SOIL AMELIORATION AND BORON NUTRITION EFFECTS ON THE GROWTH OF SUNFLOWERS (*Helianthus annuus* L.) ON AN AVALON MEDIUM SANDY LOAM

by

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DECLARATION

I declare that the results contained in this thesis are from my own original work except as acknowledged herein

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CONTENTS

ABSTRACT

Studies with sunflowers (*Helianthus annuus*) on an Avalon medium sandy loam, both in pots and in the field, indicated that the poor growth of this crop on this soil was largely due to soil acidity. Marked improvements in plant growth were brought about by liming as shown by measurements of emergence, seedling mass, population, plant heights, leaf areas and yield. Based largely on soil and plant analyses, it was concluded that improved growth with soil amelioration resulted from reduced aluminium toxicity and, since lime was more efficient than gypsum in neutralizing toxic Al, lime was markedly superior to the latter in improving plant growth. An annual application of 2 400 kg agricultural lime/ha increased seed yields >5 fold in the first and >10 fold in the second season in which the field experiment was carried out. In the pot experiment, no benefit of liming above the level required to neutralize toxic Al (~pH (N KCl) 4,5) was recorded and, on the contrary, yields tended to be depressed above this level. Highly significant linear relationships between yield and exch. Al (meq/100g) were recorded in the pot and field experiements and, averaged over two seasons, seed yields in the field were increased 12% for each 0,1 meq/100g reduction in exch. Al. Another factor which decreased sunflower seed yields on this soil was boron deficiency and symptoms of B deficiency in the field were identified and described. At the levels of boron in the unfertilized soil, this deficiency affected the reproductive, rather than the vegetative stage of growth and correction of B deficiency by applying 10 kg borax/ha per annum increased seed yields by 38% and 18% in the two seasons, respectively. Soil amelioration had only a slight effect on the boron nutrition of sunflowers in this study. The chemical composition of the plant tissue was found to be a suitable means of quantifying B deficiency in sunflowers, the B concentration being a slightly superior method in most cases to the Ca:B ratio in plant tissue. Using field data, critical B concentrations in (i) month-old seedlings, (ii) the topmost, fully-mature leaf at flowering and (iii) in the seed were determined. The relationships were established between the amount of borax applied to the soil and the B concentration in plant tissues and these relationships could be used as a basis for recommending corrective B fertilization.

INTRODUCTION

For many years, it has been accepted in South Africa that sunflowers (Helianthus annuus) do not grow well on sandy soils. No definite reasons for the poor growth were put forward but, in general, it has led to sunflower production being confined primarily to soils of heavier texture.

This investigation was initiated to study the possible causes of poor sunflower growth on sandy soils. On the Avalon medium sandy loam, described by Farina & Graven (1972), at the Dundee Agricultural Research Station, sunflower growth had been noted to be extremely poor. Germination and emergence were erratic and, soon after emergence, many seedlings died. Further growth and yield of the crop were seriously affected. Furthermore, root development was extremely poor and restricted to a depth of less than ~10 cm.

Soils of the Avalon[1] and associated forms are widespread throughout the Tugela Basin of Northern Natal (Van Der Eyk, MacVicar & De Villiers, 1969; Farina, 1970) and are derived from the Ecca shales and sandstones laid down in large bodies of fresh water 250 - 750 million years ago (King, 1972). The predominant clay minerals are kaolinite and illite (Ludorf & Scotney, 1975). These soils are also common throughout the important grain-producing areas of the Highveld.

With correct management, the deeper soils of the Avalon form have a high cropping potential. To realise this potential, however, particular attention must be paid to soil fertility since native nutrient levels are low. The organic carbon level in the soil is particularly low, being only ~0,3% in the A horizon of the Avalon medium sandy loam (Van Der Eyk et al., 1969).

On this soil, deficiencies of N, P and K have been recorded. In particular, the nitrogen and phosphorus reserves are low and marked responses of maize (Zea mays) to applications of these nutrients have been recorded (Farina & Mapham, 1973). Potassium deficiency has been recorded, particularly in the A horizon, but appreciable K reserves are present in the plinthic, B_{22} horizon (Farina, 1970). Besides shortages of N, P and K, deficiencies of other nutrients have been observed. Deficiencies of sulphur in trudan (Sorghum sudanense) (Croft & Graven, 1974) and boron in groundnuts (Arachis hypogaea) (Snyman, 1972) have been recorded.

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1 Alfisols and Ultisols

Molybdenum deficiency in maize has been recorded (Blamey, 1971) and zinc deficiency symptoms in this crop have also been observed. Magnesium deficiency symptoms in maize have also been identified, in spite of appreciable Mg reserves in the subsurface horizons.

Correctly fertilized, maize grain yields of over 10 000 kg/ha have been recorded on the Avalon medium sandy loam. With these yields, however, rapid nutrient removal occurs. This would seriously limit subsequent cropping on this soil which has a base saturation of ~60% and a cation-exchange capacity of only 1,6 meq/100g in the A horizon (Farina & Graven, 1972).

In the soil at the site under study (Appendix I; Plate 1), previous cropping practices have undoubtedly resulted in appreciable nutrient removal since the base saturation was only 47%. From a physical point of view, however, the soil is well-suited to cropping. The medium sandy loam A horizon has the advantages of light soil texture but excess leaching of nutrients is prevented by the heavier B_{21} and B_{22} horizons. The heavier textured, sub-surface horizons also prevent excess moisture loss which reduces the severity of periodic, mid-summer droughts.

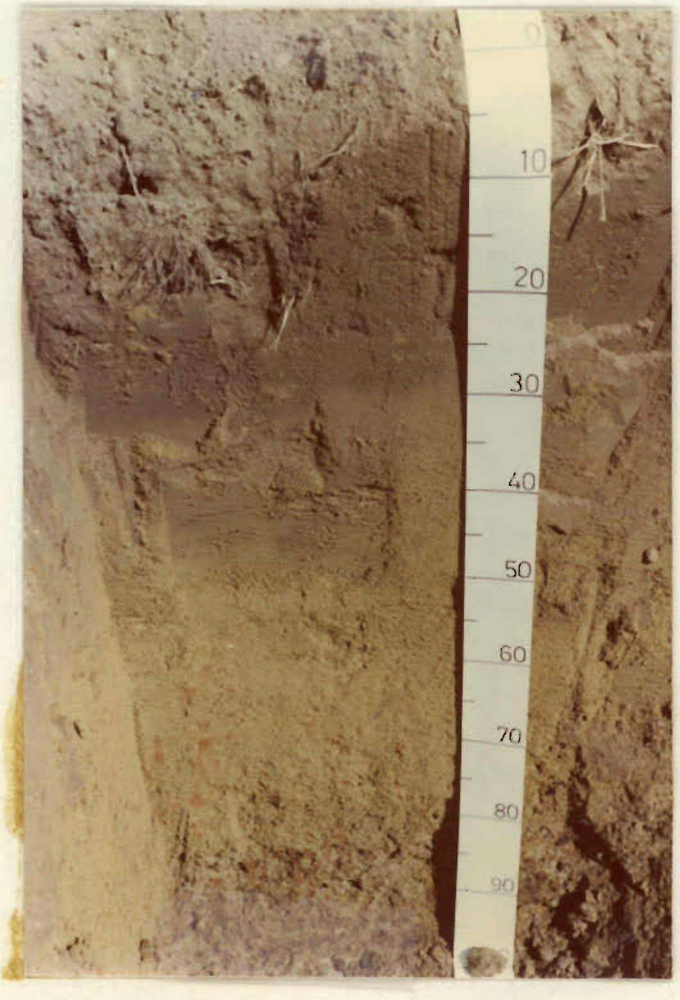

PLATE 1 The Avalon soil form (depth in cm)

Climatically, the drier phase of the Tall Grass Veld (Phillips, 1969) is well-suited to sunflower seed production. A fairly long growing season, in excess of 150 days, is experienced during which approximately 80% of the 740 mm annual rain falls (Table 1).

TABLE 1 Selected mean agrometeorological data for Dundee Agricultural Research Station (1968/69 - 1974/75)

Month	Temperature (°C)			Rainfall	Class A pan evap.
	Max	Min	Mean	(mm)	(mm)
July	20,0	1,2	10,6	7	73
August	22,1	3,4	12,7	32	149
September	25,1	7,6	16,4	19	161
October	26,6	11,2	18,9	60	196
November	25,8	12,6	19,2	96	162
December	27,8	14,0	20,9	116	168
January	27,6	15,0	21,3	151	193
February	26,3	14,2	20,3	109	165
March	26,1	13,3	19,7	65	130
April	23,2	11,2	17,2	61	108
May	21,1	5,6	13,4	17	90
June	19,4	0,6	10,0	6	80
			Totals	739	1 675

On a Doveton clay loam, at the Dundee Agricultural Research Sation, good yields of sunflower seed have been recorded over a number of seasons (Blamey & Chapman, 1975). Seed yields of the low oil (32%), open-pollinated cultivar, Kort Rus, have exceeded 3 000 kg/ha. Yields of the high oil (> 40%), open-pollinated cultivars have been appreciably less. The cultivar, Smena, for example, with an oil concentration of 44% in the seed, produced 1 200 kg seed/ha (Blamey & Chapman, 1975).

In South Africa, the demand for vegetable oil has increased appreciably in the past few years, particularly since the introduction of yellow margarine which, by law[2], must be made from vegetable oil. To meet this demand, increasing areas have been planted to the two most important oilseed crops, groundnuts and sunflowers, resulting in increased oilseed production (Fig. 1). In 1972/73, the area planted to sunflowers was 346 000 ha yielding 233 000 tonne sunflower seed (Anonymous, 1974) of which 74% was of the high oil type.

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[2] Government Gazette R1495 of 22nd August 1971

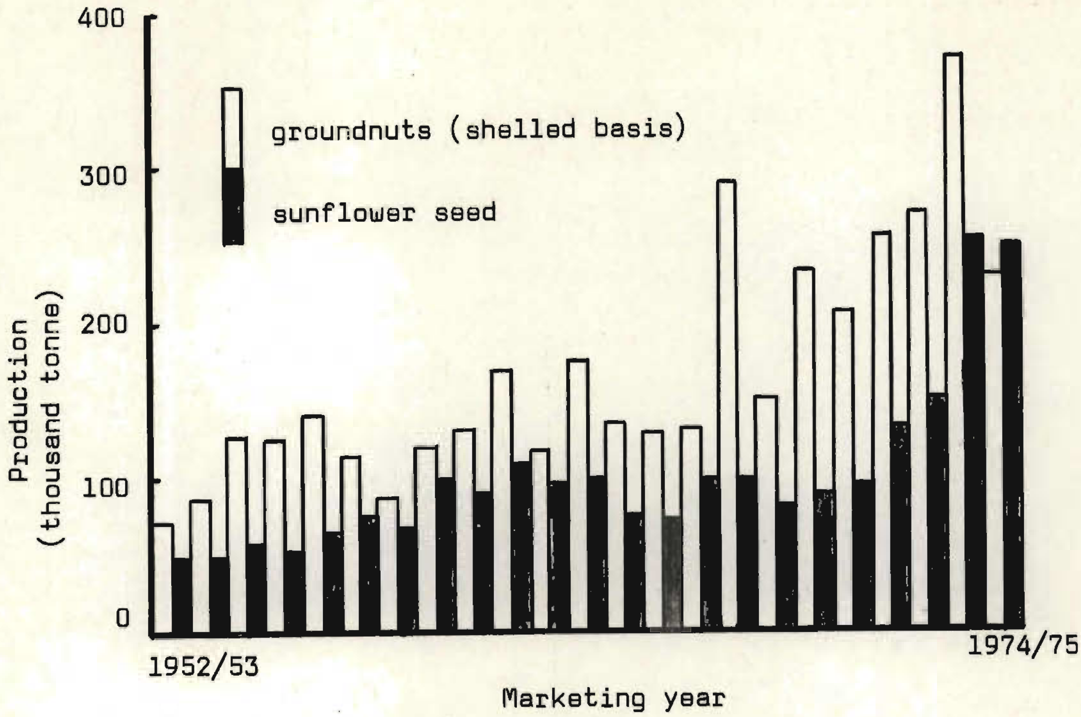

FIG. 1 Groundnut and sunflower seed production for the marketing years 1952/53 to 1974/75 (Anonymous, 1973; Anonymous, 1974)

In spite of the increasing production of vegetable oil, sunflower seed yields per ha have not increased appreciably, averaging 728 kg/ha from 1970/71 to 1972/73 (Anonymous, 1974). Although sunflowers are not widely grown on the Avalon soil, this study aimed not only at solving certain production problems on this more difficult soil but also at providing insight into problems that might limit production on less extreme soils.

Preliminary investigations in pots and in the field (unpublished), indicated that two separate but interrelated factors seriously limited sunflower growth on the Avalon medium sandy loam, viz soil acidity and boron deficiency. This thesis is limited to the study of certain aspects of these two problems in their effects on sunflower growth on the Avalon medium sandy loam.

CHAPTER I

AMELIORATION OF AN ACID AVALON MEDIUM SANDY LOAM AND EFFECTS ON THE GROWTH OF SUNFLOWERS: I SOIL ANALYSIS

INTRODUCTION

The liming of acid soils, in order to improve crop growth, has been an agricultural practice for centuries. However, the reasons for improved growth are not always clear and, in all probability, vary from site to site (Vlamis, 1953; Coleman, Kamprath & Weed, 1958; Adams & Pearson, 1967). This uncertainty stems from the number of soil characteristics altered by liming and "hinders our ability to determine with certainty the precise factor which is responsible for poor growth ..." (Jackson, 1967). Graven (1973) claimed that "not infrequently it (is) inordinately difficult to interpret the results of liming experiments."

Fundamentally, there are two causes of poor plant growth in acid soils, (i) the presence of toxic substances and (ii) deficiencies of plant nutrients. Soluble aluminium is widely held to be the major cause of poor plant growth in many acid soils (Vlamis, 1953; Jenny, 1961; Adams & Lund, 1966 ; Adams & Pearson, 1967; Coleman & Thomas, 1967; Reeve & Sumner, 1970b) since it is toxic to root growth (Vlamis, 1953; Coleman _et al_., 1958; Foy & Brown, 1963; Pratt, 1966). However, excess manganese may also hinder crop growth on acid soils (Labanauskas, 1966) particularly under flooded conditions (Graven, Attoe & Smith, 1965). It has been accepted (Adams & Pearson, 1967) that soil pH _per se_ is not a direct factor, but is a symptom associated with other soil properties causing poor growth.

In acid soils, deficiencies of basic metal cations, particularly calcium and magnesium, are likely to occur (Moser, 1942; Coleman _et al_., 1958; Howard & Adams, 1965). Of particular importance in acid soils, is the likelihood of P deficiency resulting from fixation in the soil (Hsu, 1965; Smith, 1965) or immobilization in the plant (Coleman _et al_., 1958; Jackson, 1967). Foy & Brown (1963) found that the most characteristic symptom of Al toxicity was, in fact, P deficiency. The mechanism of Al toxicity, although not fully understood, appears to be related to the uptake and translocation of phosphate (Coleman _et al_., 1958). Of the micronutrients, molybdenum is most likely to be deficient in acid soils (Lewis, 1943) and a Mo deficiency in maize has been recorded on the Avalon soil (Blamey, 1971). The leaching of boron from acid soils may also cause problems in certain situations (Bradford, 1966).

Methods for the quantitative measurement both of toxic substances and of plant nutrients in soils are useful but do not always reflect plant response. Both Al (McLean, 1965) and Mn (Adams, 1965) in the soil can be measured by convenient chemical methods. However, a number of environmental factors (e.g. microbial activity, moist and dry soil conditions, variation in soil fertility) affect Mn availability and the measurement of plant-available Mn is, in many cases, not reliable (Browman, Chesters & Pionke, 1969; Shuman & Anderson, 1974). The storage of moist soil samples or air-drying the samples markedly affects the quantity of Mn extracted (Adams, 1965; Adams & Pearson, 1967). Grant, Tanner & Madziva (1973) have concluded that "there is considerable difficulty in establishing a relationship between soil pH and any measure of available manganese ...."

Exchangeable Ca, Mg and K, which are readily measured by soil extraction with N ammonium acetate, pH 7, have been found to represent readily available basic metal cations (Heald, 1965; Pratt, 1965). In the Avalon medium sandy loam, extraction of soil P with 0,05N H_2SO_4 has been found to be a satisfactory measure of plant-available phosphorus (Farina & Mapham, 1973).

On the assumption that Al toxicity is the major cause of poor plant growth in acid soils, a number of workers (Pratt, 1966; Kamprath, 1970; Reeve & Sumner, 1970b) have proposed that lime should be applied on the basis of neutralizing Al rather than to achieve any specific pH near neutrality. In temperate regions, it has been a successful practice to lime to ~pH 6,5, but extrapolation of this practice to soils of the warmer regions has not been successful and depressed crop growth has been recorded with liming to near neutrality (Reeve & Sumner, 1970b; Martini, Kochhann, Siqueira & Borkert, 1974). Reeve & Sumner (1970b) found that gypsum applications, although not affecting soil pH, increased plant growth in an Oxisol by decreasing exch. Al.

In order to identify the cause or causes of poor sunflower growth on the acid Avalon soil, it was decided first to investigate the effects of soil amelioration with lime or gypsum on various soil characteristics. Particular emphasis was placed on the neutralizing of toxic aluminium.

EXPERIMENTAL PROCEDURE

Field Experiment

A field experiment was carried out for two consecutive seasons, 1973/74 and 1974/75, at the Dundee Agricultural Research Station on an Avalon medium sandy loam (Appendix I). Soil analyses (0 - 15 cm) before fertilization and treatment application were as follows: soil pH (H_2O) 4,6; soil pH (N KCl) 3,9; exch. Ca 0,32 meq/100g; exch. Mg 0,12 meq/100g; exch. K 0,11 meq/100g; exch. Na 0,02 meq/100g; exch. Al 0,88 meq/100g.

Agrometeorological data for the two seasons (Appendix II) indicated that the rainfall of 1973/74 was close to the seasonal mean for Dundee Agricultural Research Station (p. 4) whereas that of 1974/75 was very high in comparison. Class A Pan evaporation and air temperatures were appreciably lower in 1974/75 than in the previous season.

Annual treatment applications were applied and consisted of four levels each of agricultural lime (L) and gypsum (G) (0, 800, 1 600 and 2 400 kg/ha) and borax (B) applied at 0, 5, 10 and 30 kg/ha. Mechanical and chemical composition of lime and gypsum are presented in Table 2. Treatments were applie in an unreplicated 4^3 factorial design in blocks of 16, with the interaction LGB completely confounded (Cochran & Cox, 1957)[1]. Typical statistical analysis is presented in Appendix III.

TABLE 2 Mechanical and chemical composition of lime and gypsum

Mechanical composition (mm)	Lime (%)	Gypsum (%)
> 1,70	3	10
1,70 - 0,85	30	22
0,85 - 0,25	37	39
< 0,25	30	29

Chemical composition of lime	(%)	Chemical composition of gypsum	(%)
$CaCO_3$	84	$CaSO_4.2H_2O$	86
$MgCO_3$	2	$MgSO_4.6H_2O$	2
Insoluble material	7	Insoluble material	11
Water	4		

[1] Plan 6.3 p. 234.

Treatments were broadcast by hand and disced in to a depth of 15 cm on 10th September 1973 and 5th November 1974, eleven and four weeks before planting in the two seasons, respectively. In the second season, earlier treatment application was prevented by the late spring rains but reaction was largely complete when samples were taken two weeks after planting (p. 16). Gross plot size was 68,58m^2 with a net plot of 43,89m^2.

In both seasons, uniform fertilizer rates of N, P and K were approximately the same, being 120 kg N, 26 kg P and 42 kg K per ha in 1973/74 and 134 kg N, 30 kg P and 50 kg K per ha in 1974/75. In 1973/74, uniform fertilizer rates applied before planting were 200 kg 2.3.2 (30)/ha, 200 kg ammonium sulphate (21%N)/ha, 50 kg KCl (50%K)/ha and 20 kg zinc sulphate/ha. In 1974/75, the rates were 200 kg ammonium sulphate (21%N)/ha, 153 kg double superphosphate (19,6%P)/ha, 100 kg KCl (50%K)/ha, 20 kg zinc sulphate/ha and 20 kg magnesium sulphate/ha. In both seasons, a side dressing of 200 kg urea (46%N)/ha was applied five weeks after planting.

The experiment was planted on 29th November in both seasons. Two weeks after planting, soil samples were taken with a Beater auger (Beater, 1955) to a depth of 15 cm. Thirty cores, with a diameter of 2 cm, were taken per net plot, bulked, air-dried and ground to pass through a 2 mm sieve. Soil was sampled in a similar manner after harvesting and again after ploughing.

At the end of the 1974/75 season, soil was sampled, before ploughing, to a depth of 60 cm, in increments of 15 cm, using a split-core sampler. Six cores, with a diameter of 2 cm, were taken from all plots receiving no gypsum and treated as above.

Pot Experiment

Since the rate of liming selected for the field experiment was based on the premise that the soil should be limed to neutralize toxic aluminium (Kamprath, 1970; Reeve & Sumner, 1970b), it was decided to test whether this premise was true for sunflowers grown on this soil. Soil was sampled (0 - 15 cm) from a site adjacent to the field experiment and soil analyses were similar to those in the field experiment before fertilization (p. 8).

Seven rates of precipitated $CaCO_3$ (AR Grade), equivalent to 0, 1 000, 2 000, 3 000, 4 000, 5 000 and 6 000 kg/ha, were equilibrated with the soil

(8% moisture) at room temperature for nine months before planting. (For comparative purposes, the same rates of agricultural lime were also applied.) Lime rates were calculated on the basis of $2,3 \times 10^6$ kg soil per hectare to a depth of 15 cm (Appendix I). Treatments were arranged in a randomized block design with four replications and typical statistical analysis is presented in Appendix III. In this experiment, 7 000 g soil (oven-dry basis) was placed in 4,5 litre, undrained, plastic pots lined with black polythene, and agitated to approximate field bulk density.

Uniform nutrient rates were applied as follows: 26 ppm N; 23 ppm P; 17 ppm K; 4 ppm Mg; 6 ppm S; 0,7 ppm B. Molybdenum was applied as a seed dressing at a rate of 100 g sodium molybdate per 100 kg seed. Before planting, soil sub-samples totalling ~50 g were randomly selected from each pot.

Laboratory Procedures[2]

Soil pH

In the initial stages of the field experiment, soil reaction was measured in H_2O, 0,01M $CaCl_2$ and N KCl. In each case, pH was measured using a soil:solution ratio of 1:2,5, after stirring intermittently for one hour and allowing to stand overnight. The pH was measured with a pH Meter (Metrohm Herisau E 520) with the bulb of the glass reference electrode in the sediment and the porous plug of the calomel electrode in the supernatant (Orchard, 1972).

For a number of reasons, only the pH in N KCl was determined after the first few series of analyses. The 'salt effect' seriously affected the pH measured in H_2O and the standard deviation of pH (H_2O) was higher than with the other two methods. Aduayi (1972) also found soil pH measured in water to be less consistent than when measured in 0,01M $CaCl_2$. Over the pH (N KCl) range 3,7 - 4,4, highly significant relationships existed between all three methods of pH measurement, especially between pH measured in N KCl and 0,01M $CaCl_2$ (Table 3).

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[2] Laboratory procedures used in this study were based on those used by the Soil Science Section, Cedara Agricultural Research Institute. The advice of Mr P. Channon on these procedures is gratefully acknowledged.

TABLE 3 Relationships between three methods of soil pH measurement (n=64)

(y)	(x)	Regression equation	r
pH(H_2O)	pH(N KCl)	y = -0,15 + 1,16x	0,923***
pH(H_2O)	pH(0,01M $CaCl_2$)	y = 0,83 + 0,88x	0,919***
pH(NKCl)	pH(0,01M $CaCl_2$)	y = 0,87 + 0,75x	0,988***

Soil pH measured in N KCl had a lower C.V. (1,5%) than either of the other two methods, which each had a C.V. of 2,2%. A further reason for using pH (N KCl) instead of pH (0,01M $CaCl_2$) was the widespread use of the former in soil testing laboratories in spite of the latter being less open to criticism from a theoretical point of view (Orchard, 1972).

Exchangeable basic cations

Soil samples (air-dry) were analysed for exch. Ca, Mg, K and Na by shaking for 30 min with N ammonium acetate, pH 7, using a soil:solution ratio of 1:10. After shaking, the suspension was filtered through Whatman No. 541 filter paper (doubled) and cations in the filtrate were measured on a Zeiss flame spectrophotometer. Total exchangeable bases (S) was calculated as $\sum$exch. Ca, Mg, K, Na. All analyses were calculated on an oven-dry (105°C) basis. Beyond an exploratory investigation, exch. Mn in the soil was not determined because of the drawbacks involved in estimating plant-available Mn in the soil (Adams, 1965; Adams & Pearson, 1967).

Exchangeable aluminium

Exch. Al was extracted with N KCl after the method of McLean (1965) which has been used in a number of investigations (Evans & Kamprath, 1970; Kamprath, 1970; Dalal, 1975; Thomas, 1975). A 10 g soil sample was shaken for exactly 4 min on a reciprocating shaker (175 cycles/min) with 50 ml N KCl in a stoppered 100 ml polypropylene centrifuge tube. The suspension was then centrifuged for 2 min at 3 000 r.p.m. and a 25 ml aliquot taken. Exch. Al was determined by titration with 0,01N NaOH using phenolphthalein indicator.

McLean (1965) regarded this measure as total exchangeable acidity, i.e. exch. Al + H. By precipitating Al with NaF and determining exch. H, it was found in this soil that exch. H constituted less than 5% of the total exchangeable acidity (pH (N KCl) 3,7 - 4,5) and there was no significant relationship between exch. H and total exchangeable acidity. This result complied with the result reached by McLean (1965) that "in many if not most soils, the entire soil acidity component important in liming practices appears to be Al."

Cation-exchange capacity

In this study, CEC was calculated as Σexch. Ca, Mg, K, Na, Al. This method, often disregarding exch. K and Na, has been widely used in the study of acid soils (Coleman *et al.*, 1958; Lin & Coleman, 1960; Adams & Pearson, 1967; Evans & Kamprath, 1970; Kamprath, 1970) and Chapman (1965) stated that this method provides the most accurate estimate of CEC in acid soils. However, the presence of free $CaCO_3$ or $CaSO_4$ in the soil could introduce errors because of their solubility. In spite of this, it was considered that other methods of CEC determination would not prove superior since the use of buffered solutions at high pH do not relate to conditions existing in the field (Orchard, 1972).

Aluminium saturation

Aluminium saturation was calculated according to the formula,

$$\text{Al saturation (\%)} = \frac{\text{exch. Al (meq/100g)} \times 100}{\text{CEC (meq/100g)}}$$ (Adams & Pearson, 1967).

Soil P test

Plant-available phosphorus in the soil was estimated using a modification of the method of Farina & Mapham (1973) which they had found best for relating P soil test to the response of maize to P fertilization on this soil. A 5 g sample was shaken for exactly 4 min on a reciprocating shaker (175 cycles/min) with 50 ml 0,05N H_2SO_4 in a stoppered, 100 ml polypropylene centrifuge tube. The suspension was centrifuged for 2 min at 3 000 r.p.m. and a 25 ml aliquot of the suspension filtered through two Whatman No. 541 filter papers containing ~l charcoal. (The charcoal, Darco G 60, was rendered free of P by washing with H_2SO_4 and removing all trace of the acid with deionized water.) Phosphorus in the filtrate was measured colorimetrically by the vanadate-molybdate method.

RESULTS AND DISCUSSION

Pot Experiment

Soil pH

As was expected, applications of precipitated $CaCO_3$ resulted in a most marked increase in soil pH (N KCl), the addition of 6 000 kg/ha increasing soil pH (N KCl) from 3,7 to 7,0 (Table 4; Fig. 2).

TABLE 4 Effects of precipitated $CaCO_3$ applications on soil analyses (0 - 15 cm)

$CaCO_3$ applied (t/ha)	pH(N KCl)	Exchangeable cations (meq/100g)				CEC (meq/100g)	Al satn (%)
		Ca	Mg	S	Al		
0	3,69	0,36	0,20	0,76	1,17	1,93	60,6
1	3,94	1,05	0,23	1,49	0,57	2,07	27,6
2	4,27	1,62	0,21	2,03	0,19	2,22	8,4
3	4,83	2,20	0,19	2,59	0,04	2,63	1,7
4	5,58	2,82	0,21	3,23	0,01	3,25	0,4
5	6,23	3,29	0,19	3,68	0,01	3,69	0,2
6	6,98	3,85	0,16	4,20	0,01	4,21	0,2
Mean	5,07	2,17	0,20	2,57	0,26	2,86	14,2
LSD's 0,05	0,11	0,14	0,02	0,19	0,01	0,19	1,4
0,01	0,15	0,20	0,03	0,26	0,02	0,27	1,9

Exchangeable cations

The exch. Ca in the soil was linearly increased from 0,36 meq/100g without liming to 3,85 meq/100g with 6 000 kg $CaCO_3$/ha. (Table 4). Inexplicably, treatments significantly affected the exch. Mg in the soil although AR Grade $CaCO_3$ was used (Table 4). However, no systematic trend was observed, and the effect was probably due to error. Exch. K and Na were not significantly affected by treatment application, the mean levels being 0,17 and 0,03 meq/100g respectively. With liming, the increasing level of exch. Ca in the soil was mainly responsible for the highly significant increase in total exchangeable bases (Table 4).

As was expected, liming caused a highly significant decrease in exch. Al and Al saturation (Table 4; Fig. 2). However, the effect of lime was quadratic and even at pH (N KCl) 4,8, some aluminium was extracted. A similar effect, attributed to extraction of non-exchangeable Al, was found by McLean (1965).

Cation-exchange capacity was greatly increased by liming from 1,93 meq/100g without liming to 4,21 meq/100g at 6 000 kg $CaCO_3$/ha (Table 4).

Comparison of agricultural lime and precipitated $CaCO_3$

Tisdale & Nelson (1967) presented a means whereby the effectiveness of lime can be estimated from its mechanical composition. Using this technique, it was postulated from the data presented in Table 2 (p. 8), that the agricultural lime used in these studies would have an efficiency rating of only 58% compared to lime with particle size <0,25 mm. From its mechanical and chemical composition ($CaMg(CO_3)_2$ = 86%), the lime would only have an efficiency of 50% compared to precipitated $CaCO_3$.

A comparison of the agricultural lime with precipitated $CaCO_3$ by soil equilibration has shown similar results (Fig. 2). Liming the soil to pH (N KCl) 4,5 required 5,2 tonne agricultural lime/ha and only 2,3 tonne $CaCO_3$/ha. Thus, in this equilibration study, the agricultural lime was only 44% as efficient as the precipitated $CaCO_3$.

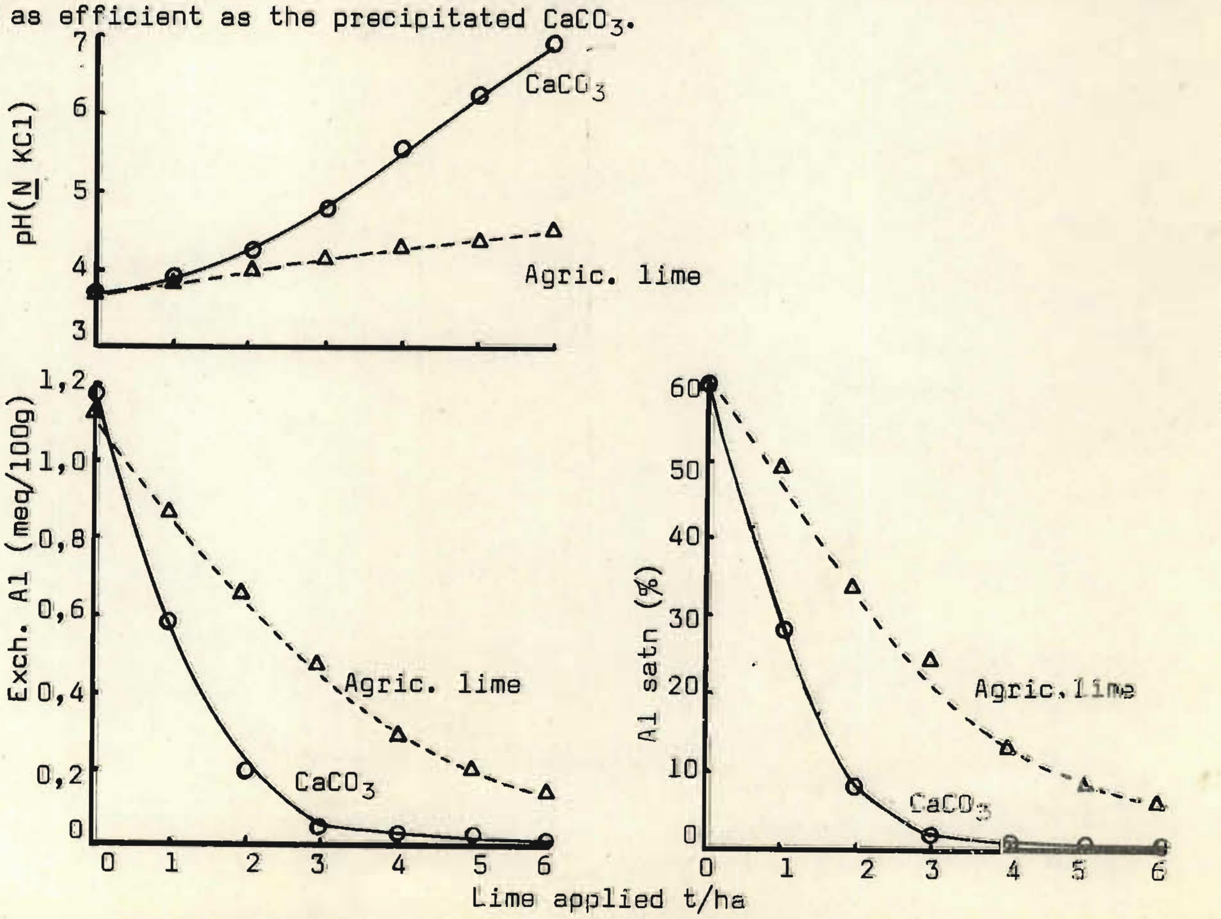

FIG. 2 Comparison of the effects of agricultural lime and precipitated $CaCO_3$

Comparison of the efficiency of the two liming materials in decreasing exch. Al and Al saturation (Fig. 2), again showed the relatively poor effect of the agricultural lime. Even the efficiency of the precipitated $CaCO_3$ was low, however, the addition of 1 meq/100g $CaCO_3$ (~1 tonne/ha) reducing exch. Al by ~0,45 meq/100g. A similar inefficiency of reaction was noted by Reeve & Sumner (1970b). The efficiency of the agricultural lime was even lower, 1 meq/100g of which only reduced exch. Al by approximately 0,18 meq/100g.

An application of 6 000 kg agricultural lime/ha increased the exch. Ca in the soil by 1,40 meq/100g compared to the same rate of $CaCO_3$, which increased exch. Ca by 3,49 meq/100g (Table 4). Exch. Mg was increased 0,03 meq/100g by an application of 6 000 kg agricultural lime/ha due to the small amount of $MgCO_3$ present in the limestone.

Field Experiment

Soil pH

The first annual application of lime in 1973/74 resulted in a highly significant increase in soil pH (H_2O) and pH (N KCl) (Table 5). Gypsum applications, on the other hand, increased pH (N KCl) but decreased pH (H_2O). This latter effect of gypsum can possibly be attributed to the 'salt effect' caused by the slight solubility of gypsum, since gypsum applications did result in a small, but significant, decrease in exch. Al (p.19). The effect of lime was significantly superior to that of gypsum but even 2 400 kg lime/ha only increased pH (N KCl) by 0,4. The highest rate of lime was applied in order to increase soil pH (N KCl) to 4,5 but, unfortunately, the quality of the limestone was not taken into consideration. Thus, in the first year of the trial, soil pH (N KCl) was only increased to 4,12 at L_3 from 3,73 at L_0 (Table 5).

TABLE 5 Soil pH at the beginning and at the end of the two seasons, 1973/74 and 1974/75

Treatment		pH(H_2O)	pH(N KCl)				
		12/12/73[1]	12/12/73[1]	29/3/74[2]	10/4/74[3]	13/12/74[1]	10/4/75[2]
L_0		4,17	3,73	3,86	3,82	3,79	3,84
L_1		4,32	3,86	3,98	3,88	4,00	4,07
L_2		4,44	3,97	4,08	3,96	4,16	4,39
L_3		4,66	4,12	4,24	4,05	4,47	4,87
G_0		4,43	3,88	4,02	3,92	4,06	4,22
G_1		4,42	3,91	4,03	3,93	4,13	4,29
G_2		4,39	3,93	4,05	3,92	4,12	4,30
G_3		4,36	3,96	4,05	3,95	4,10	4,37
Mean		4,40	3,92	4,04	3,93	4,10	4,29
LSD's	0,05	0,07	0,04	0,06	0,04	0,11	0,16
	0,01	0,10	0,06	0,08	0,06	0,15	0,22

1 two weeks after planting
2 end of growing season
3 after ploughing

By the end of the 1973/74 season (i.e. on 29/3/74), the mean soil pH (N KCl) had increased to 4,04 from 3,92 at the beginning of the season. This was not due to increased reaction of the lime since the same increase was observed at L_0 (Table 5). This increase in soil pH (N KCl) could be attributed to leaching of Al from the 0 - 15 cm layer of soil from which soil samples were taken (p 21). By the end of the first season, the effect of gypsum on soil pH (N KCl) had decreased and was not significant.

In 1974/75, further lime applications again significantly increased soil pH (N KCl), two annual applications of 2 400 kg/ha resulting in pH (N KCl) 4,47. This confirmed the results of the pot experiment that the agricultural lime was only half as efficient as precipitated $CaCO_3$ in increasing soil pH. (The exact relationship could not be calculated in this case becasue of the diluting effect of ploughing.)

As in the previous season, soil pH (N KCl) increased from the beginning to the end of the 1974/75 season. Gypsum applications had no significant effect on soil pH (N KCl) during 1974/75.

Exchangeable calcium

In 1973/74, lime and gypsum applications both resulted in highly significant increases in exch. Ca. There were no significant differences (Brownlee, 1965) between the effects of L and G, either at the beginning or at the end of the season, nor between the individual ameliorants (Fig. 3). Thus it was possible to fit a common line to estimate the effects of amelioration on exch. Ca and to calculate that 1 000 kg lime or gypsum per ha increased exch. Ca by 0,30 meq/100g.

In the subsequent season, there was a significant difference between the effects of lime and gypsum applications on exch. Ca (Fig. 3). There was, however, no difference between the effects of the individual ameliorant from the beginning to the end of the growing season. Liming increased exch. Ca by 0,47 meq/100g per 1 000 kg/ha applied and the same rate of gypsum increased exch. Ca by 0,24 meq/100g.

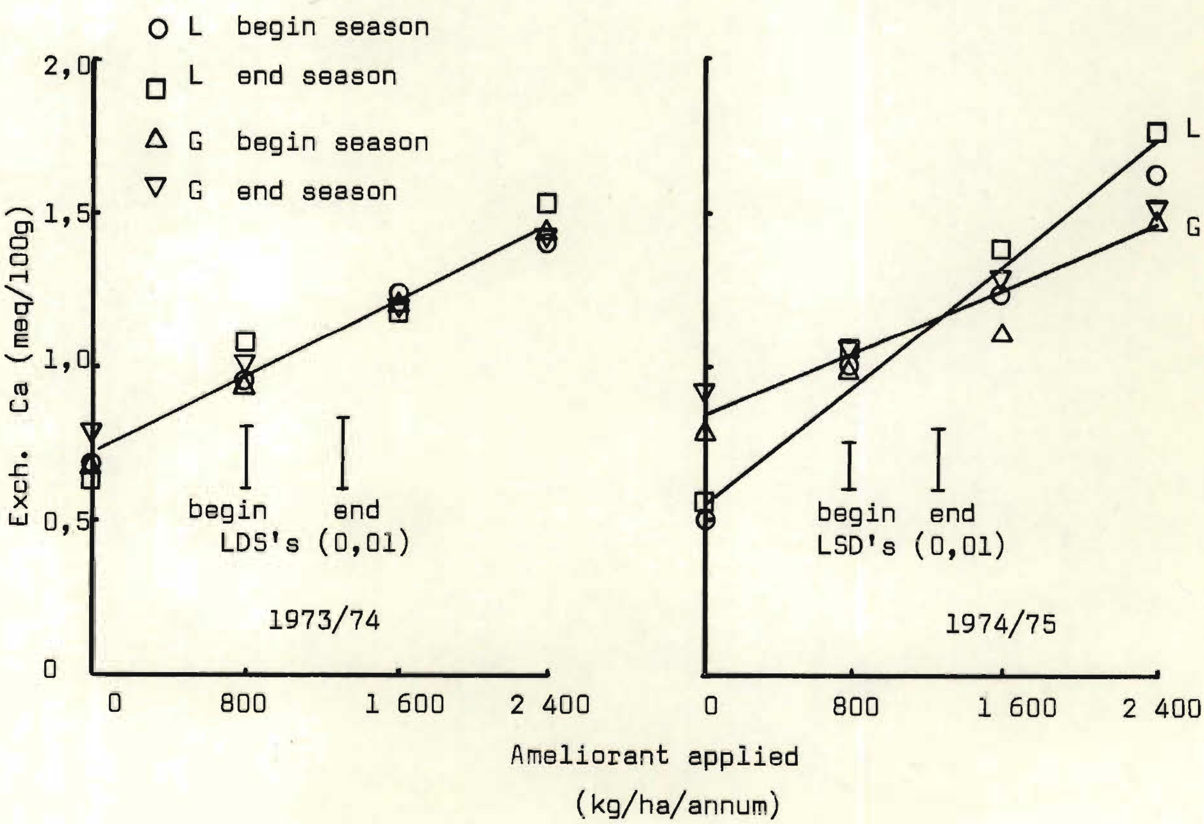

FIG. 3 Effects of annual applications of lime and gypsum on exch. Ca (meq/100g) at the beginning and end of two seasons

Exchangeable magnesium

Because of the $MgCO_3$ (2%) present in the lime, liming significantly increased the exch. Mg in the soil. In 1973/74, liming at a rate of 2 400 kg/ha linearly increased exch. Mg to 0,10 meq/100g from 0,08 meq/100g at L_0. In the second season, in spite of $MgSO_4$ fertilization, exch. Mg at L_0 six weeks after application was only 0,04 meq/100g. This was significantly increased to 0,08 meq/100g at L_3.

