NUTRITIONAL STUDIES WITH A SPANISH - TYPE GROUNDNUT ON AN AVALON MEDIUM SANDY LOAM SOIL

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ABSTRACT

Calcium requirements of a Spanish-type groundnut cultivar on an Avalon medium sandy loam soil

The effect of different levels of application of agricultural lime, dolomitic lime and gypsum on yield and quality of the Nelson Spanish groundnut cultivar was studied in a field experiment. The effect of the applied treatments was studied by means of detailed soil and plant analyses. The results reported were obtained in a season with below normal rainfall. The so-called "typical drought damage" symptoms were found to be largely due to nutritional deficiency conditions.

A linear increase in kernel yield was obtained as a result of increased levels of exchangeable calcium in the soil. Calcium uptake by the fruit proceeded more efficiently where gypsum was used as calcium carrier. The calcium content of the fruit was increased as a result of increases in the level of exchangeable calcium in the soil. The gypsum treatments resulted in a marked increase in shelling percentage, percentage ovarian cavities filled and increased kernel yield. The mechanism of action of the gypsum treatments was not solely improved cal= cium nutritional conditions. A poor correlation between calcium content of the soil and the groundnut fruit, and shelling percentage and percentage ovarian cavities filled was obtained in the case of agricultural lime and dolomitic lime treatments.

The level of exchangeable soil calcium and soil pH on the majority of groundnut fields investigated was found to be low enough to expect considerable increases in yield following on applications of agricultural lime. Such an increase in pH would result in an improved nitrogen status of the plants as a result of more efficient nitrogen fixation.

Applications of agricultural lime should be supplemented with a supply of calcium in a more soluble form, such as gypsum. The more soluble calcium carrier would provide a supply of readily available calcium for uptake over periods of moisture stress.

The relationship between chemical composition of the soil and plant, and yield and quality factors were studied.

The occurrence, cause and control of hollow heart and black plumule damage in groundnut kernels

Hollow heart and black plumule are symptoms of nutritional abnormalities in groundnut kernels. Although the occurrence of these symptoms are associated with the occurrence of drought conditions, the calcium and boron status of the Avalon medium sandy loam is low enough to result in the occurrence of these symptoms on a small scale under normal rainfall conditions. The supply of available boron in the soil is decreased as a result of fixation into an unavailable form during dry periods. Decreased boron concentrations in the plant under these conditions results in the occurrence of boron deficiency symptoms in the kernels (hollow heart damage). At the same time, it is suggested, that due to the nutritional association between calcium and boron in the plant, the decreased levels of boron in the plant results in a decreased metabolic activity of calcium indicated by the occurrence of black plumule damage (a calcium deficiency symptom).

The critical level of boron in the kernel as far as both hollow heart and black plumule damage is concerned, appears to be between 10,2 and 13,9 ppm.

Applications of gypsum resulted in a marked decrease in hollow heart and black plumule damage. This treatment resulted not only in increased levels of calcium in the kernel, but at the same time appears to prevent the fixation of boron thus allowing normal uptake of boron by the plant. Applications of agricultural and dolomitic lime had no effect on the occurrence of either form of damage. These treatments were associated with a marked increase in calcium content and a decrease in boron content of the kernels. The ratio

$$\frac{\text{Ca content of the kernel (ppm)}}{\text{K content x Mg content of the kernel}}$$

was found to be fairly closely correlated with the occurrence of black plumule damage. The calcium, potassium and magnesium status of the soil was of little value for the purpose of predicting hollow heart damage. The intensity of hollow heart and black plumule damage was increased by applications of urea. Cultivars differed in their susceptibility to hollow heart and black plumule damage.

An application of 26 kg/ha borax virtually eliminated both forms of damage.

CHAPTER I

INTRODUCTION

Approximately 80% of the groundnut crop in Natal is produced on the sandy, hydromorphic soils of Northern Natal. These soils occur in areas climatically suited to crop production, and high yields can be obtained. During summer, rain= fall in these areas is generally adequate and well distributed, and temperatures are high. The physical characteristics of these soils provide favourable moisture storage conditions. Rainfall is readily absorbed by the sandy topsoil and is prevented from draining away by hardpans or clay layers at depths of between 50 and 100 cm.

The area of these soils available for cash crop production at any one site is, however, limited, largely because of the undulating nature of the topography and a serious soil erosion hazard. It is therefore necessary that the limited area of land available for cash crop production should be utilized to the best possible advantage, and so the attainment of high yields per unit area is an important research objective.

Based on results obtained from an agronomic research programme in progress since 1962, an intensive production system for groundnuts has been developed in Natal. With high plant population densities, herbicides and control of leafspot diseases, kernel yields of up to 3000 kg/ha have been obtained under dryland conditions. Such high yields would obviously make greater demands on the plant nutrient supplying capacity of the soil. Nutritional studies with groundnuts were therefore undertaken on various sites through-out Natal.

Consistent with results obtained from most groundnut producing areas of the world, yield and quality responses were obtained after applications of calcium-bearing materials such as super-phosphate, calcitic- and dolomitic lime. The level of response varied considerably from season to season. The mechanism of calcium uptake by the groundnut fruit is known to be dependent on moisture conditions in the topsoil (the zone of fruit formation). A variable plant response, depending on intensity and distribution of rainfall could therefore be expected.

In order to obtain a better understanding of the influence of nutrient calcium on ground=nut yield and quality, a field experiment in which these aspects were examined was commenced on the Dundee Research Station in Northern Natal in 1967. This research station is centrally situated in relation to the most important groundnut producing area in Natal.

