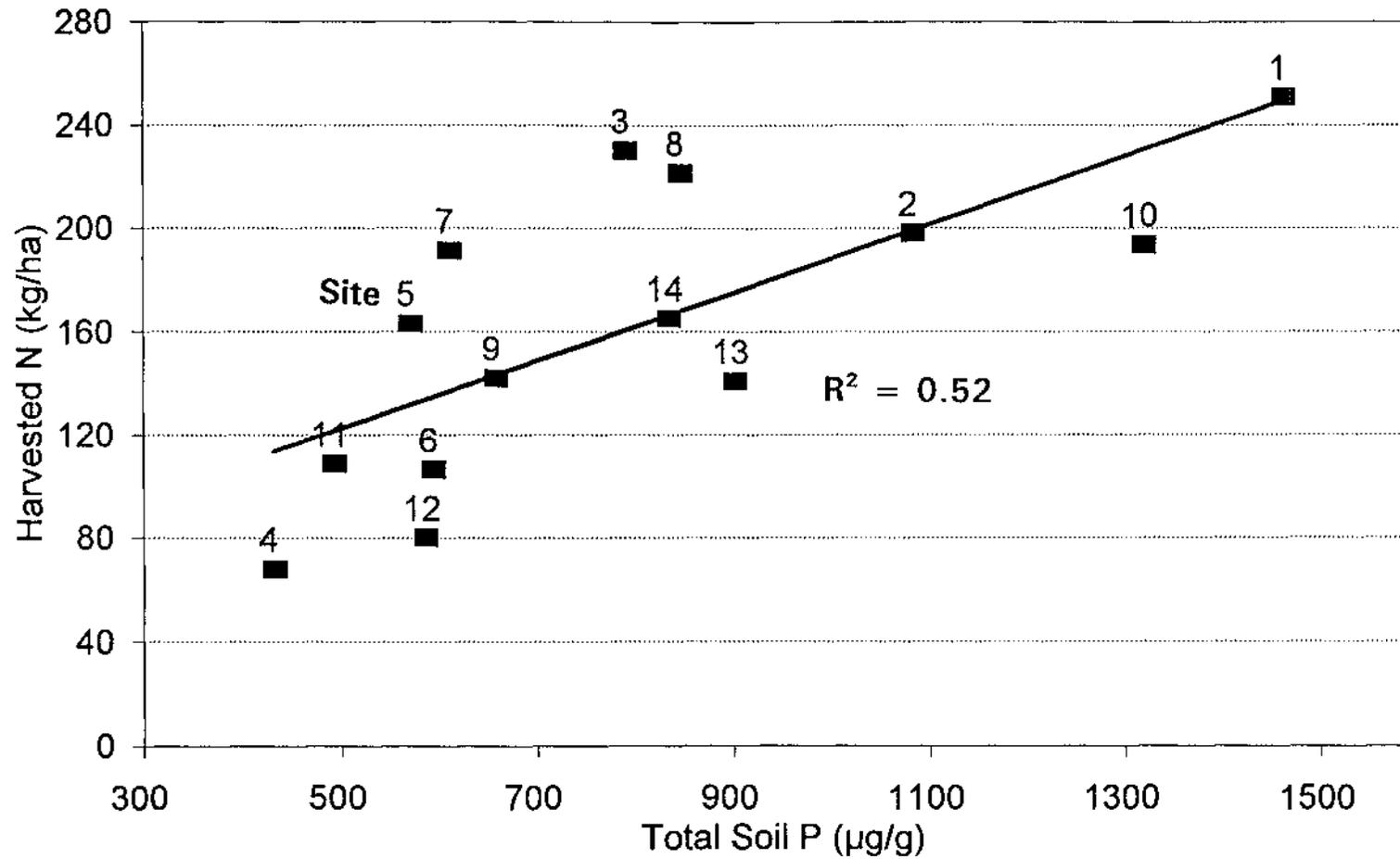


Figure 5.9 The relationship between total N harvested and total soil P over the period 5.8.93 to 9.12.93 (Julian Days 217 to 343)

The purpose of measuring ARA rates was to produce an estimate of the level and rate of N fixation occurring in the legume-based pasture system, and to use this estimate as an index of the level of N input from clovers as a measure of the efficiency of P and S input from fertiliser.

5.7.1 Seasonal Variation of Acetylene Reduction

Acetylene reduction levels for August 1993 to January 1994 (plus one sampling in March) are shown in Figures 5.10a (Mauriceville sites), 5.10b (Gladstone sites) and 5.10c (Whareama sites). Acetylene reduction has a linear relationship with nitrogen fixation (Hoglund and Brock, 1978), and therefore has been used here for convenience as an index of N fixation activity.

It is apparent from these preliminary results that when ARA sampling ceased in January, climate (lack of rainfall) was having a large effect on levels of N fixation. For example in early January ARA activity at Whareama sites had fallen dramatically, due to soil moisture stress. This decline in N fixation was also apparent at Gladstone sites but had only just begun at this time. In contrast, some Mauriceville sites were at their highest recorded level of N fixation in early January, and were showing no sign of declining. This shows a definite effect of climate on nitrogen fixation in this region, where the clovers at the drier Whareama sites had a very short growing season in which to fix nitrogen, while the damper Gladstone sites had a slightly prolonged N fixing period, and Mauriceville sites an even longer period.

Although a definite decline in N fixation to very low levels was shown to occur by March, the N fixation data presented is somewhat incomplete and of a preliminary nature. However, two important observations have been made in this section of study. Firstly, it is apparent that the period in which most N fixation occurs is drastically shortened where early summer dry conditions occur. This short N fixation season will decrease N inputs on an annual basis.