Notwithstanding the 2% magnesium sulphate in the gypsum, applications of this ameliorant had no significant effect on exch. Mg in either of the two seasons.

Exchangeable potassium and sodium

Treatments had no noticable effects on exch. K or Na in either of the two seasons. Mean levels of exch. K in the two seasons were 0,15 and 0,14 meq/100g respectively, and those for exch. Na were 0,02 and 0,03 meq/100g, respectively.

Total exchangeable bases

Largely due to the effects of amelioration on exch. Ca, the total exchangeable bases was increased by lime and gypsum applications (Table 6). Lime and gypsum applications increased S by the same amount in 1973/74 but, in 1974/75, t effect of lime appeared slightly superior to that of gypsum. Similar effects of these two ameliorants on exch. Ca were noted in the two seasons (Fig. 3).

TABLE 6 Amelioration effects on total exchangeable bases (S) two weeks after planting in both seasons

Treatment		S (meq/100g)	
		1973/74	1974/75
L_0		0,94	0,70
L_1		1,23	1,24
L_2		1,50	1,46
L_3		1,68	1,88
G_0		0,97	1,08
G_1		1,21	1,21
G_2		1,44	1,31
G_3		1,72	1,68
Mean		1,34	1,32
LSD's	0,05	0,15	0,16
	0,01	0,21	0,22

Exchangeable aluminium

In both seasons, lime and gypsum applications resulted in highly significant decreases in exch. Al (Table 7), lime being significantly superior to gypsum. In the absence of gypsum, 2 400 kg lime/ha reduced exch. Al from 0,94 to 0,42 meq/100g and from 1,02 to 0,21 meq/100g in the two seasons, respectively. The same rate of gypsum, in the absence of lime, only decreased exch. Al to 0,72 and 0,73 meq/100g in the two seasons, respectively. Thus, in both seasons, 2 400 kg gypsum/ha was not as effective as 800 kg lime/ha in reducing exch. Al.

Gypsum applications reduced exch. Al in the soil, not due to any acid neutralizing ability, but probably due to a 'self liming' effect (i.e. SO_4^{--}-induced Al polymerization by ligand exchange of OH^-) as described by Chang & Thomas (1963) and Reeve & Sumner (1970a).

In the second season, a highly significant L'G' interaction on exch. Al occurred (Table 7). Gypsum applications appeared to be relatively efficient in reducing exch. Al where no lime was applied but had no significant effect where lime was applied.

TABLE 7 Lime x gypsum interactions on exch. Al (meq/100g) two weeks after planting in both seasons

			L				G mean
			0	1	2	3	
12/12/73	G	0	0,94	0,69	0,56	0,42	0,65
		1	0,82	0,67	0,46	0,39	0,59
		2	0,81	0,60	0,45	0,37	0,56
		3	0,72	0,56	0,50	0,31	0,52
	L Mean		0,82	0,63	0,50	0,37	0,58
13/12/74	G	0	1,02	0,68	0,38	0,21	0,57
		1	0,88	0,56	0,27	0,16	0,47
		2	0,82	0,47	0,33	0,20	0,45
		3	0,73	0,43	0,30	0,14	0,40
	L Mean		0,86	0,53	0,32	0,18	0,47

	LSD's		
	Body		Means
12/12/73	0,05	0,12	0,06
	0,01	0,16	0,08
13/12/74	0,05	0,12	0,06
	0,01	0,16	0,08

As with soil pH ($\underline{N}$ KCl) (p.16), there was a change in exch. Al from the beginning to the end of the growing season. In 1973/74, at all rates of lime, exch. Al decreased with time (Fig. 4), indicating the possible leaching of Al from the 0 - 15 cm soil layer over the growing season. This possibility was strengthened by the fact that ploughing to a depth of 30 cm resulted in an increase in exch. Al in the 0 - 15 cm layer, even at L_0. There was, indeed, a greater increase in exch. Al after ploughing where lime was applied but this was due to the diluting effect of the ploughing operation.

It was strange, however, that only a slight decrease in exch. Al was observed at L_0 from the beginning to the end of the second season (Fig. 4), whereas the higher rainfall of 1974/75 should have resulted in greater leaching of Al from the 0 - 15 cm layer than in the previous season.

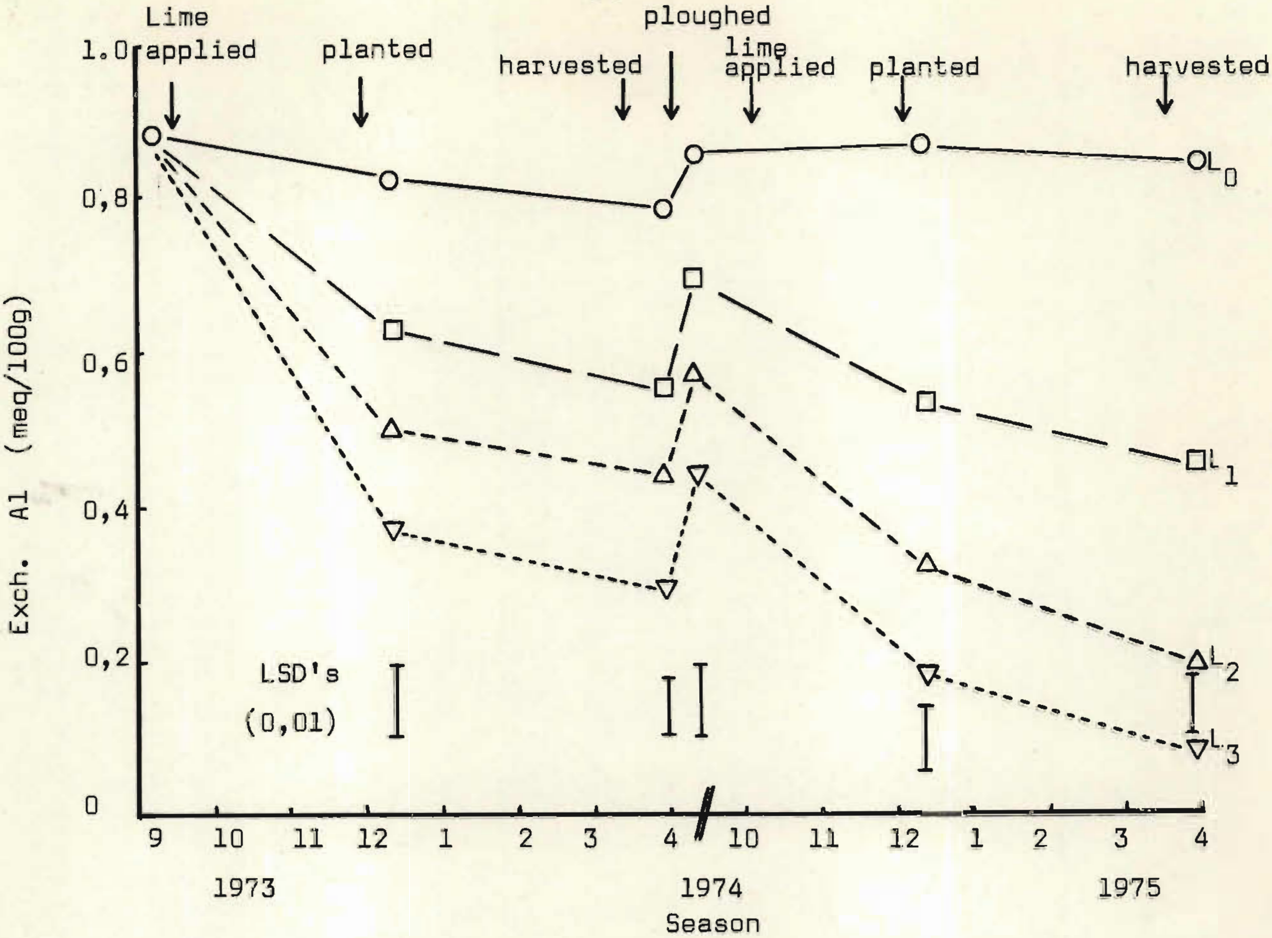

FIG. 4 Lime effects on exch. Al (meq/100g) over two seasons

Cation-exchange capacity

Cation-exchange capacity was highly significantly increased by both lime and gypsum applications. Bhumbla & McLean (1965) (according to Coleman & Thomas, 1967) also found CEC to be increased with liming. In 1973/74, gypsum appeared to be slightly superior to lime in increasing CEC, but there was no difference between ameliorants in 1974/75 (Fig. 5). Similar treatment effects were noted at the end of both seasons.

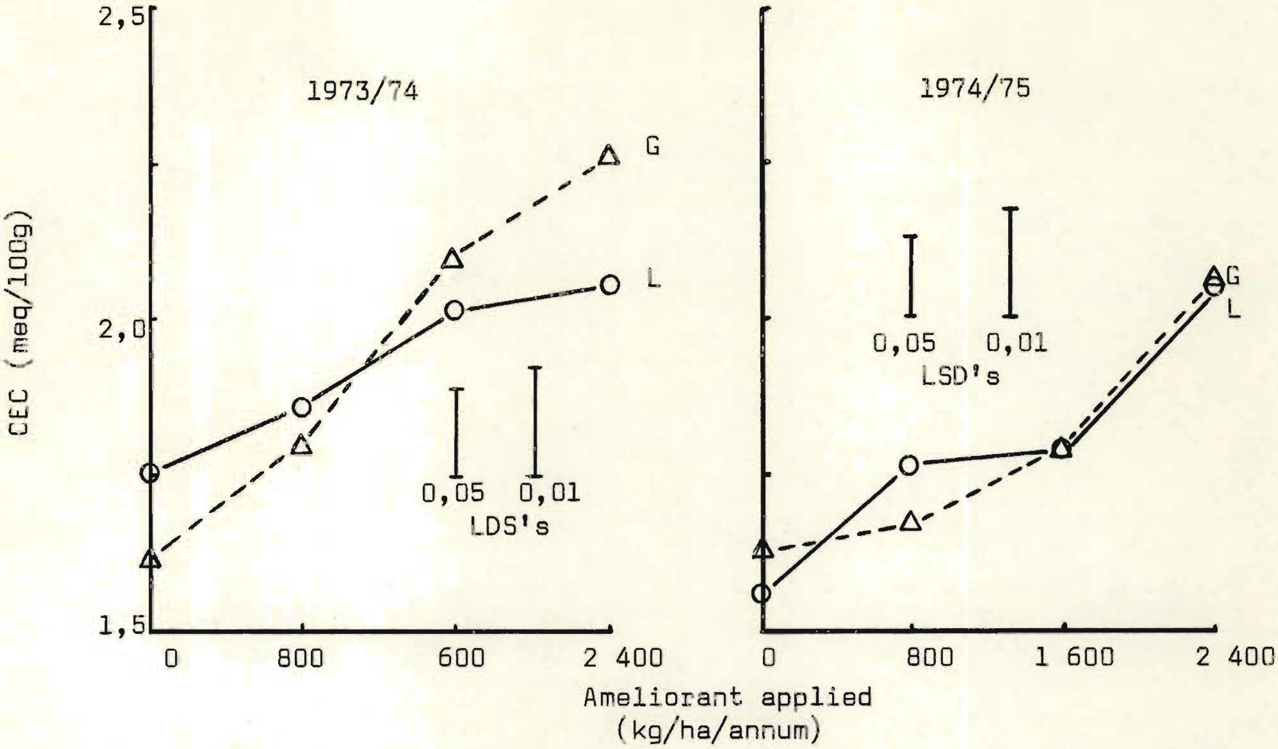

FIG. 5 Amelioration effects on CEC (meq/100g) at the beginning of both seasons

<u>Aluminium saturation</u>

In both seasons, both ameliorants significantly reduced the Al saturation in the soil (Table 8). This was to be expected from the effects of amelioration on exch. Al and CEC. Further, as expected, lime was superior to gypsum in decreasing aluminium saturation.

In both seasons, a highly significant L'G' interaction on Al saturation occurred, indicating that gypsum was more efficient in reducing Al saturation in the absence of lime. Where lime was applied, gypsum applications were much less effective (Table 8).

<u>Soil P test</u>

In 1973/74, the mean level of 0,05N H_2SO_4-extractable P was 17 $\pm$ 2 ppm, which would be sufficient for a maize grain yield of 5 800 kg/ha (Farina & Mapham, 1973). Amelioration of the soil with lime or gypsum had no significant effect on P soil test.

TABLE. 8 Lime x gypsum interactions on Al saturation (%) two weeks after planting in both seasons

			L				G
			0	1	2	3	Mean
12/12/73	G	0	64,1	43,3	32,5	24,6	41,1
		1	49,0	37,6	25,2	21,0	33,2
		2	42,4	31,2	22,9	17,8	28,6
		3	35,9	26,4	26,1	12,3	25,2
	L Mean		47,9	34,6	26,7	18,9	32,0
13/12/74	G	0	69,0	44,0	23,2	11,5	37,0
		1	58,3	36,9	15,9	8,0	29,8
		2	53,4	25,7	19,6	10,5	27,3
		3	43,1	19,5	15,7	6,0	21,1
	L Mean		56,0	31,5	18,6	9,0	28,8

LSD's		Body	Means
12/12/73	0,05	8,5	4,3
	0,01	11,5	5,8
13/12/74	0,05	8,9	4,5
	0,01	12,1	6,0

In the second season, liming caused a slight, but significant, increase in P soil test from 20 ppm at L_0 to 22 ppm at L_3. This increase could have been caused either by increased plant-available P with liming and/or by increased chemical extraction of P with increasing pH. The latter possibility is the more probable, since soil extraction with 0,05N H_2SO_4 is more efficient in extracting Ca-phosphates than Al-phosphates.

Relationship between soil pH (N KCl) and exch. Al

Since there appears to be no fixed relationship between soil pH (N KCl) and exch. Al with changes in soil texture (Adams & Pearson, 1967), it was considered necessary to investigate this relationship in the Avalon medium sandy loam. In order to do this, use was made of soil analysis data (0 - 15 cm) over the two seasons.

Two curves were fitted to estimate the relationship between soil pH (N KCl) (x) and exch.Al (meq/100g)(y), viz the quadratic and square root functions. The latter proved slightly superior, as shown by an increased correlation between observed and fitted values of y, over the pH (N KCl) range 3,7 - 5,2 and has been presented in Fig. 6 (Appendix III).

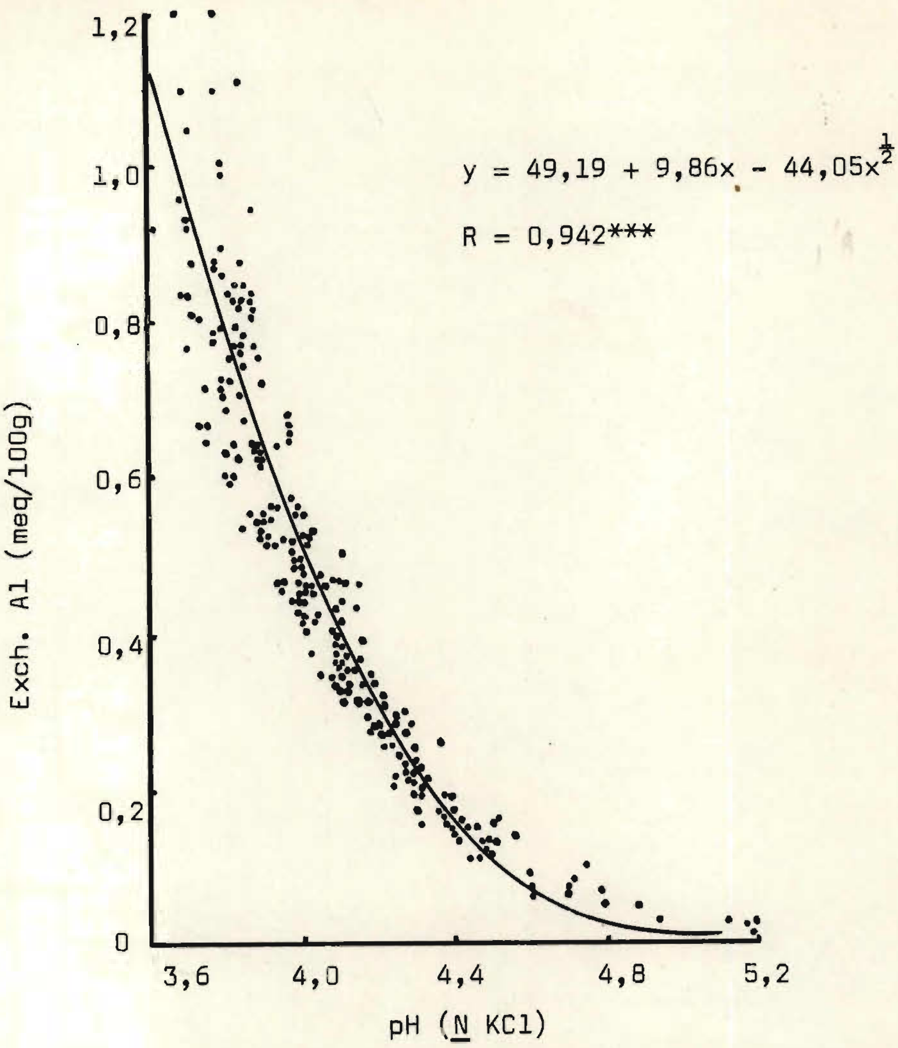

FIG. 6 Relationship between exch. Al (meq/100g) and pH (N KCl) on an Avalon medium sandy loam (0 - 15 cm) (n = 256)

Dalal (1975) found that the predominant Al species up to pH (N KCl) 4,5 was Al^{3+} and that the neutral species, $Al(OH)_3^0$, predominated from pH (N KCl) 4,5 - 6,3. Using the relationship between soil pH (N KCl) and exch. Al established in this study, it was calculated that, at pH (N KCl) 4,5 the Al extracted was 0,13 meq/100g. This may be regarded as non-exchangeable Al remove by this technique. McLean (1965) also found "that when a soil initially high in exch. Al was limed, appreciable amounts of Al remained extractable with neutral salt solution even at soil pH 6 or above." This was considered some form of hydroxy Al and not exchangeable Al.

Lime effects on soil analysis with depth

Of particular interest in this study, were the effects of liming on soil reaction, exch. Al and Al saturation with increasing soil depth. (As indicated in the next chapter, gypsum application had only slight effects on sunflower growth, and the effects of gypsum applications on soil analysis with depth were not persued beyond exploratory tests.) As with many other studies (Coleman <u>et al</u>., 1958; Reeve & Sumner, 1972; Venter, Gous & Möhr, 1973), lime did not increase soil pH (<u>N</u> KCl) below the region of placement (Fig. 7), two seasons after the first application of lime. Liming markedly increased soil pH (<u>N</u> KCl) in the 0 - 15 cm layer (cf. Table 5) and in the 15 - 30 cm layer, the latter effect being due to ploughing at the end of the first season. No significant effect of lime was recorded below these depths (Fig. 7).

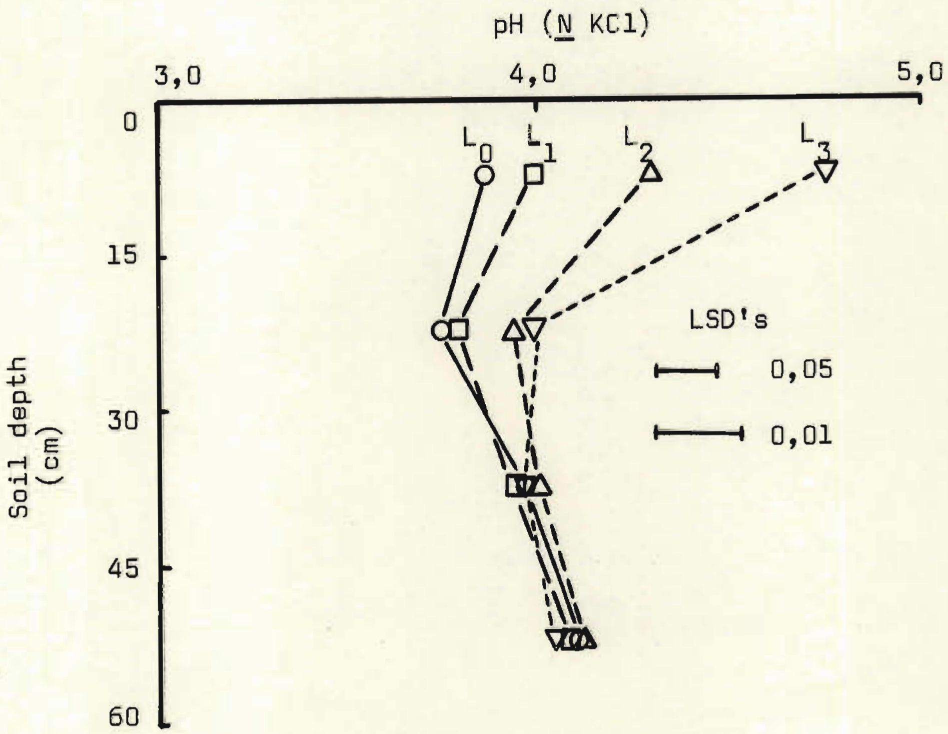

FIG. 7 Lime effects on soil pH (<u>N</u> KCl) with increasing depth, at the end of the 1974/75 season

In keeping with the effect of lime on soil pH (<u>N</u> KCl), liming had no significant effect on exch. Al or Al saturation below the plough layer (Table 9). There appeared to be a slight, non-significant, decrease in exch. Al due to liming in the 30 - 45 cm layer, but this was probably due to variation in ploughing depth rather than movement of lime down the profile. There was no discernable movement of calcium into the 30 - 45 cm layer, in spite of the possibility of this occurring in sandy soils (Coleman <u>et al</u>., 1958).

TABLE 9 Effects of lime applications on exch. Al (meq/100g) and Al saturation (%) with increasing soil depth

Exch. Al (meq/100g)

Depth (cm)	Annual lime application (kg/ha)				Mean
	0	800	1 600	2 400	
0 - 15	0,98	0,59	0,23	0,09	0,47
15 - 30	1,07	0,93	0,70	0,64	0,83
30 - 45	1,04	0,90	0,93	0,82	0,92
45 - 60	0,78	0,66	0,80	0,78	0,76
Mean	0,97	0,77	0,67	0,58	0,75

LSD's	Body	Means
0,05	0,19	0,09
0,01	0,25	0,12

Al satn (%)

Depth (cm)	Annual lime application (kg/ha)				Mean
	0	800	1 600	2 400	
0 - 15	64,9	32,3	14,7	4,2	29,0
15 - 30	66,0	56,6	40,2	36,5	49,8
30 - 45	45,0	38,3	39,6	37,1	40,0
45 - 60	28,0	21,3	28,5	27,5	26,3
Mean	51,0	37,1	30,7	26,3	36,3

LSD's	Body	Means
0,05	9,3	4,6
0,01	12,3	6,2

Without lime, there was a slight increase in exch. Al and Al saturation from the 0 - 15 cm to the 15 - 30 cm soil layer (Table 9). This indicated that, at least within the A horizon, aluminium tended to leach down the profile, which was in keeping with the observation that ploughing at the end of the first season increased exch. Al in the 0 - 15 cm soil layer (p. 21). This was further confirmed by measuring exch.Al in the L_0G_0 plots in 5 cm depth increments. Exch. Al increased as follows to a depth of 30 cm: 0,94; 0,93; 1,01; 0,98; 1,11; 1,03 meq/100g (S.E. of a single reading = 0,03 meq/100g).

SUMMARY AND CONCLUSIONS

The comparison of the two soil ameliorants, lime and gypsum, in the field showed the marked superiority of lime in increasing soil pH (N KCl) and reducing toxic aluminium. In fact, the poor effect of gypsum would make it economically inadvisable for its use in the amelioration of this acid soil. Both lime and gypsum applications increased exch. Ca in the soil to approximately the same level, at least in the first season. Liming also increased exch. Mg slightly, but neither ameliorant affected exch. K or Na.

The agricultural lime used in these studies was found to be only half as effective as precipitated $CaCO_3$ in increasing soil pH (N KCl). This low neutralizing ability was largely due to the coarseness of the product. From a crop production point of view, this would greatly increase the cost of liming since substantial cost factors are the transport and application of the lime in addition to the cost of the lime itself.

Dalal (1975) found that no Al^{3+} should be present in the soil at pH (N KCl) 4,5 and above. However, in spite of liming to this level in both the field and pot experiments, exch. Al was not reduced to zero. It was concluded that a certain amount of non-exchangeable aluminium was extracted (McLean, 1965) which wa estimated to be 0,13 meq/100g at pH (N KCl) 4,5.

Analysis of the soil to a depth of 60 cm indicated that, where no lime was applied, some Al leached down the profile in the A horizon. This confirmed the observation that ploughing to a depth of 30 cm increased exch. Al in the 0 - 15 cm layer. It could also be concluded that the neutralizing effect of lime did not extend below the zone of placement. This was in keeping with the work of others although Coleman et al., (1958) did suggest that appreciable amounts of Ca could be leached from soils of low cation-exchange capacity.

CHAPTER II

AMELIORATION OF AN ACID AVALON MEDIUM SANDY LOAM AND EFFECTS ON THE GROWTH OF SUNFLOWERS : II PLANT GROWTH

INTRODUCTION

In the high rainfall areas of South Africa that are suitable for crop production, soil acidity is one of the major limiting factors (Graven, 1973). However, crops differ greatly in their sensitivity to acid soil conditions (McLean & Gilbert, 1927; Foy & Brown, 1964; Adams & Pearson, 1967; Jackson, 1967; Adams & Pearson, 1970; Long & Foy, 1970; Long, Langdale & Myhre, 1973). These differences appear to be due to differences in the ability of roots to grow in acid soil. Adams & Pearson (1970) found that cotton roots were unable to penetrate an acid subsoil whereas groundnut roots were unaffected. Chapman (1966) listed sunflowers as moderately sensitive to soil acidity in comparison with maize which is slightly sensitive. Foy, Orellana, Schwartz & Flemming (1974) found sunflower genotypes to differ in their sensitivity to aluminium in acid soil Very poor sunflower growth has been noted on the Avalon medium sandy loam and pilot trials indicated that this poor growth was largely due to soil acidity.

Because of the interrelationship between a number of factors in the soil acidity complex, e.g. soil pH, exch. Al, exch. Mn, exchangeable bases and the availability of other plant nutrients, the interpretation of liming experiments is difficult (Coleman <u>et al</u>., 1958; Jackson, 1967; Graven, 1973). However, for the results to be of wider use than on the immediate experimental site, it is necessary that the cause or causes of the poor sunflower growth at this site be isolated.

As discussed previously (p. 6), toxic aluminium is widely held to be the major cause of poor plant growth on acid soils. Thus, Kamprath (1970) and Reeve & Sumner (1970b) proposed that lime should be applied to neutralize toxic Al and thus prevent its adverse effect on root growth. Reeve & Sumner (1970b) found that not only was the amount of lime required to increase soil pH to 6,5 considerably more than that required to eliminate toxic Al, but that the growth of trudan was depressed when pH was increased from the level required to neutralize toxic Al up to pH 6,5. However, the two proposals that the Avalon soil be limed to neutralize toxic Al or to pH 6,5 have not been tested with respect to the growth of sunflowers.

The possible detrimental effects of excess manganese on sunflower growth on this soil must also be investigated. Crops differ greatly in their sensitivity to excess Mn (Labanauskas, 1966) because they vary in Mn absorption capacity and/or the ability to tolerate accumulations in plant tissue without adverse effects (Jackson, 1967). It appears that no one method exists to estimate plant-available Mn in the soil under all conditions (p.7) but Labanauskas (1966) claimed that the Mn concentration in the leaf was a good measure of the status of Mn nutrition of the plant. Unfortunately, the Mn toxicity level in sunflowers is not known, but Labanauskas (1966) claimed that, in general, amounts over 1 000 ppm Mn in plant tissue could be regarded as toxic. Bates (1971) stressed the importance of comparing nutrient concentrations in tissu of the same physiological age and this would be of particular importance with Mn since the concentration, and hence the severity of toxicity, tends to increase with age (Cheng & Ouellette, 1971).

The effects of amelioration on the availability of plant nutrients must also be investigated to ascertain their possible effects on the growth of sunflowers on this acid soil. Of particular importance in this regard, are Ca and Mg which are likely to be deficient in acid, sandy soils (Adams & Pearson, 1967) and the levels of exch. Ca and Mg in this soil can be regarded as particularly low (p.8). The effects of amelioration on P uptake must also be investigated in spite of the relatively high P soil test (p. 22).

In this study, the effects were measured of soil amelioration on the growth and chemical composition of sunflowers on the Avalon medium sandy loam in an attempt to determine the cause of poor sunflower growth on this acid soil.

EXPERIMENTAL PROCEDURE

Pot experiment

The pot experiment, with seven rates of $CaCO_3$ applied (0 - 6 000 kg/ha) (p. 9), was planted on 9th July 1975. Ten sunflower seeds (cv. Smena) were planted per pot and thinned out to five seedlings after emergence. This experiment was conducted in a glasshouse in which the air temperatures ranged from a mean daily maximum of $32,0 \pm 1,2^{\circ}$ C to a mean daily minimum of $21,0 \pm 3,2^{\circ}$ C. After emergence, the pots were watered daily to constant mass, calculated on the basis of 12,5% moisture in the soil. This level of moisture was determined as that which was held by the soil after gravitational water had drained away. Pots were rotated within blocks every second day to limit the effects of light and temperature gradients on plant growth.

Four weeks after planting (i.e. on 6th August 1975) the seedlings were harvested. The tops were cut at ground level and dried to constant mass at 80^{0} C in a forced-draught oven. After removing the tops, the soil in the pots was carefully washed from the roots and root mass per pot was measured after being dried at 80^{0} C.

Nutrient solution experiments

As will be discussed later, liming markedly reduced manganese concentrations in sunflowers in the field (p. 44). Since it was not known whether these concentrations would affect growth, and excess Mn may be of importance in acid soil infertility under certain conditions (Jackson, 1967), it was decided to study this aspect more closely. Crops differ greatly in their sensitivity to excess Mn and Mn toxicity levels in sunflowers are not known. Thus, the effects of high Mn concentrations in nutrient solution on the growth and Mn concentrations of sunflower seedlings were investigated.

Two nutrient solution experiments were carried out, the first in the glasshouse under the same conditions as the pot experiment, and the second in the open from 20/9/75 - 18/10/75. In both experiments, sunflower seeds (cv. Smena) were placed in a moistened paper towel to germinate. When the radicle had grown to a length of ~2 cm (i.e. after four days), eight germinated seeds were transplanted into moistened, commercial vermiculite in drained, 4,5 litre, polythene pots. After watering with deionized water for a further two days, to ensure successful transplantation, nutrient solutions were added. The basic nutrient solution, described by Jyung, Ehmann, Schlender & Scala (1975) was as follows: 5,9 mM $Ca(NO_3)_2$; 0,58 mM KH_2PO_4; 0,58 mM $NH_4H_2PO_4$; 5,2 mM KNO_3; 1,8 mM $MgSO_4$; 0,58 mM KCl; 46 μM H_3BO_3; 0,1 μM Na_2MoO_4; 0,32 μM $CuSO_4$; 8,9 μM FeEDTA (an equimolar complex of $FeSO_4$ and Na_2EDTA); 0,31 μM $ZnSO_4$.

In Experiment I, five treatments consisting of concentrations of 0,5, 1,0, 2,0, 4,0 and 8,0 ppm Mn were added to the basic nutrient solution and applied to the pots. The lowest rate, 0,5 ppm Mn, was applied as being adequate according to Hewitt (1952) and Jyung et al. (1975). The highest rate, 8 ppm, was applied because Hewitt (1952) suggested that 5 ppm Mn may be toxic for some plant species. In Experiment II, however, appreciably higher Mn concentrations were applied, viz 5, 10, 15, 20, 30 and 40 ppm Mn. In both experiments, there were two replications.

From two days after transplanting, the nutrient solutions, including treatments, were applied daily to the pots. One litre of solution was added to each pot and allowed to stand for one hour, after which excess solution was drained away. Using this technique, it was possible to eliminate the possible confounding effect of poor substrate aeration (Graven <u>et al</u>., 1965) and to prevent moisture stress which would possibly affect the interpretation of results.

Four weeks after germination of the seed, the tops were harvested and dried to constant mass at 80^{o} C and the seedling mass measured. Plant material was milled and a sample taken to determine the Mn concentration in the tissue.

Field experiment

Plant growth

The field experiment (p.8) was planted on 29th November in both the 1973/74 and 1974/75 seasons. Five seeds of the cultivar, Smena, were planted 5 cm deep (Stoyanova, 1969) in hills 30 cm apart in 76 cm rows. Before planting, the seed was treated with 100g sodium molybdate per 100 kg seed to prevent a possible Mo deficiency which had been recorded in maize on this soil (Blamey, 1971). One month after planting, seedlings were thinned out to one per hill, i.e. to a population of 43 700 per ha. Those seedlings removed (tops only) were dried at 80^{o} C and their mass measured. This was not carried out in 1974/75 because damage by light hail to the topgrowth made it unlikely that results of value would be obtained.

Plant counts were taken at weekly intervals before thinning in 1973/74 and fortnightly thereafter in both seasons. At weekly intervals after thinning, heights were measured of 20 randomly-selected plants in each plot and an estimate of the mean plant height per plot calculated.

Leaf area

Treatment effects on leaf areas at flowering were tested non-destructively by determining the relationships between leaf area and length and breadth. This was carried out in 1973/74 but not in 1974/75 because of a second light hail-storm at this stage of development. The study was confined to the period of flowering, i.e. when the ray florets became visible, since it was at flowering that sunflowers were found to have maximum leaf area index (LAI) (Rabey & Allison, 1970)

Five plants of the cultivar, Smena, were randomly selected from a population of 44 000 plants per ha. The areas of the 60 leaves on the five plants were measured by tracing onto graph paper and the length and maximum breadth of each leaf measured.

A highly significant correlation was found between leaf area (y) and leaf length (x_1) ($y = -94,60 + 14,67x_1$; $r = 0,908$***) and between leaf area and leaf breadth (x_2) ($y = -44,21 + 13,51x_2$; $r = 0,979$***). However, in both cases, there appeared to be a systematic trend away from the straight line at the extremes.

A multiple regression of leaf area on leaf length, leaf breadth and the product of length and breadth (x_3) was carried out. The regression analysis indicated that it was only necessary to use x_3 for the estimation of leaf area. The inclusion of x_1 or x_2 did not add significantly to the regression equation.

A highly significant correlation ($r = 0,993$***) was found between measured leaf area and the product of length and breadth. The regression equation obtained was $y = -2,72 + 0,71x_3$. However, the constant, -2,72, was not significantly different from zero (Rayner, 1969) and the relationship, $y = 0,691\ 6x_3$, was fitted instead (Fig. 8). This relationship remained constant over the range studied and was not affected by leaf shape. Furthermore, the equations for estimating leaf area were calculated for each plant separately and were not significantly different ($F_{1,50} = 0,25$) (Brownlee, 1965).

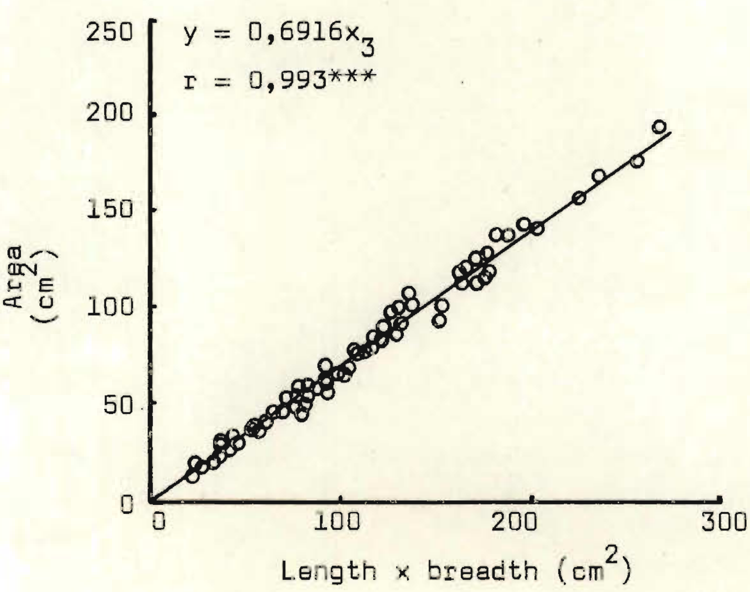

FIG. 8 Relationship between leaf area and leaf length x breadth for

The standard error for b = 0,691 6 was 0,005 477 and the confidence limits were 0,691 6 $\pm$ 0,011 0 (95%) and 0,691 6 $\pm$ 0,014 6 (99%). The confidence limits for the estimated areas ($\hat{y}$) were given by the equation, $\hat{y} \pm x_3 \times t_{59} \times 0{,}005\ 477$

Clements & Goldsmith (1924) (according to Martin, 1935) found the relationship between sunflower leaf area and length x breadth to be $y = 1{,}34x_3$. The value for b found in this study was highly significantly different from 1,34 and indicated that the relationship must be recalibrated for differing conditions such as cultivars. It is difficult, however, to understand how a value for b >1 can be obtained using this technique and an error in the reported value is suspected.

Under the conditions of this study, the relationship, $y = 0{,}691\ 6x_3$, gave a good estimate of leaf area. The sixty leaves resulted in confidence limits (95%) for b ranging over only $\pm$ 1,6% of b. It could therefore be concluded that 60 leaves were a reasonable minimum for estimating b.

At flowering, the areas of each leaf of ten randomly-selected plants in each plot were calculated using the formula above. Leaf area index per plot was calculated according to the formula,

$$LAI = \frac{\text{mean leaf area per plant } (m^2) \times \text{plant popn per ha}}{10^4\ (m^2)} .$$

Chemical composition

Seedlings, harvested one month after planting, and the topmost, fully-expanded leaf at flowering, removed from 50 randomly-selected plants in each plot, were dried at 80° C and milled prior to chemical analysis. The topmost, fully-expanded leaf was sampled as suggested by Bates (1971) since "this probably is as effective a way as any of providing tissue of the same physiological age on deficient and adequately fertilized plants." Chemical analysis of a subsample of winnowed seed was carried out on an air-dry basis. Blanks and standards were analyzed as a normal laboratory procedure.

Plant samples were analyzed for Ca, Mg, K, Mn and P by dry ashing (450° C) a 2 g subsample, the ash being taken up in dilute HCl. Cations were measured flame spectrophotometrically and P was measured colorimetrically using the vanadate-molybdate method.

Plant and seed yield

The experiment was harvested on 11th March 1974 and 24th March 1975 in the two seasons, respectively. In 1973/74, the total plant mass, uncorrected for moisture content, was also measured.

The seed from each plot was air dried under cover, threshed and winnowed and the mass was measured on an air-dry basis. Before winnowing, a sample of seed was taken for determining the percentage unfilled seeds (i.e. seeds in which the embryo had not developed). Determinations of 100-seed mass and hectolitre mass were carried out on the winnowed grain, as was the oil concentration in the seed, which was measured by nuclear magnetic resonance (NMR).[1]

RESULTS AND DISCUSSION

Pot experiment

Applications of $CaCO_3$ resulted in a highly significant increase in seedling (tops) yield (Fig. 9). Soon after emergence, the benefit of liming was evident and, by the time of harvesting, many seedlings had died in those pots receiving no lime. Maximum yield was obtained with an application equivalent to 3 000 kg $CaCO_3$/ha. There was no further benefit in liming above this level (i.e. pH (N KCl) 4,8; exch. Al 0,04 meq/100g) and, in fact, there was a tendency for growth to be slightly depressed above this level of liming.