An intensive study was undertaken to determine how calcium bearing materials affect groundnut kernel yield and quality. Using comprehensive plant and soil ana=lysis an attempt was made to explain variations in yield and quality.

Internal damage ("hollow heart" and "black plumule") was observed in groundnut kernels on a number of experiments on the Dundee Research Station, over the 1967/68 season. The occurrence of these deficiency conditions has been reported to be closely associated with drought conditions, and these symptoms are generally regarded as typical of "drought damage". Observations on the pattern of occurrence of both these forms of internal damage were made on all groundnut experiments planted.

The work reported in this thesis is largely based on results obtained over the 1968/69 season. This was a season with an abnormally low rainfall over the latter half of the growing season, and provided conditions under which significant responses to applications of especially gypsum are obtained. By concentrating on results obtained over a season with critical conditions, an attempt is made to obtain a better under=standing of the factors determining responses in a season with below normal rain=fall.

CHAPTER II

CALCIUM REQUIREMENTS OF A SPANISH-TYPE GROUNDNUT CULTIVAR ON AN AVALON MEDIUM SANDY LOAM SOIL

The majority of research reports dealing with the calcium requirements of ground= nuts are devoted to a study of response of large-seeded cultivars. Various workers have reported on the pronounced differences between groundnut cultivars in their calcium requirements (Gore, 1941; West, 1942; Sellschop, 1962). Experimental data under South-African conditions are not available on the response of small-seeded "Spanish-type" groundnuts to variable levels of soil calcium. Virtually the whole of the groundnut crop in Natal consists of these small-seeded types, mainly a Spanish-type cultivar "Natal Common".

EXPERIMENTAL PROCEDURE

Data reported in this chapter were obtained from field experiments planted on the Dundee Agricultural Research Station in Northern Natal.

Soil type - Avalon medium sandy loam

Two or more soils of the Avalon and Glencoe forms, as described by van der Eyk, MacVicar & de Villiers (1969) are regularly associated in the Northern Natal land= scape and are dominant constituents of five E mapping associations. Sandy variants of the Avalon and closely related series occur largely in the Northern portion of the Tugela Basin, and are suitable for groundnut production. It is anticipated that the Avalon medium sandy loam soil will be representative of almost 200 000 ha in the Tugela Basin. Moreover, very similar sandy soils are known to occur extensively in other parts of Natal and the most important cropping areas of the Transvaal and Orange Free State.

These soils developed on drift material originating from Karoo sandstone (Ecca) and are usually deep to moderately deep. The topsoils are well drained and these soils are generally moderately leached, yellowish-brown to grey-brown in colour. Iron and manganese oxide accumulations are a characteristic feature and these may occur as mottles, concretions or hardpans, resulting from active hydromorphism in the subsoils.

The surface horizons have a single grain or, at best, weakly developed structures and a very low organic matter content. Structure becomes stronger, consistence firmer and clay content, pH and exchangeable calcium all increase with depth. The predominate clay minerals are kaolinite and illite with some muscovite.

For reference purposes physical properties of a profile representative of the particular Avalon medium sandy loam used in these investigations are presented in Table 1.

TABLE 1. Selected physical and chemical characteristics of six soil horizons of an Avalon medium sandy loam (Farina, 1971)

	Horizon (cm)					
	0 - 15	15 - 30	30 - 45	45 - 60	60 - 75	75 - 90
	Particle size distribution % (Hydrometer)					
coarse sand	12	12	12	9	7	6
medium sand	27	24	27	18	12	11
fine sand	43	45	31	33	30	28
silt	4	4	6	6	8	8
clay	14	15	24	34	42	46
	Extractable cations in me% soil (N NH_4OAc pH 7)					
Na	,02	,02	,03	,12	,28	,34
K	,16	,15	,14	,12	,36	,58
Ca	,56	,63	,69	,69	,94	1,40
Mg	,22	,26	,81	1,87	4,19	4,56
* S value (me%)	,96	1,06	1,67	2,80	5,77	6,88
** C. E. C (me%)	1,61	1,70	3,24	4,58	8,43	9,00
% Base saturation	59,5	62,5	51,5	61,0	68,5	76,5
pH, N KCl (1:2)	3,9	3,9	3,9	4,0	4,5	4,9
pH, H_2O (1:2)	4,9	4,7	4,6	5,0	6,1	6,4

* Sum of metal cations

** Cation exchange capacity

Treatments

Five rates of application of three different calcium carriers were applied annually in all possible combinations in a field experiment.

The three calcium carriers were agricultural lime, dolomitic lime and gypsum, and are referred to in the text as AL, DL and G respectively. Each of the carriers was applied at five different levels, 0, 1, 2, 3 and 4. The rates of application for the three different calcium carriers are given in Table 2.

TABLE 2. Amounts of three calcium carriers applied at five treatment levels

Calcium carrier	Treatment code	Level of application					
		0	1	2	3	4	
Agricultural lime	AL	0	265	530	795	1060	kg/ha $CaCO_3$
Dolomitic lime	DL	0	132	264	396	528	kg/ha $CaCO_3$
		0	132	264	396	528	kg/ha $MgCO_3$
Gypsum	G	0	530	1060	1590	2120	kg/ha $CaSO_4$

Note: The code AL 0 and AL 4 would refer to respectively the lowest and highest level of application of Agricultural Lime.