Secondly, it is apparent that N fixation levels in these pastures are low. The highest ARA peak heights in Figures 5.10a to 5.10c represent N fixation levels of around 1.5 kgN/ha/d, which for the spring / early summer period peak N would be assumed to be the highest

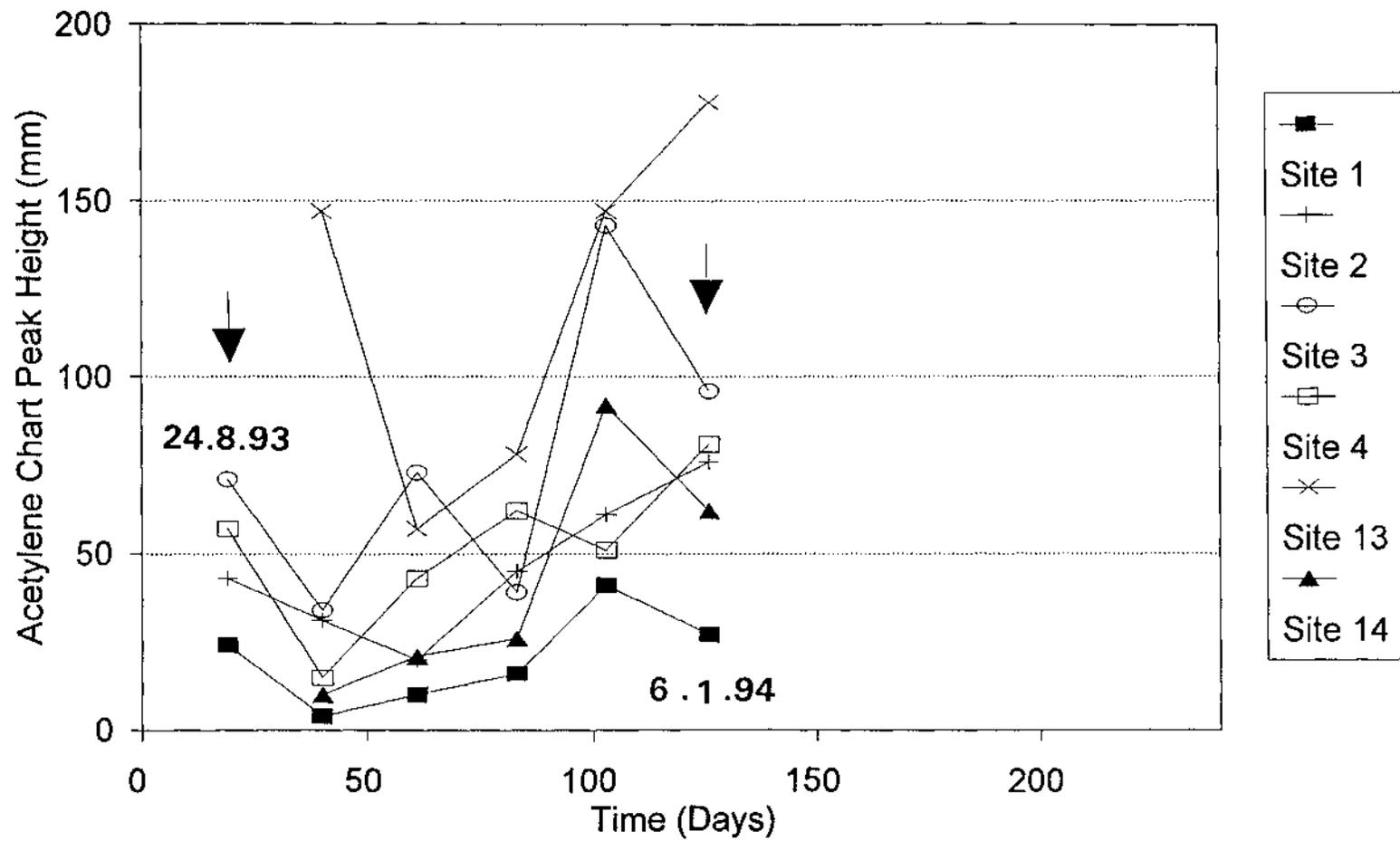


Figure 5.10a

Acetylene reduction activity from 24.8.93 to 6.1.94 at Mauriceville sites

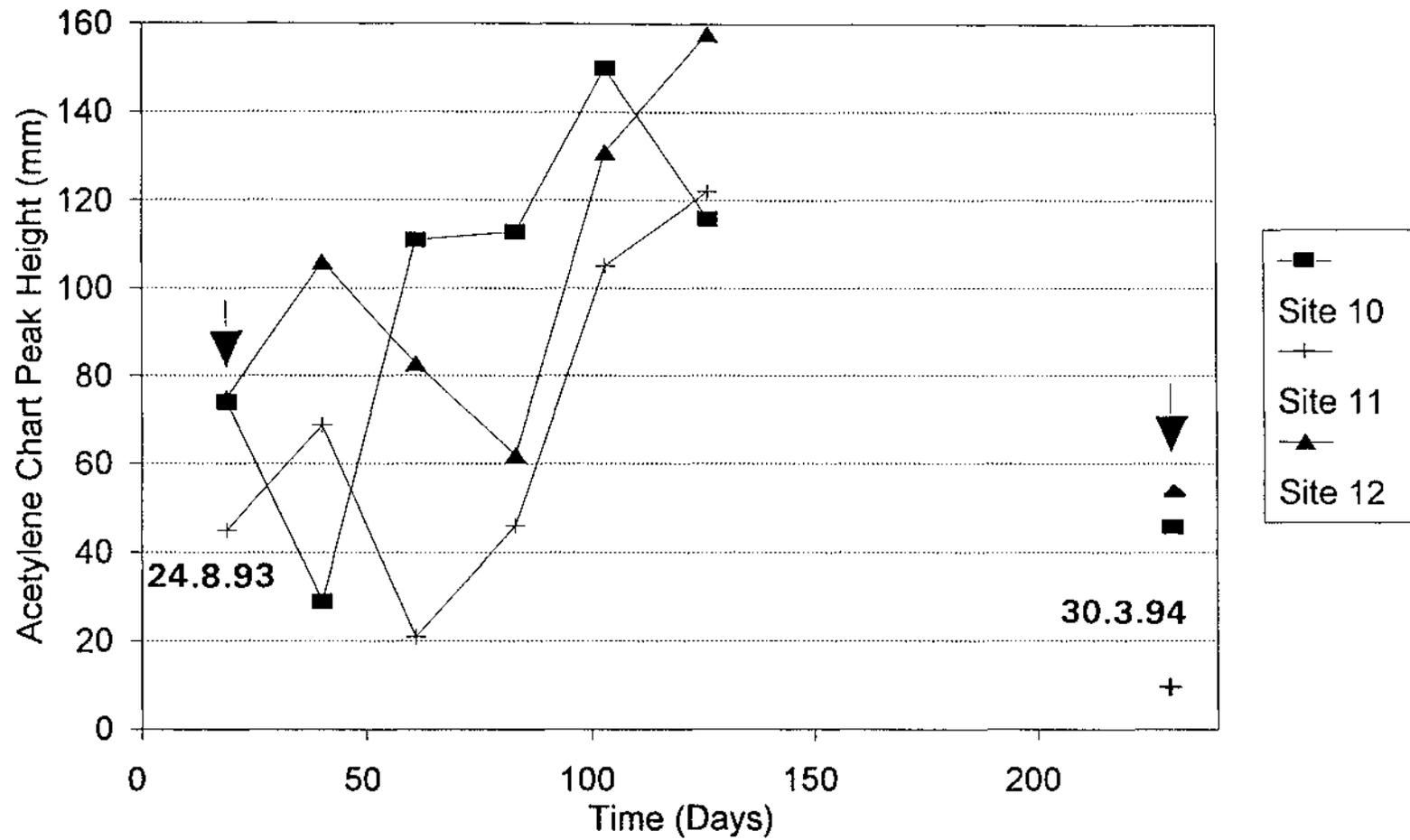


Figure 5.10b

Acetylene reduction activity from 24.8.93 to 30.3.94 at Gladstone sites

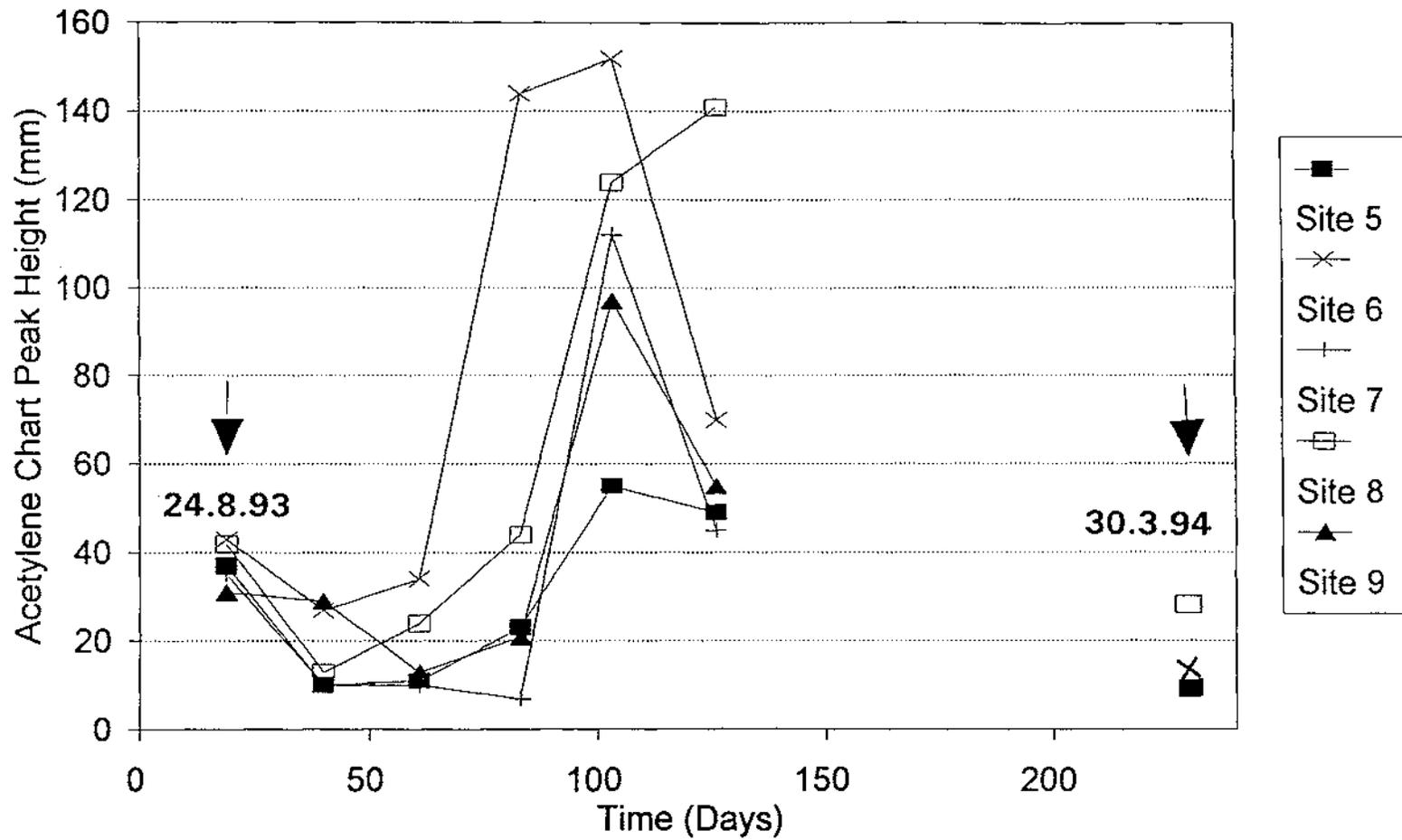


Figure 5.10c Acetylene reduction activity from 24.8.93 to 30.3.94 at Whareama sites

annual N fixation rates. When considering that these are peak N fixing periods which are apparently in some regimes only sustained for short periods, it could be assumed that annual N fixation levels in drier areas of the Wairarapa are low indeed. As a comparison, a general summary of the N fixation rates measured in the D.S.I.R. national series of N-Fixation trials are given in Table 5.2 below (Crouchley, 1979).

It is important to remember that these are preliminary N fixation studies only, and more research is required in order to quantify the annual levels of N fixed in these pastures, and to examine the effect of climate on N fixation and soil N supply.