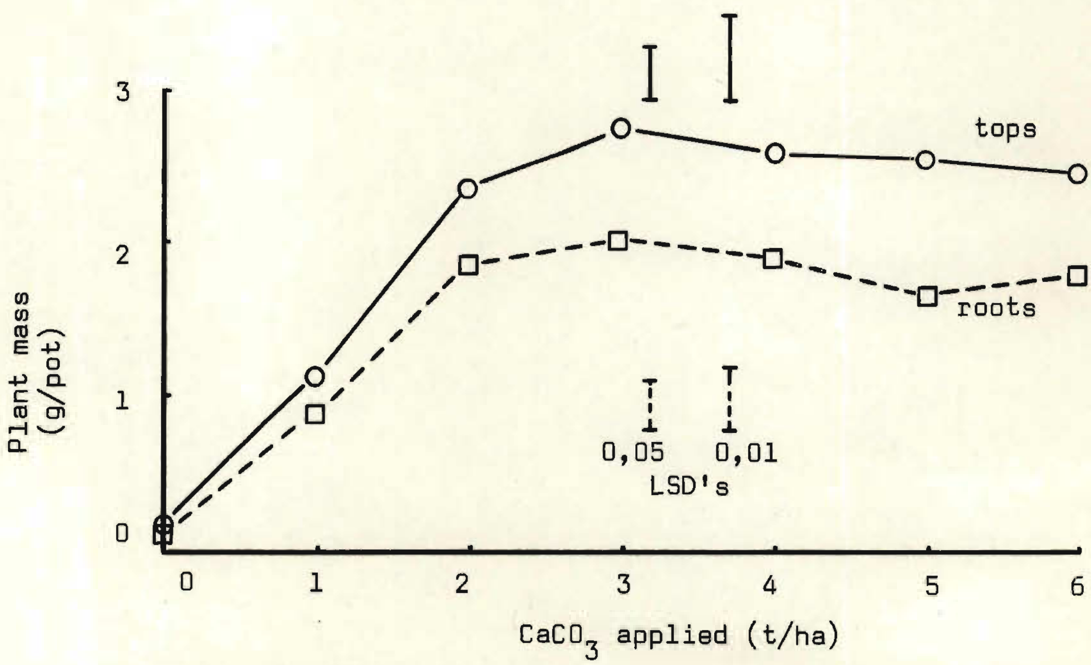

FIG. 9 Effects of precipitated $CaCO_3$ applications on sunflower seedling top and root mass one month after planting

[1] Oil determinations were kindly carried out by Mr J.C.G. du Preez, Oilseeds

As with seedling tops, root growth was significantly increased by liming (Fig. 9) and maximum root growth, as measured by root mass, was recorded with an application of 3 000 kg $CaCO_3$/ha as was the case with top growth. This was in keeping with the premise that toxic Al was responsible for poor sunflower growth on this soil since Al has been shown to severely curtail root growth in nutrient solutions (McLean & Gilbert, 1927; Hortenstine & Fiskell, 1961; Rees & Sidrak, 1961; Foy et al., 1974).

The findings of this experiment did not support the idea that lime should be applied to adjust the soil pH to 6,5 - 6,8 (Coleman et al., 1958; Shoemaker, McLean & Pratt, 1961; Adams & Pearson, 1967), but confirmed the findings of Reeve & Sumner (1970a,b) and Martini et al. (1974), who found that lime should be applied to neutralize toxic aluminium for the optimum growth of trudan and soybeans (Glycine max), respectively.

Field experiment

Seedling growth

Within one week of emergence, the beneficial effect of liming was visible in the growth of the seedlings. In the absence of lime, emergence was poor, growth was stunted and necrotic patches appeared on the cotyledons and leaves (Plate 2). In nutrient solution cultures with sunflowers, Hortenstine & Fiskell (1961) noted that levels of Al above 6 ppm in solution resulted in the cessation of root growth and that the leaf margins turned brown and the cotyledons died. Thus, the symptoms indicated that Al toxicity was the possible cause of poor growth in this case. Furthermore, the immediately-apparent adverse effects of soil acidity support this since Vlamis (1953) found that the effects of Al toxicity were immediate and drastic but the effects of Mn toxicity were aggrevated with time. In this study, gypsum applications had no visible effect on seedling growth.

As early as one week after planting (i.e. on 7/12/73), the percentage of emerged seedlings was significantly less at L_0 compared with all treatments wher lime had been applied (Table 10), an effect that persisted up to one month after planting.

The effect of lime on seedling mass one month after planting was most marked, the seedling mass at L_3 being almost three times that at L_0 (Table 10).

PLATE 2 Young sunflower seedlings (~1 week after emergence) on the unlimed plots showed symptoms of a severe disorder

TABLE 10 Lime effects on emerged seedlings and seedling mass one month after planting on 29/11/73

Lime Applied (kg/ha)	Emerged seedlings (%)			Seedling mass (kg/ha)
	7/12/73	13/12/73	19/12/73	
0	83,0	89,2	82,1	22,3
800	88,9	94,1	90,3	44,5
1 600	89,2	94,6	90,3	55,1
2 400	90,8	96,4	92,2	64,0
Mean	88,0	93,6	88,7	46,5
LSD's 0,05	5,4	4,0	5,4	8,3
0,01	7,1	5,4	6,2	11,2

The highly significant, linear effect of L indicated that, even with the relatively high rates of lime, optimum growth conditions had not been obtained.

Gyspum applications had no significant effect on seedling mass and since lime and gypsum applications increased exch. Ca in the soil to approximately the same level (p.17), it could be established that calcium deficiency was not the cause of poor sunflower growth on this soil.

Plant population

After thinning to a population of 43 700 plants/ha, a steady decrease in population occurred in both seasons where no lime had been applied (Fig. 10). Six weeks after thinning (i.e. ten weeks after planting) the plant population at L_0 was only 40% of the original population in 1973/74 and 61% of the original population in 1974/75.

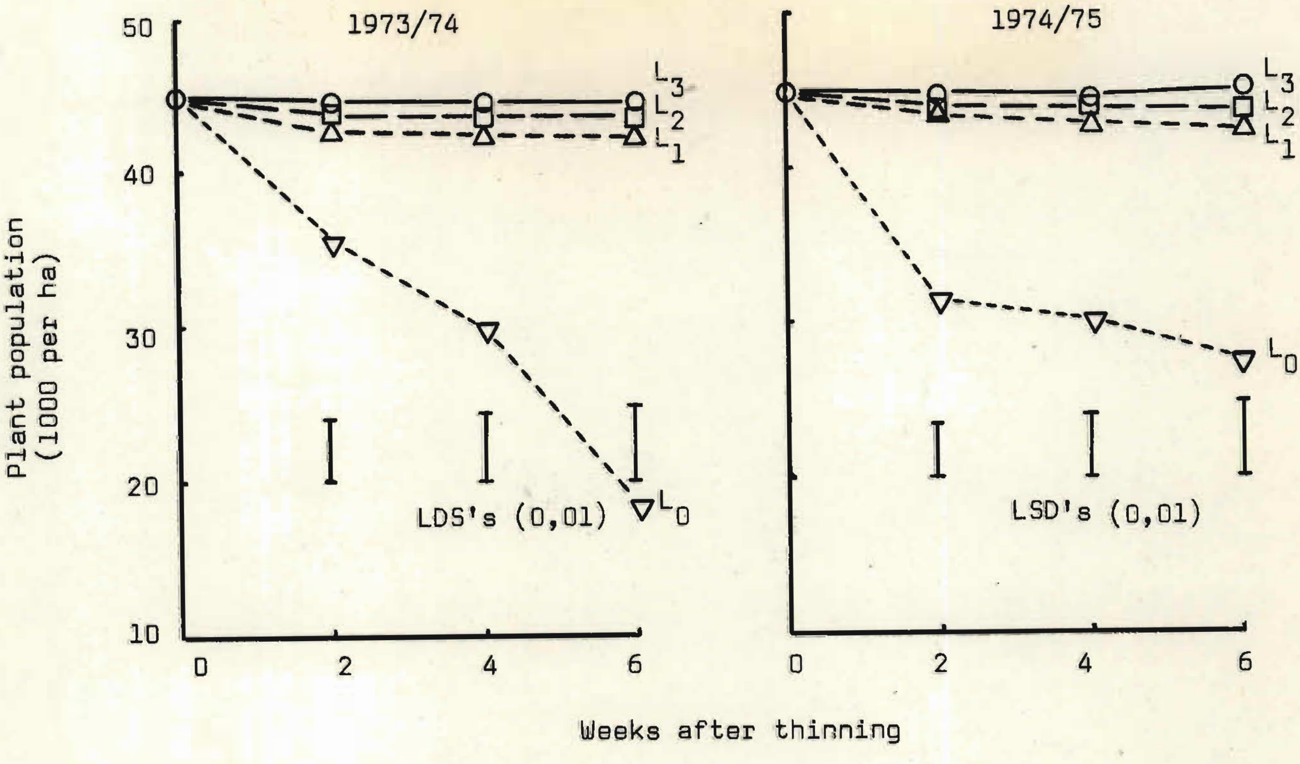

FIG. 10 Lime effects on plant population from thinning until six weeks thereafter

The severity of soil acidity on the survival of the sunflower seedlings can be seen in Plate 3 where many of the plants, relatively early in the season, had already died. Many surviving plants died later in the season (Fig 10).

Plant height

In 1973/74 and 1974/75, the beneficial effect of liming on plant height was evident throughout the season (Fig. 11). Weekly measurements revealed that plant heights at L_0 were consistently and significantly inferior to those receiving lime.

PLATE 3 The severely stunted growth of the seedlings on the unlimed plots (foreground) was evident as was the decrease in population in comparison with the limed plots (background)

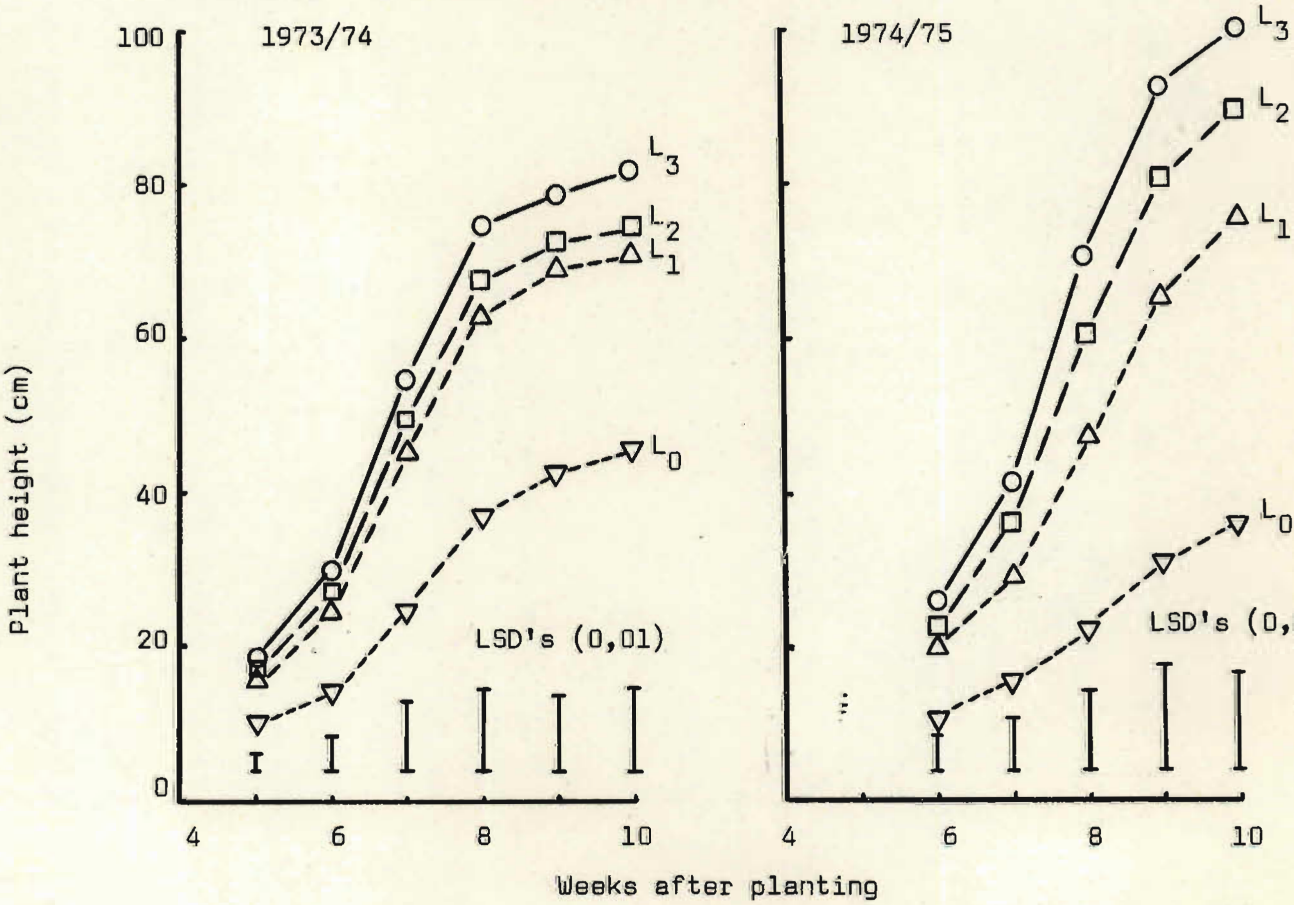

FIG. 11 Lime effects on plant height from five to ten weeks after planting

Symptoms of a severe disorder were apparent in the plants in plots which received no lime. Besides stunted growth, the leaves of the surviving plants became chlorotic and necrotic particularly along the margins and at the tips (Plate 4). The older leaves were more severly affected and eventually died.

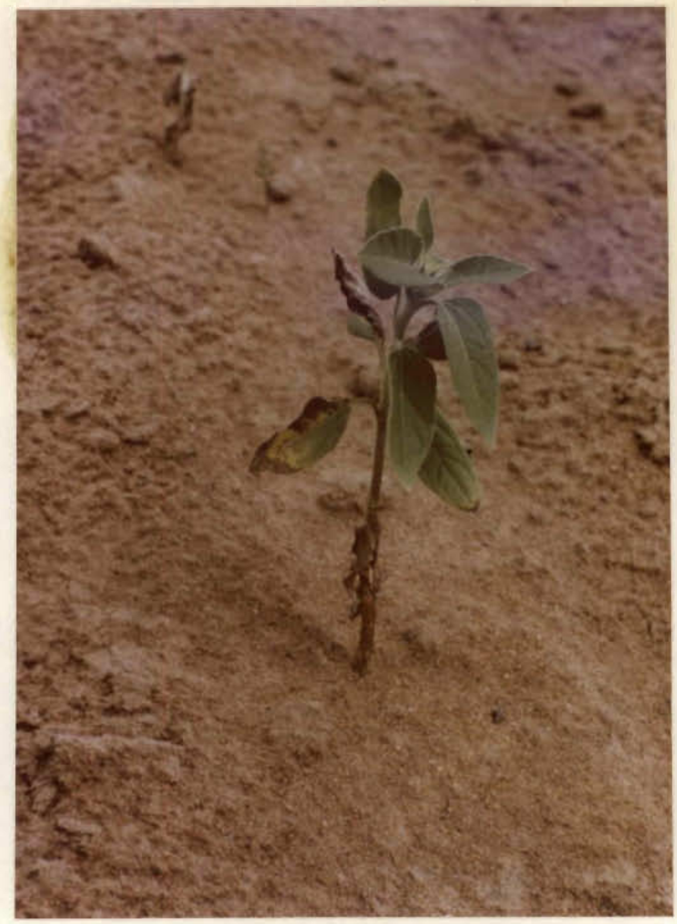

PLATE 4 In the unlimed plots, the leaves of the sunflower seedlings showed severe chlorosis and necrosis

Root growth

In both seasons, root growth was severly limited in plots which received no lime. The tap root did not penetrate more than 10 - 15 cm and adventitious root development also occurred only above this depth (Plate 5). This restrictio of root development and the fact that Al tended to accumulate below 10 - 15 cm in the soil (p. 26) clearly indicated that Al toxicity was a severly limiting factor in sunflower growth on this soil.

PLATE 5 Limited root growth was clearly evident in the unlimed plots where root growth was restricted to a depth of ~10 cm

Leaf area at flowering

In 1973/74, measurements of leaf area at flowering showed that liming increased the leaf area index highly significantly (Table 11). All components of LAI, viz plant population per unit area (Fig. 10), number of leaves per plant and the mean area of one leaf, were significantly increased by liming (Table 11). A combination of these factors resulted in a LAI at L_3 seven times that at L_0. As with seedling mass, however, the highly significant, linear effect of L indicated that optimum growth conditions had not been obtained.

The severity of the effect of soil acidity on sunflower leaf area and on plant growth can be gauged from Plate 6. Also noticeable is the effect of limin on plant population and plant height.

Calcium concentration in plant tissue

In sunflower seedlings, both lime and gypsum applications significantly increased the Ca concentration linearly and quadratically (Table 12). Lime appeared slightly superior to gypsum in increasing the Ca concentration in the seedlings, particularly in the first season. Since lime and gypsum had similar effects on exch. Ca in the soil (p.17) and on the Ca concentration in the seedlings, but differed in their effects on growth, the poor growth of sunflowers on this soil could not be attributed to a calcium deficiency. In this study, Ca extraction of the soil with N NH_4OAc, pH 7, corresponded well with Ca uptake by the plant, and supported the claim by Heald (1965) that this method of soil extraction is a good measure of plant-available calcium.

TABLE 11 Effect of lime applications on leaf areas of sunflower plants at flowering (1973/74)

Lime Applied (kg/ha)	Leaves per plant	Area of one leaf (cm^2)	Leaf area per plant (cm^2)	LAI
0	11,5	43,0	526	0,12
800	14,3	95,0	1 385	0,58
1 600	14,7	104,5	1 544	0,66
2 400	15,7	125,6	1 935	0,83
Mean	14,0	92,0	1 347	0,54
LSD's 0,05	0,9	19,0	331	0,15
0,01	1,2	25,7	449	0,20

PLATE 6 No lime was applied to the plot in the foreground whereas the plot in the background received an equivalent of 2 400 kg lime/ha

TABLE 12 Interactions of lime and gypsum on Ca concentration (%) in seedlings in two seasons

Season			L 0	L 1	L 2	L 3	G Mean
1973/74	G	0	1,13	1,49	1,67	1,77	1,52
		1	1,43	1,73	1,88	2,01	1,77
		2	1,57	1,72	1,84	2,00	1,77
		3	1,59	1,83	1,88	1,90	1,80
	L Mean		1,43	1,70	1,82	1,91	1,72
1974/75	G	0	1,21	1,89	2,21	2,68	2,00
		1	1,84	2,25	2,18	2,76	2,26
		2	1,88	2,44	2,51	2,45	2,32
		3	2,20	2,57	2,71	2,55	2,51
	L Mean		1,78	2,29	2,40	2,61	2,27

LSD's	0,05	0,01
1973/74 Body	0,20	0,27
1973/74 Means	0,10	0,13
1974/75 Body	0,35	0,48
1974/75 Means	0,18	0,24

In both seasons, a highly significant L'G' interaction occurred affecting the Ca concentration in the seedlings (Table 12). From this interaction, and from the quadratic effects of L and G, it was evident that Ca was not taken up and translocated to the tops indiscriminately.

In the mature leaves at flowering, similar ameliorant effects on Ca concentration were recorded except that no L'G' interactions were recorded. Liming, from L_0 to L_3, increased the Ca concentration from 1,14 - 1,82% and from 1,28 - 2,21% in the two seasons, respectively and gypsum applications, from G_0 to G_3, resulted in increases from 1,14 - 1,61% and from 1,58 - 2,03% in the two seasons, respectively.

In the seed, however, substantially different treatment effects from those on the Ca concentration in vegetative tissue were recorded. Lime had no significant effect in either of the two seasons, but gypsum applications increased the Ca concentration from 0,11 to 0,12% and from 0,08 - 0,09% in the two seasons, respectively.

Magnesium concentration in plant tissue

Liming resulted in a highly significant increase in the Mg concentration in the seedlings in both seasons (Table 13). This effect could be attributed to either improved root growth with liming or to increased exch. Mg in the soil (p. 18) or both. On the other hand, gyspum applications had the opposite effect, significantly decreasing the Mg concentration in the seedlings (Table 13) This was possibly caused by competition between Ca and Mg for uptake sites on the roots.

TABLE 13 Lime and gypsum effects on Mg concentration (%) in sunflower seedlings in both seasons

Rate (kg/ha)	Treatment			
	Lime		Gypsum	
	1973/74	1974/75	1973/74	1974/75
0	0,42	0,30	0,49	0,41
800	0,46	0,37	0,47	0,38
1 600	0,47	0,38	0,45	0,34
2 400	0,51	0,42	0,45	0,35
Mean	0,46	0,37	0,46	0,37

		1973/74	1974/75
LSD's	0,05	0,03	0,03
	0,01	0,04	0,05

Since gypsum applications decreased the Mg concentration in the seedlings, but did not adversely affect growth, poor sunflower growth on this acid soil was not caused by Mg deficiency. This is supported by the findings of the pot experiment, in that there was no relationship between seedling growth and exch. Mg in the soil (Table 4, Fig. 9).

Liming, once again, significantly increased the Mg concentration in the mature leaves at flowering from 0,53 to 0,61% and from 0,24 to 0,42% in the two seasons, respectively, but gypsum applications had no significant effect. The Mg concentration in the seed was not significantly affected by soil amelioration with either lime or gypsum. Mean Mg concentrations in the seed wer 0,34 and 0,30% in the two seasons, respectively.

Unexpectedly, the application of magnesium sulphate fertilizer in the second season was not reflected in increased exch. Mg in the soil (p.18) nor in increased Mg concentration in the plants. It was possible that the Mg leached rapidly from the zone of application and was, therefore, not detected by soil sampling nor reached by the sunflower roots.

Potassium concentration in plant tissue

In both seasons, liming significantly increased the K concentration in month-old sunflower seedlings. From L_0 to L_3, the K concentration was increased from 2,71 to 3,78% and from 3,03 to 3,87% in the two seasons, respectively. This effect of liming on K uptake was probably caused by increased root growth with liming since exch. K in the soil was not affected by treatment application.

In the mature leaves at flowering, treatment effects on the K concentration were inconsistent. In the first season, gypsum applications caused a slight, but significant, increase in K concentration from 3,57% at G_0 to 3,77% at G_3, but lime applications had no effect. In the second season, liming significantly decreased the K concentration from 3,48% at L_0 to 3,20% at L_3 and gypsum application had no effect. The causes of these effects were not evident, but the effects were unlikely to be of practical importance since Robinson (1970) found the K concentration in apparently normal, mature sunflowers to be 3,18%.

Reflecting the effect of lime on K concentration in the mature leaves, liming slightly decreased the K concentration in the seed from 0,92% at L_0 to 0,88% at L_3 in 1974/75. Treatments had no significant effects on the K concentration in the seed in the previous season.

Manganese concentration in plant tissue

In both seasons, liming consistently decreased the Mn concentration in all plant tissues studied (Table 14) but gypsum applications had no significant effects. The marked effect of liming in reducing Mn uptake is in keeping with the generally-accepted view that increasing pH reduces Mn availability in the soil (Adams & Pearson, 1967). There appears to be no agreement on the effects of gypsum on Mn availability since gypsum applications have been found to have no effect[2], to have increased (Vlamis, 1953; Reeve & Sumner, 1970a) and to have decreased (Snyman, 1972) Mn availability and Mn concentrations in plant tissue.

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[2]Farina, M.P.W., Cedara Agricultural Research Institute, personal communication.

TABLE 14 Lime effects on Mn concentration (ppm) in month-old seedlings, topmost, mature leaf at flowering and seed in two seasons

Lime Applied (kg/ha/annum)	Seedlings		Topmost, mature leaf		Seed	
	1973/74	1974/75	1973/74	1974/75	1973/74	1974/75
0	829	416	955	495	66	81
800	823	454	947	501	61	67
1 600	698	305	838	317	52	52
2 400	598	252	763	252	50	45
Mean	737	357	858	391	57	61
LSD's 0,05	86	48	92	69	6	6
0,01	116	65	125	93	9	8

The higher Mn concentration in the topmost, mature leaf at flowering than in the seedlings was in keeping with the findings of Jackson (1967) and Cheng & Ouellette (1972). The latter found that Mn built up gradually in potato (Solanum tuberosum) plants and toxicity symptoms only became visible in the late bloom stage.

Comparison of the seasonal effects on the Mn concentration in vegetative tissue indicated the much higher Mn levels in the first season in comparison with the second. The Mn concentration at L_0 in the second season was lower than that at L_3 in the first. The reason for this is not evident, particularly in view of the substantially higher rainfall of the second season (Appendix II). Graven et al. (1965) showed that the Mn concentration in lucerne (Medicago sativa was greatly increased by flooding, and temprary flooding did occur in the second season. This difference in Mn concentration between seasons indicated that Mn toxicity was probably not a major factor causing poor sunflower growth on this soil since the beneficial effects of liming on growth were similar in the two seasons. Furthermore, liming at a rate of 800 kg/ha did not decrease the Mn concentration in the seedlings and mature leaves (Table 14), but markedly improved growth.

Labanauskas (1966) claimed that, in general, "where amounts of over 1 000 ppm (Mn) are found, plant growth performance may be affected" which is a level higher than those found in this study. However, since no reference to Mn toxicit levels in sunflowers could be found in the literature, the possiblity of excess Mn causing poor sunflower growth on this soil could not be conclusively eliminated on the basis of the results of the field experiment, alone.

In both nutrient solution experiments, high Mn concentrations in solution had no significant effect on seedling top growth (Table 15). Hewitt (1952) had suggested that 5 ppm Mn in nutrient solution could possibly be toxic for some plant species, but concentrations of up to 40 ppm Mn had no detrimental effect on sunflower seedling growth in these trials. This could possibly have been caused by the vermiculite rendering Mn unavailable to the seedlings, but even concentrations of up to 9,6 ppm Mn in the leachate had no effect on growth. (This latter aspect has been included to prevent erroneous conclusions as to the Mn concentration in the solution in contact with the roots, which was possibly somewhere between the Mn concentration in the applied solution and that in the leachate.)

TABLE 15 Effects of Mn concentrations in nutrient solution on sunflower seedling growth and Mn concentration in the seedlings in two experiments

	[Mn] in nutrient soln (ppm)	[Mn] in leachate (ppm)	Seedling mass (g/pot)	[Mn] in seedlings (ppm)
Expt I	0,5	0,10	4,90	101
	1,0	0,10	4,63	110
	2,0	0,20	4,58	144
	4,0	0,42	4,80	175
	8,0	1,80	4,90	300
	Mean	0,52	4,76	166
	LSD's 0,05	-	0,77(NS)	62
	0,01	-	1,20(NS)	103
Expt II	5,0	0,95	4,28	273
	10,0	1,65	3,62	440
	15,0	3,25	4,01	547
	20,0	7,40	4,04	707
	30,0	9,20	4,13	969
	40,0	9,60	4,29	1 064
	Mean	5,34	4,06	815
	LSD's 0,05	-	0,58(NS)	390
	0,01	-	0,90(NS)	612

In Experiment I, increasing the Mn concentration in solution from 0,5 to 8,0 ppm significantly increased the Mn concentration in the seedlings from 101 - 300 ppm (Table 15). These concentrations were less than those found in the seedlings in the field experiment and no conclusions could be drawn as to the effects of these higher concentrations in plant tissue on the growth of the plants. The Mn concentrations found in the seedlings in the nutrient solution experiment differed markedly from the results of Collander (1941) who found, in separate studies, that 0,5 ppm Mn in nutrient solution resulted in 1 521 and 794 ppm Mn in sunflower seedlings.

In Experiment II, increasing the Mn concentration in solution from 5 to 40 ppm significantly increased the Mn concentration in the seedlings from 273 to 1 064 ppm, but, once again, had no significant effect on seedling top growth (Table 15). From this it could be concluded that, since the Mn concentrations in plant tissue were appreciably higher than those found in the seedlings in the field, and had no detrimental effect on growth, the adverse effects of soil acidity in the Avalon medium sandy loam on the growth of sunflowers was not due to Mn toxicity. In particular, in spite of the high Mn concentrations in solution, no symptoms of any abnormality in the top or root growth were observed.

Phosphorus concentration in plant tissue

Except for the P concentration in the seed in 1973/74, liming consistently and significantly increased the P concentration in the tissues studied (Table 16). This was in keeping with the results of Foy & Brown (1963) who found that P uptake by cotton (Gossypium sp.) was inhibited in acid soils. Estrada & Cummings (1968), on the other hand, found that liming to pH 6,5 decreased the P uptake by maize plants.

In 1973/74, soil extraction with 0,05N H_2SO_4 indicated no treatment effects (p. 22) and the level of P in the soil would have been sufficient for a maize grain yield of 5 800 kg/ha (Farina & Mapham, 1973). In the subsequent season, the increased P soil test from 20 - 22 ppm with liming would only have increased maize grain yield by 1,4% (Farina & Mapham, 1973) were this increase in P soil test due to increased plant-available P with liming and not caused by differences resulting from the extraction method used.

TABLE 16 Lime effects on P concentration (%) in plant tissue in two seasons

Lime (kg/ha)		Seedlings		Mature leaves		Seed	
		1973/74	1974/75	1973/74	1974/75	1973/74	1974/75
0		0,152	0,205	0,250	0,289	0,490	0,547
800		0,157	0,214	0,253	0,333	0,497	0,541
1 600		0,172	0,236	0,266	0,358	0,507	0,562
2 400		0,176	0,248	0,288	0,383	0,517	0,572
Mean		0,165	0,226	0,264	0,341	0,503	0,556
LSD's	0,05	0,014	0,014	0,020	0,018	0,038	0,024
	0,01	0,020	0,019	0,027	0,025	0,051	0,033

In this study, it is not likely that the poor growth of sunflowers was primarily caused by P deficiency since, at the levels of P in the soil, adequate plant growth should have been possible. Sunflowers have been regarded as good extractors of P from the soil, and at the levels of soil P in this study, good growth of maize has been recorded (Farina & Mapham, 1973). The increased P uptake observed may be attributed to improved root growth with liming as was also found by Reeve & Sumner (1970b) with trudan on Natal Oxisols.

Total plant mass at maturity

In 1973/74, total plant mass at maturity was highly significantly increased by liming (Table 17), 2 400 kg lime/ha increasing plant mass more than four fold. This increase was to be expected from the marked effects of liming on plant growth (Plate 6). On average, gypsum applications had no significant effect on the total plant mass (Table 17).

A significant L'G' interaction on the total plant mass was observed (Table 17) indicating a slight beneficial effect of gypsum in the absence of lime On the other hand, gypsum applications tended to decrease plant mass in the presence of lime.

TABLE 17 Lime x gypsum interaction on total plant mass (kg/ha), uncorrected for moisture, in 1973/74

	L				G
	0	1	2	3	Mean
G 0	224	1 546	2 341	3 059	1 793
G 1	678	1 316	2 076	2 446	1 629
G 2	433	2 051	2 361	2 646	1 873
G 3	746	1 845	1 529	2 543	1 666
L Mean	520	1 690	2 077	2 674	1 740

LSD's

	0,05	0,01
Body	751	1 018
Means	375	509

Seed yield

In both seasons, seed yield was markedly increased by liming (Table 18). In the first season, seed yields, at G_0, were increased from 67 kg/ha without lime to 1 112 kg/ha with lime applied at a rate of 2 400 kg/ha. This latter yield was similar to the mean yield (four years) of Smena, 1 200 kg/ha, on the Doveton soil at Dundee where sunflowers have been grown successfully for a number of years (Blamey & Chapman, 1975). In the second season, however, seed yields were substantially decreased by adverse weather conditions (hail, low solar radiation and temporary flooding) but yields were, nevertheless, increased more than 10-fold by liming (Table 18).

In the first season, but not in the second, a significant L'G' interaction indicated the slight beneficial effect of gypsum applications on seed yield in the absence of lime. As with the total plant mass at maturity (Table 17), gypsum applications had a slight depressing effect on seed yield where lime was applied (Table 18).

Seed characteristics

Liming significantly improved all the seed characteristics measured, althoug in some cases, only slightly (Table 19), but gypsum applications had little effect. Oil concentration in the seed was increased by liming, from L_0 to L_3, from 34 - 36% in 1973/74 and from 33 - 38% in 1974/75. These levels were particularly low for Smena which should have an oil concentration in the seed of approximately 44% when grown in Northern Natal (Blamey & Chapman, 1975).

TABLE 18 Lime x gypsum interactions on seed yield (kg/ha) over two seasons

		L				G		LSD's	
		0	1	2	3	Mean		0,05	0,01
G	0	67	516	847	1 112	635			
	1	203	460	793	882	585	Body	276	374
	2	147	701	774	830	613	Means	138	187
	3	264	571	616	927	594			
L Mean		170	562	757	938	607			
G	0	14	234	539	747	384	Body	236	319
	1	85	339	476	748	412	Means	118	159
	2	69	418	587	827	475			
	3	61	503	502	694	440			
L Mean		57	374	526	754	428			

TABLE 19 Lime and gypsum effects on seed characteristics in two seasons

Treatment	Oil concentration (%)		Empty seeds (%)		100 seed mass (g)		Hectolitre mass (kg/hl)	
	1973/74	1974/75	1973/74	1974/75	1973/74	1974/75	1973/74	1974/75
L_0	34,2	32,7	18,5	24,5	5,4	4,3	26,8	28,0
L_1	34,6	35,4	13,5	16,7	6,1	5,6	27,1	24,8
L_2	35,9	36,9	13,7	15,6	6,3	5,6	27,5	29,2
L_3	36,3	37,8	12,9	14,7	6,7	6,0	27,8	29,5
G_0	35,3	36,7	15,3	15,5	6,1	5,2	27,3	29,3
G_1	35,4	34,9	15,2	21,3	6,0	5,3	27,4	28,5
G_2	35,8	35,7	13,9	18,9	6,1	5,5	27,5	28,5
G_3	34,5	35,5	14,1	15,8	6,2	5,6	27,0	28,8
Mean	35,3	35,7	14,7	17,9	6,1	5,4	27,3	28,8
LSD's 0,05	1,2	0,9	2,4	5,0	0,3	0,3	0,6	0,5
0,01	1,7	1,3	3,3	6,8	0,4	0,4	0,9	0,7

Liming significantly increased the hectolitre mass (Table 19) but, as with the oil concentration, the hectolitre mass was also low compared to an average 35,0 kg/hl for Smena grown on the Doveton soil (Blamey & Chapman, 1975). The low hectolitre mass and low oil concentration point to some other factor, e.g. disease or premature senescence of the leaves, affecting the maturity of the crop.

The mass of 100 seeds was significantly increased by liming from 5,4 g at L_0 to 6,7 g at L_3 in 1973/74 and from 4,3 - 6,0 g at these levels in 1974/75. This compared favourably with the mean mass of 100 seeds of Smena, 5,3 g, grown on the Doveton soil (Blamey & Chapman, 1975). Indicative of the improved growth conditions, liming significantly decreased the percentage empty seeds in both seasons (Table 19).

Gypsum applications, only in 1974/75, slightly decreased the oil concentration and hectolitre mass and slightly increased the 100-seed mass (Table 19).

SUMMARY AND CONCLUSIONS

In both the pot and field experiments, the adverse effects of the acid soil conditions on sunflower growth were demonstrated. In general, most marked beneficial effects of liming were recorded but gypsum applications produced only slight, if any, improvements in growth.

The detrimental effects on growth of the acid soil conditions were immediately apparent and persisted throughout the growing season. It was concluded that these effects were largely due to aluminium toxicity. Vlamis (1953) found that symptoms of Al toxicity were immediate and drastic whereas manganese toxicity was a cumulative process aggravated with time. Symptoms of th seedlings in the L_0 plots appeared to match those described by Hortenstine & Fiskell (1966) who studied the effects of Al in solution on sunflower growth. Furthermore, poor root growth was observed in the absence of lime, in pots as well as in the field, supporting the proposal of Al causing poor crop growth on account of its being a root toxin (Vlamis, 1953; Coleman et al., 1958; Foy & Brown, 1963; Pratt, 1966).

From the field experiment alone, manganese toxicity could not be entirely eliminated as contributing to poor growth since Mn toxicity levels in sunflowers are not known. Mn concentrations in the vegetative tissue differed markdely in the two seasons, but the beneficial effects of liming in the two seasons differed only in degree. Results from the nutrient solution experiments indicated that Mn concentrations in the seedlings of>1 000 ppm were not toxic for sunflower growth since, at this concentration, no adverse effect on top growth was measured. Furthermore, increasing the Mn concentrations in nutrient solutions from 0,5 up to 40 ppm had no observable adverse effect on root growth.

Calcium deficiency was not the cause of poor growth since both lime and gypsum applications increased exch. Ca in the soil and Ca uptake by the plants but differed in their effects on plant growth. Magnesium deficiency was eliminated as the major cause of poor growth since gypsum applications decreased the Mg concentrations in the seedlings but did not adversely affect growth. Furthermore, in the pot experiment, there was no relationship between exch. Mg and plant growth. The high level of P in the soil precluded phosphorus deficiency being the primary cause of poor sunflower growth and the increased P uptake brought about by liming may be regarded as due to improved root growth. This further confirmed the proposal that Al toxicity was responsible for poor growth, since the detrimental effects of Al toxicity are related to P uptake and translocation (Coleman et al., 1958; Foy & Brown, 1963).

From the results of the pot experiment, the premise was confirmed that, for the optimum growth of sunflowers, this soil should be limed in order to neutralize toxic aluminium. No benefit was observed of liming to a higher, empirically-selected pH,e.g.pH 6,5, but the correct level of liming must be established by further investigation.

CHAPTER III

RELATIONSHIPS BETWEEN SUNFLOWER YIELD AND ALUMINIUM TOXICITY IN AN AVALON MEDIUM SANDY LOAM

INTRODUCTION

In both the pot and field experiments, the adverse effects of soil acidity in the Avalon medium sandy loam on sunflower growth were demonstrated and it was concluded that this poor growth was largely caused by aluminium toxicity. Resulting from this, it was necessary to establish the relationships between soil test and crop yield, since "to become useful, crop response data will have to be correlated with a soil test .... to evaluate soil fertility" (Pesek, 1956). Furthermore, statistical methods must be used to establish the appropriate form of the relationships between soil test and crop yield (i.e. the response functior and, as Heady (1956) has concluded, "every fertilizer recommendation to farmers implies knowledge of the mathematical nature of the response function."

In the study of this acid soil, crop yield can be related to three soil tests, viz soil pH (N KCl), exch. Al (meq/100g) and Al saturation (%), which were determined using the analytical techniques described in Chapter I. Low soil pH, although not a primary cause of poor crop growth, is a symptom of conditions under which some other soil property may limit crop growth (Adams & Pearson, 1967) and can be used as such. In fact, a very close relationship was found between soil pH (N KCl) and exch. Al (meq/100g) in this soil (p. 24).

As discussed previously, two proposals have been put forward regarding the amount of lime that should be applied to acid soils. For a number of years, it was recommended that soils should be limed to increase the soil reaction to pH(H_2 6,5 or above (Coleman et al., 1958; Shoemaker et al., 1961; Adams & Pearson, 1967). More recently, however, Kamprath (1970), Reeve & Sumner (1970b) and Martini et al. (1974) have recommended that, since Al toxicity was the major cause of poor plant growth on acid soils, only sufficient lime need be applied to neutralize this toxic aluminium. Accordingly, lime should be applied to ~ pH (N KCl) 4,5 since above this pH, Al^{3+} is not present in appreciable amounts (Dalal, 1975). These two hypotheses were investigated with respect to sunflower growth on the Avalon medium sandy loam and the use of soil pH (N KCl) as the independent variable (x) in the study of crop response to soil amelioration may be used to establish the pH to be achieved by liming.

Since aluminium toxicity was found to be the major cause of poor sunflower growth on this acid soil, crop response should be closely related to soluble Al in the soil. Two measures of toxic Al in the soil have been used in an effort to relate crop growth to soil test, viz exch. Al (meq/100g) and Al saturation (%). The latter has been proposed as being particularly relavent to establishing relationships between crop growth and Al toxicity in different soils (Abruna-Rodriguez, Vincente-Chandler, Pearson & Silva, 1970), but Adams & Pearson (1967) claimed that the use of Al saturation as a measure of Al toxicity did not have universal applicability. Further investigation involving sunflower growth on different soils was beyond the scope of this study.

Since Adams & Pearson (1967) concluded that "there are sufficient data available to establish that neither exchangeable Al nor Al saturation, as currently defined, is suitable for general application to all soils for defining toxic levels of Al" it was necessary to establish these relationships for the soil under study. Furthermore, it was necessary to determine the relationships between sunflower growth and Al toxicity since plant species differ markedly in their tolerance of toxic aluminium.

MATERIALS AND METHODS

Data from both the pot and field experiments were used separately to establish mathematical relationships between yield and measures of soil acidity. Sunflower growth was measured in the pot experiment as the vegetative seedling mass, tops and roots, and in the field experiment as the seed yield. These criteria were used as the dependent variate (y) to establish the relationships between sunflower yield and (i) soil pH (N KCl), (ii) exch. Al (meq/100g) and (iii) Al saturation (%) which were considered as the independent variate (x).

The data from the pot experiment, in which soil reaction was increased up to pH (N KCl) 7,0, were used in an effort to establish the approximate level to which lime should be applied for maximum yield. It was recognised that soil calibration using data from pot experiments has limitations, similar to those using pot experiments to establish critical nutrient concentrations in plant tissues (Bates, 1971), and care should be used in their interpretation. In this study, results from the pot experiment were required to test whether lime should be applied to eliminate toxic Al (~pH (N KCL) 4,5) or whether the soil should be limed to some higher pH (say pH 6,5) for maximum growth of sunflowers on this soil.

Certain drawbacks in the use of the field experiment for calibrating the effect of soil acidity on yield were evident. The absence of explicit replication the use of only two seasons' data and, in particular, the atypical weather conditions of the second season may reduce the generality of the conclusions. Borax applications were found to increase seed yields (Chapter IV), but the effect was substantially less than that of lime, and the exclusion of the data from the B_0 plots resulted in only a slight increase in precision. In order to combine data from the two seasons, seed yield (y) was expressed as a percentage of the mean seed yield at L_3 in the respective season. This procedure has been found to be satisfactory for combining data from different seasons (Mapham & Farina, 1974).