These levels of application were chosen for the following two reasons:

(a) To obtain a range of more or less regularly spaced levels of base saturation, viz. 30, 40, 50, 60 and 70% with the application levels 0, 1, 2, 3 and 4 respectively. This objective was obtained only in the first year (1967/68) of the experiment owing to carry-over from year to year and unfavourable soil moisture conditions.

(b) To obtain variable Ca : Mg ratios in the soil. This objective was obtained, as evident from soil analyses data presented later in the text.

Design

The 15 treatment combinations were replicated four times in a randomised blocks design consisting of 60 plots. The gross plot size was 11 m x 4,572 m and consisted of six planted rows 76,2 cm apart. Borders of 1 m were discarded at each end and four rows were harvested so that the nett plot size was 27,432 m^2.

Cultivar

An improved Spanish-type cultivar "Nelson Spanish" was planted. It is similar to the locally grown Natal Common in terms of growth habit, length of growing season and yield potential, but produces a higher percentage of extra large kernels suitable for the confectionary trade. It has a wide range of regional adaptability and gives fair yields under a wide range of soil fertility conditions. This cultivar belongs to the sequentially branched group (Bunting, 1955).

Cultural methods

The seed was treated with a copper-sulphur base seed protectant. The experiment was hand planted with seeds 8 cm apart in the rows. Since well nodulated groundnuts had been grown on the experimental area in the past, neither seed nor soil was treated with nitrogen-fixing bacteria. The experiment was kept weed-free through regular hand cultivation. All plots were sprayed regularly with a fungicide to protect the experiment from leafspot diseases.

A basal fertilizer dressing consisting of 160 kg/ha double superphosphate (19,6% P, 2,6% S, 20% CaO and 0,6% MgO) and 80 kg/ha potassium chloride (50% K) was applied to all plots. The basal fertilizer dressing, together with the calcium treatments, was applied broadcast over the plots immediately after the first spring rains and worked into the soil with a disc-plough to a depth of approximately 26 cm. The treatments were usually applied at least one month before planting time.

Harvesting technique

The experiment was harvested not earlier than 140 days after planting. The plants were lifted with digging forks, stacked on tripods and left to cure for a period of at least 30 days. After lifting the plants, the plots were dug-up with digging forks in order to recover any pods that had been separated from the plants and left in the soil. These pods were added to the total plot yield. The pods were removed from the plants by hand. Samples for grading determinations were obtained from the total plot yield immediately after picking (before the material was winnowed), foreign material being removed by hand in order to retain unfilled pods.

Samples for chemical analysis

Soil

Prior to harvesting (towards the end of March) soil samples were collected with a Beater soil sampler from the surface 15 cm of each plot. Thirty cores per plot were taken at random except for the restriction that 10 be about 10 cm away from the plants, 10 quarterway between the rows and 10 halfway between the rows. These soil samples were air-dried and then ground to 2 mm.

Plant material

(a) Vegetative tissues. Two months after the appearance of the first flowers, samples of the apical 10 cm of main stem together with leaves were collected for chemical analysis. Forty such samples were taken at random from the four centre rows of each plot. The plant material obtained was bulked, washed in dis= tilled water, oven-dried to constant weight at 90^{o}C and milled.

(b) Shells. A random sample of 500 g clean pods was obtained from each plot after harvesting, and hand-shelled. These shells were washed in distilled water, oven-dried to constant weight and milled.

(c) Kernels. The kernels obtained from the above 500 g sample of pods were ground-up in a stainless steel sample mill, and the milled material kept in polythene bags at a low temperature.

Analytical methods

Soil

Soil pH was measured in water and in a N KCl solution (a 1 : 2 dilution being used in both cases), giving measures of actual and potential acidity respectively. Exchangea= ble calcium, potassium and magnesium in the soil were extracted by shaking with neutral N NH_4OAc for 30 minutes (using a 1 : 25 soil to solution ratio) and deter= mined flame spectrophotometrically. Available boron was extracted from the soil by refluxing with hot water according to the method of Berger and Truog (1944). Boron was then determined by the method of Dible, Truog & Berger (1954), with mi= nor modifications to cope with the large number of analyses required.

Plant material

Extracts were prepared by ashing 2 g samples of vegetative tissues, shells and kernels at $450^{o}C$ and dissolution in 1 : 4 HCl. Potassium, calcium and magnesium were measured flame spectrophotometrically, phosphate was determined by the phosphomolybdovanadate method and nitrogen content by the Kjeldahl procedure.

The total boron content of the kernels was determined by ashing 2 g kernels in the presence of saturated $Ca(OH)_2$ solution at a temperature of $450^{o}C$. The ashed material was taken up in 20 ml $\frac{N}{10}$ HCl and the total boron content determined ac= cording to the method of Dible *et al.* (1954).

Results obtained from all the above analyses are presented on a dry-matter basis.

Quality determinations

Shelling percentage. A 500 g sample of pods was collected from each plot. After foreign material had been removed from the sample by hand, a 400 g subsample was handshelled and the shelling percentage determined by weight.

Kernel size distribution. Kernels obtained from the shelling percentage deter= mination were graded for size by means of a set of standard groundnut grading screens.

Kernels riding a 20 x 7,50 mm slotted screen were termed Extra Large Kernels (ELK).

Kernels passing through the above screen but riding a 20 x 6,75 mm slotted grading screen were termed Large Kernels (LK).