Table 5.2 Summary of Climate, Herbage Yield and Nitrogen Fixation Levels in the D.S.I.R. National Series of N-Fixation Trials (1979)

Location	Soil Group	Rainfall (mm)	Yield (tDM/ha/yr)	N-Fixed (kgN/ha/yr)
Kaikohe (Northland)	Northern Podzol	1797 (1974) 1704 (1975)	11.4 to 14.1	368 (1974) 392 (1975)
Manutuke (Gisborne)	Central Recent Soil	962 (1974) 842 (1975)	14.1 (1974) 15.2 (1975)	92 (1974) 122 (1975)
Wairakei (Taupo)	Central YBP	1383 (1974) 1240 (1975)	7.3 (1975)	141 (1974) 170 (1975)
"Balantrae" (South N.I.)	YGE/YBE Intergrade	1322 (1974) 1301 (1975)	4.4 to 12.4	10 to 65
Kairanga (Manawatu)	Central Recent Soil	1053 (1974) 1086 (1975)	11.4 (1974) 16.1 (1975)	211 (1974) 242 (1975)
Palmerston North	Central Recent Soil	1079 (1974) 1182 (1975)	12.7	184 (1974) 232 (1975)
Masterton (Wairarapa)	Central YGE	1068 (1974) 854 (1975)	9.4 (1974) 12.2 (1975)	90 (1974) 241 (1975)
Kirwee (Canterbury)	Southern YGE	1088 (1974) 795 (1975)	11.7 (1974) 8.1 (1975)	106 (1974) 145 (1975)
Gore (Southland)	Southern YGE	877 (1974) 933 (1975)	10.3 (1974) 11.7 (1975)	Low

Adapted from *N.Z. Journal of Experimental Agriculture* (1979), Vol 7, 1:1-51.

5.7.2 The Relationship Between Acetylene Reduction Activity and Legume Yield

The relationship between legume yield (at each harvest) and ARA measured on the day of harvest is represented in Figure 5.11. A good linear correlation $R^2=0.63$ existed between legume yield and level of ARA. In general, sites with higher legume yields also fixed more nitrogen. However, there are a number of problems associated with attempting to establish a relationship between harvestable legume yield and ARA.

Firstly, sward composition varies greatly across all sites (Figures 5.4a to 5.4c). Different clovers are present at different sites, and have different growth cycles. For example, site 9 has a large proportion of suckling clovers (annuals), which reach the reproductive stage earlier than perennial clovers, and fix little nitrogen once flowering has occurred. In contrast, site 10 has predominantly white clover (perennial), which will continue to fix nitrogen after flowering. Therefore, in theory, all other factors being constant, sites 9 and 10 could yield the same quantity of legume DM, but site 10 would fix more N on an annual basis.

In addition, on the day of measurement, the ARA will be effected by soil moisture levels, temperature and soil nutrient status. If either is limiting, it is possible that ARA can be substantially reduced, and will not reflect the previous months legume growth. Legume growth may also have been limited during the previous month, whereas on the day of harvest soil conditions may be optimum for ARA.

Therefore it is clear that although there is a reasonably good relationship between ARA and legume DM yield at these sites, more work is required in order to detail the influence of sward composition, soil nutrient status and climate on these indices.

5.8 CONCLUSIONS

In general, spring and summer temperatures were average across most sites, with the exception of a warmer than average December at Mauriceville. Rainfall was below average across most sites in spring, but was followed by a much wetter than average November.

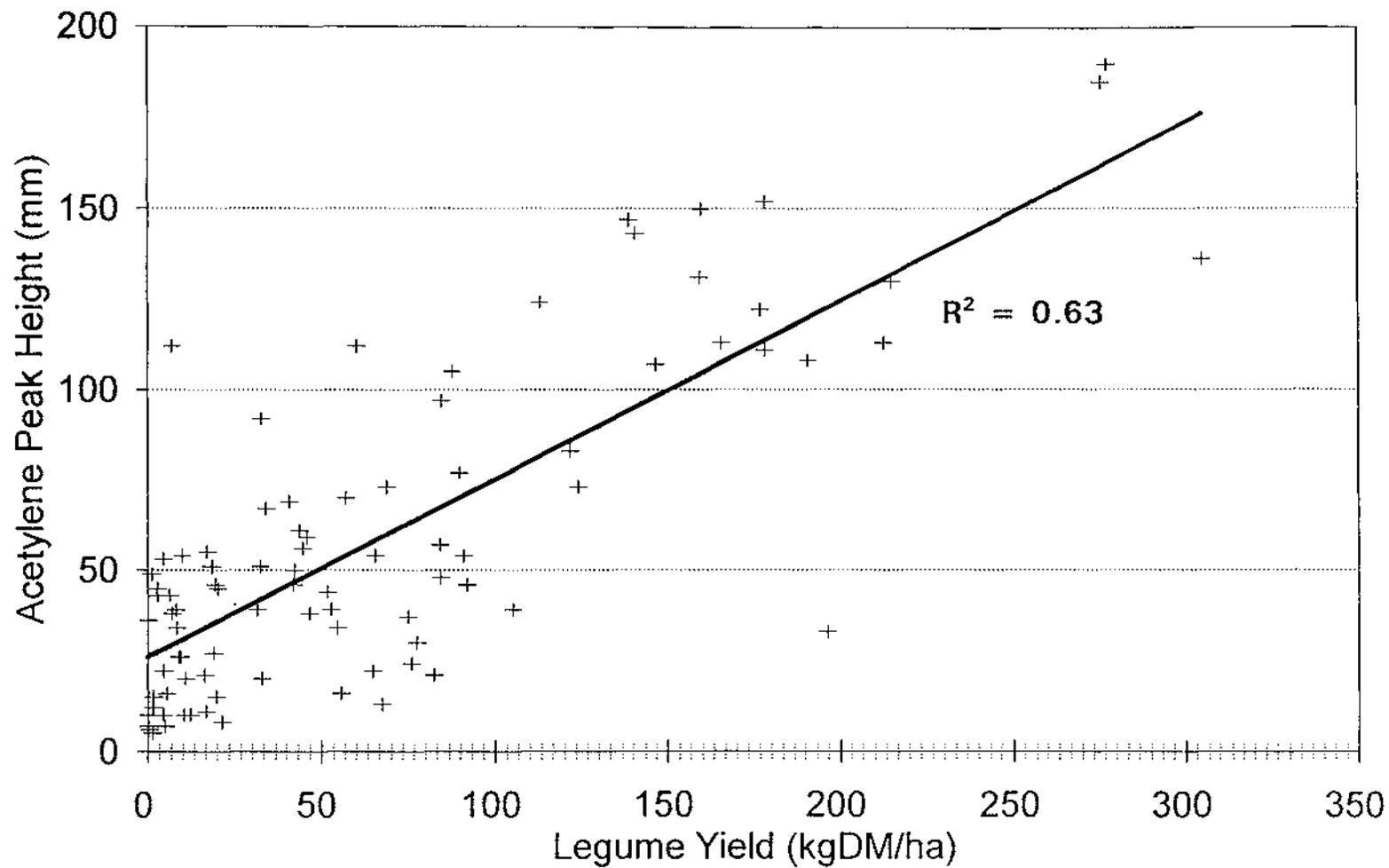


Figure 5.11

The relationship between legume dry matter yield and acetylene reduced for the period 24.8.93 to 30.3.94