Certain a priori functions, both linear and curvilinear, were fitted to the data, using the method of least squares, in order to estimate the relationship between yield and soil test. The 'goodness of fit' of the various curves was compared and that with the best fit was selected as that which minimized the residual sum of squares and maximized the correlation between observed and fitted values of y (R).

RESULTS AND DISCUSSION

Pot experiment

As could be inferred from the results of the pot experiment presented in the foregoing chapters (Table 4, Fig. 9), there was a very close relationship between seedling yield, both tops and roots, and soil pH (N KCl). These relationships were clearly curvilinear and, as a first step, the quadratic and square root functions were fitted to the data, which included data from the seven pots to which the agricultural lime had been applied (p.10).

The use of either the quadratic or square root functions to estimate the relationships between plant mass (y) and soil pH (N KCl) (x) showed a highly significant correlation between the observed and fitted values of y (Table 20). But the pattern of residuals, as outlined by Mapham (1975), showed the poor fit of both these curves, since there were systematic deviations between the observed and fitted values of y. It could, thus, be concluded that "it seems that the size of R does not express the presence or absence of systematic deviations from the fitted model" (Mapham, 1975) and that these two curves were not satisfactory for estimating the relationship between seedling yield and pH (N KCl).

Since the fitting of a single model to the regression curve was unsatisfactory, it was decided to approximate the regression curve by a sequence of submodels[1], as outlined by Hudson (1966). In this case, two linear submodels, $f_1(x)$ and $f_2(x)$, were fitted to the data and, since the join point of $f_1(x)$ and $f_2(x)$ was not known, the final overall solution was based on the minimization of the pooled residual sum of squares. There are certain theoretical objections to the use of such submodels in that it may not always be evident why one biological law would hold in one region of the response curve and not in another. In this case, however, since Al^{3+}, which is toxic to root growth, is present only below pH (N KCl) 4,5, it is evident that a distinct change in the relationship between plant growth and pH (N KCl) may be present at this point.

From a series of simple linear regression analyses, the pooled residual sum of squares of $f_1(x)$ and $f_2(x)$ was minimized with the two curves presented in Table 20. The pooled residual sum of squares for these two functions was markedly lower than the residual sum of squares for either the quadratic or square root functions and confirmed the superiority of the two linear submodels for estimating the response function (Table 20).

TABLE 20 Relationships between seedling growth (top and root mass) and soil pH (N KCl)(n = 35)

Equations fitted	[1]Sum of squared error terms	R
y=top mass (g); x = pH (N KCl)		
$y= -15,784 + 6,504x - 0,563x^2$	6,238	0,885
$y= -63,992 - 11,787x + 56,186x^{\frac{1}{2}}$	5,216	0,906
$f_1(x)=y= -12,544 + 3,443x; f_2(x)=y= 2,907 - 0,063x$	2,636	0,953
y=root mass (g); x = pH (N KCl)		
$y= -11,790 + 4,921x - 0,434x^2$	5,146	0,820
$y= -49,418 - 9,272x + 43,730x^{\frac{1}{2}}$	4,388	0,849
$f_1(x)=y= 9,977 + 2,751x; f_2(x)=y=2,573-0,136x$	3,623	0,880

[1] pooled in the case of the segmented curves

The suitability of using the two linear regression lines in estimating the relationship between soil pH (N KCl) and (i) top yield and (ii) root yield is shown in Fig. 12. From the equations of the two submodels, the abscissa of the point of intersection (join point) of the two regression lines was calculated

[1]The suggestions of Professor A.A. Rayner & Dr R.M. Pringle to investigate this aspect are gratefully acknowledged.

as, $\hat{x} = \frac{a_2 - a_1}{b_1 - b_2}$. Since the growth of the sunflower seedlings, both tops and roots, was slightly depressed at pH (N KCl) levels above the join point (as shown by the negative slope of $f_2(x)$, Fig. 12), maximum seedling yields were recorded at the join point which was pH (N KCl) 4,43 for the tops and pH (N KCl) 4,35 for the roots.

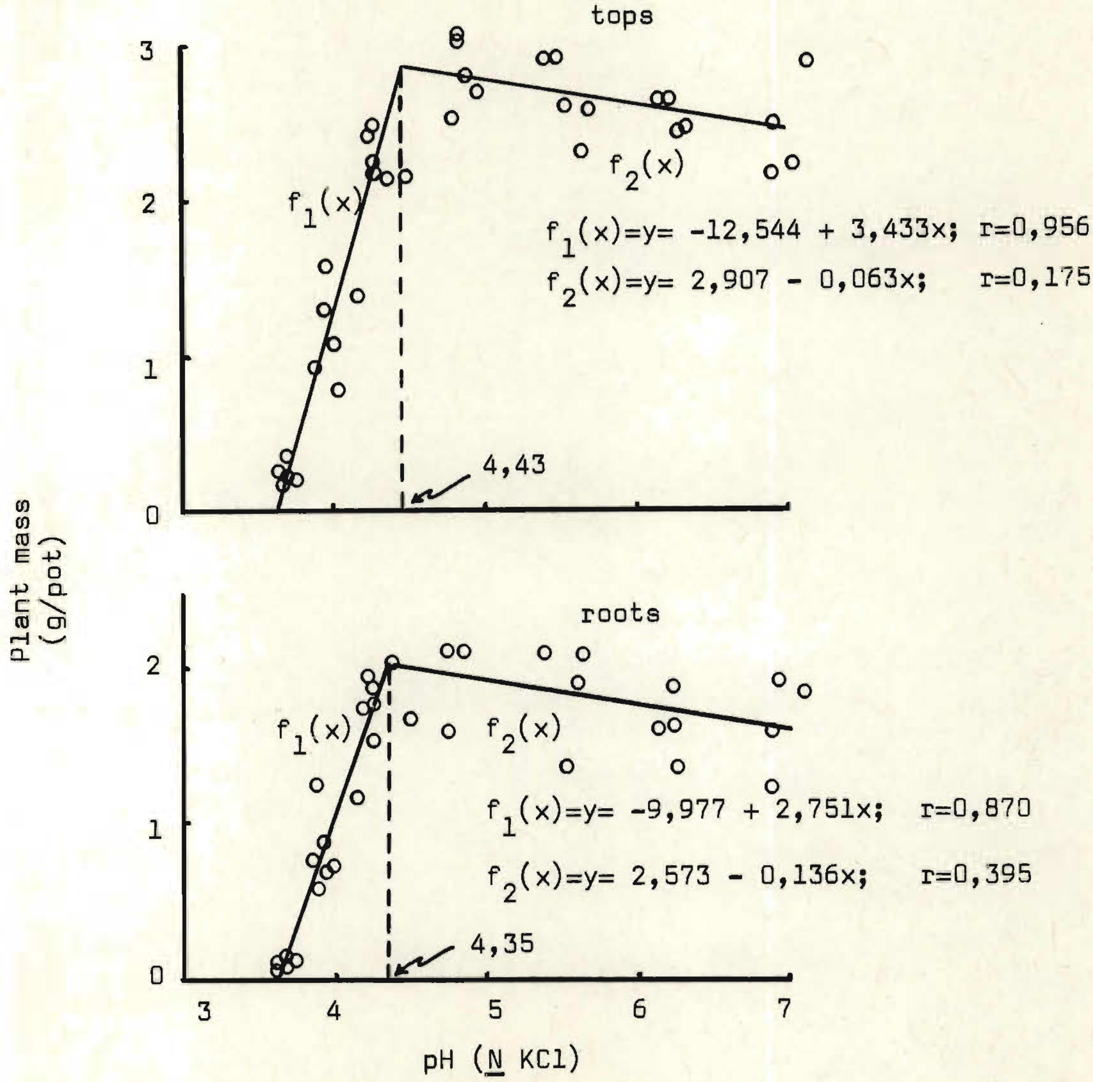


FIG. 12 Relationships between sunflower seedling mass (tops and roots) and soil pH (N KCl)

Confidence limits were calculated for these join points (Kastenbaum, 1959) as pH (N KCl) 4,43 ± 0,23 (95%) and ± 0,24 (99%) in the case of the tops, and pH (N KCl) 4,35 ± 0,24 (95%) and ± 0,25 (99%) in the case of the roots. Thus, in both cases, it could be concluded that maximum seedling growth was recorded at approximately that pH (N KCl) level corresponding with the elimination of toxic aluminium from the root environment (i.e. ~ pH (N KCl) 4,5). This level to which lime should be applied was appreciably less than that which has been recommended to increase soil pH to 6,5.

Since toxic aluminium was shown to be the major cause of poor sunflower growth on this soil, a close relationship was expected between seedling growth and exch. Al (meq/100g). This was confirmed by the highly significant, linear correlations between exch. Al (meq/100g) and (i) seedling top mass (r = 0,955***) and (ii) seedling root mass (r = 0,917***) (Fig. 13). In this study, exch. Al (meq/100g) proved slightly superior to Al saturation (%) as a measure of toxic Al in the soil. In this latter case, the regression between Al satn (%) (x) and top mass (g) (y) was given by the equation y = 2,56 - 0,04x (r = 0,947***) and that between Al satn (%) (x) and root mass (g) (y) was estimated by the equation, y = 1,94 - 0,03x (r = 0,915***). The application of more lime than that required to neutralise toxic Al actually depressed growth slightly (Fig. 12) and the poorer fit of the function where exch. Al approached zero was a further indication of this (Fig. 13).

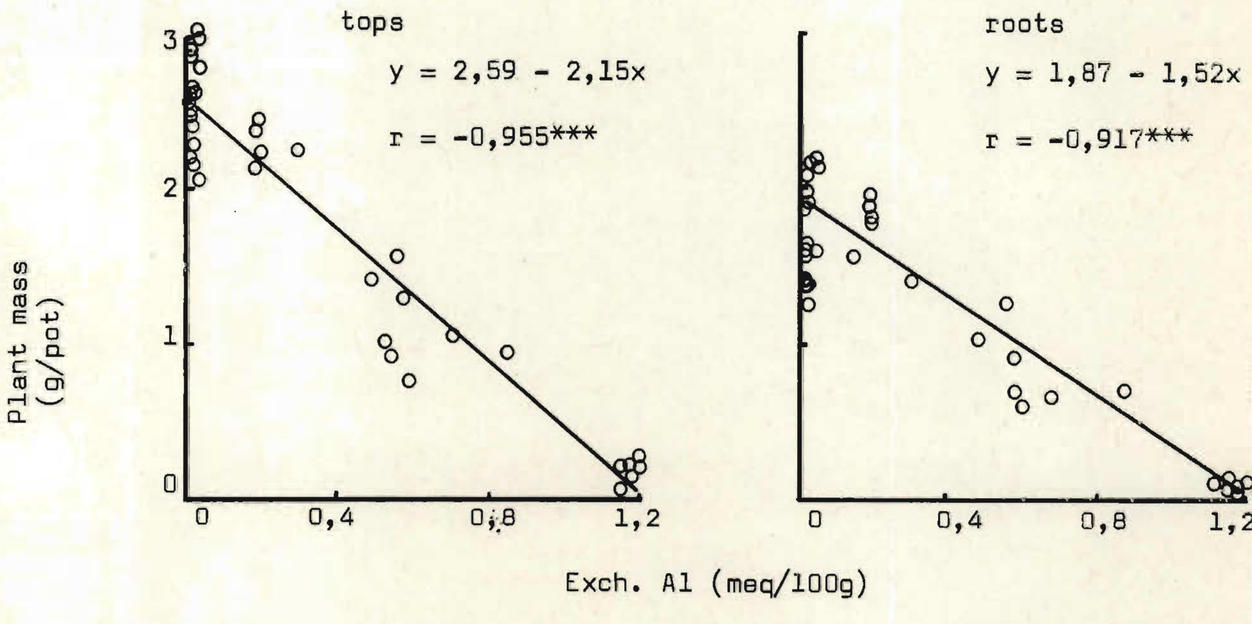


FIG. 13 Relationships between sunflower seedling mass (tops and roots) and exch. Al (meq/100g) in the soil

Field Experiment

Highly significant relationships were recorded between sunflower seed yield, expressed as a percentage of the yield at L_3 and the three measures of soil acidity, soil pH (N KCl), exch. Al (meq/100g) and Al saturation (%), using the two seasons' data. With the use of two seasons' data, the best relationship between soil pH (N KCl) (x) and seed yield (%) (y) was obtained using the quadratic equation, $y = -1\,214{,}2 + 522{,}8x - 50{,}8x^2$ ($R = 0{,}673$). No conclusion could be reached regarding the optimum pH for sunflower growth on this soil, because the pH (N KCl) was only increased to 4,47 at the highest rate of lime in the second season (p. 13).

There was a highly significant linear relationship between exch. Al (meq/100g) (x) and seed yield (%) (y) using the two seasons' data, which was best estimated by the equation, $y = 124{,}33 - 119{,}46x$ ($r = 0{,}764^{***}$). This relationship proved slightly superior to that between Al saturation (%) (x) and seed yield (%) (y)($y = 114{,}09 - 1{,}734x$; $r = 0{,}758^{***}$) in relating the effects of Al toxicity to the growth of sunflowers. Using the two seasons' data separately, it was shown that exch. Al (meq/100g) was substantially superior to Al saturation (%) as a measure of Al toxicity, particularly in the first season (Table 21). This was to be expected, since gypsum applications markedly decreased Al saturation but had only a slight effect on seed yield (Table 8, 18).

TABLE 21 Relationships between sunflower seed yield (%) (y) and exch. Al (meq/100g) and Al saturation (%) in 1973/74 and 1974/75 (n=64)

Season	Equation fitted	Sum of squared error terms	r
x = exch. Al (meq/100g)			
1973/74	$y = 157{,}57 - 159{,}94x$	29 448	0,818
1974/75	$y = 112{,}12 - 114{,}23x$	36 024	0,812
x = Al saturation (%)			
1973/74	$y = 129{,}85 - 2{,}034x$	40 733	0,736
1974/75	$y = 105{,}40 - 1{,}647x$	36 468	0,808

Comparison of the seasonal effects on the relationship between seed yield and exch. Al showed the marked superiority of the first season over the second (Fig. 14). Using the regression equations obtained, it could be calculated that where exch. Al (meq/100g) was (hypothetically) reduced to zero, seed yields of

1 470 and 844 kg/ha were possible in the two seasons, respectively. This confirmed the observations that, from an agrometeorological point of view, the second season was inferior to the first.

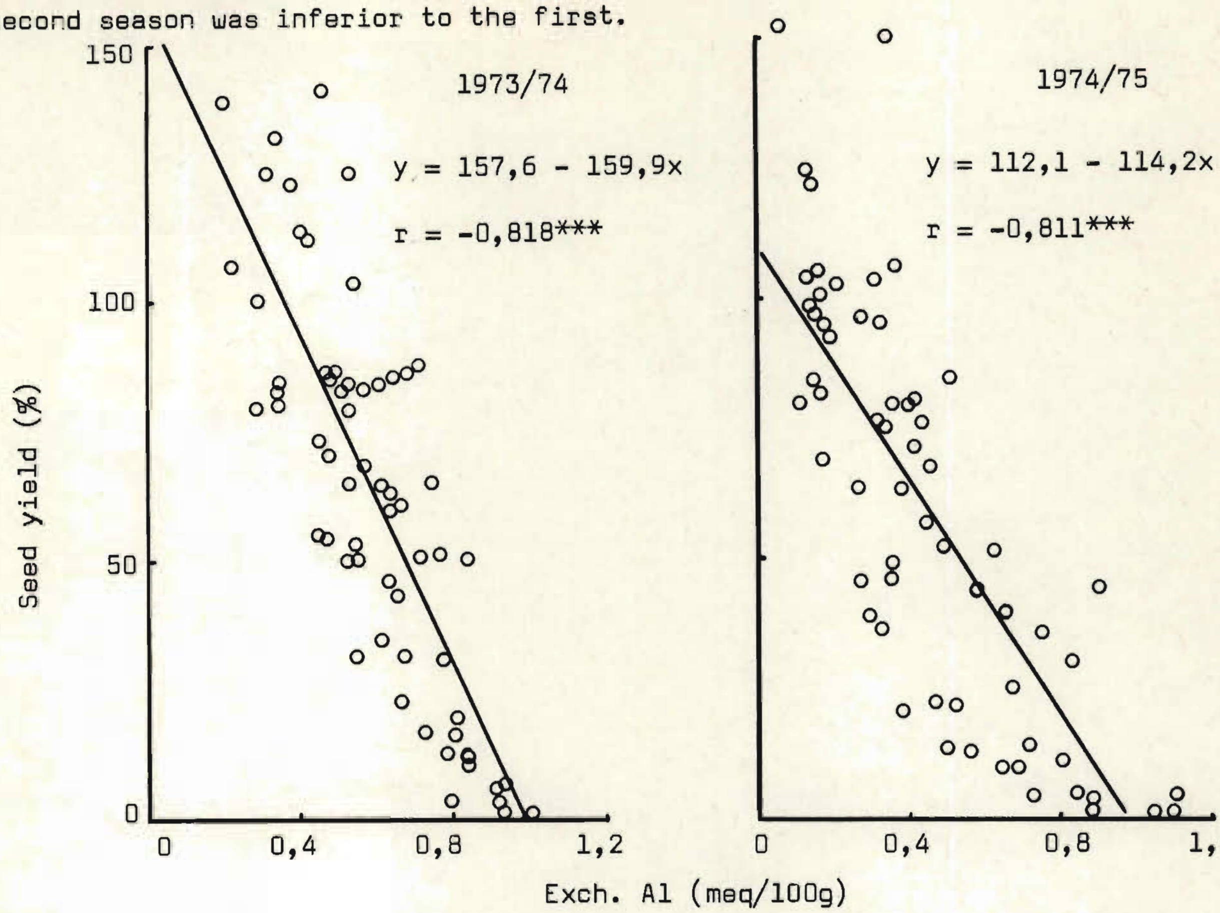


FIG. 14 Relationships between sunflower seed yield (expressed as a percentage of mean seed yield at L_3) and exch. Al (meq/100g) in two seasons

Although in this study, the use of Al saturation was slightly inferior to exch. Al as a measure of Al toxicity, the former may have applicability in comparing the effects of Al toxicity on different soil types (Adams, Pearson & Doss, 1967 ; Abruna-Rodriguez et al., 1970; Evans & Kamprath, 1970). Gypsum applications introduced a confounding effect on this relationship, and the regression of seed yield (%) on Al saturation (%) was calculated using both seasons' data from all plots receiving no gypsum (Fig. 15). This relationship could possibly be used for comparing the effects of Al toxicity on sunflower growth on different soil types, an investigation which is, however, beyond the scope of this present study.

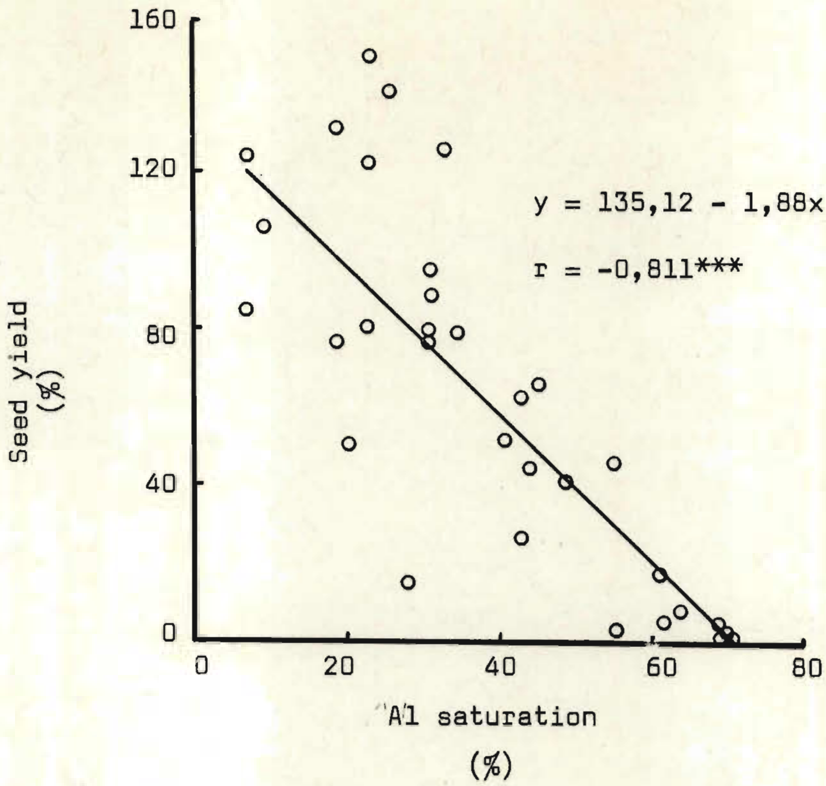


FIG. 15 Relationship between sunflower seed yield and Al saturation in the absence of gypsum applications (two seasons' data) (n = 32)

SUMMARY AND CONCLUSIONS

Results from the pot experiment confirmed many findings in recent years (Kamprath, 1970; Reeve & Sumner, 1970b; Martini et al., 1974) that, at least in the soils of the warmer regions of the world, lime should be applied to eliminate toxic aluminium rather than to some empirical pH ~6,5. From this study, it could be concluded that liming above pH (N KCl) 4,5 was of no further benefit to sunflower growth and, indeed, yields were slightly depressed. Similar results, varying only in the magnitude of the depressing effect of liming above pH (N KCl) 4,5, were recorded by Reeve & Sumner (1970b) and Martini et al., (1974) with trudan and soybeans, respectively.

Using the relationship established between pH (N KCl) and exch. Al (meq/100g) for this soil (Fig. 6), it could be concluded that an Avalon medium sandy loam, containing appreciable quantities of exchangeable Al, should be limed in order to reduce the exch. Al to 0,13 meq/100g. This would require approximately 2 200 kg $CaCO_3$/ha or 5 500 kg agricultural lime/ha (of the quality used in these studies) to decrease exch. Al by 1 meq/100g (Fig. 2).

In both the pot and field experiments, close relationships existed between sunflower yield and exch. Al (meq/100g) and most marked yield increases were recorded with a decrease in exchangeable Al. Averaged over two seasons, sunflower seed yields in the field were increased by 12% for each 0,1 meq/100g reduction in exch. Al.

The magnitude of this response appeared to be influenced by a number of factors. Firstly, the sunflower plant may be regarded as sensitive to Al toxicity. Secondly, the low CEC of this soil probably played an important role in accentuating the severity of the effects of aluminium toxicity. Thirdly, the low organic matter content ($\sim$ 0,3% organic C) of this soil probably played an important role in the manifestation of aluminium toxicity. Thomas (1975) found that, at low pH, "even small increases in organic matter give a substantial reduction in exchangeable Al."

Because of the widespread distribution of acid soils in the high rainfall areas of South Africa (Graven, 1973), it is possible that aluminium toxicity is an important factor responsible for poor sunflower yields in many other situations. The results obtained on the Avalon medium sandy loam, indicate that further investigation of the problem of aluminium toxicity in sunflowers on other soil types would be worth-while.

CHAPTER IV

BORON NUTRITION OF SUNFLOWERS ON AN AVALON MEDIUM SANDY LOAM

INTRODUCTION

That boron is essential for the growth of higher plants was conclusively demonstrated by Sommer & Lipman (1926) and Sommer (1927) (according to Bradford, 1966). Since that time, numerous instances of B deficiency in plants have been recorded. Sypmtoms of boron deficiency vary with plant species, but usually involve the breakdown of meristematic tissue (Schuster & Stephenson, 1940 ; Stiles, 1961; Bradford, 1966; Oertli & Roth, 1969; Hundt, Bergmann, Fischer & Schilling, 1970) and abnormalities of the reproductive organs (Stiles, 1961; Shatilov & Ikonnikov, 1969). Boron is also necessary for pollen germination (Pawlowski, 1966; Maun, Teare & Canode, 1969; Benner & Townsend, 1973) and good root development (Haynes & Robbins, 1948). The functions of B in the plant have been associated with water relations, sugar translocation, cation and anion absorption and the metabolism of nitrogen, phosphorus, carbohydrates and fats (Stiles, 1961; Shkol'nik & Kopmane, 1970).

The boron requirements of plant species differ greatly as do their tolerance to excess boron in the soil (Eaton, 1944; Oertli & Roth, 1969). Bradford (1966) found that in a wide variety of plants, B deficiency was characterized by levels of less than 10 - 15 ppm B in the dry matter; levels of 25 - 100 ppm B indicated an adequate supply and more than 200 ppm was often associated with boron toxicity.

Sunflowers have been found to be particularly sensitive to boron deficiency and this may be attributed to a high B requirement since sunflower roots have a high B-absorption capacity (Tanaka, 1967). Use has been made of sunflowers in a pot technique for assessing available boron in soils (Schuster & Stephenson, 1940; Tisdale & Nelson, 1966). Instances of sunflower response to applied B in the field are, however, uncommon, as are reports of critical B concentrations in sunflower tissues. Bradford (1966), in an extensive review, cited only one reference (Tanada & Dean, 1942) to B levels in sunflower tissue. These authors found that, in pots, six-week-old sunflower plants showing deficiency sypmtoms contained 8 - 23 ppm B while, in the same study, 12 - 150 ppm B indicated an adequate supply. Robinson (1970) found apparently normal seedlings to contain 38 ppm B and seed to contain 18 ppm B.

A number of soil factors have been shown to affect boron availability. In particular, increasing soil pH decreases B uptake by plants (Plant, 1953; Gupta & Cutcliffe, 1972; Snyman, 1972). Hatcher, Bower & Clark (1967) claimed that the lime-induced boron deficiency resulted from the additional adsorption of B by $Al(OH)_3$ precipitated by liming. On the other hand, Drake, Sieling & Scarseth (1941) and Majewski & Janiszewska (1970) found no relationship between soil pH and B fixation in the soil and Drake et al. (1941) determined that boron solubility was unaffected over the range pH 4,1 - 11,6. Adams & Pearson (1967) concluded that, in the southern U.S.A., "lime induced B deficiency as such probably does not occur frequently below pH 6,5."

In addition to soil reaction, soil texture has been reported to affect B availability since less B is required on sandy soils to meet plant requirements (Wilson, Lovvorn & Woodhouse, 1951; Wear & Patterson, 1962). Because of this, care must be exercised to prevent boron toxicity in sandy soils resulting from excess B fertilization.

Bradford (1966) listed a number of soil situations in which B deficiency is likely to occur. Of these, three apply to the Avalon medium sandy loam, viz the soil is derived from fresh water sediments (King, 1972) and the soil is naturally acid and sandy. Furthermore, boron deficiency has been reported i crops grown on this soil. Venter & Farina (1972) observed a marked response of dryland wheat (Triticum vulgare) to borax applications and Snyman (1972) reported B deficiency symptoms in groundnuts. Snyman (1972) found the hot-water-soluble B in this soil to be 0,2 ppm which was indicative of the potentia B deficiency in sunflowers since Majewski & Janiszewska (1970) found this crop to respond to B applications when the level of B in the soil was <0,4 ppm.

In preliminary investigations on the Avalon soil (unpublished), abnormalities were noted in sunflower seedlings and mature plants where no borax had been applied. The present study developed from these investigations and aimed at (i) describing boron deficiency symptoms in sunflowers in the field and (ii) establishing the effects of applied B. The effects of soil amelioration on the B nutrition of sunflowers were also investigated.

MATERIALS AND METHODS

A field trial was carried out in two consecutive seasons, 1973/74 and 1974/75, on an Avalon medium sandy loam at the Dundee Agricultural Research Station. This experiment has been described in detail in the foregoing chapters with respect to the effects of soil amelioration on sunflower growth. The effects of annual borax applications of 0, 5, 10 and 30 kg/ha, and the interactions between these applications and soil amelioration, were also investigated. Details of the measurements taken in the field have been described (p. 31) and, in addition, the percentage deformed sunflower heads were determined after harvesting. For statistical analysis, these data were subject to angular transformation (Rayner, 1969). Because of the effect of liming on plant population (p. 37), the percentages were based on unequal numbers, but it was not necessary to conduct a weighted analysis (Cochran, 1943).

The quantity of hot-water-soluble boron in the soil is generally accepted as a good estimate of the availability of boron for plants (Wear, 1965). In this study, however, measurement of hot-water-soluble B was not carried out because it was considered that, on this sandy soil, rapid leaching of B would occur (Wilson et al., 1951; Bigger & Fireman, 1960) which would render soil analysis (0 - 15 cm) for plant-available B of little use. Furthermore, changes in soil pH (Wear & Patterson, 1962) and wetting and drying of the soil (Parks & White, 1952; Biggar & Fireman, 1960; Snyman, 1972) would render interpretation of soil analysis for boron difficult.

In this study, it was considered that tissue analyses for B would be superior to soil analyses (Dewan, 1942, Ouellette & Lachance, 1954 according to Bradford, 1966; Reid & Cox, 1973) as a measure of the boron nutritional status of the sunflower plants. Ouellette & Lachance (1954) (according to Bradford, 1966) concluded that visual symptoms and plant analysis were more reliable than soil analysis for the diagnosis of B deficiency.

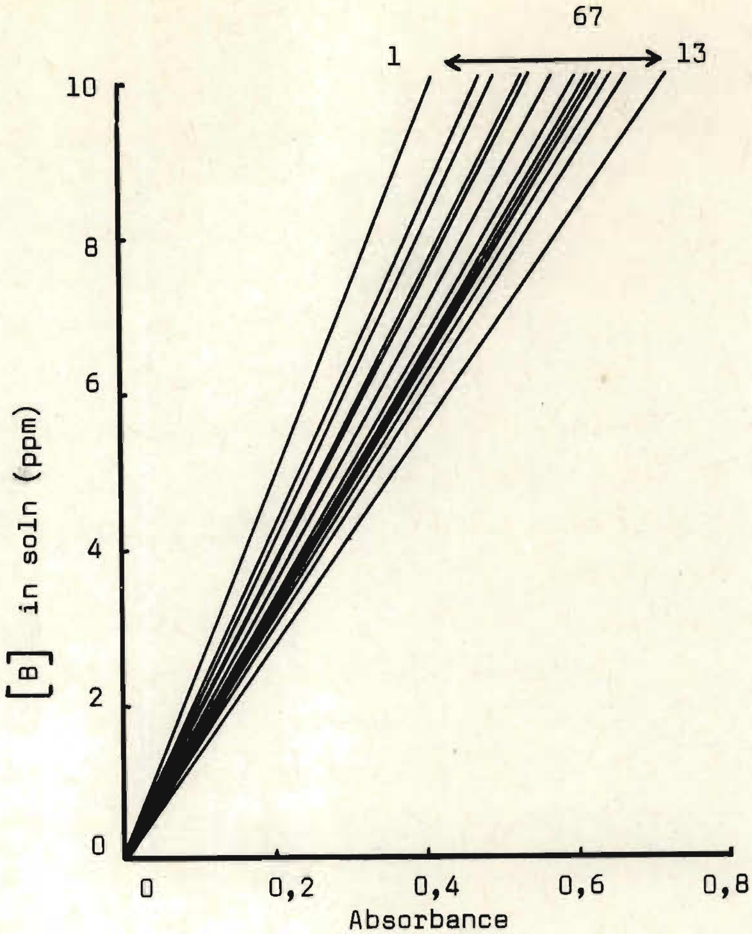
Three plant tissues were sampled, viz the month-old seedlings, the topmost, fully-mature leaf at flowering and the seed, and analyzed for boron using the colorimetric method of Hatcher & Wilcox (1950). In addition, in the 1974/75 season, the variation in chemical composition over the growing season of the topmost, mature leaf was studied by sampling 30 plants from the L_2G_0 plots from 6 - 10 weeks after planting. In the pot experiment, described in the foregoing chapters, the effect of liming from pH (N KCl) 3,9 - 7,0 on the boron concentration of sunflower seedlings was also investigated. (Boron had been applied at a rate of 0,7 ppm to the soil.) There was insufficient plant material where no lime was applied to investigate the effects of lower soil pH on boron nutrition.

Plant vegetative tissue was dried to constant mass at $80^{o}C$ and milled prior to chemical analysis. The seed was milled and analyses carried out on an air-dry basis. (Blanks and standards were analyzed as a normal laboratory procedure.) A 5 g sample of milled plant material was thoroughly mixed with 0,5 g CaO as described by Hatcher & Wilcox (1950) and dry ashed at $520^{o}C$. The ash was taken up in 10 ml 1:1 $HCl:H_2O$, heated on a water bath for 30 min. and the suspension filtered through Whatman No. 541 filter paper. The filtrate was diluted to 50 ml of which 2 ml was used for the B analysis procedure. Further dilution of the filtrate was required when the B concentration in solution exceeded 10 ppm.

Hatcher & Wilcox (1950) made use of the colour change of carmine in concentrated H_2SO_4 from bright red in the absence of B to blue-red or blue in the presence of boron. In this study, the transmittance at 585 mμ was measured on a Bausch & Lomb Spectronic 20 spectrophotometer. The method was found to be entirely satisfactory, except for the danger of using concentrated H_2SO_4, and a large number of samples were analyzed. (It was possible to determine the B concentration in approximately 70 samples in one day.)

Over the period of this study, substantial differences in the slopes of the standard curves were recorded (Fig. 16). These differences were thought to be due to differences in temperature during the period of colour development, but except for random variation, no differences in the values of the standard controls were recorded.

The calcium:boron ratio in plant tissue has been claimed to be a good measure of the boron nutrition of plants (Drake et al., 1941; Ruhal & Deo, 197 Gupta, 1972; Gupta & Cutcliffe, 1972). Thus, the calcium concentration in plant tissue was determined flame spectrophotometrically as described in Chapter II and the Ca:B ratio in plant tissues calculated.



No.	Equation	r
1	$\hat{y} = 23,717x$	0,998 046
2	$\hat{y} = 20,753x$	0,998 953
3	$\hat{y} = 20,025x$	0,998 627
4	$\hat{y} = 18,624x$	0,999 958
5	$\hat{y} = 18,366x$	0,997 984
6	$\hat{y} = 17,516x$	0,999 864
7	$\hat{y} = 16,555x$	0,999 673
8	$\hat{y} = 15,991x$	0,999 435
9	$\hat{y} = 15,946x$	0,999 750
10	$\hat{y} = 15,904x$	0,999 812
11	$\hat{y} = 15,325x$	0,999 280
12	$\hat{y} = 14,899x$	0,999 317
13	$\hat{y} = 13,817x$	0,998 182

FIG. 16 Variation in the slope of the B standard curves (n = 6) using the method of Hatcher & Wilcox (1950) (not in chronological order)

RESULTS AND DISCUSSION

Field experiment

Plant growth

Before flowering, applications of borax had no discernable effects on plant growth. Borax applications had no significant effects on emergence, seedling mass, population, plant height, LAI and total plant mass at maturity nor on the Ca, Mg, K or P concentrations in plant tissues. At flowering, however, leaf abnormalities were observed in plots where no borax had been applied (Plate 7). The upper leaves became hardened, malformed and necrotic and, in affected plants, the peduncle had a corky appearance. Malformations of the flowers (Plate 8) were observed in those plots where no borax had been applied and this malformation affected the dried capitulum (Plate 9), resultin in areas where no seed developed. These symptoms appeared less severe in the second season, in which more rain was recorded than in the first, in keeping with the close association between moisture supply and B availability in this soil (Snyman, 1972).

In both seasons, applications of borax resulted in a highly significant decrease in the percentage deformed heads (Fig. 17). Applications of 10 kg borax/ha decreased the percentage deformed heads (detransformed) from 27% at B_0 to less than 5% in 1973/74 and from 14% at B_0 to less than 4% in the second season. An application of 30 kg borax/ha was of no further benefit in decreasing the incedence of deformed heads in either season.

PLATE 7 Boron deficiency symptoms in sunflower leaves at flowering

PLATE 8 Where no borax was applied, malformation of the flower head (capitulum) was evident in many plants

PLATE 9 The malformation of the capitulum at flowering resulted in areas of poor seed set

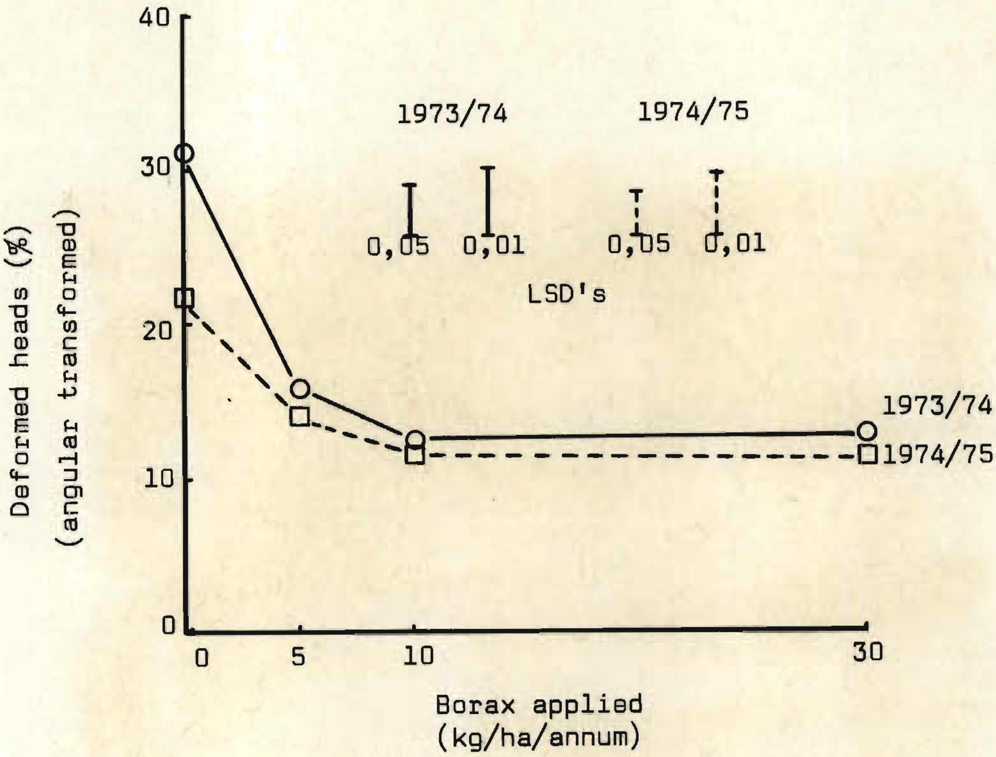


FIG. 17 Effects of borax applications on deformed sunflower heads (angular transformation)

In both seasons, liming significantly decreased the percentage deformed heads. In the first season, the deformed heads were decreased from 15% at L_0 to 10% at all rates of lime and, in the second season from 14% at L_0 to 5% at all rates of lime. The beneficial effect of lime was possibly due to improved root growth but, more probably, resulted from the very low population at L_0 (p. 37) because the percentage deformed heads from L_1 to L_3 did not differ but growth conditions were markedly different.

Seed yield and characteristics

Because of soil variability and the marked effect of exch. Al on plant growth (Chapter II, III), the seed yield was adjusted for exch. Al before treatment application in 1973/74 using covariance analysis. In the first season, seed yield was highly significantly increased by 38% by the applicatio of 10 kg borax/ha (Fig. 18). An application of 30 kg borax/ha resulted in no further benefit but tended to decrease seed yield in comparison with B_2. In 1974/75, the effects of borax applications were much reduced, 10 kg borax/ha increasing seed yields by 18% (NS) (Fig. 18). This was possibly due to the poorer weather conditions (hail, low solar radiation and temporary flooding) of 1974/75 or the increased B availability in the wetter season. Once again, 30 kg borax/ha proved slightly inferior to 10 kg borax/ha which indicated a possible B toxic effect with the highest rate of borax application studied.

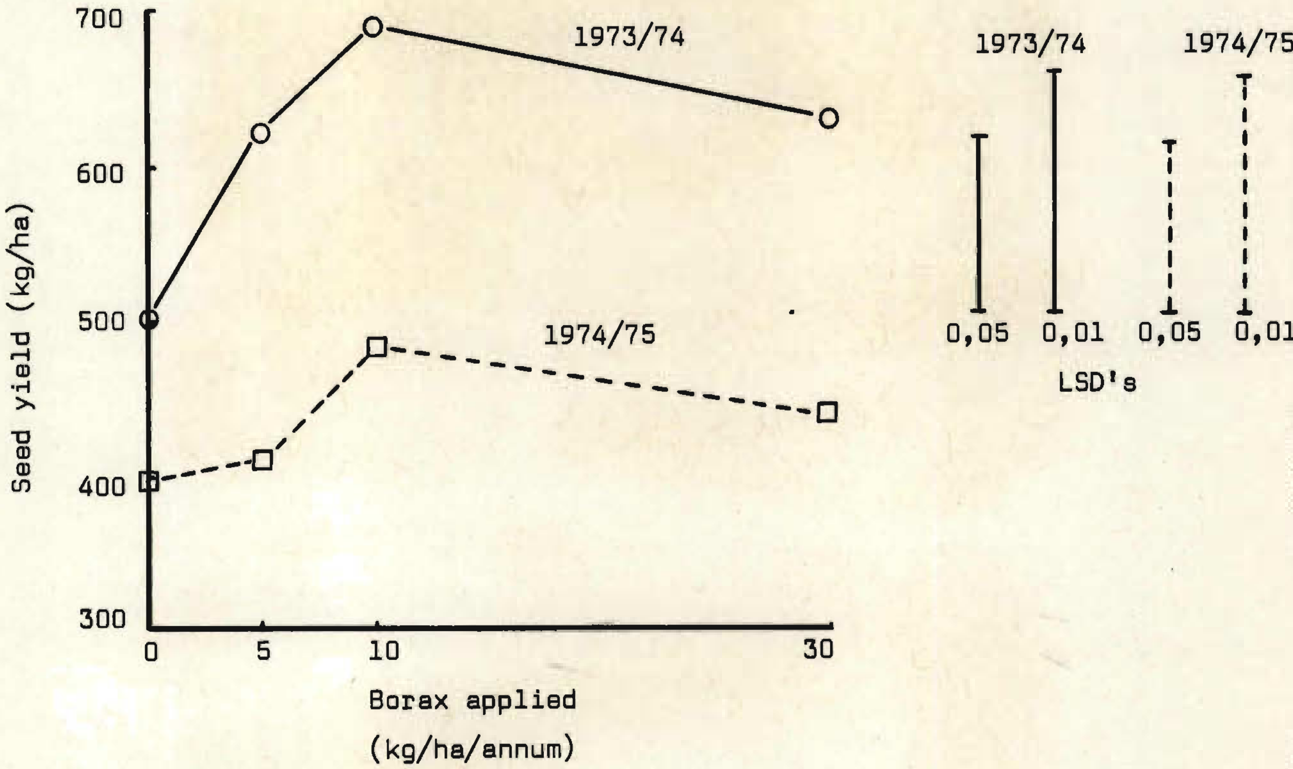


FIG. 18 Effects of annual applications of borax on sunflower seed yields in 1973/74 and 1974/75

In both seasons, the percentage empty seeds was decreased and the 100-seed mass was increased by borax applications (Table 22), the latter result being in keeping with that of Shatilov & Ikonnikov (1969). These observations confirmed the findings of Stiles (1961) in so far as boron deficiency affected the reproductive system. In the present study, this was confirmed (1973/74) by the relationship between seed yield and vegetative material and seed yield per unit leaf area (Table 22), borax applications significantly increasing these relationships. Thus, in this study, at the levels of B studied, boron deficienc had a detrimental effect on the reproductive rather than on the vegetative stage of growth.