Kernels passing both the above screens but riding a 20 x 6,00 mm screen were termed Medium Sized Kernels (MK).

Each of the above fractions were weighed and expressed as a percentage of the total weight of the original sample of kernels. The results are reported as % ELK, % LK and % MK.

Statistical treatment of data

Results were analysed using the appropriate analysis of variance for the experimental design used. Data was transformed where necessary, but untransformed data is pre= sented in the text. Minimum differences required for statistical significance at the 0,5 and 0,1 per cent levels are indicated by two labelled vertical lines on all graphs.

Climatic data

A daily rainfall record for the 1968/69 season is given in Table 3. It will be noted that with the exception of March 1969, rainfall over the whole of the growing season was well below the 25-year mean. Of particular importance was the very low rainfall over the period December 25, 1968 up to January 26, 1969.

Temperatures were within the normal range.

TABLE 3. Daily rainfall data, Dundee research station from 1st November 1968 to 31st March, 1969

Date within month	Month				
	November 1968	December	January 1969	February	March
	mm	mm	mm	mm	mm
1					15
2		1			14
3		20		20	
4		25	(50)*	(81)*	(110)*
5		5			14
6		8	15	8	
7		21			11
8	19			21	
9	22			5	5
10				5	14
11					27
12	1				2
13				(90)*	1
14	2	5	(60)*		(120)*
15	17 (a)	(30)*			
16			11		
17	2	(b)	10	6	
18	10				
19					
20	4			2	
21					
22					
23	1			(100)*	
24		27	(70)*		
25		(40)*			
26	1			20	7
27		2	65	3	18
28			6		2
29		2			9
30					6
31					(c)
Total	79	116	107	90	145
25-year mean	114	138	139	122	106

(a) Planting date
(b) Harvesting
(b) Appearance of first flowers
* Number of days after planting are given in brackets

EFFECT OF CALCIUM CARRIER ON CHEMICAL CHARACTERISTICS OF AN AVALON MEDIUM SANDY LOAM SOIL

Soil pH

pH (H_2O) Fig. 1

The mean of pH readings of the soil on untreated plots was 4,9 at the end of the 1968/69 season, and no significant change in this figure was observed in subsequent years of the experiment. As might be expected the gypsum treatments had very little effect on pH which remained practically unchanged at 4,9 even at the highest level of gypsum application. The AL and DL treatments resulted in a highly significant linear increase in pH reading as illustrated in Fig. 1. There was no significant difference in soil pH between the AL and DL treated plots. The maximum pH at= tained on this experiment was 6,2.

pH (N KCl) Fig. 2

Soil pH on untreated plots was 3,9 by this method. The general response pattern to applied treatments was the same as in the case of pH measured in water, except in the case of gypsum treatments where a relatively small but significant increase in pH was obtained. In general the change in pH as measured by this method was of greater magnitude than when measured in water. The highest pH attained on gyp= sum-treated plots was 4,3 as against the 5,4 in the case of both the AL and DL treatments.

Discussion

The ideal pH (measured in water) for an agricultural soil is generally stated to be between 6 and 7 (Ignatieff, 1952), with a lower limit of pH acceptable for most crops on tropical soils given as 5,5. The optimum pH range for groundnuts is general=

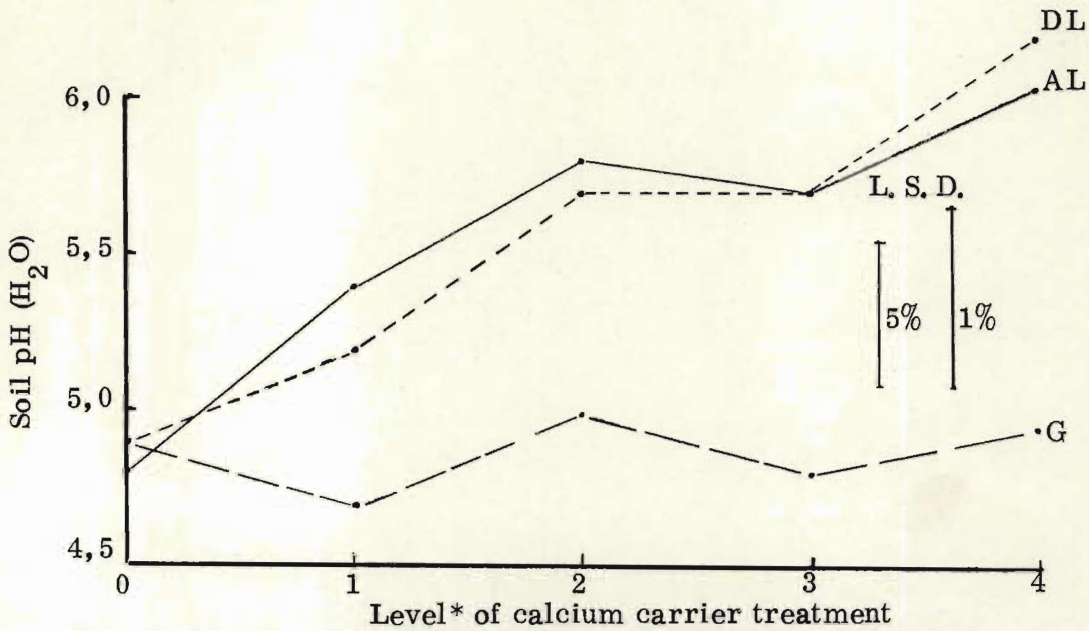

Fig. 1. Effect of calcium carrier treatments on soil pH (H_2O)