Soil moisture contents declined throughout the growing season, as a direct result of climate. Whareama and Gladstone sites dried to low soil moisture levels (volumetric water content = 0.2 or less) much quicker than Mauriceville sites which tended to have adequate soil moisture until late summer. This suggests that climate has major influence over the duration of the main pasture growth period in the selected climate zones, as it was apparent that when soil volumetric water content fell to a level of 0.2 or below, pasture growth stopped at most sites.

Total herbage yield varied from 4 tDM/ha at site 4 to 15.5 tDM/ha at site 1, reflecting the influence of both climate and soil fertility status. It was noted that soil fertility status had a much larger effect on yield than did climate, where very large yield increases were observed at sites with historically high fertiliser inputs i.e. when compared with non-fertilised sites.

Accumulated herbage yield had a curvilinear relationship with Olsen P ($R^2=0.64$) and a linear relationship with sulphate S ($R^2=0.64$). Therefore it appears that pasture yield is P and S limited at these sites. In general, high fertility sites yielded higher than low fertility sites, once again reflecting soil P, S and N deficiencies, and the relative value fertiliser application. It is apparent that the most profitable options, in all rainfall regimes, were sites which had received frequent fertiliser applications. Herbage yield for this growth period had weaker relationships with resin extractable P and mineralisable N, suggesting that these indices are less suitable for predicting pasture yield.

Legume herbage yield ranged from 0.02 tDM/ha at site 7 to 2.7 tDM/ha at site 10. Unlike total herbage yield, legume yield was not correlated with soil fertility status, but instead appeared to be related to climate and historical pasture management.

Measurements of herbage N and P concentrations from August 1993 to January 1994 showed a marked difference in herbage N concentration between legume and grass species, reflecting that nutrient concentrations were changing over the growing season in response to pasture growth conditions i.e. growth rate. However, the pattern of how herbage N and P concentrations changed at different sites was somewhat unclear, therefore more experimental work is required to explain these results.

Total harvested P showed a strong linear correlation with total N harvested ($R^2=0.97$) and a good correlation with total soil P ($R^2=0.52$). This indicates that pasture N and P uptake is strongly related to soil P status and therefore fertiliser history. Greater rates and frequency of fertiliser application (represented by higher total soil P levels) have resulted in increased levels of plant-available soil N. Total harvested N levels were very similar to soil mineralisable N values (as measured by soil incubation), suggesting that such soil incubations may provide valuable information regarding soil levels of plant-available N.

Preliminary acetylene reduction (nitrogen fixation) results showed the marked effect of drought on the duration of peak nitrogen fixation activity. Drier Whareama sites were shown to have a very short period of peak N fixation (late spring), while those sites which dried out later in the season (especially Mauriceville sites) had a significantly longer period of peak N fixation. The implications of these results are discussed, but it is clear that more research is needed in order to fully explain the complex processes involved.

A good linear relationship was found to exist between acetylene reduction activity (ARA) and legume yield ($R^2=0.63$), which suggests that legume yield could be used as a measure of N fixation. However, using legume yield as an index for N fixation levels has limitations, including variation in sward composition, soil nutrient status and climate. Further research is required in order to detail the factors most influencing levels of annual N fixation in these pastures.

CHAPTER 6: CONCLUSION AND INTERPRETATION

6.1 INTRODUCTION

During the agricultural depression of the mid-1980's, sustainability of soil fertility in the Wairarapa region was being questioned because low farmer income had reduced or removed maintenance fertiliser inputs. Researchers were required to answer the question, "What levels of fertiliser inputs produced sustainable productivity?"

However, the slight upturn in farm profitability during the early 1990's has slightly changed the question. The focus is now on how to best maintain the productivity of pasture soils in this region. Do traditional P and S fertiliser applications stimulate pasture legumes to fix nitrogen in quantities adequate for pasture growth, or would a blend of N plus P and S fertilisers be a more efficient fertiliser policy?

Whatever the soil productivity question, the first stage attempted by any researcher is to characterise and describe the climate, soil nutrient status and current pasture productivity. Such characterisation has been the main objective of this current study, with the view of undertaking future studies examining in more detail the complex soil / climate / pasture interactions in hill country soils of the Wairarapa. Hence the focus of this current study could be described as the examination of the influence of past fertiliser applications on current levels of pastoral productivity, in different rainfall regimes of Wairarapa hill country.

6.2 LITERATURE REVIEW (CHAPTER 2)

A review of literature indicated that research detailing the influence of historical fertiliser applications on soil characteristics and pasture production is scarce for the different rainfall regimes and soil groups of the Wairarapa region. It was concluded from a review of climate and soil resources that it was necessary to find a series of pasture sites varying in fertiliser history, within each rainfall regime for the study to be applicable to Wairarapa hill country. Measurements such as total soil P, S, N, C and plant-available P and S have been shown to be useful indicators of past productivity and fertiliser history. Field measurements of nitrogen

fixation levels were indicated as being useful for gauging the effectiveness of legume based pasture systems.

6.3 SOIL SURVEY (CHAPTER 4)

Analyses of soils from 14 sites in the Wairarapa, each varying in fertiliser history and climate regime, provided valuable information about changes in soil characteristics that have taken place because of different fertiliser application histories.

Fertiliser history had a large influence on the accumulation of soil P, S and N in hill country soils of this region. Over all sites, P, S and N accumulated more rapidly where higher or more frequent fertiliser applications (either single superphosphate (SSP) or diammonium phosphate) took place.