Borax applications slightly increased the oil concentration in the seed from 34 to 36% in 1973/74 but had no effect in the second season.

TABLE 22 Effect of borax applications on percentage empty seeds, 100-seed mass, ratio of seed to vegetative mass and seed yield per unit leaf area

Borax applied (kg/ha)	Empty seeds (%)		100-seed mass (g)		Seed: vegetative mass	Seed yield per leaf area (g/m^2)
	1973/74	1974/75	1973/74	1974/75		
0	16,67	21,3	5,46	5,04	0,442	83,0
5	15,04	17,3	6,21	5,49	0,503	84,9
10	13,02	15,3	6,43	5,48	0,523	104,4
30	13,89	17,6	6,32	5,49	0,558	101,2
Mean	14,65	17,9	6,11	5,38	0,507	93,4
LSD's 0,05	2,24	5,0	0,25	0,27	0,075	16,0
0,01	NS	NS	0,34	0,37	0,102	NS

Boron concentration in the seedlings

Applications of borax resulted in marked, highly significant increases in the B concentration in month-old sunflower seedlings in both seasons (Fig. 19). In 1973/74, the B concentration was increased from 23 ppm at B_0 to 103 ppm at B_3. In 1974/75, where no borax was applied, substantially more B was present in the seedlings, 35 ppm, than in the previous season. This supported the findings of Snyman (1972) that increased moisture availability increased the B supply in the soil since the December rainfall for the two seasons was 46 and 274 mm, respectively. Thus, with the increased boron in the seedlings at B_0, the severity of B deficiency in the second season was likely to be diminished. This was indeed so, as shown by the decreased incedence of deformed heads and the smaller response in seed yield to borax applications in the second season.

Based on the work of Wilson et al. (1951), it was thought that boron would leach rapidly from the topsoil. This appeared to be so, since little increase in B concnetration in the seedlings in the second season was observed compared to that in the fist, in spite of additional B application and improved conditions for B absorption in 1974/75.

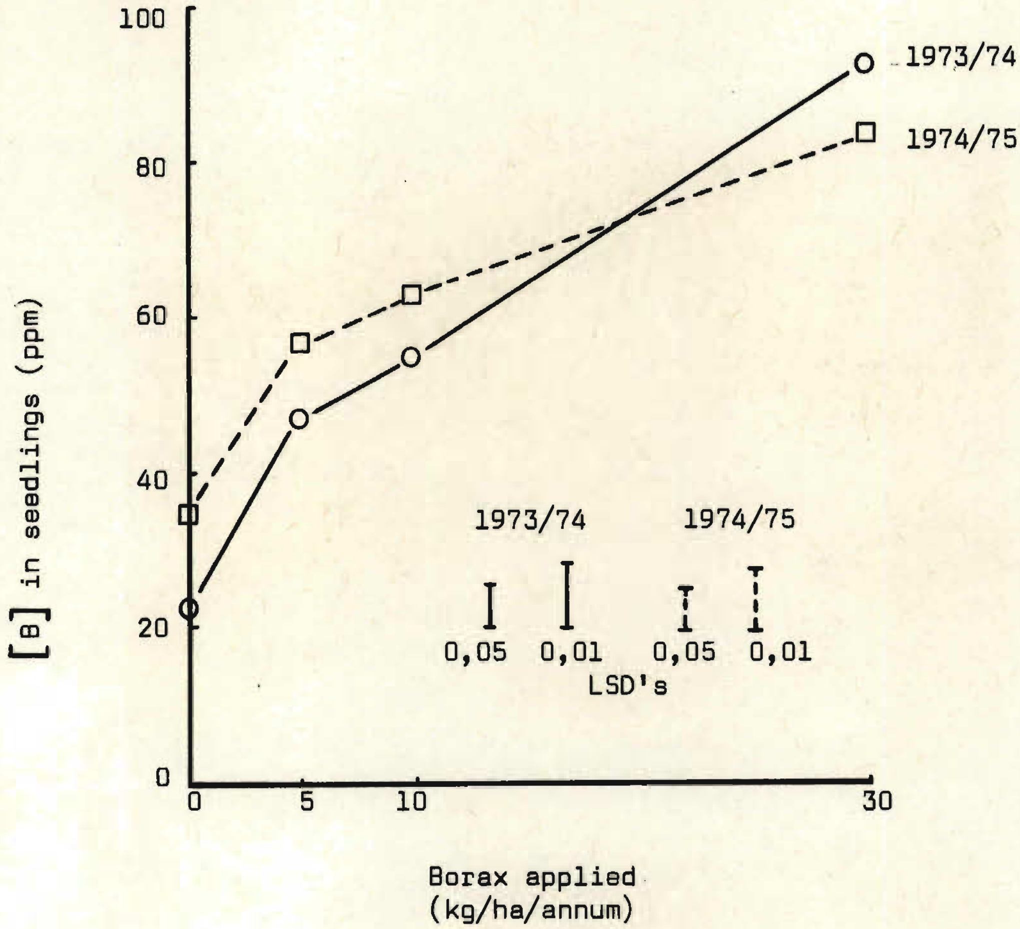


FIG. 19 Effects of borax applications on the B concentration in month-old sunflower seedlings

In 1973/74, the L'B' and G'B' interactions had highly significant effects on the boron concentration in month-old seedlings and a highly significant L'B' interaction was also recorded in 1974/75 (Fig. 20). In all these cases, amelioration of the soil only decreased the B concentration in the seedlings when 30 kg borax/ha was applied. At lower rates of borax, soil amelioration had no significant effect on boron uptake.

Because of these interactions, lime and gypsum applications tended, on average, to decrease the boron concentration in the seedlings. These effects were of little magnitude, however, with lime decreasing the B concentration by .6 ppm in both seasons and gypsum decreasing the amount by 4 ppm in 1973/74 only.

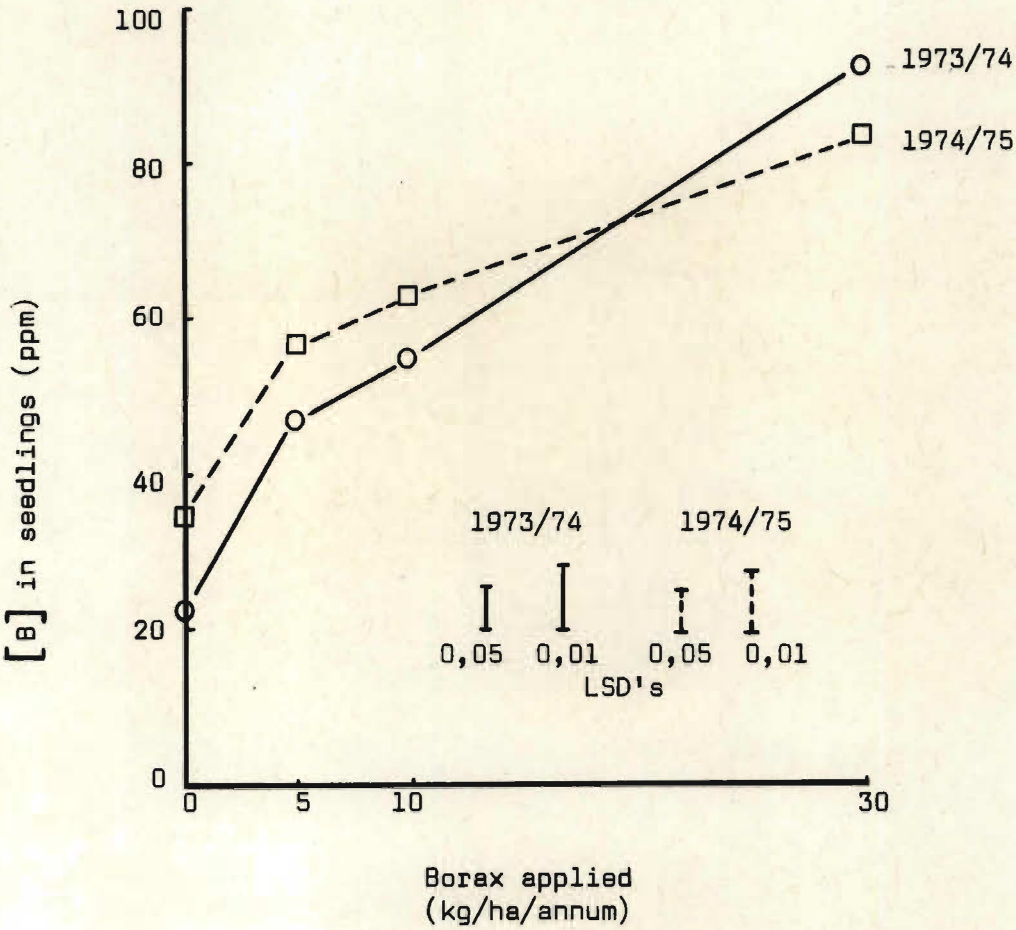


FIG. 19 Effects of borax applications on the B concentration in month-old sunflower seedlings

In 1973/74, the L'B' and G'B' interactions had highly significant effects on the boron concentration in month-old seedlings and a highly significant L'B' interaction was also recorded in 1974/75 (Fig. 20). In all these cases, amelioration of the soil only decreased the B concentration in the seedlings when 30 kg borax/ha was applied. At lower rates of borax, soil amelioration had no significant effect on boron uptake.

Because of these interactions, lime and gypsum applications tended, on average, to decrease the boron concentration in the seedlings. These effects were of little magnitude, however, with lime decreasing the B concentration by 6 ppm in both seasons and gypsum decreasing the amount by 4 ppm in 1973/74 only.

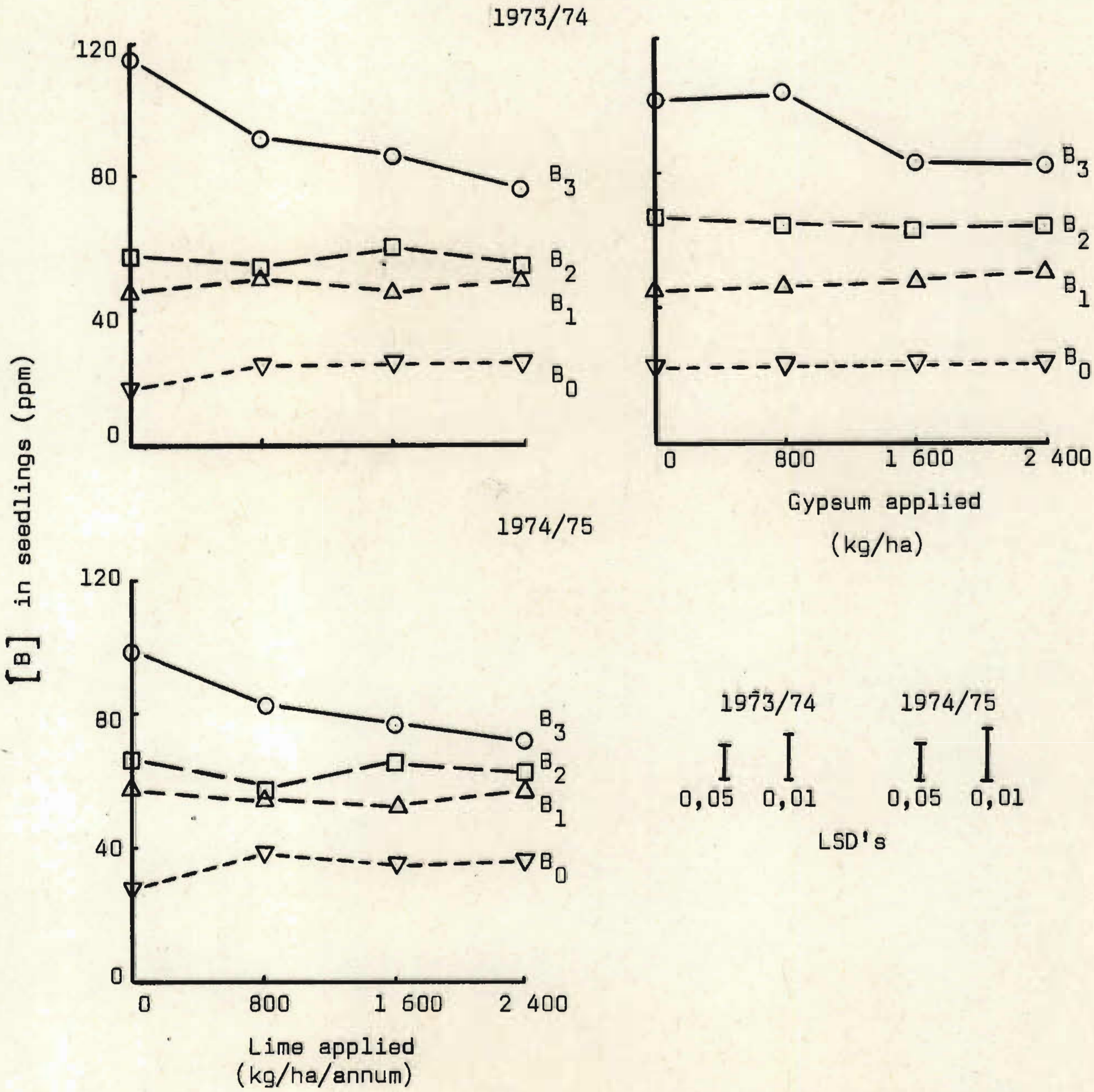


FIG. 20 Interactions between soil amelioration and borax applications on the B concentration in month-old sunflower seedlings

Ca:B ratio in seedlings

Borax applications resulted in a highly significant decrease in the Ca:B ratio in sunflower seedlings in both seasons. In 1973/74, the Ca:B ratio was decreased from 859 at B_0 to 195 at B_3 and, in the subsequent season, from 644 at B_0 to 294 at B_3.

Soil amelioration had no significant effect on the Ca:B ratio in the seedlings in the first season but, in 1974/75, the application of either lime or gypsum significantly increased the Ca:B ratio in the seedlings. The effects were of little magnitude, however, and largely due to the increased Ca concentration in the seedlings with amelioration. Liming linearly increased the Ca:B ratio from 352 at L_0 to 496 at L_3 and gypsum applications increased the Ca:B ratio from 385 at G_0 to 473 at G_3.

Boron concentration in the topmost, fully-mature leaf at flowering

Borax applications resulted in highly significant increases in the boron concentrations in mature sunflower leaves at flowering in both seasons (Fig. 21). In the first season, B concentration was increased from 10 ppm at B_0 to 103 ppm at B_3. In keeping with the findings on B concentration in the seedlings, seasonal effects resulted in greater B uptake in 1974/75 than 1973/74 even in the absence of applied borax. Where no borax was applied, the B concentration increased from 10 ppm in 1973/74 to 19 ppm in 1974/75.

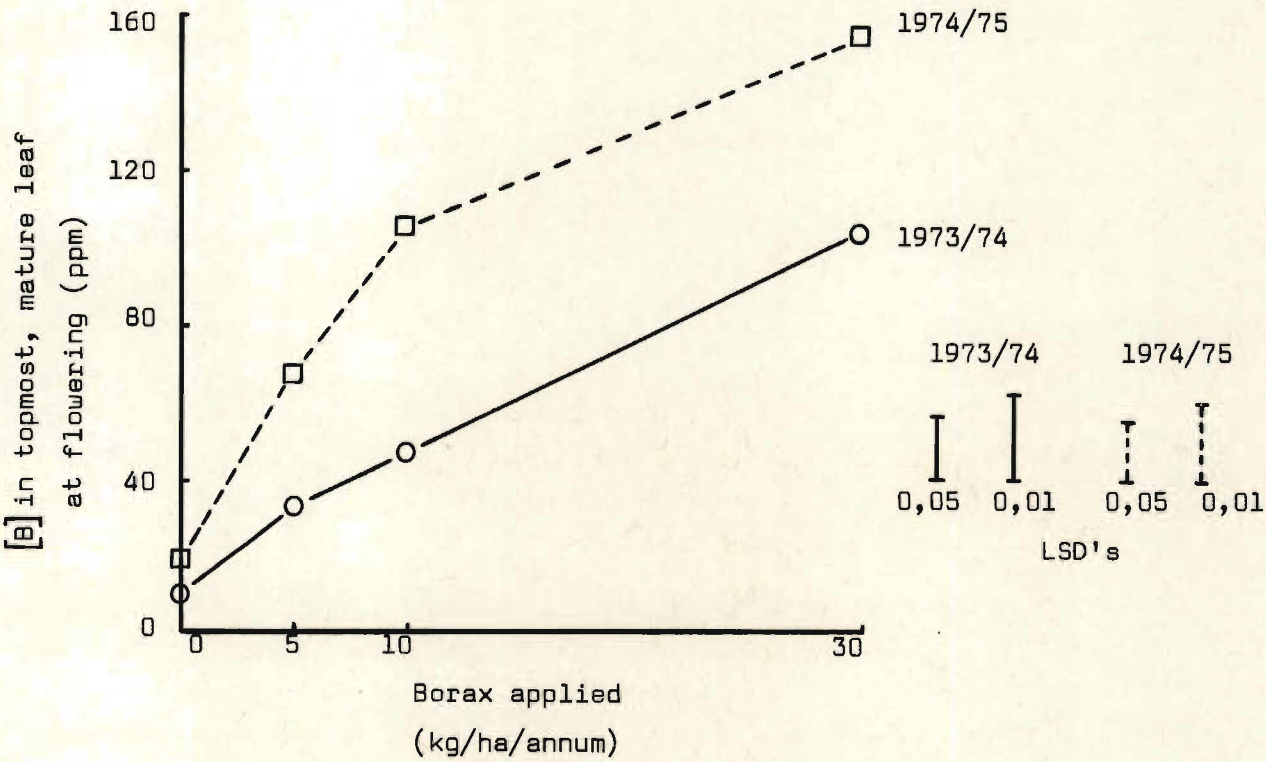


FIG. 21 Effects of borax applications on the B concentration in the topmost, fully-mature leaf at flowering

The residual effect of borax applied in the first season was evident by the marked increase in B concentration in the leaves in the second season (Fig. 21). In fact, at B_3, the B concentration was increased by one half due to this residual effect from 103 ppm in 1973/74 to 154 ppm in 1974/75. Since this residual effect of applied borax was only apparent in the leaves and not in the seedlings, it appeared that the B leached from the topsoil and was only taken up by the deeper roots later in the season.

In the first season, only the linear effect of B was highly significant, showing no discrimination in the uptake of applied boron. In the second season, however, the quadratic effect of B was also highly significant which indicated that above 100 ppm B in the leaf tissue there was some discrimination against further B uptake (Fig. 21).

Soil amelioration with either lime or gypsum had no significant effect on the boron concentration in the mature leaves at flowering in either of the two seasons.

Ca:B ratio in the topmost, fully-mature leaf at flowering

In both seasons, lime and borax applications significantly affected the Ca:B ratio in the mature leaves at flowering (Table 23). Gypsum applications, on the other hand, had no significant effects on the Ca:B ratio in the leaves.

TABLE 23 Effect of lime and borax application on Ca:B ratio in the topmost, fully-mature leaf at flowering

Level	1973/74		1974/75	
	Treatment		Treatment	
	L	B	L	B
0	487	1 435	255	969
1	532	516	335	296
2	684	372	494	189
3	803	181	485	115
Mean	626	626	392	392
LSD's 0,05	220		96	
0,01	299		130	

As with the seedlings, liming caused the increase in the Ca:B ratio largely by increasing the Ca concentration in the leaves. Borax applications decreased the Ca:B ratio by significantly increasing the B concentration in the leaves.

<u>Boron concentration in the topmost, fully-mature leaf over the growing season</u>

At each week of sampling, the boron concentration in the leaf was increas where higher rates of borax had been applied (Fig. 22) and of particular interest in this study was the consistently lower B concentration in the leave where no borax had been applied.

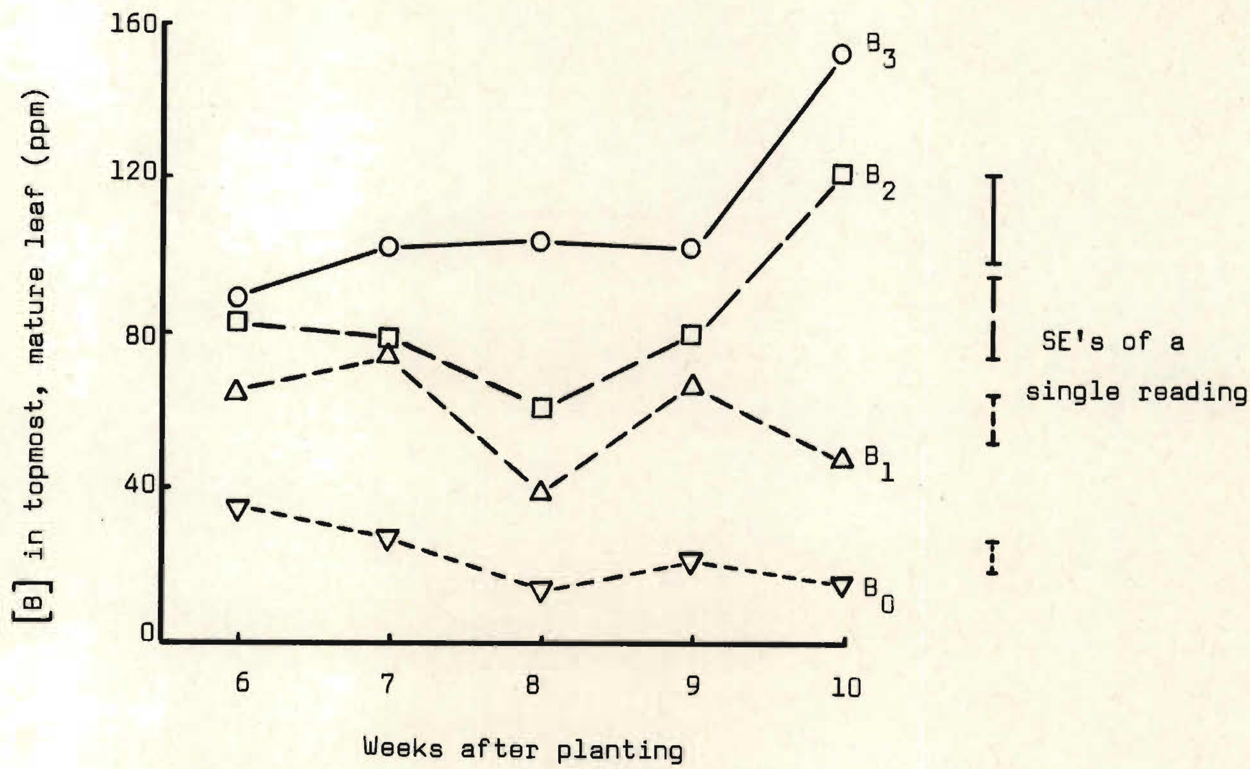


FIG. 22 Boron concentrations in the topmost, fully-mature leaf over the growing season (1974/75)

The boron concentration in the leaves at B_0 was significantly lower than that where only 5 kg borax/ha had been applied for two seasons (t_4 = 8,17**). Furthermore, at B_0 the mean B concentration in the leaves over the season was not significantly different (t_4 = 0,95 NS) from the mean B concentration in the topmost, mature leaf at flowering. This was in keeping with the suggestic of Bates (1971) that the topmost, fully-mature leaf should be sampled so that the nutrient concentrations in tissue of comparable physiological age would be compared for diagnostic purposes. It was surprising that such consistent results were obtained over five weeks of growth with the corresponding variation in weather conditions and was indicative of the low levels of available B in the soil. Considerably more variation in B concentration in the leaves was evident where B was in greater supply (Fig. 22).

Ca:B ratio in the topmost, fully-mature leaf over the growing season

The Ca:B ratio in the topmost, fully-mature leaf showed considerably more variation over the growing season than the boron concentration (Table 24). This was particularly so at B_0 where the Ca:B ratio increased from 339 to 1 186 over the five-week sampling period. Thus, as a measure of B deficiency in sunflowers in this soil, it was postulated that the Ca:B ratio would not be as good as the B concentration alone. At B_0, the mean Ca:B ratio over the growing season was, however, not significantly different (t_4 = 1,68NS) from the Ca:B ratio in the leaves at flowering.

TABLE 24 Ca:B ratio in the topmost, fully-matured leaf over the growing season

Weeks after planting	Borax applied (kg/ha/annum)			
	0	5	10	30
6	339	232	217	164
7	456	202	225	156
8	824	305	192	140
9	777	205	156	114
10	1 186	419	147	133
Mean	717	272	187	141
S.E. of mean	151	41	16	9
S.E. of single reading	302	82	31	18

Boron concentration in the seed

Marked differences between the boron concentrations in the seed and those in the vegetative tissues were apparent in both seasons (cf. Fig. 19, 21, 23). Where no borax was applied, the boron concentration in the seed was similar to that in the vegetative tissues, but the concentrations differed markedly with B fertilization. In the vegetative tissue, the B concentrations approached, or exceeded, 100 ppm but the concentration in the seed did not exceed 20 ppm B. Even in the second season, which was more favourable for B uptake and where a second annual application of borax was administered, the concentration in the seed was only 16,5 ppm B at B_3. There were no great differences in B concentration in the seed between seasons, the mean B concentration in the seed in the second season being slightly less than that of the first.

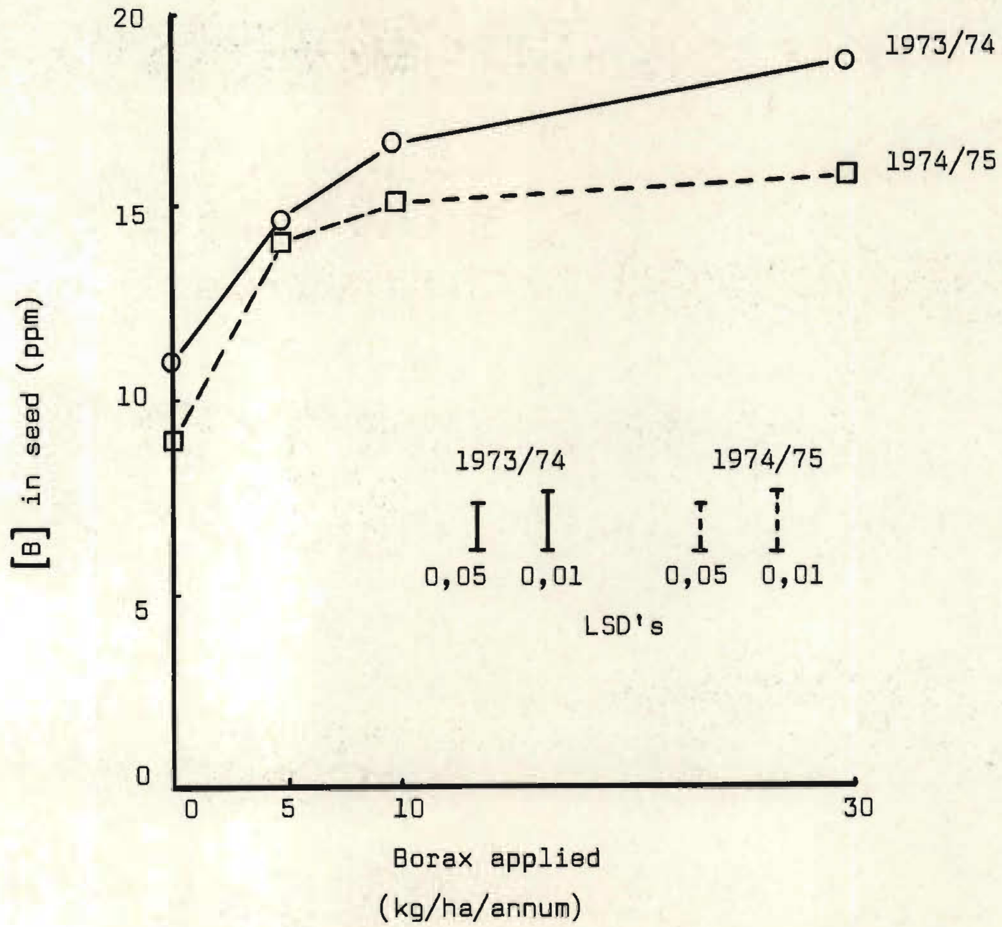


FIG. 23 Effects of borax applications on the B concentration in sunflower seed

There was a highly significant, quadratic effect of B in both seasons which indicated a mechanism whereby excess boron was prevented from being translocated to the seed. This would be valuable in preventing B toxicity being carried over from one generation to another.

In 1973/74, liming caused a slight, but significant, increase in the B concentration in the seed from 13,9 ppm at L_0 to 15,7 ppm at all levels of lime applied. In the subsequent season, this effect was not evident and, in both seasons, gypsum applications had no significant effect on the B concentration in the seed.

Ca:B ratio in the seed

In both seasons, borax applications significantly decreased the Ca:B ratio in the seed (Fig. 24). Because of the higher Ca concentration in the seed in the first season, the Ca:B ratio was higher in 1973/74, in spite of the lower B concentration in the seed in the second season. Since the Ca:B ratio in the seed at B_0 was similar in both seasons, 107 and 97, respectively, and particularly in view of the differences between seasons, the Ca:B ratio in the seed could possibly be a useful criterion of B deficiency in sunflowers on this soil. This will be discussed further in the next chapter.

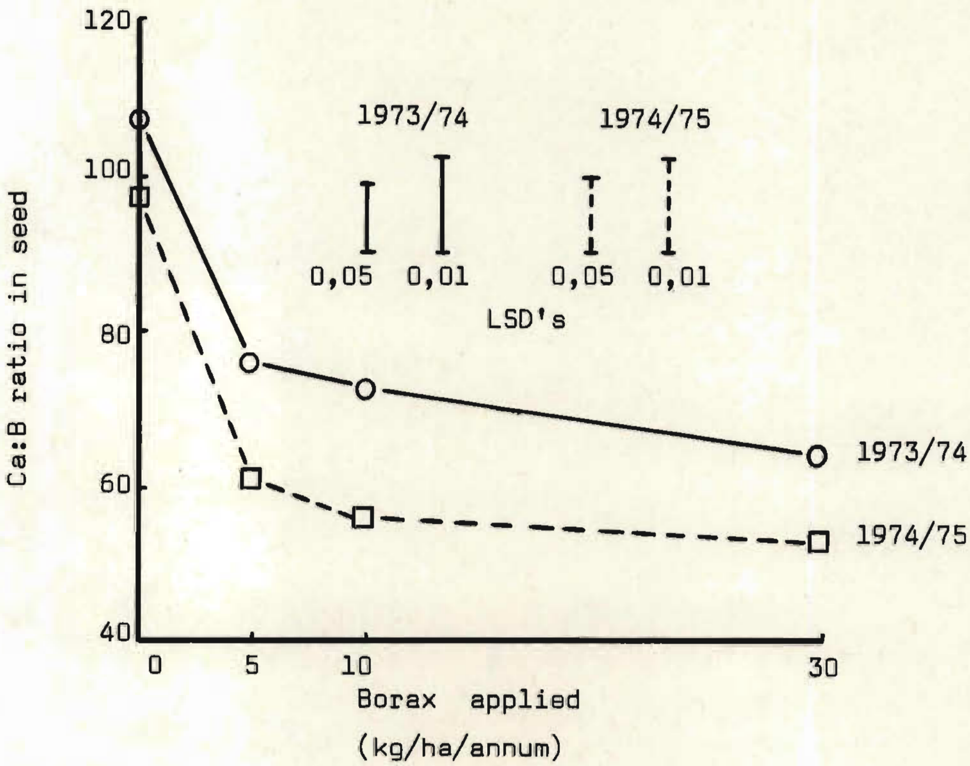


FIG. 24 Effects of borax applications on the Ca:B ratio in sunflower seed

Pot experiment

Boron concentration in the seedlings

In the field experiment, liming had relatively slight and inconsistent effects on the boron nutrition of sunflowers on the Avalon medium sandy loam.

This was in spite of the generally-accepted, inverse relationship between soil pH and boron absorption by plants (p. 64). It was thought that this absence of any marked effect of L might have been due to the small changes in soil pH brought about by liming (p. 15).

In the pot experiment, where the soil reaction was increased up to pH (N KCl) 7,0, liming significantly decreased the B concentration in the seedlings (Fig. 25). Liming from pH (N KCl) 3,9 (1 000 kg $CaCO_3$/ha) to pH (N KCl) 5,6 with 4000 kg $CaCO_3$/ha decreased the B concentration in the seedlings from 75 to 63 ppm. No further decrease in boron concentration was evident at higher rates of liming. Although the effect of increasing pH on boron concentration was sigificant, the concentration in the seedlings was decreased by only 16%.

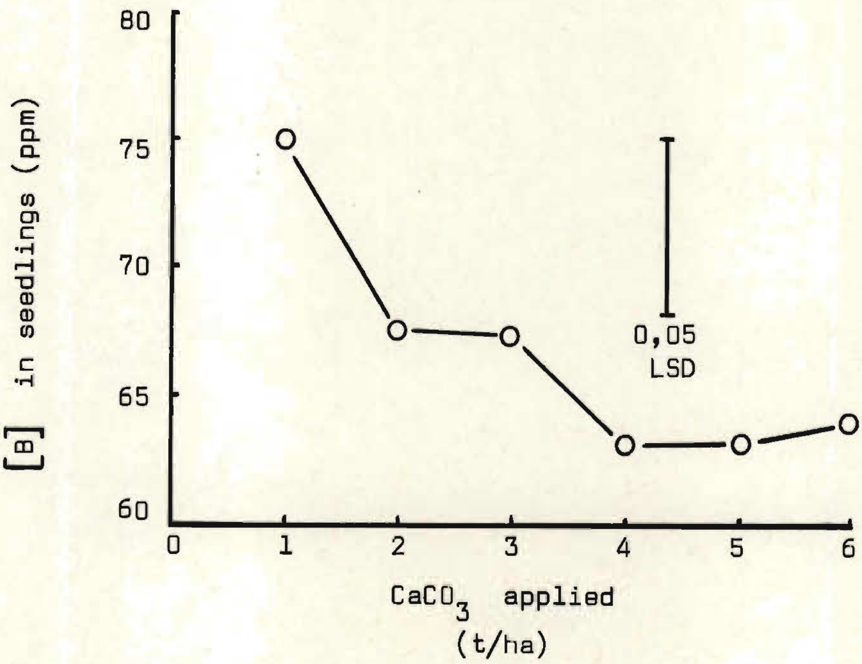


FIG. 25 Effects of precipitated $CaCO_3$ applications on the B concentration in sunflower seedlings grown in pots

SUMMARY AND CONCLUSIONS

From this work, it appeared that insufficient boron was present in the soil for the normal growth of sunflowers. In the absence of added boron, symptoms of a disorder were apparent at flowering, the most severe of which w the malformation of the flowers. This malformation resulted in areas of the head which did not produce seed and was related to the seed response of sunflowers to B fertilization on this soil. An application of 10 kg borax/ha increased seed yields by 38% and 18% in the two seasons, respectively. In both seasons, the highest applicatin of 30 kg borax/ha resulted in no further yield increase over the yield at 10kg borax/ha and, in fact, yields tended to be depressed. Since no effect of borax applications was evident before flowering, it could be concluded that in this field trial, at the levels of B in the plant tissues studied, boron played an important role in the reproductive rather than in the vegetative stage of growth.

Chemical analysis indicated that the concentration of boron in the plant tissue could be used for determining the status of B nutrition in sunflowers. Concentrations indicating boron deficiency would be in the region of 30, 25 and 10 ppm B in seedlings, in topmost, mature leaves at flowering and in the seed, respectively. In these tissues, concentrations of approximately 55, 47 and 16 ppm B were adequate but further investigation is necessary to establish critical B concentrations in plant tissues. This will be dealt with in the next chapter. Although no boron toxicity was demonstrated in this trial, boron concentrations in the vegetative tissue >100 ppm, and in the seed of > 18 ppm, could be regarded as more than adequate. No particularly obvious advantage of using the Ca:B ratio in plant tissue as a measure of boron deficiency was apparent, except, possibly, in the seed. This would also require further investigation (Chapter V).

In both the pot and field experiments, increasing the soil pH had, in general, little effect on the boron nutrition of sunflower plants in this soil. In the field, soil amelioration did decrease the B concentration in the seedlings, but only where 30 kg borax/ha had been applied. Further than this, soil amelioration had little effect on B uptake. There was, in particular, no evidence to suggest that gypsum applications increased B absorption as found by Snyman (1972) with groundnuts grown on this soil. It must be borne in mind, however, that the work of Snyman (1972) was carried out in a dry season, with a rainfall from 1st November to 28th February of only 392 mm, whereas no moisture stress was evident in the two seasons when this present study was carried out (Appendix II).

It was possible that, in the field, the absence of any marked pH x B interaction was due to the small changes in pH brought about by liming and that increased root growth compensated for any decrease in B solubility in the soil. In the pot experiment, however, liming increased soil pH (N KCl) up to 7,0, but only decreased the boron concentration by 12 ppm. The absence of any significant effect of liming on B uptake at higher pH was not due to increased root proliferation compensating for decreased B availability, since root growth was not increased above pH (N KCl) 4,8 yet neither was B uptake depressed.

The sampling of the topmost, fully mature leaf over the growing season showed little change in B concentration, particularly where no borax was applied. Thus, it could be concluded that this method of sampling would be well-suited for establishing critical B concentrations in sunflowers. This rather severe test supported the suggestion of Bates (1971) that nutrient concentrations in tissues of the same physiological age should be compared.

It may be postulated that, whereas vegetative tissue could be used to establish boron toxicity levels in sunflowers, the seed could not. The presence of a mechanism whereby excess B was excluded from the seed would probably not permit a sufficiently high boron concentration in the seed for toxicity to be evaluated with any precision. Further investigation, beyond the scope of this study, is necessary to establish this.

CHAPTER V

RELATIONSHIPS BETWEEN BORON DEFICIENCY SYMPTOMS IN SUNFLOWERS AND THE BORON CONCENTRATIONS AND CALCIUM:BORON RATIOS IN PLANT TISSUES

INTRODUCTION

For a number of years, it has been recommended that sunflowers be used in a pot technique to ascertain the B-supplying power of a soil (Schuster & Stephenson, 1940; Tisdale & Nelson, 1966). With this technique, the B supply in the soil is gauged by the number of days before sunflower seedlings exhibit boron deficiency symptoms.

In spite of this technique, based on the supposition that sunflowers are particularly sensitive to B deficiency, no firm data could be found in the literature on the citical boron concentration in sunflowers. Tanada & Dean (1942) did establish in a pot experiment that sunflower seedlings, suffering from boron deficiency, contained 8 - 23 ppm B in the tops, but, at the same time, they found that 12 - 150 ppm B indicated an adequate supply. As Bates (1971) has stated, however, "it would be rather surprising if ciritica concentrations in the field were the same as in the greenhouse and particularly in solution cultures." A number of authors (according to Bates, 1971) concluded that critical concentrations of plant nutrients should be determined in the field.

The concept of a critical concentration of a plant nutrient is basic to establishing the nutrient level for adequate growth and, particularly, in recommending corrective fertilization. The critical concentration of a nutrient, insofar as deficiency is concerned, can be defined as that concentration of an element, either alone or in relation to other elements, below which growth is depressed. Ulrich & Hills (1967) (according to Bates, 1971) selected the critical level as that which produces 90% of maximum yield. Furthermore, Bates (1971) has stated that "the concept of critical concentrations is based on a predictable functional relationship between nutrient concentration and yield." This relationship should be mathematical in form and be an experimentally established relationship between crop growth and chemical composition of plant tissue. Preferably, field data should be used to establish this relationship.

Bates (1971) has claimed that nutrient concentrations must be compared in tissue of the same physiological age and this would best be accomplished by sampling the last fully expanded leaf. A particular advantage of this method of sampling, as far as boron nutrition is concerned, is the contention that B moves passively in the transpiration stream (Kohl & Oertli, 1961; Oertli & Roth, 1969). The topmost, fully-expanded leaf which is physiologicall active would, thus, give a good indication of boron uptake. Furthermore, as found in the previous chapter, the level of B in this leaf is likely to remain relatively constant over a period of time.