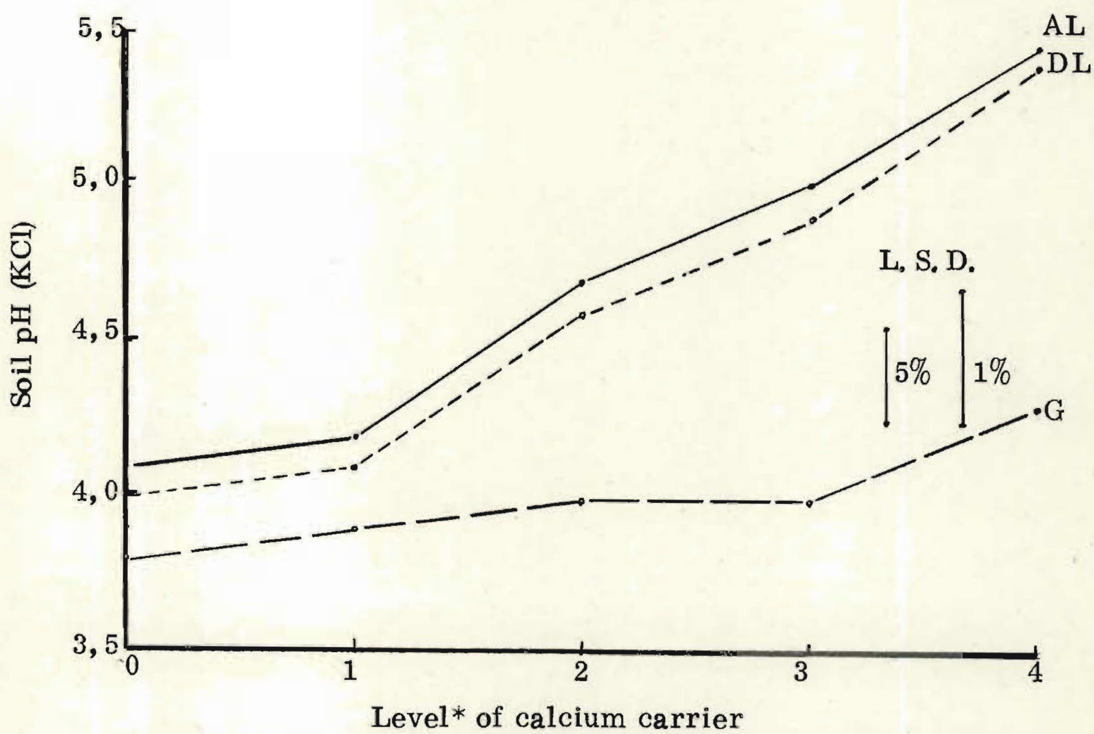

Fig. 2. Effect of calcium carrier treatments on soil pH (N KCl)

* Refer Table 2 (p. 9) for details

ly given as between 5,8 and 6,2 (Perry, 1963). There is considerable evidence, however, that groundnuts will make satisfactory growth on relatively acid soils, provided the calcium requirements of the plant are satisfied (Harris, 1959). In contrast to cotton plants which grew poorly on very acid soils, with virtually no roots in very acid subsoil material, groundnuts were found to grow equally well on the most acid and least acid subsoils of a field experiment conducted by Adams and Pearson (1970). Excavation of the soil profile in these experiments revealed the presence of numerous groundnut roots throughout the most acid subsoil to a depth of at least 90 cm. Nutrient solution experiments showed that cotton roots created a more acid environment than did groundnuts (Adams and Pearson, 1970). It was also found that groundnuts had a greater propensity for preferential absorption of lower valency ions to the exclusion of higher valency ions. Either or both these phenomena could explain the greater tolerance of groundnuts to a low soil pH and high aluminium content of the soil solution.

With the exception of molybdenum, no problems in connection with the availability of trace elements should be expected over the pH range found in this experiment. Since the availability of molybdenum is best at a pH above 5,5 and falls very rapidly with increasing acidity (Truog, 1951), molybdenum availability might be unfavourable on all untreated and gypsum-treated plots (Fig. 1).

Decreased groundnut yields as a result of manganese toxicity on very acid soils have been reported (Ollagnier & Prevot, 1955; Gillier & Silvestre, 1969). Mottled spots and concretions caused by manganese oxide in the soil on which this experiment was planted, raises the suspicion of manganese toxicity conditions at the low pH levels.

Soil pH data obtained from 100 randomly selected groundnut fields throughout Northern Natal are set out in Table 4. On the basis of data set out in this table unfavourable molybdenum availability would be expected on the majority of fields. It is evident that soil pH experienced under production conditions are within the range experienced in the experiment reported on. It is of interest to note that only about 15 per cent of the fields sampled are within the optimum pH range suggested for groundnuts.

TABLE 4. Soil pH (H_2O) on 100 randomly selected groundnut fields in Northern Natal, 1968/69

	Soil pH	Number of fields
	4,3	1
	4,4	
	4,5	
	4,6	2
	4,7	2
	4,8	4
	4,9	4
	5,0	11
	5,1	13
	5,2	9
	5,3	10
	5,4	10
	5,5	1
	5,6	3
	5,7	2
	5,8	2
	5,9	5
	6,0	4
	6,1	1
	6,2	3
	6,3	3
	6,4	1
Above	6,4	9

Soil phosphate

Considerable variation in phosphate status of the soil was observed over the plots of the experiment. The mean phosphate content over all plots was 6,5 ppm. It is of interest to note that optimum level of soil phosphate for maize production on the Avalon medium sandy loam, is regarded as 25 ppm (Farina, 1970). The calcium carrier treatments had no effect on the phosphate status of the soil.