Much less total S has accumulated at these sites than total P (total soil P:total soil S ranged from 1:0.7 to 1:1 at low fertility sites, and from 2.2:1 to 1.1:1 at high fertility sites), and when considering that traditional fertiliser applications (SSP) have an approximate P:S ratio of 9:11, it seems that S (leaching) losses may be high. In addition, soil total N levels followed a very similar pattern to that of total soil S. This was explained in terms of both soil N and S being stored primarily in organic matter. Soil P analyses appeared to be a more reliable method of estimating soil fertility status and fertiliser history than the documented fertiliser history.

Estimates of the efficiency of past fertiliser applications were made for these sites, using the results of various soil analyses. It was concluded that in this legume based pasture system, the past application of P and S fertiliser to stimulate legume growth and N fixation/soil N input appears to be particularly inefficient at increasing the amounts of soil N stored in Wairarapa hill country soils. These calculations had a number of limitations, but did tend to suggest that either N fixation rates are low or N leaching, product losses etc are large in these soils. Further research is needed to fully explain these results.

6.4 SEASON'S PASTURE PRODUCTION (CHAPTER 5)

Over the 1993/94 growing season, it was apparent that climate had a major influence over pasture yield across all three selected climate zones. Using sites of comparative high fertility status, it was shown that wetter Mauriceville sites (15.5 tDM/ha) yielded more pasture dry matter than Gladstone sites (10 tDM/ha), which in turn yielded more than the drier Whareama sites (8.1 TDM/ha). However, it was shown that across all sites, soil fertility status had a greater influence on pasture yield than did climate, where higher total yields were associated with higher levels of fertility e.g. site 4 (Olsen P = 9 $\mu\text{gP/g}$) yielded 4 tDM/ha while site 1 (Olsen P = 40 $\mu\text{gP/g}$) yielded 15.5 tDM/ha. Therefore, it is apparent that large increases in herbage yield have resulted from historical superphosphate applications at these sites.

A simplified gross margin calculation based, on field measurements of pasture yield, was used to assess the economics of past fertiliser applications (Appendix 2). The most profitable options in all rainfall regimes were sites which had received frequent fertiliser applications. Therefore, good fertiliser histories are economically efficient, which is an important factor in assessing the sustainability of agricultural practices.

Using herbage N and P analyses, pasture growth was indeed shown to be N and P limited at these sites, and that greater rates and frequency of fertiliser application resulted in large increases in pasture N uptake i.e. when compared with that of low fertility sites. This implies that past P and S fertiliser applications provide a current soil fertility status that is effective in providing large increases in plant-available soil N (sourced from pasture legumes) compared to unfertilised systems.

Preliminary N fixation results indicated that levels of annual N inputs from legumes may be low where climate (i.e. soil moisture) is the main factor limiting legume growth. The duration of the summer peak period of N fixation (early summer) was longer at the wetter Mauriceville sites than at drier sites (Whareama and Gladstone). Annual soil N inputs may be higher at Mauriceville sites as a result of climate. The proportion of legume in the sward and the legume species present in the sward had a marked effect on annual N fixation levels.

Swards having higher clover content, particularly perennial clover species, fixed the highest levels of N on an annual basis. Further research is required in order to fully explain the seasonal variation in the preliminary N fixation data.

As noted earlier, soil P accumulation due to the application of superphosphate is far greater than the accumulation of soil N and S in the hill country soils of the Wairarapa. Therefore, fertiliser P use appears ineffective at raising soil N status. However, it is also apparent that although soil N accumulation is very slow, there is a large increase in herbage yield and pasture N uptake where fertiliser P and S inputs have been higher.

It is possible therefore, that a very rapid cycling of soil/plant N is occurring in this legume based pasture system. This would to some extent explain the large increases in pasture yield with increased fertiliser use, and the slow accumulation of soil N. It is suggested that annual leaching and losses of N from the system are large and nearly equal to the annual N fixation rates.

A simplified N cycle for Wairarapa hill country pastures is shown in Figure 6.1, using a high fertility (site 1) and low fertility (site 4) site as examples. Annual nitrogen fixation levels, pasture N uptake and total soil nitrogen values are those obtained in the course of this study, while N leaching loss is estimated to be 14 kgN/ha/yr (Lambert et al, 1982), and N loss from product and stock transfer is estimated to be 8 kgN/ssu/yr (During, 1984a). Stocking rates of 6.5 and 20 ssu/ha were assumed for the low and high fertility sites respectively (see gross margin analysis, Appendix 2).

When taking account of all N losses and gains in this system (Figure 6.1), net annual soil N accumulation in the high and low fertility situation should approximate 279 and 36 kgN/ha/yr respectively. However, it is apparent from relatively small differences in total soil N levels between sites that N has not been accumulating at the high fertility site at this rate, or at least not for any extended period of time.

Using the available data, it must therefore be concluded that N is not accumulating as quickly as expected at the high fertility site. The reason for this slow accumulation of soil N is