A shortcoming of tissue analysis with annual crops, however, is that corrective amendments can usually only be made in the subsequent season. Where tissue can be studied early in the growth of the crop (e.g. seedlings), corrective treatments could be applied in the same season. This would be particularly applicable to the boron nutrition of sunflowers on this soil, since the detrimental effects of B deficiency were only apparent at flowering.

Two concepts have been held to gauge the status of boron nutrition in plants. Firstly, the B concentration in plant tissue (Youssif, Bingham & Yermands, 1972; Gupta, 1972) and, secondly, the Ca:B ratio in the plant (Stiles, 1961; Ruhal & Deo, 1971; Gupta, 1972) have been regarded to provide a good indication of the status of B nutrition. Thus, both these concepts must be tested with regard to boron nutrition of sunflowers on the Avalon medium sandy loam.

The relationships between boron deficiency and (i) the boron concentration and (ii) the Ca:B ratio in plant tissue were studied with a view to establishing critical levels in the plant. Furthermore, based on the effects of borax applications on B concentrations in plant tissue, B fertilization requirement was investigated. The establishment of these relationships was most important since "to become useful, crop response data will have to be correlated with a soil test and plant tissue test (or a combination of these or other tests) to evaluate soil fertility or the resources already in hand" (Pesek, 1956).

MATERIALS AND METHODS

Data from the field experiment in the first season, 1973/74, was used since, in this season, greatest response to applied borax was recorded and, in particular, there were no residual effects of borax applications. The data from the field experiment have been presented in the foregoing chapters, and those used in this study have been summarized in Table 25.

TABLE 25 Effect of borax applications on sunflower seed yield, percentage deformed heads, B concentration and Ca:B ratio in plant tissues (1973/74)

	Borax applied (kg/ha)				Mean	LSD's	
	0	5	10	30		0,05	0,01
Seed yield (kg/ha)	497	618	685	627	607	115	156
Deformed heads (%)[1]	31,0	16,0	12,4	12,9	18,1	3,2	4,3
Deformed heads (%)[2]	27,0	8,9	4,7	5,0	11,4	-	-
[B] in seedlings (ppm)	22,7	47,2	54,6	92,5	54,2	4,9	6,6
[B] in leaf (ppm)	10,5	33,0	46,6	103,3	48,3	16,3	22,0
[B] in seed (ppm)	10,9	15,6	16,2	18,5	15,3	1,2	1,6
Ca:B ratio in seedlings	859	370	320	195	436	121	164
Ca:B ratio in leaf	1 435	517	372	181	626	221	299
Ca:B ratio in seed	107	76	72	64	80	9	12

1 Angular transformed

2 Detransformed

As recorded above (Table 18), liming had a much greater effect on sunflower seed yield (which was increased from 170 kg/ha at L_0 to 938 kg/ha at L_3) than did applications of borax. Thus, it was not possible to investigate the relationship between seed yield and B concentration or Ca:B ratio in plant tissues. However, liming had only a slight effect on the occurrance of boron deficiency symptoms and the relationships between percentage deformed heads and (i) the B concentration and (ii) the Ca:B ratio in plant tissues were investigated. Using the percentage deformed heads as the dependent variable (y) rather than yield was no serious drawback, since the detrimental effect of B deficiency was associated with poor seed set in the deformed heads.

The B concentrations and Ca:B ratios in (i) the sunflower seedlings, (ii) the topmost, fully-mature leaf at flowering and (iii) in the seed were used as the independent variable (x). The B concentrations and Ca:B ratios in the vegetative tissue had a wide spread and would, thus, possibly prove superior to seed chemical composition in establishing critical levels. Furthermore, the range in B concentration and Ca:B ratio from B_0 to B_3 would be useful for decisions on corrective fertilization, since adequate or deficient levels would be clearly evident.

Since there appears to be no biological proof that any one response function should be superior to another (Heady, 1956), a number of functions, having linear and curvilinear form, were fitted to the data. Seven functions were fitted using normal regression techniques in order to obtain a mathematical relationship between deformed heads and chemical composition. In the case of the relationship between the deformed heads and B concentration in the tissue, a further, exponential function[1] was fitted using the method of Nelder & Mead (1965). The 'goodness of fit' of all the functions was compared and the function with best fit was established as that which minimized the residual sum of squares and maximized the correlation (R) between observed and fitted values of y. As outlined by Mapham & Farina (1974), there is, in general, no fixed relationship between residual sum of squares and the correlation coefficient for non-linear models.

RESULTS AND DISCUSSION

Relationship between deformed heads and chemical composition of sunflower seedlings

There was a highly significant correlation between the percentage deformed heads and the boron concentration in the seedlings using all eight of the functions investigated (Table 26). However, the straight line relationships were inferior to those functions having a curvilinear form, as shown by the decreased residual sum of squares and increased correlation coefficients of the latter. The close relationship between boron deficiency symptoms, which appeared later in the season, and the B concentration in month-old seedlings indicated that young plant tissue may be useful for determining the critical B concentration.

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[1]The help of Mr S. Minnaar in the fitting of this curve is gratefully acknowledged.

TABLE 26. Relationship between deformed heads (%) and the boron concentration (ppm) and Ca:B ratio in sunflower seedlings (n = 64)

y = deformed heads (%)
x = B concentration (ppm)

Equation fitted	Parameter estimates				Sum of squared error terms	R
	a	b	c	d		
$y = a + bx$	25,131	-0,253			4 962	0,622
$y = a + bx^2$	16,641	-0,0014			6 321	0,469
$y = a + bx^{\frac{1}{2}}$	41,028	-4,160			4,176	0,696
$y = a + b \log x$	68,503	-14,830			3 586	0,746
$y = a + bx + cx^{\frac{1}{2}}$	86,701	0,933	-17,684		2 988	0,794
$y = a + bx + cx^2$	43,808	-0,979	0,005581		2 993	0,794
$y = a + bx + cx^{\frac{1}{2}} + dx^2$	66,806	0,007451	-9,289	0,002 788	2 942	0,798
$y = a + b \exp(-cx)$	1,637	57,150	0,04190		3 013	0,792
y = deformed heads (%) x = Ca:B ratio						
$y = a + bx$	0,222	0,026			4 112	0,702
$y = a + bx^2$	7 458	0,000014			5 101	0,608
$y = a + bx^{\frac{1}{2}}$	-13,610	1,258			4 018	0,710
$y = a + b \log x$	-63,179	12,668			4 432	0,674
$y = a + bx + cx^{\frac{1}{2}}$	-10,892	0,00534	1,004		4 011	0,710
$y = a + bx + cx^2$	-5,192	0,04739	-0,000014		3 813	0,727
$y = a + bx + cx^{\frac{1}{2}} + dx^2$	42,531	0,236	-5,882	0,000 060	3 443	0,758

The function showing the best fit (R = 0,798) had the form, $y = a + bx + cx^{\frac{1}{2}} + dx^2$, where y = deformed heads (%) and x = B concentration in the seedlings (ppm) (Table 26; Fig. 26).

In most cases, the relationship between deformed heads and B concentration in the seedlings proved superior to that between deformed heads and Ca:B ratio (Table 26). This is contrary to the results of Drake et al., (1941), Ruhal & Deo (1971) and Gupta (1972) who found that the Ca:B ratio in plant tissue was closely related to the severity of boron deficiency. There was, therefore, no advantage in using the Ca:B ratio in the seedlings rather than the B concentration alone in order to estimate the status of boron nutrition of sunflowers on this soil.

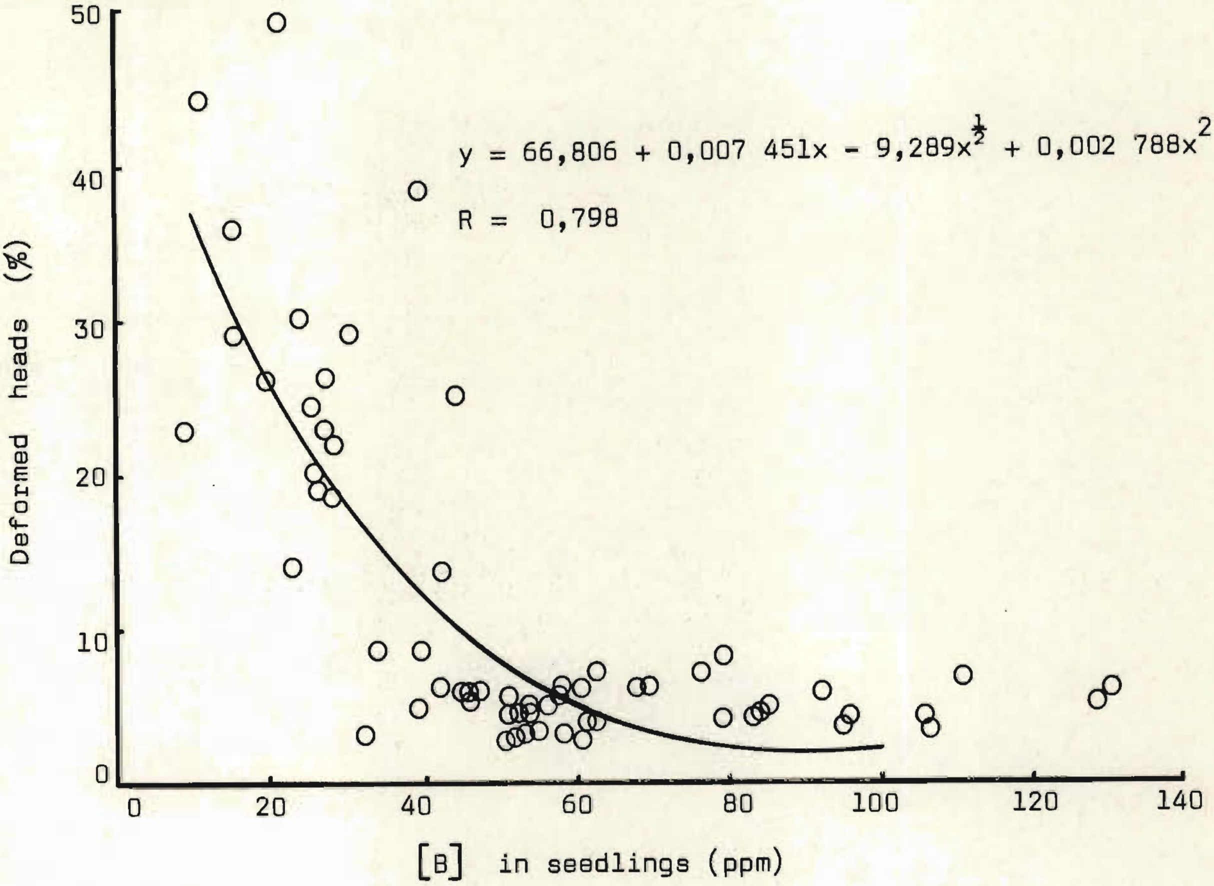

FIG. 26 Relationship between percentage deformed heads and the B concentration in month-old sunflower seedlings

<u>Relationship between deformed heads and chemical composition of the topmost, fully-mature leaf at flowering</u>

As with the seedlings, all functions studied showed highly significant correlations between observed and fitted values of y (Table 27). Once again, the boron concentration in the plant tissue proved superior to the Ca:B ratio in estimating the severity of boron deficiency symptoms in sunflowers on this soil. This was particularly evident in those functions with a curvilinear form, which were, in fact, superior to those estimating a linear relationship between deficiency symptoms and chemical composition (Table 27).

The exponential function, $y = a + b \exp(-cx)$, with y = deformed heads (%) and x = B concentration in the leaves (ppm) proved the best fit (Table 27; Fig. 27). With this curve, a distinct change in slope was evident from deficient to adequate levels of B which would aid in determining the critical B concentration in the topmost, fully-mature leaf at flowering.

TABLE 27 Relationship between deformed heads (%) and B concentration (ppm) and Ca:B ratio in the topmost, fully-mature leaf at flowering (n = 64)

y = deformed heads (%)
x = B concentration (ppm)

Equation fitted	Parameter estimates a	b	c	d	Sum of squared error terms	R
$y = a + bx$	18,261	-0,142			5 935	0,517
$y = a + bx^2$	13,996	-0,000636			7 043	0,361
$y = a + bx^{\frac{1}{2}}$	27,280	-2,489			5 048	0,614
$y = a + b \log x$	42,852	-8,946			4 143	0,699
$y = a + bx + cx^{\frac{1}{2}}$	54,281	0,612	-11,364		3 510	0,753
$y = a + bx + cx^2$	26,537	-0,531	0,00262		4 344	0,681
$y = a + bx + cx^{\frac{1}{2}} + dx^2$	80,799	1,945	-23,346	-0,003626	3,156	0,781
$y = a + b \exp(-cx)$	4,4808	58,368	0,09766		3 096	0,786
y = deformed heads (%) x = Ca:B ratio						
$y = a + bx$	3,957	0,112			5 136	0,605
$y = a + bx^2$	8,895	0,000003			6 438	0,453
$y = a + bx^{\frac{1}{2}}$	-5,229	0,724			4 795	0,639
$y = a + b \log x$	-40,389	8,496			4 971	0,622
$y = a + bx + cx^{\frac{1}{2}}$	-10,111	-0,007337	1,137		4 740	0,644
$y = a + bx + cx^2$	-1,123	0,02758	0,000007		4 365	0,679
$y = a + bx + cx^{\frac{1}{2}} + dx^2$	16,109	0,07484	-1,822	-0,000014	4 193	0,694

Relationship between deformed heads and chemical composition of the seed

In spite of the small range in B concentration and Ca:B ratio in the seed, good relationships between deformed heads and chemical composition were observed (Table 28). The highest correlation between observed and fitted values of y was given by the function, $y = a + bx + cx^{\frac{1}{2}} + dx^2$, with y = deformed heads (%) and x = Ca:B ratio in the seed (Table 28). However, the same function, with x = B concentration in the seed (ppm) was only slightly inferior to this and no great advantage was evident from using the Ca:B ratio instead of the B concentration in the seed to estimate the severity of B deficiency in sunflowers on this soil. It was decided, therefore, to use the B concentration as a measure of the status of B nutrition in this study, particularly in view of this criterion being superior to the Ca:B ratio in the other tissues studied (Fig. 28).

TABLE 28 Relationship between deformed heads (%) and B concentration (ppm) and Ca:B ratio in sunflower seed (n = 64)

y = deformed heads (%)
x = B concentration (ppm)

Equation fitted	Parameter estimates				Sum of squared error terms	R
	a	b	c	d		
$y = a + bx$	52,961	-2,721			2 987	0,795
$y = a + bx^2$	32,908	-0,088			3 527	0,752
$y = a + bx^{\frac{1}{2}}$	92,161	-20,795			2 766	0,812
$y = a + b \log x$	116,544	-38,944			2 592	0,825
$y = a + bx + cx^{\frac{1}{2}}$	269,900	12,945	-117,478		2 296	0,847
$y = a + bx + cx^2$	110,835	-11,163	0,291		2 238	0,851
$y = a + bx + cx^{\frac{1}{2}} + dx^2$	-139,982	-47,858	181,966	0,720	2 205	0,853
$y = a + b \exp(-cx)$	2,691	182,63	0,18003		2 354	0,843
y = deformed heads (%) x = Ca:B ratio						
$y = a + bx$	-26,304	0,472			2 695	0,817
$y = a + bx^2$	-6,965	0,0027			2 431	0,837
$y = a + bx^{\frac{1}{2}}$	-64,215	8,518			2 923	0,800
$y = a + b \log x$	-152,080	37,558			3 213	0,777
$y = a + bx + cx^{\frac{1}{2}}$	113,149	2,365	-35,007		2 282	0,848
$y = a + bx + cx^2$	12,206	-0,454	0,00524		2 350	0,843
$y = a + b + cx^{\frac{1}{2}} + dx^2$	613,031	14,323	-178,625	-0,023736	2 153	0,857

The exponential equation (Fig.27) showed the best fit in the relationship between deformed heads and B concentration in the topmost, fully-mature leaf at flowering and this equation was used to establish the critical B concentration in this tissue, in spite of problems associated with the fitting of the curve. This equation has an added attraction, in that the estimated percentage deformed heads decreases to a minimum and does not increase as with the other curvilinear functions fitted.

The relationship plotted in Fig. 28 was used to determine the critical B concentration in sunflower seed although the relationship between deformed heads and Ca:B ratio proved slightly superior.

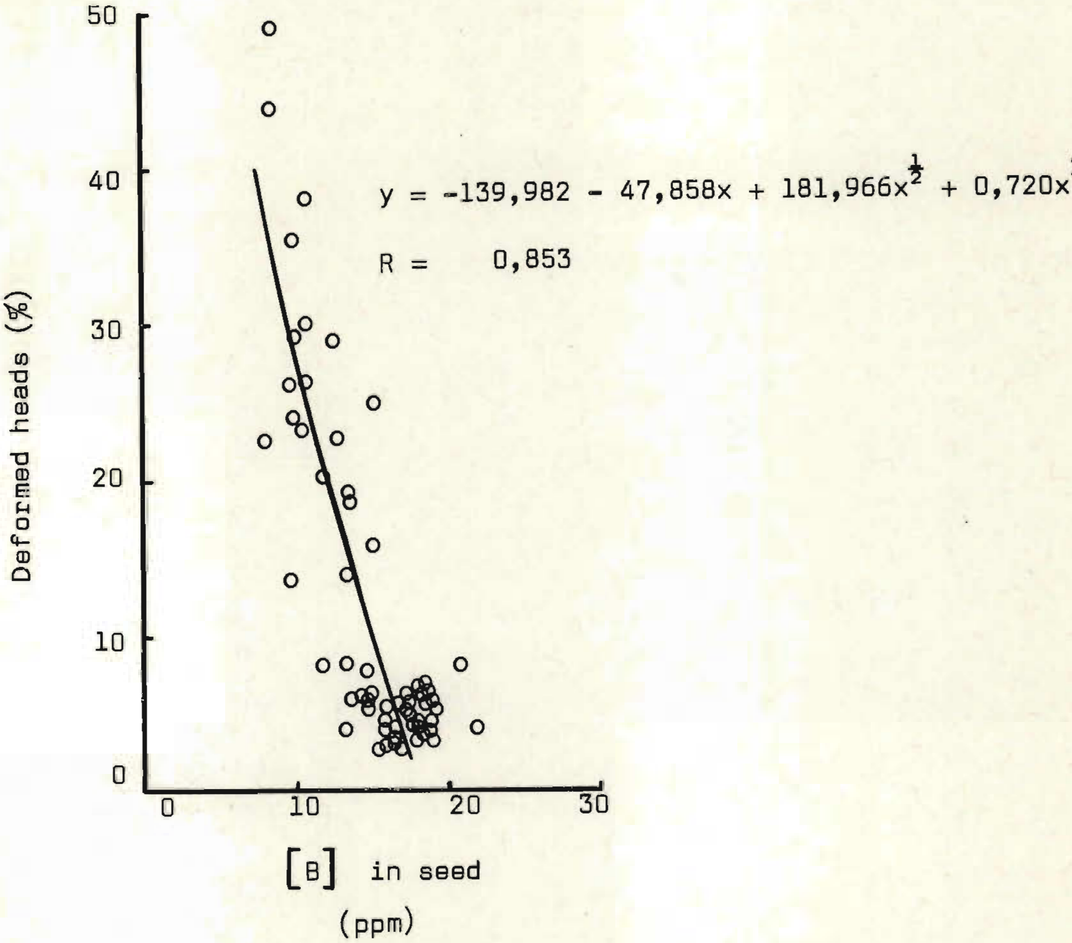

FIG. 28 Relationship between percentage deformed heads and the B concentration in sunflower seed

Ulrich & Hills (1967) (according to Bates, 1971) selected the critical level of a nutrient as that which produces 90% of the maximum yield. Analagous to this, the critical concentration of boron in sunflower tissues could be considered as that concentration of B which resulted in 90% reduction in deficiency symptoms. Thus the critical concentration of boron could be regarded as that level in plant tissue corresponding to 10% deformed heads. However, the mode (i.e. where the relative frequency is a maximum) of the deformed heads in this study probably lay in the region of 5% and the concentration of B in plant tissue resulting in 5% deformed heads could be considered the critical concentration. This latter proposal could be regarded as the more conservative estimate of critical B concentration.

Using the functions best estimating the relationship between deformed heads (y) and B concentration in plant tissue (x) and the definitions of the critical concentration, above, the critical boron concentrations in (i) month-old seedlings, (ii) the topmost, fully-mature leaf at flowering and (iii) in the seed were calculated (Table 29). These critical concentrations differed substantially between the different tissues studied and once again supported the suggestion of Bates (1971) that tissue of the same physiological age be sampled in order to determine the critical nutrient concentrations. Differences in critical concentration were particularly marked between the vegetative tissue and the seed.

TABLE 29 Critical boron concentration (ppm) in (i) month-old sunflower seedlings, (ii) the topmost, fully-mature leaf at flowering and (iii) in the seed

Plant tissue	Equation fitted	10% deformed heads	5% deformed heads
		B concentration	
		(ppm)	(ppm)
(i) seedling	$y=66,806+0,007451x-9,289x^{\frac{1}{2}}+0,002788x^2$	46	61
(ii) mature leaf	$y=4,4808+58,368 \exp(-0,09766x)$	29	57
(iii) seed	$y=-139,982-47,858+181,966x^{\frac{1}{2}}+0,720x^2$	14,6	16,8

Correction of boron deficiency

For prognostic purposes, it is necessary to know the relationship between added borax and the expected increase in boron concentration in the plant tissue. However, in the literature, no reference was found regarding the corrective application of B fertilizer in sunflowers. The relationship between applied borax and B concentration in the plant differed in the different tissues studied (Table 25) and separate relationships had to be calculated for (i) the month-old seedlings, (ii) the topmost, fully-mature leaf at flowering and (iii) the seed. In all cases, the linear effect of B had the greatest effect (i.e. the highest F value) and, thus, the straight line relationship between added borax and B concentration in plant tissue was calculated (Fig. 29).

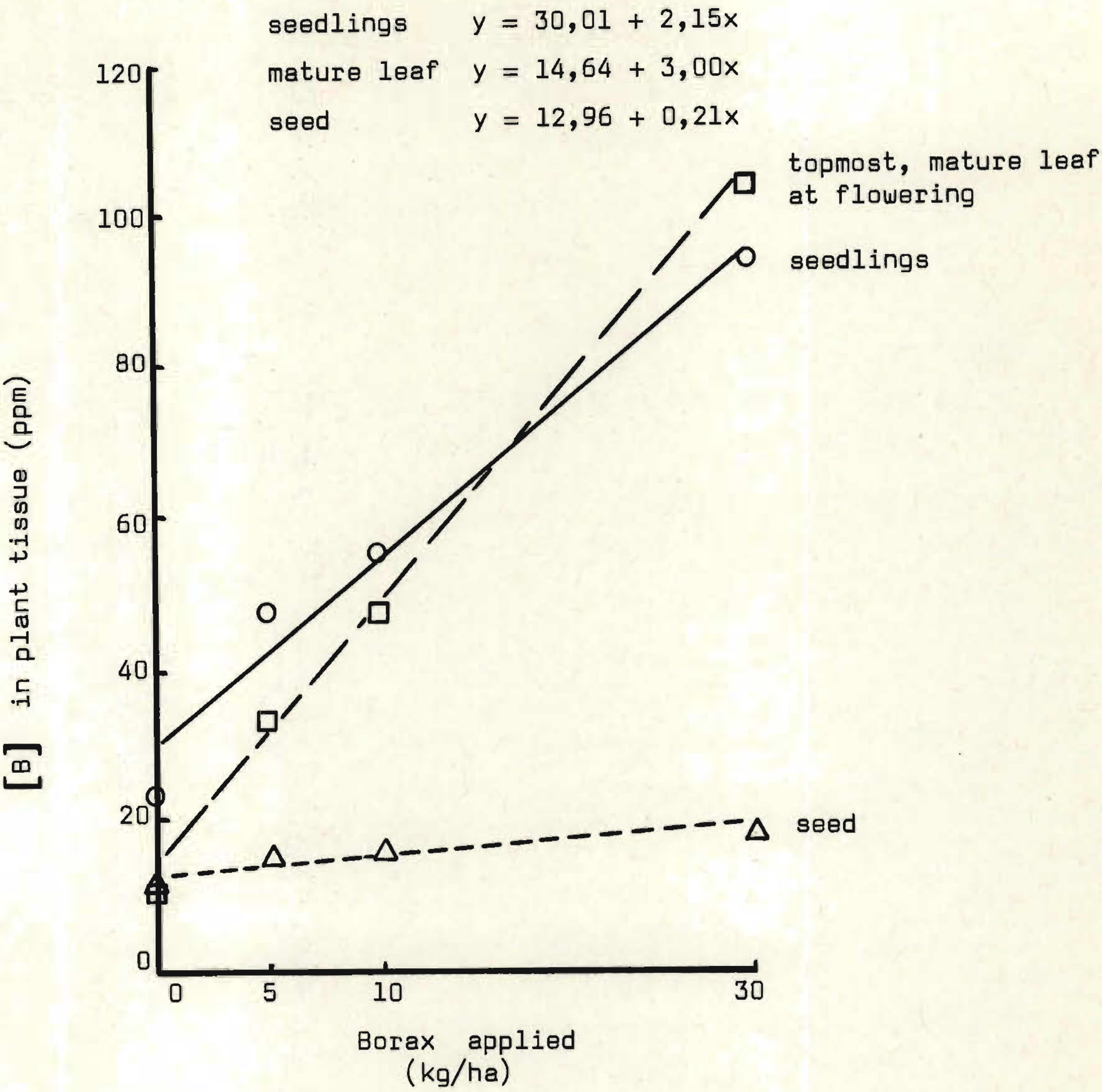

FIG. 29 Relationships between borax applications and the B concentration in plant tissues

An application of 1 kg borax/ha would be expected to increase the boron concentration in (i) the seedlings by 2 ppm, (ii) in the topmost, fully-mature leaf by 3 ppm and (iii) in the seed by 0,2 ppm (Fig. 29). However, the use of the straight line relationship to estimate increase in B concentration in plant tissue with borax fertilization would, at low B concentrations, result in an under-estimation of the increase in B concentration in the seedlings and seed. (In the leaves at flowering, only the linear effect of B was significant.) From a practical point of view, this is not likely to be of great importance since it is difficult to apply low rates of borax accurately on a field scale. Should the better fitting equations be required, however, these can be calculated from the data presented in Table 25.

Critical B concentration in the topmost, mature leaf at flowering using two seasons' data

Since the topmost, mature leaf at flowering was found to be a good index tissue to determine the status of B nutrition of sunflowers, it was decided to establish the relationship between B deficiency and B concentration in this tissue using the data of the two seasons. Unfortunately, liming significantly decreased the percentage deformed heads in the second season (p. 70) and, therefore, the data from the L_0 plots was disregarded.

The relationship between the percentage deformed heads and the B concentration in the topmost, mature leaf at flowering was clearly curvilinear, and only the four curvilinear functions were fitted (Table 30). Highly significant correlations between the observed and estimated values of y were recorded using all the functions fitted (Table 30) and, once again, the exponential function proved the best fit.

TABLE 30 Relationship between deformed sunflower heads (%) and B concentration in the topmost, mature leaf at flowering (two seasons' data)

Equation fitted	Parameter estimates				Sum of squared error terms	R
	a	b	c	d		
$y=a+bx+cx^2$	22.250	- 0.394	0.00180		5 270	0.678

ERRATUM

p. 96, paragraph 1: Replace last sentence with: The significant decrease in percentage deformed heads due to liming (p. 70) was in the second season greater than in the first and was of the same order as the decrease in deformed heads due to borax and, therefore, the data from the L_0 plots were disregarded.

estimates of critical B concentrations than those established from the results of one season.

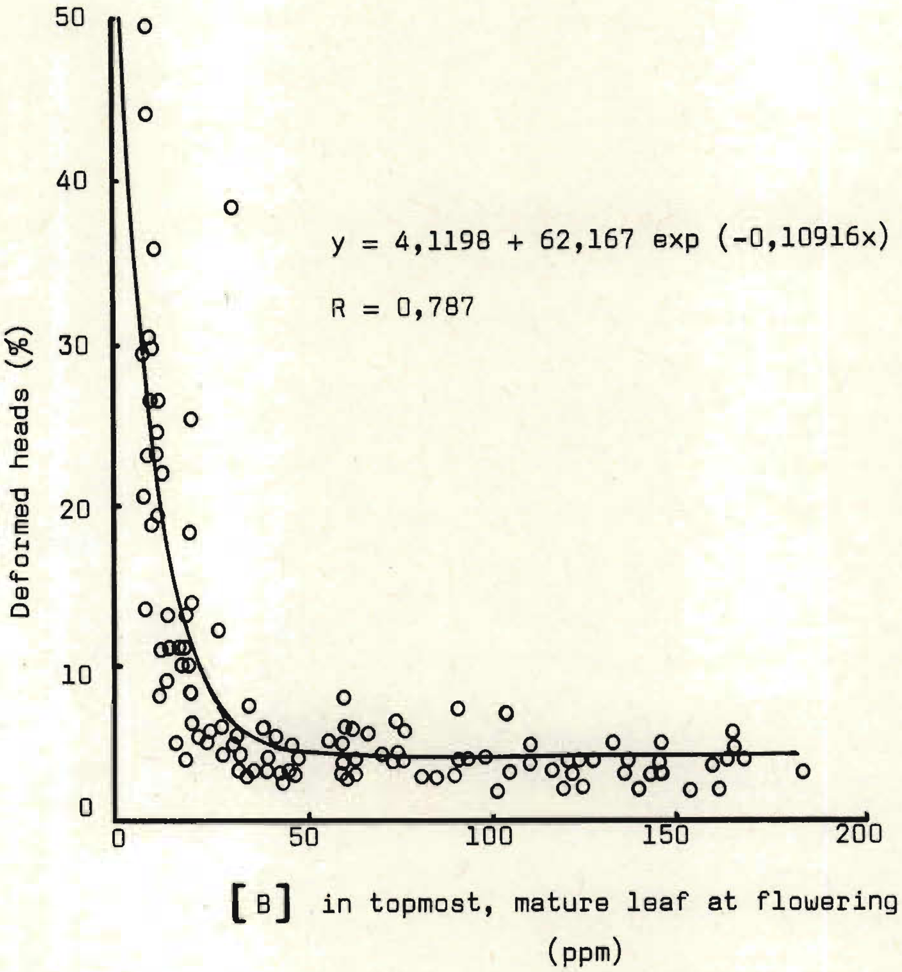

FIG. 30 Relationship between deformed heads (%) and B concentration in the topmost, mature leaf at flowering (two seasons' data) (n = 112)

SUMMARY AND CONCLUSIONS

There were highly significant correlations between the percentage deformed heads and the boron concentrations in all three tissues studied. In only one case, that of the seed, did the Ca:B ratio prove slightly superior to B concentration for estimating the severity of boron deficiency. This difference was so slight that it was decided throughout to use the B concentration in plant tissue as a measure of the status of boron nutrition of sunflowers on this soil.

From this study, it was concluded that tissue analysis for B could be most useful for diagnostic purposes in sunflowers. Firstly, by analysis of plant tissue, it would be possible to predict whether sunflowers would be likely to suffer from boron deficiency. This would be done by comparison with the critical boron concentrations established for the three tissues studied. Secondly it is possible to predict the amount of borax that should be applied to this soil to overcome the adverse effects of boron deficiency (i.e. to increase the B concentration in the plant tissue above the critical level).

Further advantages are apparent from this study as well. The use of seedling for tissue analyses overcomes one of the objections to the use of tissue analyses in annual crops, viz that corrective treatments can only be applied in a subsequent season. Dependent on a rapid analytical service, it would be possible to analyze month-old seedlings, determine the corrective treatment and apply B fertilizer before the adverse effects of B deficiency became apparent at flowering (However, cognizance would have to be taken of the possibility of sufficient B being present in the subsoil to meet plant needs.) Another use to which the results of this study could be put, is to use sunflowers as a test plant in the field to establish the B-supplying power of the soil, but further work in this regard would be necessary. An advantage of the relationship between B deficiency and B concentration in the seed is the possibility of using tissue analysis of the seed to estimate the extent of boron deficiency in sunflowers in a certain area.

Inherent in these last two porposals, however, is the necessity for further study. Critical boron concentrations for other cultivars must be determined, since it cannot be assumed that all cultivars would behave in the same way as Smena, the cultivar used in this study (Bates, 1971). Also, it would be necessary to establish whether sunflowers would behave differently with regard to the critical B concentration when grown on different soils. Since liming had a most profound effect on growth, but did not appreciably affect B uptake, it is possible that this factor would not be of great significance. But in other soil types, the amount of B fixation is likely to differ considerably (Wilson et al., 1951; Wear & Patterson, 1962) from that in the Avalon medium sandy loam and this would affect the relationship between B fertilization and B concentration in plant tissue.

GENERAL DISCUSSION AND CONCLUSIONS

The first aim of this study, to determine which factors possibly caused the poor growth of sunflowers on sandy soils, was realized when it was established that both soil acidity and boron deficiency severly affected sunflower production on the Avalon medium sandy loam. Other factors would, certainly, be involved in other situations but a study of the effects of soil acidity and B nutrition on sunflower growth in this case would probably prove relavent to many other situations.

In order to isolate the cause of poor plant growth on the acid Avalon soil, it was necessary to study quantitatively the effects of amelioration on soil characteristics. Of particular importance in this regard, was the superiority of lime over gypsum in increasing soil pH (N KCl) and decreasing exch. Al (meq/100g). But the neutralizing ability of the agricultural lime used was poor (< 50%) compared to precipitated $CaCO_3$, mainly because of the coarse mechanical composition of the lime. Lime and gypsum applications significantly increased exch. Ca, total exchangeable bases (S) and CEC, the effects of the two ameliorants being not entirely dissimilar. Liming also slightly increased exch. Mg in the soil, but it was considered that this would not have great bearing on sunflower growth in this study.

Sunflower growth in both the pot and field experiments on this acid soil was found to be particularly poor mainly on account of aluminium toxicity. This conclusion was reached largely by eliminating other possible causes. Based on soil analyses and nutrient concentrations in the plant, Ca, Mg and P deficiencies were not considered as major causes of poor growth. Mn toxicity, particularly in the first season, could not be entirely eliminated as a contributory factor to poor growth, since Mn toxicity levels in sunflowers are not known. But Mn concentrations in vegetative tissue differed greatly in the two seasons, whereas the effects of soil amelioration on crop growth did not. Results from the nutrient solution experiments indicated that sunflower seedling growth was not affected with Mn concentrations in the tissue of over 1 000 ppm.

The following evidence directly supported Al toxicity being the major cause of poor sunflower growth on this soil. Vlamis (1953) noted that the effects of Al toxicity were immediate and drastic, an effect observed in the pot and field experiments. The symptoms in the seedlings appeared to be similar to those described by Hortenstine & Fiskell (1961) who studied Al toxicity in sunflowers in nutrient solutions. In particular, however, aluminium has been shown to be toxic to root growth (Vlamis, 1953; Coleman et al., 1958; Hortenstine & Fiskell, 1961; Foy & Brown, 1963; Pratt, 1966) and the adverse effects of soil acidity on root growth was observed in the field and pot experiments. In the field, root growth in the unlimed soil was largely restricted to the soil above ~10 cm and exch. Al was observed to increase below this level.

Since it was established that Al toxicity was the main cause of poor sunflower growth on this soil, relationships between yield and measures of Al toxicity were evaluated. This has a bearing on the applicability of the results of this study to the growth of sunflowers on similar soils with not necessarily the same degree of acidity. As Heady (1956) has stated, fertilizer recommendations are based on a knowledge of the mathematical form of the response function.

In support of the findings of Kamprath (1970), Reeve & Sumner (1970b) and Martini et al., (1974), it was concluded from the results of the pot experiment that there was no benefit in liming above a level required to neutralize toxic aluminium (~ pH (N KCl) 4,5). In order to establish this, use was made of fitting segmented curves (Hudson, 1966) and no yield increases were recorded above pH (N KCl) 4,43 $\pm$ 0,24 in the case of the seedling tops and pH (N KCl) 4,35 $\pm$ 0,25 with the roots. Close linear relationships between yield and exch. Al were recorded in the pot and field experiments and, averaged over two seasons, seed yield in the field was increased 12% for each 0,1 meq/100g reduction in exch. Al.

The principle established in this study, viz that Al toxicity severly limits sunflower growth on this acid soil, implies that other soils should be evaluated using more suitable experimental designs (Heady, 1956; Mapham, 1975) for calibrating the relationship between yield and aluminium toxicity. Since many soils in the high rainfall areas of South Africa, which are suitable for crop production, are acid (Graven, 1973) soil acidity is most likely a severly limiting factor in sunflower production in South Africa. Further work is, therefore, necessary to establish the relationships between sunflower growth and soil amelioration on other soil types.

It was also concluded that insufficient boron was present in this soil for succesful sunflower production. The levels of boron in the soil, moreover, were insufficient for the reproductive rather than the vegetative phase of growth. In particular, boron deficiency caused malformations of the flowers which resulted in areas of the head where no seed set. Thus, the correction of this deficiency by an application of 10 kg borax/ha increased seed yields by 38% and 18% in the two seasons of the field experiment, respectively. The danger of inducing B toxicity in sunflowers by excess B fertilization was demonstrated on this sandy soil because 30 kg borax/ha tended to depress seed yields in comparison with 10 kg borax/ha.

In spite of the generally-held opinion that an increase in soil pH decreases boron uptake by plants, liming this soil had little effect on the boron nutrition of sunflowers. In the field experiment, soil amelioration with either lime or gypsum decreased the B concentration in the seedlings, but only at the highest rate of B fertilization. Thus, soil amelioration would possibly be effective in reducing the toxic effects of excess boron in the soil. More important, however, the absence of any marked effect of soil pH on B uptake led to the conclusion that liming to increase crop growth would not result in a great increase in B fertilizer requirement.

Plant chemical analysis was found to be eminently suitable for the quantitative identification of boron deficiency in sunflowers in the field. Highly significant relationships between the symptom of boron deficiency, the percentage deformed heads, and tissue analysis were recorded. Using these relationships, critical boron concentrations in (i) month-old seedlings, (ii) the topmost, mature leaf at flowering and (iii) the seed were calculated. Based on the expected B concentrations corresponding to 10% deformed heads, the critical levels in these tissues were (i) 46 ppm, (ii) 26 ppm and (iii) 14,6 ppm, respectively. It was found to be essential, however, that the B concentrations in tissue of the same age be compared, as suggested by Bates (1971), since different relationships and critical concentrations were recorded for the different tissues studied. It appeared that the topmost, mature leaf would be the best index tissue for measuring the status of B nutrition in the plant, even if sampled at different times during the growing season.

In the field study, it was also possible to establish relationships between applied borax and B concentrations in the different tissues studied. Using these relationships, accurate estimates of the amount of borax to be applied to correct boron deficiency in sunflowers on the Avalon medium sandy loam can be recommended.

A C K N O W L E D G E M E N T S

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REFERENCES

ABRUNA-RODRIGUEZ, F., VINCENTE-CHANDLER, J., PEARSON, R.W. & SILVA, S., 1970. Crop response to soil acidity factors in Ultisols and Oxisols : I. Tobacco. Soil Sci. Soc. Am. Proc. 34, 629 - 634.

ADAMS, F., 1965. Manganese. In: Black, C.A. (Ed.). Methods of soil analysis. Chemical and microbiological properties. Agronomy No. 9, Part 2. American Society of Agronomy, Madison, Wisconsin, U.S.A. 1011 - 1018.

ADAMS, F. & LUND, Z.F., 1966. Effect of chemical acitivy of soil solution aluminum on cotton root penetration of acid subsoils. Soil Sci. 101, 193 - 198.

ADAMS, F. & PEARSON, R.W., 1967. Crop response to lime in the Southern United States and Puerto Rico. In: Pearson, R.W. & Adams, F. (Eds.). Soil acidity and liming. Agronomy No. 12. American Society of Agronomy, Madison, Wisconsin, U.S.A. 161 - 206.

ADAMS, F. & PEARSON, R.W., 1970 Differential response of cotton and peanuts to subsoil acidity. Agron. J. 62, 9 - 12.

ADAMS, F., PEARSON, R.W. & DOSS, B.D., 1967. Relative effects of acid subsoils on cotton yields in field experiments and on cotton roots in growth chamber experiments. Agron. J. 59, 453 - 456.

ADUAYI, E.A., 1972. Soil pH as measured in different solutions with water and with 0.01M $CaCl_2$ and the nutrient content of some coffee soils. Turrialba 22, 305 - 310 (Soils Fertil. 36, 218).

ANONYMOUS, 1973. Republic of South Africa Oilseeds Control Board 21st Annual Report, Pretoria.

ANONYMOUS, 1974. Neigings in die landbousektor. Agrekon, Department of Agricultural Economics and Marketing, Pretoria.

BATES, T.E., 1971. Factors affecting critical nutrient concentrations in plants and their evaluation : A Review. Soil Sci. 112, 116 - 130.

BEATER, B.E., 1955. A new pattern soil sampler. Proc. S. Afr. Sug. Technol. Ass. 29, 113 - 114.

BENNER, L.R. & TOWNSEND, C.E., 1973. Growth of alsike clover pollen *in vitro*. Crop Sci. 13, 540 - 542.

BIGGAR, J.W. & FIREMAN, M., 1960. Boron adsorption and release by soils. Soil Sci. Soc. Am. Proc. 24, 115 - 120.