Exchangeable calcium in the soil

Fig. 3

The mean exchangeable calcium content of the soil on untreated plots was

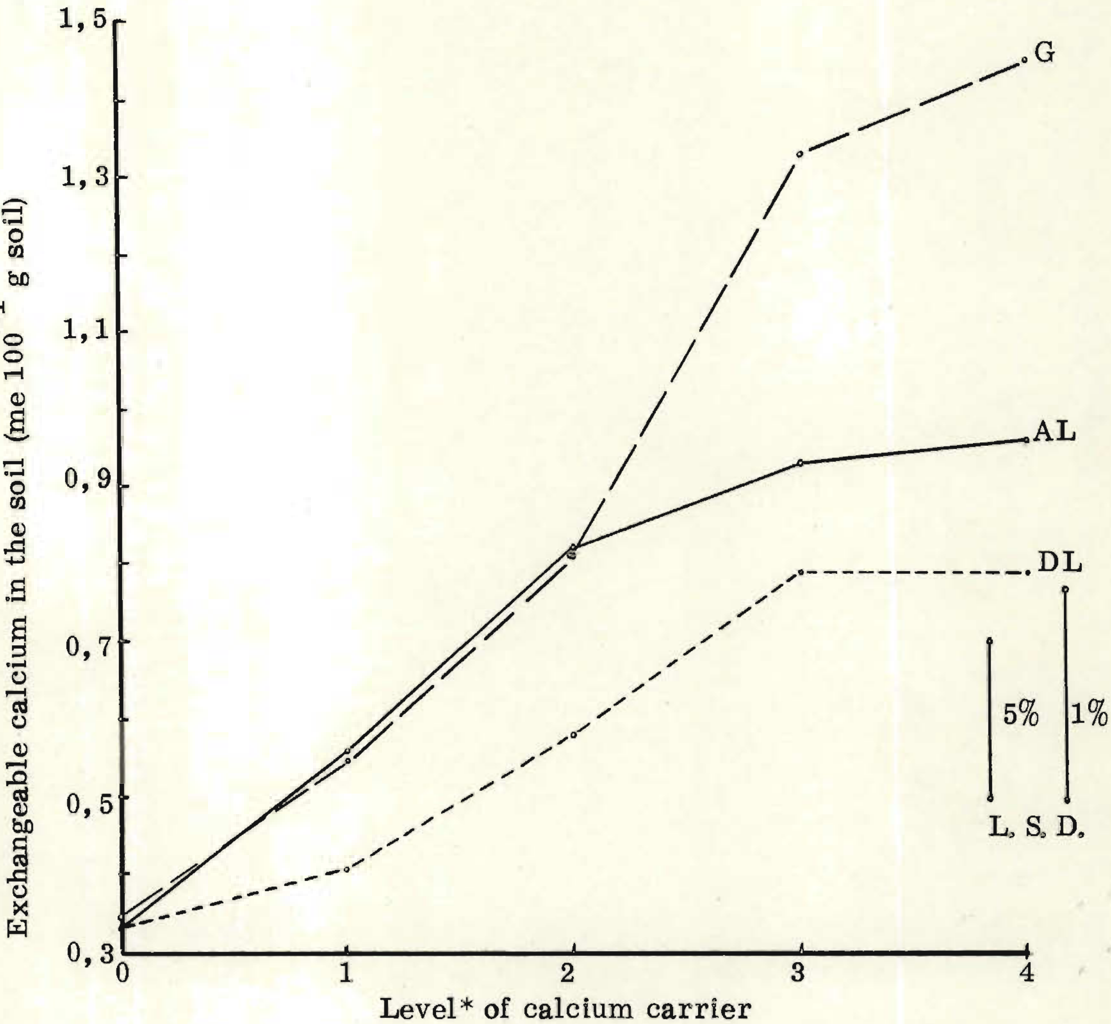

Fig. 3. Effect of calcium carrier treatment on exchangeable calcium in the soil

* Refer Table 2 (p. 9) for details

0,33 me 100^{-1} g soil, being at the same level as the majority of the groundnut producing soils of the region (see Table 5).

TABLE 5. Exchangeable calcium content of soil obtained from 100 randomly selected groundnut fields in Northern Natal, 1968/69

Exchangeable calcium me 100^{-1} g soil	Number of fields
Less than 0,200	5
0,201 - 0,400	19
0,401 - 0,600	20
0,601 - 0,800	11
0,801 - 1,000	4
1,001 - 1,200	9
1,201 - 1,400	5
1,401 - 1,600	7
1,601 - 1,800	5
1,801 - 2,000	5
More than 2,000	10

Although a highly significant increase in the exchangeable calcium content of the soil was obtained with increasing applications of the different carriers, the rate of increase differed markedly with the calcium carrier used. The exchangeable cal= cium content of the soil on DL treated plots was significantly lower than on the AL treatments. The lower calcium status of the DL treated plots could be expected in view of the fact that only half the amount of calcium was supplied in comparison with the AL treatment. A fairly consistent difference in exchangeable calcium content between the AL and DL treatments was maintained. There was no significant dif= ference in exchangeable calcium content of the soil on the AL1, DL 1 and G 1 treated plots. At higher levels of application the difference between the AL and DL treat= ments became significant at the 5 per cent level. A significantly higher exchangeable calcium status was, however, observed at the higher levels of gypsum application.