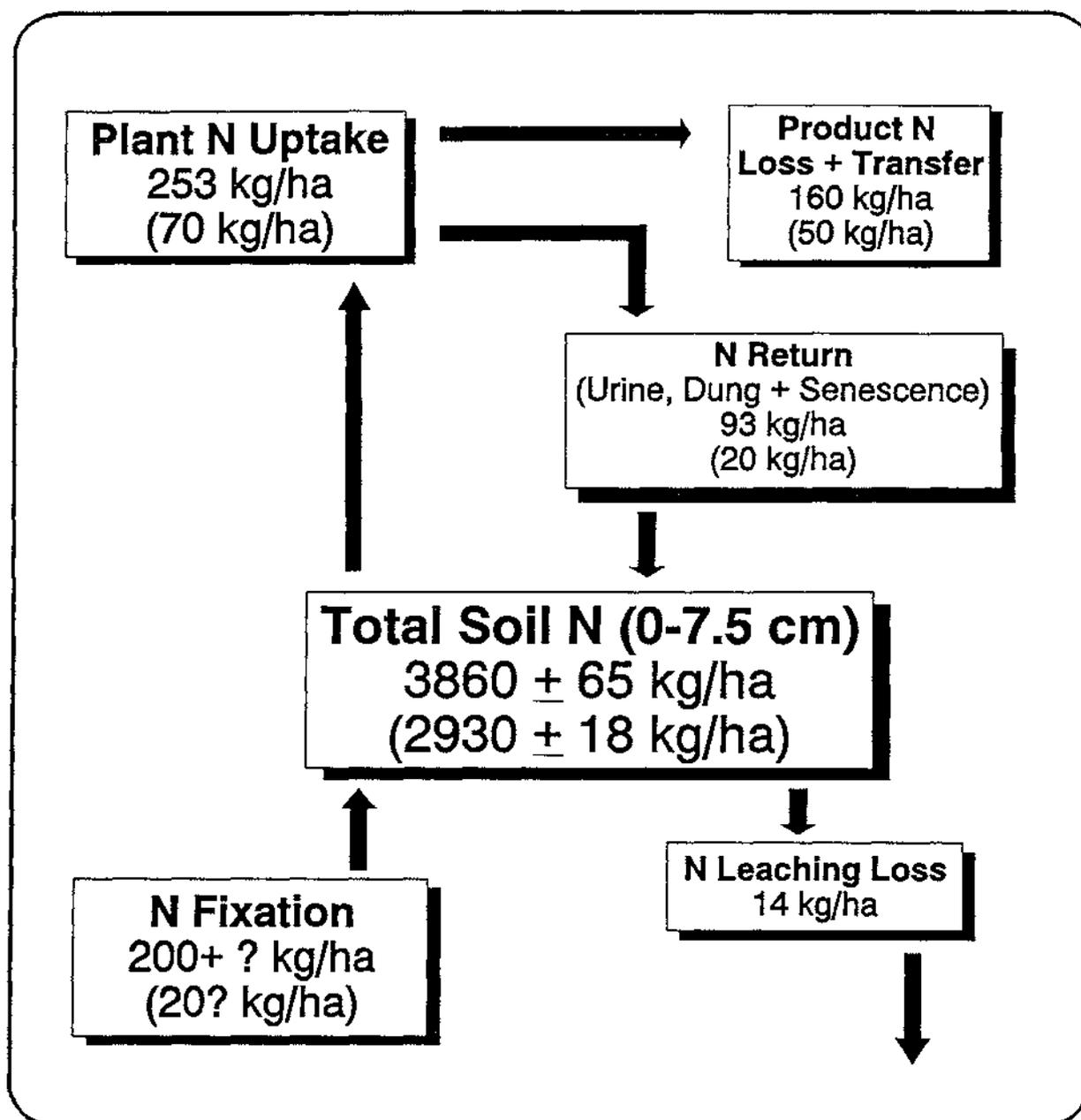


Figure 6.1 A simplified annual nitrogen cycle in high fertility and (low fertility) Wairarapa hill country pasture.

uncertain, but may result from N losses being greater and/or N fixation rates being lower than those estimated. Another reason may be that all N entering the system is going back into the cycle, and hence very little N is left to accumulate in the soil, resulting in very slow soil N accumulation.

Therefore, further research is required in order to fully quantify the inputs and losses of soil N, and therefore detail the N cycle in this legume based pasture system.

Levels of nutrient cycling need to be quantified before definite conclusions can be drawn regarding the efficiency of historical superphosphate fertiliser applications on soils of the Wairarapa hill country.

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Appendix 1 Calculation of soil nutrient accumulation (from fertiliser application) and nutrient loss

Site 8

Year	Fertiliser	Rate (kg/ha)	%P	%S	%N	kgP/ha	kgS/ha	kgN/ha	P Loss
1960	Nil	0	0	0	0	0.00	0.00	0.00	-4
1961	Superphosphate	250	9	11	0	22.50	27.50	0.00	-4
1962	Nil	0	0	0	0	0.00	0.00	0.00	-4
1963	Superphosphate	250	9	11	0	22.50	27.50	0.00	-4
1964	Nil	0	0	0	0	0.00	0.00	0.00	-4
1965	Superphosphate	250	9	11	0	22.50	27.50	0.00	-4
1966	Nil	0	0	0	0	0.00	0.00	0.00	-4
1967	Superphosphate	250	9	11	0	22.50	27.50	0.00	-4
1968	Nil	0	0	0	0	0.00	0.00	0.00	-4
1969	Superphosphate	250	9	11	0	22.50	27.50	0.00	-4
1970	Nil	0	0	0	0	0.00	0.00	0.00	-4
1971	Superphosphate	250	9	11	0	22.50	27.50	0.00	-4
1972	Nil	0	0	0	0	0.00	0.00	0.00	-4
1973	Superphosphate	250	9	11	0	22.50	27.50	0.00	-4
1974	Nil	0	0	0	0	0.00	0.00	0.00	-4
1975	Superphosphate	250	9	11	0	22.50	27.50	0.00	-4
1976	Nil	0	0	0	0	0.00	0.00	0.00	-4
1977	Superphosphate	250	9	11	0	22.50	27.50	0.00	-4
1978	Nil	0	0	0	0	0.00	0.00	0.00	-4
1979	Superphosphate	250	9	11	0	22.50	27.50	0.00	-4
1980	Superphosphate	250	9	11	0	22.50	27.50	0.00	-4
1981	Superphosphate	250	9	11	0	22.50	27.50	0.00	-4
1982	Superphosphate	250	9	11	0	22.50	27.50	0.00	-4
1983	DAP	75	20	2	18	15.00	1.50	13.50	-4
1984	Superphosphate	167	9	11	0	15.03	18.37	0.00	-4
1985	DAP	75	20	2	18	15.00	1.50	13.50	-4
1986	Superphosphate	167	9	11	0	15.03	18.37	0.00	-4
1987	DAP	75	20	2	18	15.00	1.50	13.50	-4
1988	Superphosphate	167	9	11	0	15.03	18.37	0.00	-4
1989	DAP+S	75	20	13	18	15.00	9.75	13.50	-4
1990	Superphosphate	167	9	11	0	15.03	18.37	0.00	-4
	Urea	65	0	0	46	0.00	0.00	29.90	0
1991	DAP+S	75	20	13	18	15.00	9.75	13.50	-4
1992	Superphosphate	167	9	11	0	15.03	18.37	0.00	-4
1993	DAP+S	75	20	13	18	15.00	9.75	13.50	-4
Total						457.65	483.10	110.90	-136
Nett Accumulation						321.65			