BLAMEY, F.P.C., 1971. Molybdenum in maize (*Zea mays* L.) production in Northern Natal. M.Sc. Agric. Thesis, University of Natal.

BLAMEY, F.P.C. & CHAPMAN, J. 1975. Sunflower cultivars for Northern Natal. Natal Agric. Res. Bull. No. 2.

BRADFORD, G.R., 1966. Boron. In: Chapman, H.D. (Ed.). Diagnostic criteria for plants and soils. University of California 33 - 61.

BROWMAN, M.G., CHESTERS, G. & PIONKE, H.B., 1969. Evaluation of tests for predicting the availability of soil manganese to plants. J. agric. Sci., Camb. 72, 335 - 340.

BROWNLEE, K.A., 1965. Statistical theory and methodology in science and engineering. Wiley & Sons, New York.

CHANG, M.L. & THOMAS, G.W., 1963. A suggested mechanism for sulphate adsorption by soils. Soil Sci. Soc. Am. Proc. 27, 281 - 283.

CHAPMAN, H.D., 1965. Cation-exchange capacity. In: Black, C.A. (Ed.). Methods of soil analysis. Chemical and microbiological properties. Agronomy No. 9, Part 2. American Society of Agronomy, Madison, Wisconsin, U.S.A. 891 - 901.

CHAPMAN, H.D., 1966. Calcium. In: Chapman, H.D. (Ed.). Diagnostic criteria for plants and soils. University of California. 65 - 92.

CHENG, B.T. & OUELLETTE, G.J., 1971. Manganese availability in soil. Soils Fertil. 34, 589 - 595.

COCHRAN, W.G., 1943. Analysis of variance for percentages based on unequal numbers. J. Am. statist. Ass. 38, 287 - 301.

COCHRAN, W.G. & COX, G.M., 1957. Experimental designs. 2nd Ed. Wiley & Sons, New York.

COLEMAN, N.T., KAMPRATH, E.J. & WEED, S.B., 1958. Liming. Adv. Agron. 10, 475 - 522.

COLEMAN, N.T. & THOMAS, G.W., 1967. The basic chemistry of soil acidity. In: Pearson, R.W. & Adams, F. (Eds.). Soil acidity and liming. Agronomy No.12. American Society of Agronomy, Madison, Wisconsin, U.S.A. 1 - 41.

COLLANDER, R., 1941. Selective absorption of cations by higher plants. Pl. Physiol., Lancaster. 16, 691 - 720.

CROFT, P. & GRAVEN, E.H., 1974. Sulphur studies on some Natal soils. Crop Production 3, 67 - 70.

DALAL, R.L., 1975. Hydrolysis products of solution and exchangeable aluminum in acidic soils. Soil Sci. 119, 127 - 131.

DRAKE, M., SIELING, D.H. & SCARSETH, G.D., 1941. Calcium-boron ratio as an important factor in controlling the boron starvation of plants. J. Amer. Soc. Agron. 33, 454 - 462.

EATON, F.M., 1944. Deficiency, toxicity and accumulation of boron in plants. J. agric. Res. 69, 237 - 277.

ESTRADA, J. & CUMMINGS, G.A.,1968. Effects of lime and phosphorus treatments in specific horizons of acid soil on growth and chemical content of corn (*Zea mays* L.). Agron. J. 60, 447 - 450.

EVANS, C.E. & KAMPRATH, E.J., 1970. Lime response as related to percent Al saturation, solution Al and organic matter content. Soil Sci. Soc. Am. Proc. 34, 893 - 896.

FARINA, M.P.W., 1970. Potassium suties on an Avalon medium sandy loam. Ph.D. Thesis, University of Natal, Pietermaritzburg.

FARINA, M.P.W. & GRAVEN, E.H., 1972. Effect of rainfall and differential application of N, P, K and Ca on the downward movement of K in an Avalon medium sandy loam cropped with maize (Zea mays L.). Agrochemophysica 4, 93 - 98.

FARINA, M.P.W. & MAPHAM, W., 1973. The relationship between P soil test and maize yield on an Avalon medium sandy loam. Fert. Soc. S. Afr. J. 1, 21 - 26.

FOY, C.D. & BROWN, J.C., 1963. Toxic factors in acid soils: I. Characterization of aluminum toxicity in cotton. Soil Sci. Soc. Am. Proc. 27, 403 - 407.

FOY, C.D. & BROWN, J.C. 1964. Toxic factors in acid soils: II. Differential aluminum tolerance of plant species. Soil Sco. Soc. Am. Proc. 28, 27 - 32.

FOY, C.D., ORELLANA, R.G., SCHWARTZ, J.W. & FLEMING, A.L., 1974. Response of sunflower genotypes to aluminum in acid soil and nutrient solution. Agron. J. 66, 293 - 296.

GRANT, P.M. TANNER, P.D. & MADZIVA, T.J., 1973. Soil acidity factors affecting maize yield in Rhodesia. Fert. Soc. S.Afr.J. 1, 39 - 44.

GRAVEN, E.H., 1973. Plant nutrition in South Africa in the sevenites. Crop Production 2, 21 - 23.

GRAVEN, E.H., ATTOE, O.J. & SMITH, D., 1965. Effect of flooding on manganese toxicity in alfalfa. Soil Sci. Soc. Am. Proc. 29, 702 - 706.

GUPTA, U.C. 1972. Interaction effects of boron and lime on barley. Soil Sci. Soc. Am. Proc. 36, 332 - 334.

GUPTA, U.C. & CUTCLIFFE, J.A., 1972. Effects of lime and boron on brown heart, leaf tissue calcium/boron ratios, and boron concentrations of rutabaga. Soil Sci. Soc. Am. Proc. 36, 936 - 939.

HATCHER, J.T., BOWER, C.A. & CLARK, M., 1967. Adsorption of boron in soils as influenced by hydroxy aluminum and surface area. Soil Sci. 104, 422 - 426.

HATCHER, J.T. & WILCOX, L.V., 1950. Colorimetric determination of boron using carmine. Analyt. Chem. 22, 567 - 569.

HAYNES, J.L. & ROBBINS, W.R., 1948. Calcium and boron as essential factors in the root environment. J. Am Soc. Agron. 40, 795 - 803.

HEADY, E.O., 1956. Methodological problems in fertilizer use. In: Baum, E.L., Heady, E.O. & Blackmore, J.(Eds). Methodological procedures in the economic analysis of fertilizer use data. The Iowa State College Press 3 - 21.

HEALD, W.R., 1965. Calcium and magnesium. In: Black, C.A. (Ed.). Methods of soil analysis. Chemical and microbiological properties. Agronomy No. 9, Part 2. American Society of Agronomy, Madison, Wisconsin, U.S.A. 999 - 1010.

HEWITT, E., 1952. Sand and water culture methods used in the study of plant nutrition. Commonwealth Agricultural Bureaux, Farningham Royal, Bucks., England.

HORTENSTINE, C.C. & FISKELL, J.G.A., 1961. Effect of Al on sunflower growth and uptake of boron and calcium from nutrient solutions. Soil Sci. Soc. Am. Proc. 25, 304 - 307.

HOWARD, D.D. & ADAMS, F., 1965. Calcium requirement for penetration of subsoils by primary cotton roots. Soil Sci. Soc. Am. Proc. 29, 558 - 562.

HSU, P.H., 1965. Fixation of phosphate by aluminum and iron in acidic soils. Soil Sci. 99, 398 - 402.

HUDSON, D.J., 1966. Fitting segmented curves whose join points have to be estimated. J. Am. statist. Ass. 61, 1097 - 1129.

HUNDT, I. BERGMANN, W., FISCHER, F. & SCHILLING, G., 1970. Investigations on the influence of the micronutrient boron on the nucleic acid metabolism and the tissue structure of *Helianthus annuus* L. Albrecht-Thaer-Arch. 14, 725 - 737 (Fld Crop Abstr. 24, 717).

JACKSON, W.A., 1967. Physiological effects of soil acidity. In: Pearson, R.W. & Adams, F. (Eds). Soil acidity and liming. Agronomy No. 12. American Society of Agronomy, Madison, Wisconsin, U.S.A. 43 - 124.

JENNY, H., 1961. Reflections on the soil acidity merry-go-round. Soil Sci. Soc. Am. Proc. 25, 428 - 432.

JYUNG, W.H., EHMANN, A., SCHLENDER, K.K. & SCALA, J., 1975. Zinc nutrition and starch metabolism in *Phaselous vulgaris* L. Pl. Physiol., Lancaster 55, 414 - 420.

KAMPRATH, E.J., 1970. Exchangeable aluminium as a criterion for liming leached mineral soils. Soil Sci. Soc. Am. Proc. 34, 252 - 254.

KASTENBAUM, M., 1959. A confidence interval on the abscissa of the point of intersection of two fitted linear regressions. Biometrics 15, 323 - 324.

KOHNKE, H., 1968. Soil physics. McGraw Hill Inc., New York.

KING, L., 1972. The Natal Monocline : explaining the origin and scenery of Natal, South Africa. Geology Department, University of Natal, Durban.

KOHL, H.C.J. & OERTLI, J.J., 1961. Distribution of boron in leaves. Pl.Physiol., Lancaster 36, 420 - 424.

LABANAUSKAS, C.K., 1966. Manganese. In: Chapman, H.D. (Ed.) Diagnostic criteria for plants and soils. University of California 264 - 285.

LEWIS, A.H., 1943. The teart pastures of Somerset. J. agric. Sci., Camb. 33, 52 - 63.

LIN, C. & COLEMAN, N.T., 1960. The measurement of exchangeable aluminum in soils and clays. Soil Sci. Soc. Am. Proc. 24, 444 - 446.

LUDROF, R. & SCOTNEY, D.M., 1975. Soils of the Lion's River and Mooi River Valley Soil Conservation Districts. Tech. Comm. No. 94. Department of Agricultural Technical Services, Repulbic of South Africa.

LONG, F.L. & FOY, C.D., 1970. Plant varieties as indicators of aluminum toxicity in the A_2 horizon of a Norfolk soil. Agron.J. 62, 679 - 681.

LONG, F.L., LANGDALE, G.W. & MYHRE, D.L., 1973. Response of an Al-tolerant and an Al-sensitive genotype to lime, P and K on three Atlantic coast flatwood soils. Agron. J. 65, 26 - 30.

MAJEWSKI, F. & JANISZEWSKA, Z., 1970. Investigation on boron fertilization needs of soil. 1. Boron content in soils and plants as a basis of evaluation of boron fertilization need. Roczn. Nauk. roln. (A) 96, 269 - 301 (Fld Crop Abstr. 24 544).

MAPHAM, W.R., 1975. Some biometrical aspects of soil calibration. M.Sc. Agric. Thesis. University of Natal, Pietermaritzburg.

MAPHAM, W.R. & FARINA, M.P.W., 1974. On fitting fertilizer response surface functions with particular reference to inverse polynomials. Agrochemophysica 6, 27 - 30.

MARTIN, E.V., 1935. Effect of solar radiation on transpiration of Helianthus annuus. Pl. Physiol., Lancaster 10, 341 - 354.

MARTINI, J.A., KOCHHANN, R.A., SIQUEIRA, O.J. & BORKERT, C.M., 1974. Response of soybeans to liming as related to soil acidity, Al and Mn toxicities and P in some Oxisols of Brazil. Soil Sci. Soc. Am. Proc. 38, 616 - 620.

MAUN, M.A., TEARE, I.D. & CANODE, C.L., 1969. In vitro germination of Kentucky bluegrass pollen (Poa pratensis L. Newport). Crop Sci. 9, 389 - 390.

McLEAN, E.O., 1965. Aluminum. In: Black, C.A. (Ed). Methods of soil analysis. Chemical and microbiological properties. Agronomy No. 9, Part 2. American Society of Agronomy, Madison, Wisconsin, U.S.A. 978 - 998.

McLEAN, F.T. & GILBERT, B.E., 1927. The relative aluminum tolerance of crop plants. Soil Sci. 24, 163 - 175.

MOSER, F., 1942. Calcium nutrition at respective pH levels. Soil Sci. Soc. Am. Proc. 7, 339 - 344.

NELDER, J.A. & MEAD, R., 1965. A simplex method for function minimization. Comput. J. 7, 308 - 313.

OERTLI, J.J. & ROTH, J.A., 1969. Boron nutrition of sugar beet, cotton and soybeans. Agron. J. 61, 191 - 195.

ORCHARD, E.R., 1972. Some thoughts on soil acidity and liming. Fert. Soc. S. Afr. J. 1, 5 - 9.

PARKS, W.L. & WHITE, J.L., 1952. Boron retention by clay and humus systems saturated with various cations. Soil Sci. Soc. Am. Proc. 16, 298 - 300.

PAWLOWSKI, S.H., 1966. Low temperature storage of sunflower pollen. 2nd Int. Sunflower Conference. Research Branch, Canada Dept of Agriculture.

PESEK, J.T., 1956. Agronomic problems in securing fertilizer response data for economic analysis. In: Baum, E.L., Heady, E.O. & Blackmore, J. (Eds). Methodological procedures in the economic analysis of fertilizer use data. The Iowa State College Press 101 - 112.

PHILLIPS, J., 1969. The agricultural and related development of the Tugela Basin and its influent surrounds: a study in subtropical Africa. Natal Town and Regional Planning Commission, Pietermaritzburg.

PLANT, W., 1953. An analysis of the acid soil complex by the use of indicator plants. Pl. Soil 5, 54 - 66.

PRATT, P.F., 1965. Potassium. In: Black, C.A. (Ed.). Methods of soil analysis. Chemical and microbiological properties. Agronomy No. 9, Part 2. American Society of Agronomy, Madison, Wisconsin, U.S.A. 1022 - 1030.

PRATT, P.F., 1966. Aluminum. In: Chapman, H.D. (Ed.). Diagnostic criteria for plants and soils. University of California 3 - 12.

RABEY, G.G. & ALLISON, J.C.S., 1972. Comparative growth and yield of maize and sunflower. Rhod. J. agric. Res. 10, 105 - 108.

RAYNER, A.A., 1969. A first course in biometry for agriculture students. University of Natal Press, Pietermaritzburg.

REES, W.J. & SIRDAK, G.H., 1961. Inter-relationships of aluminium and manganese toxicities towards plants. Pl. Soil 14, 101 - 117.

REEVE, N.G. & SUMNER, M.E., 1970a. Effect of aluminum toxicity and phosphorus fixation on crop growth on Oxisols in Natal. Soil Sci. Soc. Am. Proc. 34, 263 - 267.

REEVE, N.G. & SUMNER, M.E., 1970b. Lime requirement of Natal Oxisols based on exchangeable aluminum. Soil Sci. Soc. Am. Proc. 34, 595 - 598.

REID, P.H. & COX, F.R., 1973. Soil properties, mineral nutrition and fertilization practices. In: Peanuts - culture and uses. American Peanut Research and Education Assoc. Inc., Oklahoma.

ROBINSON, R.G., 1970. Sunflower date of planting and chemical composition at various growth stages. Agron. J. 62, 665 - 666.

RUHAL, D.S. & DEO, R., 1971. Note on the effect of boron in irrigation water on 'Sonora 64' wheat (Triticum aestivum L.) Indian J. agric. Sci. 41, 577 - 578 (Fld Crop Abstr. 26, 107).

SCHUSTER, C.E. & STEPHENSON, R.E., 1940. Sunflower as an indicator plant of boron deficiency in soils. J. Amer. Soc. Agron. 32, 607 - 621.

SHATILOV, F.V. & IKONNIKOV, P.A., 1969. Effect of soil drought on the reproductive ability of sunflower fertilized with P and B. Fiziologiya Rast. 6, 1091 - 1093 (Fld Crop Abstr. 23, 372).

SHKOL'NIK, M.Ya. & KOPMANE, I.V., 1970. P metabolism in B-deficient sunflower plants. Trudybot. Inst. Akad. Nauk SSSR 4, 98 - 107. (Fld Crop Abstr. 24, 545).

SHOEMAKER, H.E. McLEAN, E.O. & PRATT, P.F., 1961. Buffer methods for determining lime requirement of soils with appreciable amounts of extractable aluminum. Soil Sci. Soc. Am. Proc. 25, 274 - 277.

SHUMAN, L.M. & ANDERSON, O.E., 1974. Evaluation of six extractants for their ability to predict manganese concentrations in wheat and soybeans. Soil Sci. Soc. Am. Proc. 38, 788 - 790.

SMITH, A.N., 1965. Aluminium and iron phosphates in soils. J. Aust. Inst. agric. Res. 31, 110 - 126.

SNYMAN, J.W., 1972. Nutritional studies with a Spanish-type groundnut on an Avalon medium sandy loam soil. Ph.D. Thesis, University of Natal, Pietermaritzburg.

STILES, W., 1961. Trace elements in plants, 3rd Ed. Cambridge University Press.

STOYANOVA, I., 1969. Determining optimum sowing depth for sunflower. Rast. Nauki 6, 27 - 32 (Fld Crop Abstr. 23, 232).

TANADA, T. & DEAN, L.A., 1942. Boron in some Hawaiian soils and crops. Hawaii. Plrs' Rec. 46, 65 - 74.

TANAKA, H., 1967. Boron absorption by crop plants as affected by other nutrients of the medium. Soil Sci. Pl. Nutr. 13, 41 - 44 (Fld Crop Abstr. 21, 278).

THOMAS, G.W., 1975. The relationship between organic matter content and exchangeable aluminum in acid soil. Soil Sci. Soc. Am. Proc. 39, 591.

TISDALE, S.L. & NELSON, W.L., 1967. Soil fertility and fertilizers. 2nd Ed. The MacMillan Company, New York.

VAN DER EYK, J.J., MACVICAR, C.N. & DE VILLIERS, J.M., 1969. Soils of the Tugela Basin. The Town and Regional Planning Commission, Pietermaritzburg.

VENTER, C.J.S. & FARINA, M.P.W., 1972. A little boron can do wonders for dryland wheat on sandy soils. Fmg S.Afr. 48, 4.

VENTER, G.C.H., GOUS, P.J. & MÖHR, P.J., 1973. Short term effects of surface applied amendments on two acid sandy loam soils in the Eastern Transvaal Highveld. Fert.Soc. S.Afr. J. 1, 27 - 38.

VLAMIS, J., 1953. Acid soil infertility as related to soil solution and solid phase effects. Soil Sci. 75, 383 - 394.

WEAR, J.I. 1965. Boron. In: Black, C.A. (Ed.). Methods of soil analysis. Chemical and microbiological properties. Agronomy No. 9, Part 2. American Society of Agronomy, Madison, Wisconsin, U.S.A. 1059 - 1063.

WEAR, J.I. & PATTERSON, R.M.,1962. Effect of soil pH and texture on the availability of water-soluble boron in the soil. Soil Sci. Soc. Am. Proc. 26, 344 - 345.

WILSON, C.M., LOVVORN, R.L. & WOODHOUSE, W.W., 1951. Movement and accumulation of water soluble boron within the soil profile. Agron. J. 43, 363 - 367.

YOUSIF, H.Y., BINGHAM, F.T. & YERMANDS, D.M., 1972. Growth, mineral composition, and seed oil of sesame (Sesamum indicum L.) as affected by boron and exchangeable sodium. Soil Sci. Soc. Am. Proc. 36, 923 - 926.

APPENDIX I

SELECTED PHYSICAL AND CHEMICAL PROPERTIES OF THE AVALON MEDIUM SANDY LOAM[1]

Analytical data		Soil depth (cm)				
		0-15	15-30	30-45	[2]45-60	60-75
Coarse sand	(%)	12	12	12	12	12
Medium sand	(%)	26	27	25	18	18
Fine sand	(%)	46	45	34	34	30
Total sand	(%)	84	84	71	64	60
Silt	(%)	3	3	6	6	8
Clay	(%)	13	13	23	30	32
Bulk density (g/cm^3)		1,6	1,5	1,6	1,5	1,5
[3]Moisture at 0,33 bar	(%)	7,9	9,4	15,5	15,7	21,9
[3]Moisture at 15 bar	(%)	3,9	5,2	7,9	8,9	12,0
[4]Available soil moisture	(%)	4,0	4,2	7,6	6,8	9,9
Available soil moisture	(mm/15cm)	9,7	9,4	18,2	15,1	22,7
Soil pH (H_2O)		4,65	4,75	5,01	5,09	5,38
Soil pH (N KCl)		3,92	3,96	4,21	4,32	4,50
Exch. Ca	(meq/100g)	0,41	0,50	0,88	0,64	0,69
Exch. Mg	(meq/100g)	0,12	0,35	0,65	1,06	1,16
Exch. K	(meq/100g)	0,09	0,10	0,09	0,05	0,09
Exch. Na	(meq/100g)	0,02	0,02	0,03	0,05	0,10
S	(meq/100g)	0,65	0,97	1,64	1,80	2,04
Exch. Al	(meq/100g)	0,72	0,63	0,48	0,63	0,37
CEC	(meq/100g)	1,37	1,59	2,12	2,43	2,41

Soil depth (cm)	Description
0 - 15	Dark greyish brown (10 YR 4/2) (Dry: greyish brown 10 YR 5/2); medium sandy loam; apedal.
15 - 30	Dark greyish brown (10 YR 4/2) (Dry: greyish brown 10 YR 5/2); medium sandy loam; apedal.
30 - 45	Brown (10 YR 4/3) (Dry: pale brown 10 YR 6/3); medium sandy loam; apedal.
[2]45 - 60	Yellowish brown (10 YR 5/4) (Dry: light yellowish brown 10 YR 6/4); medium sandy loam; apedal.
60 - 75	Brownish yellow (10 YR 6/6) mottled with red (Dry: yellow 10 YR 7/6); silty loam; apedal.

[1]Sampled from a soil pit adjacent to the field experiment

[2]Diagnostic horizon for series classification

[3]Analyses kindly carried out by Mr A. Cass

[4]Available soil moisture=Moisture at 0,33 bar - moisture at 15 bar expressed as a percentage of dry mass (Kohnke, 1968).

APPENDIX II

AGROMETEOROLOGICAL DATA FOR DUNDEE AGRICULTURAL RESEARCH STATION

FOR THE 1973/74 AND 1974/75 SEASONS

OCTOBER 1973

Day	Temperature (°C)				Rainfall (mm)	Wind run (km/day)	Bright sunshine (hours)	Class A pan evap. (mm)
	Max	Min	Mean	Grass min				
1	21,5	7,5	14,5	4,0		244	6,0	5,6
2	21,0	8,5	14,7	6,5		174	9,5	7,1
3	23,0	7,0	15,0	4,5		118	9,5	5,6
4	28,0	6,0	17,0	4,0		97	11,1	6,1
5	31,5	9,5	20,5	5,5		368	9,4	14,7
6	31,0	12,0	21,5	11,0		260	11,5	10,2
7	27,5	13,5	20,5	7,0		312	10,5	9,7
8	23,0	8,5	15,7	7,5		156	10,8	6,1
9	31,0	7,0	19,0	3,5		184	11,2	11,2
10	29,5	13,5	21,5	7,0	0,5	334	3,7	5,6
11	20,0	7,5	9,0	8,0		310	0,9	2,0
12	22,5	16,0	15,2	4,0	3,3	177	6,8	1.3
13	29.5	9,0	19,2	12,0		232	8,6	8,1
14	27,5	15,0	21,0	12,0	0,1	263	3,0	6,3
15	14,0	11,0	12,5	11,0	0,7	306	0,0	1,3
16	10,0	7,0	8,5	6,5	0,5	166	10,3	0,5
17	15,0	6,0	10,5	5,0		140	12,3	2,5
18	25,5	5,5	15,5	3,0		248	9,8	5,1
19	26,5	8,5	17,5	5,5		144	1,0	8,6
20	21,5	9,0	18,0	6,0		135	4,7	8,6
21	28,5	11,5	20,0	7,5		132	5,9	9,7
22	27,0	9,0	18,0	6,0		230	1,6	9,7
23	28,0	12,5	20,2	10,5		164	7,5	7,6
24	29,0	15,5	22,2	13,0		323	7,5	9,1
25	33,0	14,5	23,7	10,5	0,5	244	8,9	9,1
26	27,0	15,0	21,0	13,0	3,9	229	7,7	5,3
27	25,0	16,0	20,5	14,5		100	8,5	4,1
28	28,0	13,5	20,7	11,0		204	1,9	7,6
29	33,0	16,0	24,5	13,0		243	11,5	12,2
30	32,0	16,5	24,2	13,0	0,1	313	6,9	7,4
31	26,0	12,5	19,2	12,5		228	7,0	6,6
Total					9,6	6791	225,5	214,5
Mean	25,5	10,7	18,1	8,2		219	7,3	6,9

NOVEMBER 1973

Day	Temperature (°C)				Rainfall	Wind run (km/day)	Bright sunshine (hours)	Class A pan evap. (mm)
	Max	Min	Mean	Grass min				
1	31,0	13,0	22,0	13,5	13,7	294	5,0	7,1
2	17,0	13,5	15,3	12,0	3,0	208	0,0	0,5
3	22,5	10,5	16,5	10,0		181	5,4	4,1
4	27,0	12,5	20,5	11,5	1,5	275	4,7	6,1
5	24,5	12,5	18,5	11,5		164	9,7	6,1
6	25,0	10,0	17,5	6,0		240	9,7	8,6
7	24,5	14,0	19,2	12,0		240	7,8	6,6
8	25,5	14,5	20,0	13,5		157	4,7	5,6
9	31,5	14,5	23,0	10,0	4,1	373	9,4	13,7
10	28,0	15,0	21,5	1,20		380	8,3	10,2
11	21,5	9,0	14,7	4,0		229	9,4	8,1
12	17,0	9,0	13,0	5,5	1,7	219	9,0	1,8
13	19,0	9,0	14,0	7,0		169	3,5	3,6
14	22,0	11,0	16,5	8,5	12,5	159	6,0	3,3
15	22,0	8,0	15,0	6,5		155	11,0	6,1
16	27,0	9,5	18,2	6,5		117	10,3	7,6
17	30,0	11,5	20,7	7,5		157	12,3	10,7
18	29,5	10,5	20,0	5,0		205	9,8	10,2
19	21,0	13,5	17,7	10,5	3,0	206	1,0	5,1
20	24,0	12,5	18,2	10,5	42,8	235	4,7	16,0
21	23,0	12,5	17,7	11,0	28,5	202	5,9	9,1
22	22,5	12,0	17,2	8,5		101	1,6	4,1
23	25,0	15,0	20,0	12,0	3,7	107	7,5	5,8
24	26,5	14,0	20,2	10,5	10,4	215	7,5	1,8
25	29,0	14,0	21,5	11,0	2,6	290	8,9	9,7
26	25,5	15,0	20,2	11,0	4,6	190	7,7	5,1
27	30,5	14,5	22,5	11,5		389	8,5	12,7
28	18,5	13,5	16,0	12,0		265	1,9	5,1
29	27,0	11,5	19,2	9,5		270	11,5	7,6
30	31,0	15,0	23,0	11,0		264	6,9	10,2
Total					132,1	6669	209,5	212,3
Mean	24,9	12,4	18,7	9,7		222	7,0	7,1

DECEMBER 1973

Day	Temperature (°C)				Rainfall (mm)	Wind run (km/day)	Bright sunshine (hours)	Class A pan evap. (mm)
	Max	Min	Mean	Grass min				
1	16,5	14,5	15,5	12,5		300	1,8	4,1
2	19,5	8,5	14,0	6,0		130	11,1	7,1
3	25,5	7,0	16,2	2,5		151	7,0	6,1
4	27,0	12,5	19,7	8,5		261	6,1	6,1
5	29,5	14,5	22,0	9,0		292	11,6	13,7
6	27,0	16,0	21,5	11,0	1,4	282	6,1	4,6
7	25,0	14,0	19,5	11,5		159	7,4	3,6
8	29,0	13,5	21,2	11,5	0,5	163	7,2	7,1
9	20,0	15,5	17,7	11,5	10,3	291	0,3	2,3
10	15,0	9,5	12,2	9,0		196	0,6	3,1
11	20,5	9,0	14,7	8,0		135	9,0	6,1
12	29,0	9,5	19,2	7,5		116	11,1	7,1
13	27,0	15,0	21,0	12,0		186	11,4	9,7
14	31,5	15,0	23,2	12,0		184	12,0	9,7
15	28,5	15,5	22,0	12,5		278	6,3	7,1
16	19,0	12,5	15,7	12,0	8,8	119	2,1	0,0
17	27,5	13,0	20,2	10,5		208	9,0	6,6
18	22,0	16,5	19,2	16,0	0,5	136	0,3	3,6
19	24,0	16,5	20,2	15,5	5,5	137	0,6	4,1
20	24,0	17,0	20,5	16,0	5,7	183	1,2	1,5
21	25,0	14,5	19,7	11,5		208	9,8	7,6
22	23,5	12,5	18,0	10,0		162	5,9	6,6
23	25,5	14,5	20,0	12,5	0,3	195	8,2	7,4
24	27,0	16,5	21,7	12,5	13,8	204	2,7	4,6
25	23,5	15,0	19,2	13,0		103	1,5	3,6
26	27,0	15,0	21,0	12,5		203	5,2	6,6
27	22,0	15,0	18,5	13,5		236	3,4	5,1
28	24,0	14,0	19,0	13,5		116	9,5	7,1
29	30,5	12,5	21,5	9,0		113	12,5	9,1
30	30,5	13,5	22,0	9,0		129	8,0	9,7
31	29,0	17,5	23,6	14,5		106	6,1	8,1
Total					46,8	5694	195,2	188,8
Mean	25,0	13,7	19,4	11,2		183	6,3	6,1

JANUARY 1974

Day	Temperature (°C) Max	Min	Mean	Grass min	Rainfall (mm)	Wind run (km/day)	Bright Sunshine (hours)	Class A pan evap. (mm)
1	25,5	16,0	20,7	13,0	6,1	219	3,0	4,6
2	26,5	16,0	21,2	14,5	5,8	237	5,5	7,8
3	30,0	17,0	23,5	15,5		240	4,5	7,1
4	27,0	13,0	20,0	9,5		121	9,9	7,1
5	27,5	16,0	21,7	13,0		207	2,5	3,1
6	26,0	16,0	21,0	12,0		208	4,5	5,6
7	26,5	16,0	21,2	14,0		94	10,4	8,1
8	32,0	12,5	22,2	11,0		283	9,5	9,7
9	29,5	14,5	22,0	11,5		107	11,4	14,2
10	30,5	15,5	23,0	14,0	41,1	207	8,0	13,2
11	30,0	15,5	22,7	15,5	1,2	122	8,3	8,9
12	31,0	19,5	25,3	17,5		212	8,6	8,1
13	29,5	19,0	24,2	18,5	0,4	190	6,9	6,1
14	26,0	15,5	20,7	15,5		141	7,9	5,1
15	31,5	16,0	23,7	15,0		142	12,6	9,7
16	31,0	18,5	24,7	15,0		195	7,7	9,7
17	23,5	19,5	21,5	15,0		270	0,8	6,6
18	20,5	15,0	17,7	14,5	1,0	363	0,4	1,5
19	27,0	15,0	21,0	13,5		111	8,1	6,6
20	30,5	14,5	22,5	11,5		205	10,4	10,2
21	30,5	16,5	23,5	14,0	28,2	187	6,3	8,9
22	23,5	17,0	20,2	17,0	9,4	94	1,0	1,3
23	30,0	16,0	23,0	16,0	0,5	194	7,3	8,1
24	28,5	18,5	23,5	16,5	83,0	245	5,6	0,0
25	17,5	15,0	16,2	15,0	0,2	219	0,1	2,3
26	24,5	14,0	19,2	13,5		107	6,2	5,1
27	28,5	15,5	22,0	14,0		156	8,0	7,1
28	30,0	16,5	23,2	12,5		170	10,4	7,6
29	28,0	18,0	23,0	15,0	10,2	233	3,9	3,6
30	18,0	13,5	15,7	13,0		111	1,7	1,5
31	26,0	12,0	19,0	10,5		103	11,5	6,6
Total					187,0	5706	202,8	205,1
Mean	27,5	15,9	21,6	14,1		184	6,5	6,6

FEBRUARY 1974

Day	Temperature (°C) Max	Min	Mean	Grass min	Rainfall (mm)	Wind run (km/day)	Bright sunshine (hours)	Class A pan evap. (mm)
1	28,5	14,5	21,5	12,0		177	8,3	7,1
2	26,5	18,0	22,2	16,5		153	7,1	6,1
3	28,5	15,5	22,0	12,5		87	10,2	7,1
4	28,5	16,0	22,2	12,5	50,8	182	6,9	12,2
5	25,5	17,0	21,2	15,0	0,6	66	3,4	4,1
6	29,0	18,0	23,5	16,0	21,6	158	6,5	3,8
7	22,0	17,0	19,5	16,0	12,5	211	0,2	1,3
8	20,8	16,0	18,4	15,0	0,6	216	0,0	2,0
9	19,5	14,5	17,0	13,5		138	0,3	2,5
10	24,5	14,5	19,5	13,5		144	2,8	5,1
11	23,5	13,5	18,5	11,0		100	8,7	4,6
12	26,0	13,0	19,5	10,5		96	10,5	7,1
13	26,0	14,0	20,0	11,0		176	10,0	7,1
14	26,5	16,5	21,5	13,5		99	10,0	6,6
15	27,5	15,0	21,2	11,0		64	10,0	7,6
16	30,5	13,0	21,7	9,0	13,1	109	10,1	8,1
17	22,0	17,0	19,5	14,5	6,2	151	0,7	1,0
18	25,0	16,0	20,5	14,0		85	4,8	5,1
19	22,5	16,0	19,2	14,5		52	0,1	2,0
20	25,0	17,0	21,0	16,0		137	8,0	5,6
21	26,0	13,0	19,5	10,5		100	11,2	6,1
22	29,0	14,5	21,7	12,5		211	9,4	8,1
23	21,5	16,5	19,0	14,5	0,1	212	0,0	2,6
24	21,5	14,5	18,0	14,0		63	1,6	9,7
25	29,5	13,0	21,2	10,5		207	9,9	3,1
26	24,5	16,5	20,5	16,0	1,3	174	3,0	7,4
27	26,0	15,5	20,7	13,0		96	8,5	7,1
28	28,5	14,0	21,2	11,0		121	11,3	7,6
Total					106,7	3798	173,4	157,8
Mean	25,5	15,3	20,4	13,2		135	6,2	5,6

MARCH 1974

Day	Temperature (°C)				Rainfall	Wind run	Bright sunshine	Class A pan evap.
	Max	Min	Mean	Grass min	(mm)	(km/day)	(hours)	(mm)
1	30,5	14,5	22,5	11,5		107	10,9	6,1
2	28,0	15,0	21,5	12,0		277	9,7	4,6
3	24,5	16,0	20,2	15,5		124	3,9	6,1
4	26,5	15,0	20,7	11,5		105	9,7	7,1
5	27,0	16,5	21,7	14,0		128	9,1	7,1
6	26,5	15,5	21,0	13,5		105	6,2	5,6
7	27,0	17,5	22,2	15,0		130	5,7	5,6
8	29,5	17,0	23,2	14,0	5,5	103	9,1	6,6
9	27,0	14,0	20,5	11,5		105	9,7	7,6
10	26,5	14,0	20,2	11,5		158	9,7	7,1
11	26,0	15,5	20,7	12,0	2,0	74	2,8	3,6
12	26,0	13,5	19,7	11,0		149	8,0	6,1
13	27,5	14,5	21,0	12,0		183	8,9	6,1
14	29,0	14,5	21,7	11,0	2,5	87	5,9	5,1
15	27,0	16,0	21,5	14,5		70	4,4	4,1
16	29,0	15,5	22,2	12,5		105	10,2	6,1
17	29,0	16,0	22,5	12,0	2,7	232	7,6	7,4
18	18,0	12,0	15,0	11,5		186	2,7	4,1
19	19,0	7,5	13,2	4,5		126	4,0	3,6
20	22,0	5,5	13,7	1,5		76	10,1	3,1
21	26,5	9,5	18,0	6,0		85	7,1	6,1
22	29,5	12,0	20,7	8,5		62	7,0	4,6
23	29,5	15,5	22,5	11,0		96	6,4	5,6
24	26,5	16,5	21,5	14,5	1,0	70	1,4	2,5
25	27,5	16,5	22,0	14,5		84	8,0	6,1
26	28,5	13,0	20,7	9,0	5,6	133	8,2	5,6
27	20,0	15,5	17,7	14,0	0,2	72	0,1	1,8
28	27,0	15,5	21,2	12,0		70	6,9	4,6
29	26,5	13,5	20,0	10,3	1,0	268	5,1	5,6
30	15,5	10,5	13,0	9,0	0,1	157	0,7	2,8
31	21,5	11,0	16,2	10,0		103	1,8	3,6
Total					27,1	3842	200,9	161,6
Mean	25,9	14,0	20,0	11,3		123	6,5	5,2

OCTOBER 1974

Day	Temperature (°C)				Rainfall	Wind run	Bright sunshine	Class A pan evap.
	Max	Min	Mean	Grass min	(mm)	(km/day)	(hours)	(mm)
1	32,5	12,5	22,5	9,0		227	9,2	10,2
2	30,0	15,5	22,7	11,5		205	9,7	8,1
3	29,0	8,5	18,7	4,5		141	10,5	7,1
4	32,0	10,0	21,0	5,5		196	6,2	9,1
5	32,0	13,5	22,7	10,5		314	8,2	12,2
6	30,5	16,0	23,2	13,5		356	1,2	12,2
7	12,5	8,0	10,2	7,0	0,1	149	0,0	1,3
8	20,0	8,5	14,2	5,5	3,9	145	2,9	2,8
9	26,5	10,5	18,5	7,5	6,0	161	8,8	12,7
10	26,5	10,5	18,5	7,2		176	8,3	6,1
11	26,5	13,0	19,7	9,5	0,6	100	8,3	8,6
12	30,5	11,0	20,7	7,5		102	10,8	8,6
13	35,5	11,5	23,5	6,5		228	11,3	13,2
14	34,5	14,5	24,5	10,5		261	8,8	11,2
15	29,5	14,5	22,0	11,5		206	8,8	8,6
16	32,0	16,0	24,0	13,0		393	5,6	11,7
17	31,5	16,0	23,7	12,0		375	11,1	15,7
18	21,5	12,0	16,7	8,0		286	8,7	7,1
19	24,0	4,5	14,2	- 0,5		210	10,4	7,1
20	31,5	12,0	21,7	7,5		250	8,9	12,2
21	20,5	11,0	15,7	8,0		218	9,3	9,1
22	22,0	9,0	15,5	5,5		138	10,2	6,6
23	30,5	6,5	18,5	1,0		219	10,5	10,7
24	32,5	14,0	23,2	8,0	0,9	366	6,5	14,2
25	33,5	17,0	25,2	11,0		460	8,1	15,7
26	30,5	14,5	22,5	9,0		488	7,5	14,7
27	17,0	11,0	14,0	9,0		333	1,0	3,0
28	28,5	11,0	19,7	6,5		206	9,9	7,6
29	31,5	13,5	22,5	10,5	9,6	154	7,3	6,1
30	25,0	13,2	19,2	11,5	1,7	216	3,7	5,3
31	21,5	14,5	18,0	12,5		278	2,5	5,6
Total					22,7	7557	234,1	286,2
Mean	27,8	12,1	19,9	8,4		244	7,6	9,2

NOVEMBER 1974

Day	Temperature (°C) Max	Min	Mean	Grass min	Rainfall (mm)	Wind run (km/day)	Bright sunshine (hours)	Class A pan evap. (mm)
1	20,0	11,0	15,5	9,0		118	0,8	3,0
2	27,5	10,5	19,0	5,0		115	8,4	7,1
3	29,5	11,0	20,2	6,0		158	7,4	8,6
4	32,5	12,0	22,2	7,0		173	7,2	9,1
5	27,5	16,5	22,0	13,0	1,7	342	4,7	6,4
6	16,0	10,0	13,0	7,5	21,9	155	0,1	0,0
7	18,0	10,5	14,2	8,0	6,9	101	1,8	0,8
8	28,0	11,5	19,7	8,0	23,0	172	8,7	8,1
9	22,5	13,0	17,7	9,5		180	3,6	4,6
10	26,0	12,0	19,0	7,5	12,4	123	8,1	6,9
11	19,5	15,0	17,2	12,0	4,8	55	2,5	2,3
12	23,5	12,5	18,0	7,5	20,4	178	5,5	2,5
13	26,0	12,0	19,0	8,0	3,3	158	9,2	7,4
14	24,5	14,5	19,5	11,5	9,1	187	5,3	6,1
15	30,5	13,5	22,0	10,0		214	9,8	9,7
16	32,0	15,5	23,7	10,0		260	11,0	12,2
17	31,0	16,0	23,5	10,0		274	8,6	11,7
18	27,0	16,5	21,7	11,5	10,0	235	7,8	6,4
19	17,0	14,0	15,5	11,0	23,0	144	0,0	8,1
20	18,5	13,0	15,7	10,0		106	1,3	1,5
21	27,0	12,0	19,5	7,5	5,0	231	7,2	8,6
22	27,0	12,0	19,5	9,5		211	6,0	7,1
23	30,0	14,5	22,2	10,0	1,4	282	7,4	7,6
24	29,0	16,0	22,5	10,5		332	5,3	8,1
25	27,5	15,0	21,2	9,0		375	11,6	14,2
26	28,5	12,0	20,2	7,5		245	8,7	9,1
27	23,0	14,0	18,5	11,0		260	8,9	6,6
28	30,0	13,5	21,7	9,5	1,5	327	6,0	8,1
29	27,5	13,5	20,5	10,5		203	5,2	7,1
30	24,0	15,0	19,5	12,0		188	6,1	5,1
Total					144,3	6102	184,1	205,6
Mean	25,7	13,3	19,5	9,3		203	6,1	6,9