A linear increase in exchangeable calcium content of the soil was obtained in the case of the gypsum treatments.

Little information is available on the critical levels of soil calcium for groundnut production, and the available information is in most cases based on the response of large seeded types, with known high calcium requirements. Colwell & Brady (1945) reported a very close relationship between the response of groundnuts to applications of lime, and the exchangeable calcium in the soil. Lime response appeared to be more closely related to exchangeable calcium than to either percentage calcium saturation or calcium soluble in 0,1 N HCl. Colwell and Brady (1943) reported a correlation coefficient of 0,948 between the calcium content of the soil and the degree of response to gypsum by groundnuts. The critical level of exchangeable soil calcium for Spanish-type groundnuts on a Norfolk sandy loam soil in Alabama is given as between 670 and 900 kg of $CaCO_3$ equivalent per hectare (Rogers, 1948). Soils containing more than 785 kg of $CaCO_3$ equivalent per hectare showed only slight increases in yield following on lime applications.

Mehlich & Colwell (1946) and Mehlich & Reed (1947) showed that with soils containing the 1 : 1 and organic type colloids the amount of calcium in the soil was the most important criterion for calcium supply, while in the case of soils containing the 2 : 1 colloids the percentage calcium saturation was a better criterion. Strauss & Grizzard (1948) concluded that the relative amounts of nutrients in the soil exerted a far greater effect on yield than did the total amount of nutrients. In no case were they able to find a correlation between the concentration of any single nutrient and either yield factors investigated (number of nuts produced per plant and average kernel weight) or total yield.

The solubility of the calcium carrier used has to be considered when evaluating the calcium supply available to the developing fruit. Soil analysis data might not give an accurate picture of the situation if the soil samples are taken at the end of the growing season. Colwell & Brady (1945) reported that gypsum supplied as topdressing to groundnuts at an early flowering stage significantly increased fruit filling even though soil analysis showed that gypsum had been leached out of the soil before harvesting. Variable soil moisture conditions in the fruiting zone, determining the efficiency of calcium uptake by the developing fruit, makes the interpretation of soil analysis data in respect of calcium a very difficult task.

The relationship between the calcium status of the soil and various yield and quality characteristics will be discussed in Chapter II (p. 68).

Exchangeable soil potassium

The exchangeable potassium content of the soil was not affected by the level of cal= cium treatment applied but was significantly lower on gypsum-treated plots than on the AL and DL treated plots (See Table 6).

TABLE 6. Effect of calcium carrier treatment on exchangeable potassium content of the soil

Calcium carrier	Exchangeable potassium in the soil
	me 100^{-1} g soil
Agricultural lime - AL	0,13
Dolomitic lime - DL	0,13
Gypsum - G	0,11
Untreated control	0,12
L. S. D. (P = 0,05)	0,03

This observation could be explained in terms of either increased leaching on gypsum-treated plots, or a loss from the soil as a result of increased potassium uptake by higher yielding plants grown on gypsum-treated plots. Luxury or above normal uptake of potassium by the plant is decreased under conditions of favourable calcium supply, as exists on gypsum-treated plots, and it would appear that the lower potassium status of these plots must be due to leaching (Farina, 1971). The application of gypsum or other neutral calcium salts will almost invariably raise the outgo of potassium in percolating waters.

The mean exchangeable potassium content of the soil over the whole experiment was 0,12 me 100^{-1} g soil and approximately 80% of the groundnut producing soils in Northern Natal had a potassium content in the range 0,1 to 0,5 me 100^{-1} g soil.

Exchangeable soil magnesium — Fig. 4

Highly significant increases in the level of exchangeable soil magnesium were found on AL and DL treated plots. Although increasing applications of these two calcium carriers increased the difference in exchangeable magnesium content of the soil, the rate of increase in exchangeable magnesium content was maintained in both cases. The gypsum treatments had no effect on the magnesium status of the soil.

The mean exchangeable magnesium content of the untreated control plots was 0,19 me 100^{-1} g soil, being increased to a maximum of 1,59 me 100^{-1} g soil on the DL 4 plots. The majority of soils sampled in Northern Natal had an exchangeable magnesium content of between 0,1 and 0,4 me 100^{-1} g soil.

Summary of effect of calcium carrier treatments on an Avalon medium sandy loam soil

Soil pH on untreated and gypsum-treated plots is well below the optimum for legumes. On the evidence obtained from literature it would appear unlikely that aluminium toxicity is a yield limiting factor to groundnut production on these soils, even at the low pH levels experienced on this experiment. Molybdenum deficiency could be expected to occur on all untreated and gypsum-treated plots, as a result of the low pH. Manganese toxicity might also occur on these low-pH plots, especially over seasons with a normal or above-normal rainfall.