Appendix 1 (continued)

Site 6

Year	Fertiliser	Rate (kg/ha)	%P	%S	%N	kgP/ha	kgS/ha	kgN/ha	P Loss
1960	Superphosphate	250	9	11	0	22.50	27.50	0.00	-6
1961	Superphosphate	250	9	11	0	22.50	27.50	0.00	-6
1962	Superphosphate	250	9	11	0	22.50	27.50	0.00	-6
1963	Superphosphate	250	9	11	0	22.50	27.50	0.00	-6
1964	Superphosphate	250	9	11	0	22.50	27.50	0.00	-6
1965	Superphosphate	250	9	11	0	22.50	27.50	0.00	-6
1966	Superphosphate	250	9	11	0	22.50	27.50	0.00	-6
1967	Superphosphate	250	9	11	0	22.50	27.50	0.00	-6
1968	Superphosphate	250	9	11	0	22.50	27.50	0.00	-6
1969	Superphosphate	250	9	11	0	22.50	27.50	0.00	-6
1970	Superphosphate	250	9	11	0	22.50	27.50	0.00	-6
1971	Superphosphate	250	9	11	0	22.50	27.50	0.00	-6
1972	Superphosphate	250	9	11	0	22.50	27.50	0.00	-6
1973	Superphosphate	250	9	11	0	22.50	27.50	0.00	-6
1974	Superphosphate	250	9	11	0	22.50	27.50	0.00	-6
1975	Superphosphate	250	9	11	0	22.50	27.50	0.00	-6
1976	Superphosphate	250	9	11	0	22.50	27.50	0.00	-6
1977	Superphosphate	250	9	11	0	22.50	27.50	0.00	-6
1978	Superphosphate	250	9	11	0	22.50	27.50	0.00	-6
1979	Superphosphate	250	9	11	0	22.50	27.50	0.00	-6
1980	Superphosphate	250	9	11	0	22.50	27.50	0.00	-6
1981	Superphosphate	250	9	11	0	22.50	27.50	0.00	-6
1982	Superphosphate	250	9	11	0	22.50	27.50	0.00	-6
1983	Superphosphate	250	9	11	0	22.50	27.50	0.00	-6
1984	Nil	0	0	0	0	0.00	0.00	0.00	-6
1985	Nil	0	0	0	0	0.00	0.00	0.00	-6
1986	Nil	0	0	0	0	0.00	0.00	0.00	-6
1987	Nil	0	0	0	0	0.00	0.00	0.00	-6
1988	Hyphos S	110	7	28	0	7.70	30.80	0.00	-6
1989	Nil	0	0	0	0	0.00	0.00	0.00	-6
1990	Nil	0	0	0	0	0.00	0.00	0.00	-6
1991	Sulphur Super	200	8	20	0	16.00	40.00	0.00	-6
1992	Nil	0	0	0	0	0.00	0.00	0.00	-6
1993	DAP+S	95	20	13	18	19.00	12.35	17.10	-6
Total						582.7	743.15	17.1	-204
Nett Accumulation						378.7			

All following income calculations are based on a Wairarapa hill country property, with a sheep:cattle ratio of 70:30, and pasture production based on measurements made from 8/1993 to 3/1994. No dept servicing, wages, interest or taxation have been accounted for in these calculations. All values given are on a per hectare basis.

1. MAURICEVILLE

	Low Fertility	High Fertility
Pasture Yld ¹	4 tDM	15 tDM
Stocking Rate ²	6.5 ssu	25 ssu
Gross Margin/ha		
(a) Cattle ³	\$92	\$353
(b) Sheep ⁴	\$114	\$263
Total GM/ha	\$206	\$616
Expenditure		
(a) Working Expenses ⁵	\$37	\$143
(b) Repair & Maint. ⁶	\$24	\$24
(c) Fertiliser ⁷	\$0	\$52
Total Expenditure/ha	\$61	\$219
Total GM/ha	\$145	\$397

¹ using production parameters measured in tDM/ha at sites 1 and 4 (assuming this represents annual pasture production).

² estimated stocking rate assuming 1 ssu = 600 kgDM/yr

³ using a cattle GM of \$47/ssu (Lincoln University Farm Management Department, 1993), which includes all direct animal husbandry expenditure.

⁴ using a sheep GM of \$25/ssu (Lincoln University Farm Management Department,

1993), which includes all direct animal husbandry expenditure.

⁵ assuming \$5.7/ssu

⁶ assuming \$24/ha

⁷ assuming an application rate of 200 kg/ha/yr superphosphate, costing \$52/ha/yr applied

Note: all assumptions made above also apply to Gladstone and Whareama sites, unless stated otherwise.

2. GLADSTONE

	Low Fertility	High Fertility
Pasture Yld ¹	5 tDM	10.5 tDM
Stocking Rate ²	8.3 ssu	17.5 ssu
Gross Margin/ha		
(a) Cattle ³	\$117	\$247
(b) Sheep ⁴	\$145	\$306
Total GM/ha	\$262	\$553
Expenditure		
(a) Working Expenses ⁵	\$47	\$100
(b) Repair & Maint. ⁶	\$24	\$24
(c) Fertiliser ⁷	\$0	\$52
Total Expenditure/ha	\$71	\$176
Total GM/ha	\$191	\$377

¹ using pasture production measured at sites 10 and 12

Appendix 2 (continued)

3. WHAREAMA

	Low Fertility	High Fertility
Pasture Yld ¹	4.8 tDM	8.2 tDM
Stocking Rate ²	8 ssu	13.7 ssu
Gross Margin/ha		
(a) Cattle ³	\$113	\$193
(b) Sheep ⁴	\$140	\$240
Total GM/ha	\$253	\$433
Expenditure		
(a) Working Expenses ⁵	\$46	\$78
(b) Repair & Maint. ⁶	\$24	\$24
(c) Fertiliser ⁷	\$26	\$52
Total Expenditure/ha	\$96	\$154
Total GM/ha	\$157	\$279

¹ using pasture production measured at sites 10 and 12

⁷ assuming below maint. fertiliser application of 100 kg superphosphate /ha/yr, costing \$26/ha applied.