DECEMBER 1974

Day	Temperature (°C)				Rainfall (mm)	Wind run (km/day)	Bright sunshine (hours)	Class A pan evap. (mm)
	Max	Min	Mean	Grass min				
1	29,5	14,5	22,0	8,0	5,7	162	6,1	7,1
2	25,5	17,0	21,2	12,5	28,3	177	1,9	9,9
3	25,5	15,5	20,5	12,0	3,5	131	5,7	5,1
4	30,0	15,5	22,7	10,0	0,5	195	8,1	8,6
5	29,5	15,0	22,2	11,5	10,0	175	7,3	6,9
6	28,5	14,5	21,5	13,5		156	9,7	7,6
7	30,0	17,0	23,5	14,5	6,3	186	7,3	7,9
8	20,0	16,5	18,2	15,0	8,7	135	1,4	1,0
9	29,0	14,0	21,5	9,5		329	8,0	9,1
10	26,0	15,5	20,7	10,0	49,4	211	4,7	0,0
11	24,5	13,5	19,0	10,0	39,4	188	2,8	9,4
12	25,5	11,5	18,5	7,0	7,1	267	5,8	6,1
13	21,5	12,5	17,0	8,5		124	4,8	4,1
14	28,0	12,5	20,2	7,5		93	11,9	7,1
15	27,0	13,5	20,2	7,0		188	10,3	10,2
16	24,5	15,5	20,0	12,0		144	10,0	8,1
17	28,0	13,0	20,5	5,5		204	10,6	7,6
18	27,0	18,0	22,5	13,0	30,2	166	4,9	13,0
19	24,5	14,0	19,2	11,0	15,6	227	3,3	4,8
20	20,0	12,5	16,2	11,5		247	5,0	4,1
21	21,0	11,5	16,2	5,5		136	7,4	6,1
22	28,5	11,0	19,7	4,5		147	9,8	7,1
23	24,5	15,0	19,7	9,5	1,8	308	4,9	6,4
24	21,0	12,0	16,5	8,0		243	1,2	3,0
25	27,0	13,5	20,2	9,5	54,7	218	6,1	0,0
26	27,5	14,5	21,0	9,0	2,2	340	6,1	7,4
27	29,5	15,0	22,2	9,0		364	7,1	9,7
28	26,0	15,0	20,5	11,0	11,2	311	1,6	10,2
29	21,5	14,0	17,7	12,5		167	9,3	6,1
30	28,5	10,5	19,5	5,0		159	12,5	10,7
31	30,5	13,0	21,7	5,0		276	8,6	8,6
Total					274,5	6374	204,1	214,4
Mean	26,1	14,1	20,1	9,6		206	6,6	6,9

JANUARY 1975

Day	Temperature (°C) Max	Min	Mean	Grass min	Rainfall (mm)	Wind run (km/day)	Bright sunshine (hours)	Class A pan evap. (mm)
1	29,0	17,5	23,2	17,0		284	9,5	7,1
2	31,0	16,5	23,7	14,0		388	6,2	12,2
3	19,5	10,5	15,0	10,0		218	8,3	4.6
4	25,0	11,0	18,0	9,0		106	10,9	7,6
5	28,0	12,0	20,0	8,0		157	10,4	8,1
6	27,0	14,0	20,5	12,0		165	6,1	5,6
7	29,0	14,0	21,5	10,0		137	11,5	8,1
8	31,5	14,5	23,0	11,5		176	8,2	8,1
9	27,5	14,0	20,7	9,0		147	8,8	8,1
10	30,5	14,5	22,5	11,0	1,7	109	10,7	7,9
11	32,0	12,5	22,2	10,0		287	9,6	11,2
12	18,0	15,5	16,7	15,0	4,6	216	1,7	1,0
13	28,5	13,5	21,0	12,0		182	9,4	8,1
14	31,5	14,5	23,0	11,0		223	10,2	11,7
15	29,5	16,5	23,0	12,0	4,7	192	3,1	7,4
16	24,0	15,0	19,5	14,0	22,5	182	1,5	10,4
17	18,5	13,5	16,0	12,0	18,2	186	0,2	1,0
18	24,0	14,0	19,0	13,0	41,3	126	3,1	11,9
19	24,0	14,0	19,0	13,0	2,1	132	2,7	4,1
20	26,0	15,5	20,7	13,5		95	9,0	6,1
21	26,5	16,0	21,2	13,0		184	4,6	6,1
22	27,0	16,5	21,7	15,5		122	6,9	6,6
23	25,5	15,0	20,2	16,0		138	3,6	5,6
24	28,5	16,0	22,2	13,5		152	6,4	7,6
25	28,0	19,5	23,7	18,0	10,7	166	4,4	5,6
26	27,5	17,0	22,2	17,0	74,7	176	3,4	0,0
27	23,5	15,5	19,5	15,5	6,1	145	1,6	1,5
28	25,0	17,0	21,0	16,0	2,9	66	2,1	3,3
29	26,0	16,5	21,2	14,5	1,5	265	4,4	6,1
30	17,5	15,0	16,2	14,0		317	1,3	3,6
31	20,5	9,5	15,0	9,0		90	10,8	7,1
Total					190,9	5525	190,5	204,9
Mean	26,1	14,7	20,4	12,9		172	6,1	6,8

FEBRUARY 1975

Day	Temperature (°C)				Rainfall	Wind run	Bright sunshine	Class A pan evap.
	Max	Min	Mean	Grass min	(mm)	(km/day)	(hours)	(mm)
1	27,5	10,0	18,7	7,5		106	11,5	6,0
2	25,0	13,5	19,2	13,0		136	10,1	7,6
3	27,5	14,0	20,7	11,0		88	11,2	7,6
4	29,0	13,5	21,2	10,0		103	8,5	7,6
5	26,5	16,5	21,5	13,5	46,0	195	3,2	6,8
6	24,5	14,5	19,5	13,5		166	5,7	5,0
7	26,0	15,5	20,7	15,5		161	6,3	6,0
8	24,0	16,5	20,2	14,0		169	5,8	5,5
9	26,0	17,0	21,5	16,0		124	3,4	4,0
10	28,5	16,5	22,5	14,0		104	6,3	6,0
11	28,0	15,0	21,5	12,0	14,6	137	4,3	4,3
12	21,0	15,5	18,2	14,0	0,5	149	0,1	3,0
13	19,5	15,0	17,2	13,0	30,3	153	0,0	0,0
14	19,0	15,0	17,0	14,0	13,4	115	0,0	0,0
15	19,0	15,0	17,0	14,0	11,5	57	0,0	0,0
16	22,0	16,0	19,0	14,5	13,2	149	1,0	1,0
17	20,0	15,5	17,7	14,0	0,3	176	0,2	3,5
18	23,0	14,5	18,7	12,5		85	4,0	4,5
19	25,5	13,5	19,5	10,5	2,1	105	3,8	4,0
20	22,0	15,0	18,5	14,0	18,0	120	0,0	0,2
21	22,0	15,5	18,7	14,0	2,8	119	2,2	0,0
22	24,0	14,5	19,2	12,0		231	6,3	6,0
23	23,5	16,0	19,7	15,5	1,7	173	6,8	5,3
24	24,0	12,5	18,2	9,0		113	9,3	6,6
25	28,0	13,5	20,7	10,5		67	10,8	6,6
26	27,5	14,5	21,0	10,5	17,9	148	8,2	9,1
27	27,5	15,0	21,2	14,0	5,4	205	4,8	4,3
28	20,5	14,5	17,5	13,0	0,9	128	1,5	3,5
Total					178,5	3782	135,2	124,9
Mean	24,3	14,8	19,5	12,8		135	4,8	4,5

MARCH 1975

Day	Temperature (°C)				Rainfall	Wind	Bright	Class A
	Max	Min	Mean	Grass min	(mm)	run (km/day)	sunshine (hours)	pan evap. (mm)
1	27,5	13,5	20,5	10,5	1,3	160	7,9	5,8
2	23,5	12,0	17,7	8,0		89	6,0	4,5
3	27,0	14,5	20,7	11,5		189	9,0	6,6
4	24,5	15,0	19,7	12,5		214	9,2	7,1
5	27,0	14,0	20,5	11,5		106	10,5	5,5
6	28,0	14,0	21,0	10,0	13,5	81	6,0	3,3
7	21,5	18,0	19,7	15,5	7,1	108	0,8	0,0
8	23,5	14,0	18,7	10,5	0,5	125	5,5	3,5
9	25,0	12,5	18,7	9,0		87	9,9	5,5
10	26,5	13,5	20,0	9,0		70	10,8	6,0
11	25,0	12,5	18,7	8,5		229	8,7	7,6
12	18,0	14,0	16,0	12,0		71	0,0	1,5
13	20,5	14,5	17,5	11,5		79	0,7	2,5
14	22,0	10,5	16,2	5,5		167	5,3	4,5
15	21,0	13,0	17,0	11,0		127	2,9	3,5
16	24,0	9,5	16,7	4,5		76	9,0	5,0
17	21,0	11,5	16,2	7,0	17,8	135	0,0	0,5
18	13,0	8,5	10,7	6,0	4,2	27	0,1	1,7
19	20,0	9,0	14,5	6,5	13,1	102	2,0	4,5
20	23,0	10,5	16,7	6,0		119	8,9	5,0
21	23,5	12,0	17,7	9,0	0,1	93	8,8	5,3
22	26,0	10,0	18,0	6,0		273	8,3	6,0
23	27,0	13,0	20,0	8,5		195	10,6	7,6
24	25,5	10,5	18,0	6,0		226	2,6	4,0
25	24,5	12,5	18,5	8,0		113	7,9	5,5
26	25,0	11,5	18,2	7,0		107	9,6	5,0
27	25,0	12,0	18,5	7,5		133	8,7	4,5
28	26,0	14,5	20,2	11,5		63	8,4	5,5
29	27,5	12,0	19,7	7,5		110	10,6	6,6
30	26,0	10,0	18,0	4,0		99	9,1	5,5
31	27,0	14,0	20,5	9,0		84	7,4	4,5
Total					57,5	3857	205,1	145,7
Mean	24,0	12,5	18,2	8,7		124	6,6	4,7

A P P E N D I X I I I

TYPICAL STATISTICAL ANALYSES

TABLE 1 Statistical analysis of a 4^3 factorial design

SOIL PH (N KCL) 12/12/73

Y DATA IN UNITS AND ORDER AS PUNCHED

3.7100	3.8300	4.0000	3.7200	3.7000	4.0100	3.9000	3.8400
3.6900	3.9500	4.0400	3.9300	4.0000	3.9800	4.2000	3.7600
3.9000	3.7000	4.1100	3.6200	3.8700	4.0200	4.1300	3.8500
4.0100	3.7100	3.9200	3.8100	3.9900	4.0100	3.7600	3.8500
3.9600	4.0900	4.2500	3.9000	3.7800	4.0100	4.0000	3.8900
3.9900	3.7400	3.7600	4.3300	3.9000	3.7200	3.9000	3.8300
4.2100	3.9400	4.2100	3.7100	3.9400	3.7800	3.7100	4.1900
3.9600	4.2200	3.8900	3.9000	3.8400	4.1100	3.9200	3.8100

BLOCK TOTALS

62.2599	62.2599	63.0499	63.3599

ANALYSIS OF VARIANCE

SOURCE		DF	SUMS OF SQUARES		EFFECT
BLOCKS		3	0.5726722E-01		
M		1	0.3178135E 00	**	0.4509997E 01
N		1	0.1027687E 01	**	0.8109996E 01
MN		1	0.5640543E-03		0.1899986E 00
F		1	0.1593980E-01	*	0.1010023E 01
M F		1	0.7655141E-04		-0.6999494E-01
NF		1	0.7654723E-04		-0.6999303E-01
MNF		1	0.1890580E-03		-0.1099987E 00
H		1	0.3851716E-01	**	0.1570063E 01
M H		1	0.1314101E-02		0.2900043E 00
N H		1	0.1701596E-02		0.3300033E 00
MN H		1	0.5076591E-02		0.5700017E 00
FH		1	0.7655557E-04		0.6999684E-01
M FH		1	0.2889034E-02		0.4299979E 00
NFH		1	0.3515651E-03		0.1500006E 00
MNFH		1	0.5439063E-02		0.5900012E 00
C		1	0.8255519E-03		-0.2298593E 00
M C		1	0.1701615E-02		0.3300052E 00
N C		1	0.4063899E-02		-0.5099896E 00
MN C		1	0.2640745E-03		0.1300030E 00
F C		1	0.1995129E-01	*	-0.1129992E 01
M F C	(E)	1	0.1314088E-02		-0.2900028E 00
NF C	(E)	1	0.1701551E-02		-0.3299990E 00
MNF C	(E)	1	0.2139094E-02		-0.3700028E 00
MHC		1	0.2138995E-02		-0.3699942E 00
M HC	(E)	1	0.5640600E-03		0.1899996E 00
N HC	(E)	1	0.1406761E-04		0.3000545E-01
MN HC	(E)	1	0.5640770E-03		0.1900024E 00
FHC		1	0.1265709E-03		0.9000302E-01
M FHC			TOTALLY CONFOUNDED		
NFHC	(E)	1	0.1890678E-03		-0.1100015E 00
MNFHC	(E)	1	0.4515274E-03		0.1699934E 00
D		1	0.1471837E-05		-0.9705549E-02
M D		1	0.1076411E-01		0.8300019E 00
N D		1	0.6201650E-02		0.6300045E 00
MN D		1	0.7014044E-02		0.6699992E 00
F D		1	0.3515562E-03		-0.1499986E 00
M F D	(E)	1	0.9765513E-03		[illegible]

MNF D			TOTALLY CONFOUNDED		
H D		1	0.2888951E-02		-0.4299917E 00
M H D	(E)	1	0.9763739E-03		0.2500014E 00
N H D	(E)	1	0.6201528E-02		-0.6299983E 00
MN H D	(E)	1	0.2139066E-02		0.3700004E 00
FH D		1	0.5076404E-02		-0.5699912E 00
M FH D	(E)	1	0.1701551E-02		-0.3299990E 00
NFH D	(E)	1	0.4515781E-03		-0.1700029E 00
MNFH D	(E)	1	0.8265490E-03		0.2299981E 00
CD		1	0.7438920E-02		0.6899935E 00
M CD		1	0.4515730E-03		0.1700020E 00
N CD		1	0.1237650E-01		0.8899930E 00
MN CD		1	0.6890690E-03		0.2100010E 00
F CD		1	0.1405867E-04		0.2999592E-01
M F CD	(E)	1	0.7439033E-02		-0.6899967E 00
NF CD	(E)	1	0.6890627E-03		-0.2100000E 00
MNF CD	(E)	1	0.1856390E-01	*	-0.1089995E 01
HCD		1	0.1914072E-02		0.3500009E 00
M HCD	(E)	1	0.9751575E-02		0.7900005E 00
N HCD			TOTALLY CONFOUNDED		
MN HCD	(E)	1	0.7876522E-02		0.7099982E 00
FHCD		1	0.4515274E-03		0.1699934E 00
M FHCD	(E)	1	0.7876500E-02		-0.7099972E 00
NFHCD	(E)	1	0.3906280E-04		0.5000019E-01
MNFHCD	(E)	1	0.7014064E-02		-0.6700001E 00
ERROR		24	0.8059966E-01		
TOTAL		63	0.1640280E 01		

(E) DENOTES ERROR COMPONENT

SE = 0.5795100E-01 MEAN = 0.3920459E 01 C.V.= 1.4781

PRESENTATION OF RESULTS

```
        Y DATA(UNADJUSTED)

      INTERACTION  L G
      ----------------
   3.6874      3.8249      3.9274      4.0849 I    3.8812
   3.7174      3.8674      3.9874      4.0699 I    3.9106
   3.7324      3.8624      3.9849      4.1324 I    3.9281
   3.7674      3.8899      3.9949      4.1949 I    3.9618
 ------------------------------------------------------------
   3.7262      3.8612      3.9737      4.1206 I    3.9204
 L'          0.1342891E 01   **
 L''         0.5636241E-03
 L'''        0.2587416E-02
 -------------------------
             0.1346042E 01
                 800 kg/ha.
AVERAGE RESPONSE TO L IS    0.1295(+-)    0.0064
 G'          0.5382411E-01   **
 G''         0.7651178E-04
 G'''        0.6328196E-03
 -------------------------
             0.5453344E-01
                 800 Kg/ha.
AVERAGE RESPONSE TO G IS    0.0259(+-)    0.0064
 L'G'        0.1785059E-02
 L'G''       0.1665275E-02
 L'G'''      0.1172899E-02
 L''G'       0.3315378E-02
 L''G''      0.5439276E-02
 L''G'''     0.1950136E-02
 L'''G'      0.1155948E-03
 L'''G''     0.1575426E-02
 L'''G'''    0.9501357E-04
 -------------------------
             0.1711405E-01
    S.E. OF A MEAN IN BODY OF TABLE =    0.0289
                      LSD (.05) =    0.0845
                      LSD (.01) =    0.1146

      INTERACTION  L B
      ----------------
   3.7349      3.8574      4.0249      4.1224 I    3.9349
   3.7424      3.8799      3.9499      4.0524 I    3.9062
   3.7149      3.8499      3.9599      4.1274 I    3.9131
   3.7124      3.8574      3.9599      4.1799 I    3.9274
 ------------------------------------------------------------
   3.7262      3.8612      3.9737      4.1206 I    3.9204
 L'          0.1342897E 01   **
 L''         0.5637147E-03
 L'''        0.2587503E-02
 -------------------------
             0.1346048E 01

AVERAGE RESPONSE TO L IS    0.1295(+-)    0.0064
 B'          0.1941935E-03
 B''         0.7423457E-02
```

```
-------------------------
            0.8265523E-02
                  5 kg/ha.
AVERAGE RESPONSE TO B IS   -0.0015(+-)     0.0064
 L'B'          0.7612287E-02
 L'B''         0.1188240E-01
 L'B'''        0.7525520E-02
 L''B'         0.6752261E-02
 L''B''        0.6890816E-03
 L''B'''       0.5253972E-03
 L'''B'        0.6520346E-02
 L'''B''       0.9453294E-03
 L'''B'''      0.1072504E-02
-------------------------
            0.4352510E-01
    S.E. OF A MEAN IN BODY OF TABLE =     0.0289
                       LSD (.05) =     0.0845
                       LSD (.01) =     0.1146 .

          INTERACTION  G B
          ----------------
      3.8674      3.9174      3.9299      4.0249 I    3.9349
      3.8949      3.8774      3.9174      3.9349 I    3.9062
      3.8524      3.9374      3.9124      3.9499 I    3.9131
      3.9099      3.9099      3.9524      3.9374 I    3.9274
-------------------------------------------------------------
      3.8812      3.9106      3.9281      3.9618 I    3.9204
 G'            0.5382431E-01  **
 G''           0.7652846E-04
 G'''          0.6327767E-03
-------------------------
            0.5453360E-01

AVERAGE RESPONSE TO G IS    0.0259(+-)     0.0064
 B'            0.1941341E-03
 B''           0.7438756E-02
 B'''          0.6328086E-03
-------------------------
            0.8265728E-02

AVERAGE RESPONSE TO B IS   -0.0015(+-)     0.0064
 G'B'          0.9456854E-02
 G'B''         0.1665084E-02
 G'B'''        0.4657751E-02
 G''B'         0.3445082E-02
 G''B''        0.4515325E-03
 G''B'''       0.1757888E-02
 G'''B'        0.1660761E-02
 G'''B''       0.2628657E-03
 G'''B'''      0.9554799E-02
-------------------------
            0.3291255E-01
    S.E. OF A MEAN IN BODY OF TABLE =     0.0289
                       LSD (.05) =     0.0845
                       LSD (.01) =     0.1146
```

TABLE 2 Statistical analysis of a randomized block design with seven treatments and four replications

***** LIME EFFECTS ON SUNFLOWER GROWTH IN POTS *****

..... PH KCL .....

TREAT	BLOCK 1	2	3	4
1	3.70	3.68	3.68	3.70
2	3.91	3.93	3.96	3.96
3	4.25	4.28	4.25	4.28
4	4.89	4.85	4.79	4.78
5	5.70	5.42	5.55	5.65
6	6.25	6.25	6.28	6.15
7	6.96	7.14	6.92	6.90

ANALYSIS OF VARIANCE

SOURCE	DF	SUMS OF SQUARES	MEAN SQUARES	F
BLOCKS	3	0.5500001E-02		
TREATS	6	0.3659059E 02	0.6098432E 01	******* **
ERROR	18	0.9714990E-01	0.5397217E-02	
TOTAL	27	0.3669324E 02		

STANDARD ERROR OF A SINGLE PLOT = 0.7346575E-01 CV = 1.44 PERCENT

TREATMENT MEANS

TREAT	MEAN
7	6.9800
6	6.2325
5	5.5800
4	4.8275
3	4.2650
2	3.9400
1	3.6900
MEAN	5.0735

SE OF A SINGLE TREAT MEAN = 0.3673287E-01 LSDS (2 TREAT MEANS) = T(18DF) X 0.5194813E-01

= 0.1091 (5%)

0.1495 (1%)

TABLE 3 Simple linear regression

*** PLANT MASS VS. EXCH. AL ***

DATA

X Y

NO.OF PAIRS = 35

CORRELATION COEFFICIENT =-0.95450

VARIABILITY OF Y DUE TO X=91.107PERCENT

CORRECTED SUMS OF SQUARES AND PRODUCTS

XX = 0.5747874E 01

YY = 0.2904231E 02

XY =-0.1233236E 02

ANALYSIS OF VARIANCE

SOURCE	DF	SUMS OF SQUARES	MEAN SQUARES	F
DUE TO LIN REGN	1	0.2645972E 02		338.0988 **
DEVNS FROM REGN	33	0.2582590E 01	0.7826031E-01	
TOTAL	34	0.2904231E 02		

REGRESSION COEFFICIENT = -0.2145551E 01 STANDARD ERROR = 0.1166855E 00

REGRESSION EQUATION Y = 2.59464911+ -2.14555162X

XMEAN = 0.33482 YMEAN = 1.87625

X	OBSERVED Y	ESTIMATED Y	DIFFERENCE(O-E)	DIFF. AS A PRO
0.0040000	2.6280000	2.5860669	0.0419330	5.1496946
0.0060000	2.4690000	2.5817758	-0.1127758	4.5968699
0.0100000	2.2000000	2.5731935	-0.3731935	3.6559767
0.0100000	2.4750000	2.5731935	-0.0981935	4.6489957
0.0100000	2.4400000	2.5731935	-0.1331935	4.5236842
0.0100000	2.6150000	2.5731935	0.0418064	5.1494417
0.0100000	2.1610000	2.5731935	-0.4121935	3.5265668
0.0100000	2.2770000	2.5731935	-0.2961935	3.9412220
0.0100000	2.5730000	2.5731935	-0.0001935	4.9993079
0.0100000	2.8500000	2.5731935	0.2768064	5.9894761
0.0180000	2.5650000	2.5560291	0.0089708	5.0320672
0.0200000	2.9050000	2.5517380	0.3532619	6.2627751
0.0400000	2.0170000	2.5088270	-0.4918270	3.2419079
0.0420000	3.0630000	2.5045359	0.5584640	6.9962936
0.0440000	2.7890000	2.5002448	0.2887551	6.0321883
0.0480000	3.0120000	2.4916626	0.5203373	6.8600054
0.1400000	2.1610000	2.2942718	-0.1332718	4.5236043
0.1800000	2.1520000	2.2084498	-0.0564498	4.7962136
0.1880000	2.3920000	2.1912854	0.2007145	5.7174772
0.1900000	2.4940000	2.1869943	0.3070056	6.0974269
0.1900000	2.2440000	2.1869943	0.0570056	5.2037735
0.2060000	2.1480000	2.1526654	-0.0046654	4.9835227
0.2890000	2.2350000	1.9745846	0.2604153	5.9308843
0.4650000	1.3650000	1.5969675	-0.2319676	4.1708052
0.5480000	0.9110000	1.4188868	-0.5078868	3.1845004
0.5670000	1.5930000	1.3888491	0.2041508	5.7297607
0.5700000	1.3060000	1.3716846	-0.0656846	4.7652025
0.5900000	0.7680000	1.3287736	-0.5607736	2.9954504
0.6490000	1.0570000	1.2021861	-0.1451861	4.4810156
0.8560000	0.9310000	0.7580569	0.1729430	5.6182048
1.1160000	0.2040000	0.2002135	0.0037864	5.0135352
1.1400000	0.0370000	0.1487202	-0.1117202	4.6006431
1.1700000	0.2270000	0.0843537	0.1426462	5.5099054
1.1780000	0.1600000	0.0671893	0.0928106	5.3317624
1.1900000	0.2450000	0.0414426	0.2035573	5.7276389

TABLE 4 Multiple regression

X = PH KCL, Y = EXCH. AL (ME PERCENT), Y = A + B*X + C*X(1/2)

NO OF MULTIPLE OBSERVATIONS= 256 NO OF INDEP VARIABLES= 2

MEANS

1 0.4090624E 01
2 0.2021141E 01
3 0.4891523E 00

NORMAL EQUATIONS

1 0.2491129E 02
2 0.5979742E 01 0.1436928E 01
3 -0.1784967E 02 -0.4352626E 01 0.1779525E 02

ANALYSIS OF VARIANCE

SOURCE	DF	SUMS OF SQUARES	MEAN SQUARES	F
DUE TO X 1	1	0.1278981E 02		649.0159
DUE TO X 2	1	0.2993611E 01		376.4647
DUE TO REGN	2	0.1578342E 02	0.7891712E 01	992.4305
DEVNS FROM REGN	253	0.2011831E 01	0.7951903E-02	
TOTAL	255	0.1779525E 02		

MULTIPLE CORRELATION COEFFICIENT - R = 0.94177

PARTIAL REGRESSION COEFFS.

B 1 = 0.9856176E 01
B 2 =-0.4404534E 02

INVERSE MATRIX

1 0.3738035E 02
2 -0.1555574E 03 0.6480441E 03

T VALUES FOR TESTING REGR. COEFFS. DF = 253

T(B 1) = 18.0780
T(B 2) = 19.4027

TOTAL CORRELATION COEFFS

1 1.000000
2 0.999462 1.000000
3 -0.847773 -0.860759 1.000000

1ST ORDER PARTIAL CORRELATION COEFFS.

1 -1.000000
2 0.999166 -1.000000
3 0.750768 -0.773350 -1.000000

CONSTANT TERM IN REGR. EQUATION = 0.4919309E 02

OBSERVED Y	ESTIMATED Y	DIFFERENCE(O-E)	DIFF. AS A PROBIT
0.9500000	0.9221810	0.0278189	5.3119642
0.7750000	0.7438086	0.0311913	5.3497825
0.4600000	0.5271079	-0.0671079	4.2474446
0.8140000	0.9064837	-0.0924837	3.9628777
1.0990000	0.9380325	0.1609674	6.8051056
0.5270000	0.5156251	0.0113748	5.1275583
0.6160000	0.6495935	-0.0335935	4.6232787
0.6310000	0.7299132	-0.0989132	3.8907770
0.9560000	0.9540386	0.0019613	5.0219951
0.5900000	0.5865973	0.0034026	5.0381579
0.4500000	0.4819973	-0.0319973	4.6411789

0.4740000	0.5271079	-0.0531079	4.4044420
0.5250000	0.5504871	-0.0254871	4.7141844
0.3420000	0.3229368	0.0190631	5.2137756
0.6710000	0.8452230	-0.1742230	3.0462449
0.6410000	0.6495935	-0.0085935	4.9036312
0.8400000	0.9380325	-0.0980325	3.9006536
0.3520000	0.4082551	-0.0562551	4.3691496
0.9140000	1.0704669	-0.1564669	3.2453640
0.7060000	0.6891024	0.0168975	5.1894905
0.4110000	0.5042794	-0.0932794	3.9539550
0.3830000	0.3883826	-0.0053826	4.9396381
0.7120000	0.7161640	-0.0041640	4.9533038
0.4680000	0.5156251	-0.0476251	4.4659264
0.7730000	0.9221810	-0.1491810	3.3270684
0.5310000	0.6239699	-0.0929699	3.9574260
0.6060000	0.7720409	-0.1660409	3.1379999
0.4880000	0.5387284	-0.0507284	4.4311257
0.4290000	0.5156251	-0.0866251	4.0285765
0.6470000	0.8452230	-0.1982230	2.7771065
0.5370000	0.7161640	-0.1791640	2.9908363
0.4720000	0.5744210	-0.1024210	3.8514400
0.4620000	0.4286562	0.0333437	5.3739204
0.2240000	0.2800371	-0.0560371	4.3715936
0.5330000	0.6495935	-0.1165935	3.6925084
0.7870000	0.8155013	-0.0285013	4.6803831
0.4150000	0.5156251	-0.1006251	3.8715791
0.4030000	0.5271079	-0.1241079	3.6082409
0.5510000	0.6626194	-0.1116194	3.7482880
0.4480000	0.5387284	-0.0907284	3.9825617
0.6670000	0.8755488	-0.2085488	2.6613116
0.7200000	0.8452230	-0.1252230	3.5957359
0.2120000	0.2179102	-0.0059102	4.9337214
0.5510000	0.6495935	-0.0985935	3.8943622
0.8060000	0.9064837	-0.1004837	3.8731649
0.5310000	0.6495935	-0.1185935	3.6700802
0.6470000	0.7438086	-0.0968086	3.9143776
0.2830000	0.3141028	-0.0311028	4.6512090
0.4680000	0.5989139	-0.1309139	3.5319182
0.2910000	0.3141028	-0.0231028	4.7409218
0.8380000	0.9221810	-0.0841810	4.0559850
0.5700000	0.5989139	-0.0289139	4.6757565
0.7750000	0.8155013	-0.0405013	4.5458139
0.9240000	0.9221810	0.0018189	5.0203976
0.3360000	0.3318988	0.0041011	5.0459911
0.5090000	0.5744210	-0.0654210	4.2663617
0.3050000	0.3053964	-0.0003964	4.9955543
0.6310000	0.6626194	-0.0316194	4.6454160
0.6430000	0.6495935	-0.0065935	4.9260594
0.7530000	0.7299132	0.0230867	5.2588973
0.3280000	0.4082551	-0.0802551	4.1000112
0.5530000	0.6239699	-0.0709699	4.2041362
0.6410000	0.7720409	-0.1310409	3.5304934
0.8300000	0.7161640	0.1138359	6.2765677
0.6620000	0.5504871	0.1115128	6.2505161
0.4750000	0.4183893	0.0566106	5.6348371
0.8160000	0.6757889	0.1402110	6.5723409
0.9490000	0.6757889	0.2732110	8.0638162
0.4740000	0.3982530	0.0757469	5.8494342
0.5190000	0.5744210	-0.0554210	4.3785028
0.5170000	0.5156251	0.0013748	5.0154173
0.8470000	0.7025606	0.1444393	6.6197572
0.5690000	0.5271079	0.0418920	5.4697816
0.2630000	0.2402794	0.0227205	5.2547906
0.4740000	0.3595567	0.1144432	6.2833782
0.4500000	0.4082551	0.0417448	5.4681315
0.4350000	0.3690350	0.0659649	5.7397380
0.2590000	0.3053964	-0.0463964	4.4797056
0.7300000	0.6367105	0.0932894	6.0461575
0.5640000	0.5156251	0.0483748	5.5424801
0.7630000	0.6495935	0.1134064	6.2717515
0.2900000	0.2968169	-0.0068169	4.9235540
0.9920000	0.7863789	0.2056210	7.3058554
0.6870000	0.5504871	0.1365128	6.5308687
0.2900000	0.2479822	0.0420177	5.4711911
0.2750000	0.2558090	0.0191909	5.2152090
0.6640000	0.5504871	0.1135128	6.2729443
0.2440000	0.2252439	0.0187560	5.2103324
0.7940000	0.7025606	0.0914393	6.0254099
0.3710000	0.3690350	0.0019649	5.0220356
[illegible]	[illegible]		

0.3670000	0.4082551	-0.0412551	4.5373611
0.4830000	0.5156251	-0.0326251	4.6341379
0.6030000	0.7578510	-0.1548510	3.2634846
0.5240000	0.6367105	-0.1127105	3.7360528
0.4840000	0.4710598	0.0129401	5.1451120
0.3850000	0.4183893	-0.0333893	4.6255681
0.1350000	0.1115996	0.0234003	5.2624141
0.3790000	0.4183893	-0.0393893	4.5582635
0.7840000	0.6626194	0.1213805	6.3611734
0.3200000	0.3982530	-0.0782530	4.1224627
0.4510000	0.5271079	-0.0761079	4.1465177
0.5200000	0.5989139	-0.0789139	4.1150515
0.3350000	0.3883826	-0.0533826	4.4013613
0.7300000	0.7863789	-0.0563789	4.3677611
0.7580000	0.7578510	0.0001489	5.0016701
0.1590000	0.2327001	-0.0737001	4.1735195
0.6210000	0.6495935	-0.0285935	4.6793492
0.8590000	0.7863789	0.0726210	5.8143800
0.4550000	0.5865973	-0.1315973	3.5242543
0.6450000	0.6626194	-0.0176194	4.8024134
0.3000000	0.3409891	-0.0409891	4.5403439
0.4090000	0.4183893	-0.0093893	4.8947065
0.3220000	0.3595567	-0.0375567	4.5788350
0.7820000	0.7578510	0.0241489	5.2708085
0.3970000	0.4183893	-0.0213893	4.7601373
0.5840000	0.5504871	0.0335128	5.3758163
0.8280000	0.7438086	0.0841913	5.9441298
0.4600000	0.5156251	-0.0556251	4.3762136
0.3830000	0.3982530	-0.0152530	4.8289510
0.1950000	0.2402794	-0.0452794	4.4922318
0.4860000	0.5271079	-0.0411079	4.5390112
0.4250000	0.4390562	-0.0140562	4.8423721
0.4330000	0.4710598	-0.0380598	4.5731929
0.2260000	0.2402794	-0.0142794	4.8398689
0.3970000	0.4390562	-0.0420562	4.5283773
0.5560000	0.6367105	-0.0807105	4.0949040
1.0520000	0.9064837	0.1455162	6.6318336
0.7520000	0.7161640	0.0358359	5.4018679
0.2660000	0.2036092	0.0623907	5.6996563
0.9280000	0.9221810	0.0058189	5.0652540
1.2560000	0.9540386	0.3019613	8.3862252
0.4000000	0.3502082	0.0497917	5.5583693
0.4740000	0.4930703	-0.0190703	4.7861436
0.6320000	0.6495935	-0.0175935	4.8027043
1.1020000	0.9064837	0.1955162	7.1925386
0.5120000	0.4082551	0.1037448	6.1634057
0.1680000	0.1013215	0.0666784	5.7477391
0.3400000	0.3502082	-0.0102082	4.8855232
0.3800000	0.3883826	-0.0083826	4.9059958
0.3300000	0.3053964	0.0246035	5.2759068
0.1140000	0.0153260	0.0986739	6.1065392
0.8960000	0.7863789	0.1096210	6.2293018
0.3640000	0.3690350	-0.0050350	4.9435369
0.8040000	0.7863789	0.0176210	5.1976045
0.1460000	0.1699732	-0.0239732	4.7311615
1.1000000	0.8008655	0.2991344	8.3545240
0.6680000	0.5504871	0.1175128	6.3178007
0.1720000	0.1830668	-0.0110668	4.8758952
0.1400000	0.1064031	0.0335968	5.3767588
0.4640000	0.4602575	0.0037424	5.0419677
0.2040000	0.2327001	-0.0287001	4.6781540
0.8300000	0.7161640	0.1138359	6.2765677
0.3080000	0.2637600	0.0442399	5.4961108
0.4380000	0.4286562	0.0093437	5.1047820
0.3040000	0.2800371	0.0239628	5.2687216
0.2780000	0.2968169	-0.0188169	4.7889848
0.6500000	0.6495935	0.0004064	5.0045581
0.3720000	0.4183893	-0.0463893	4.4797848
0.3300000	0.4082551	-0.0782551	4.1224394
0.1580000	0.1452145	0.0127854	5.1433772
0.1440000	0.1223391	0.0216608	5.2429071
0.3520000	0.3318988	0.0201011	5.2254167
0.8000000	0.7299132	0.0700867	5.7859600
0.1340000	0.1169114	0.0170885	5.1916331
0.2240000	0.2179102	0.0060897	5.0682906
0.4200000	0.4286562	-0.0086562	4.9029282
0.3560000	0.3883826	-0.0323826	4.6368574
0.7160000	0.7863789	-0.0703789	4.2107637
0.7200000	0.7863789	-0.0663789	4.2556201
0.0780000	0.0290886	0.0489113	5.5484965
0.5160000	0.5042794	0.0117205	5.1314356
0.8440000	0.7578510	0.0861489	5.9660828
0.3800000	0.4183893	-0.0383893	4.5694976
0.6460000	0.5623845	0.0836154	5.9376721

0.1500000	0.0821375	0.0678624	5.7610166
0.8840000	0.9064837	-0.0224837	4.7478647
0.3640000	0.4183893	-0.0543893	4.3900720
0.6920000	0.7720409	-0.0800409	4.1024125
0.8780000	0.8155013	0.0624986	5.7008663
0.1680000	0.1830668	-0.0150668	4.8310388
0.2800000	0.3318988	-0.0518988	4.4180015
0.1560000	0.1335430	0.0224569	5.2518346
0.5040000	0.5387284	-0.0347284	4.6105513
0.4180000	0.4819973	-0.0639973	4.2823277
0.4960000	0.5271079	-0.0311079	4.6511522
0.1560000	0.1636056	-0.0076056	4.9147090
0.4480000	0.5504871	-0.1024871	3.8506986
0.5600000	0.6891024	-0.1291024	3.5522319
1.0130000	0.7863789	0.2266210	7.5413515
0.5510000	0.5387284	0.0122715	5.1376141
0.2460000	0.2718360	-0.0258360	4.7102720
0.7890000	0.7578510	0.0311489	5.3493073
1.1180000	0.7161640	0.4018359	9.5062287
0.1030000	0.0915018	0.0114981	5.1289409
0.5250000	0.5042794	0.0207205	5.2323625
0.4660000	0.4930703	-0.0270703	4.6964308
0.8780000	0.7161640	0.1618359	6.8148445
0.2930000	0.3229368	-0.0299368	4.6642846
0.1710000	0.1064031	0.0645968	5.7243959
0.2260000	0.2479822	-0.0219822	4.7534886
0.1610000	0.1636056	-0.0026056	4.9707795
0.0830000	0.0290886	0.0539113	5.6045670
0.0420000	0.1112712	-0.0692712	4.2231857
0.8310000	0.6757889	0.1552110	6.7405524
0.2400000	0.2402794	-0.0002794	4.9968663
0.7580000	0.7299132	0.0280867	5.3149678
0.0770000	0.0606990	0.0163009	5.1828005
1.2120000	0.8008655	0.4111344	9.6105032
0.5410000	0.4819973	0.0590026	5.6616620
0.0400000	-0.0135411	0.0535411	5.6004153
0.0420000	0.0127437	0.0292562	5.3280829
0.4200000	0.4082551	0.0117448	5.1317084
0.0750000	0.0062326	0.0687673	5.7711636
0.8390000	0.6757889	0.1632110	6.8302652
0.2000000	0.1699732	0.0300267	5.3367229
0.3430000	0.4183893	-0.0753893	4.1545759
0.1630000	0.1699732	-0.0069732	4.9218012
0.1980000	0.1830668	0.0149331	5.1674619
0.6760000	0.6626194	0.0133805	5.1500505
0.3470000	0.4390562	-0.0920562	3.9676723
0.1390000	0.1115996	0.0274003	5.3072705
0.0630000	0.0042226	0.0587773	5.6591346
0.0400000	0.1685333	-0.1285333	3.5586137
0.2380000	0.2402794	-0.0022794	4.9744381
0.8070000	0.6757889	0.1312110	6.4714140
0.0910000	0.0261214	0.0648785	5.7275547
0.1070000	0.0647627	0.0422372	5.4736525
0.4520000	0.5042794	-0.0522794	4.4137331
0.2220000	0.2479822	-0.0259822	4.7086322
0.7340000	0.7720409	-0.0380409	4.5734048
0.8330000	0.7025606	0.1304393	6.4627598
0.0280000	0.0681468	-0.0401468	4.5497894
0.4780000	0.4183893	0.0596106	5.6684794
0.8450000	0.7299132	0.1150867	6.2905945
0.2420000	0.2479822	-0.0059822	4.9329143
0.5510000	0.5387284	0.0122715	5.1376141
0.1290000	0.1278827	0.0011172	5.0125293
0.2060000	0.2800371	-0.0740371	4.1697397
0.0420000	-0.0052418	0.0472418	5.5297750
0.8670000	0.8302869	0.0367130	5.4117034
0.2140000	0.2402794	-0.0262794	4.7052997
0.6780000	0.7025606	-0.0245606	4.7245742
0.7730000	0.7161640	0.0568359	5.6373640
0.0560000	-0.0091937	0.0651937	5.7310889
0.1230000	0.1393201	-0.0163201	4.8169843
0.0770000	0.0606990	0.0163009	5.1828005
0.3890000	0.4390562	-0.0500562	4.4386645
0.1780000	0.2327001	-0.0547001	4.3865874
0.4660000	0.4602575	0.0057424	5.0643959
0.1370000	0.1636056	-0.0266056	4.7016411
0.3490000	0.4710598	-0.1220598	3.6312084
0.6070000	0.7578510	-0.1508510	3.3083410