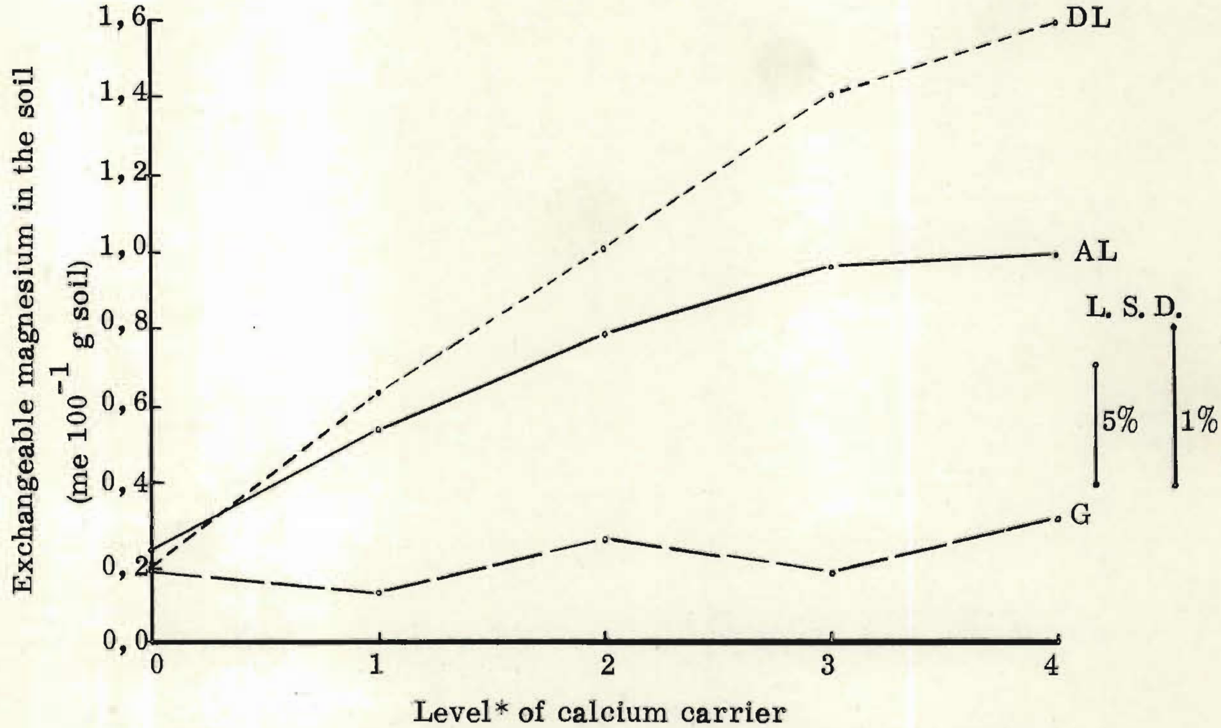

Fig. 4. Effect of calcium carrier treatment on exchangeable magnesium content of the soil

* Refer Table 2 (p. 9) for details

Even though groundnuts are very efficient phosphate "feeders", the phosphate status of the soil is probably limiting to high groundnut yields. The calcium carrier treat= ments had no effect on phosphate status of the soil. The potassium and magnesium status of the topsoil is low, but improves with increasing depth, and should there= fore not be limiting. Only gypsum had the effect of lowering the level of exchangeable potassium in the soil, while both agricultural and dolomitic lime increased the level of exchangeable magnesium in the soil.

Little information is available on optimum levels of exchangeable soil calcium for Spanish-type groundnuts, and no conclusions in this respect could be made at this stage. The determination of critical soil calcium levels for optimum fruit develop= ment is further complicated by the relation between moisture content of the topsoil and efficiency of calcium uptake by the developing fruit. The topsoil (zone of fruit formation) of the mostly sandy groundnut producing soils is very susceptible to fluctuations in soil moisture content.

CALCIUM UPTAKE AND TRANSLOCATION IN THE GROUNDNUT PLANT
A REVIEW OF LITERATURE

The groundnut (Arachis hypogaea L) is one of the few plants possessing the property of geocarpy. The plant produces above-ground flowers, the ovaries of which are lo= cated in the bottom of the calyx tube. After fertilization the ovaries develop into a gynophore which then moves downwards and penetrates about five centimeters into the ground. The geotropic control then changes and the gynophore orients horizon= tally, in which position the fruit develops.

Pettit (1895) provided the first direct evidence that the gynophores can take up water and nutrients directly from the soil solution. Burkhart and Collins (1941) demonstrated the uptake of lithium by the fruiting organs and reported that calcium in the fruiting medium had a beneficial effect on fruit quality. Their experiments were a revival of the idea of Pettit (1895), van der Wolk (1914) and Waldron (1919) that the fruiting organs actually absorbed something from the soil. Results obtained by Bledsoe and Harris (1950) showed that groundnuts did not develop fruit when only water was sup= plied to the fruiting zone, even though a complete nutrient treatment was supplied to the rooting zone. The phenomenon of calcium uptake by the gynophore and developing fruit has since been confirmed by a number of workers (Mizuno, 1965).

The essential role of calcium for fructification in the groundnut must be considered together with the fact that calcium is poorly translocated in the groundnut plant (Brady, 1948; Harris, 1949). Bledsoe, Comar & Harris (1949) confirmed limited translocation in an experiment with radio-active calcium. The Ca^{45}-ions taken up by the roots could only be found in young gynophores and not in the fruit. Mizuno (1965) observed that Ca^{45} applied to the fruiting zone could, at harvest time, be detected in all fruiting organs, being most pronounced in the shell. However, it was scarcely found anywhere in the vegetative organs of the same plant. The Ca^{45} applied to the root could be detected in all vegetative parts of the plant, especially in the leaves. No Ca^{45} was found in the fruiting organs. In this connection

Wiersum (1951) concluded that no transport of water to the developing fruit takes place via the xylem unless the fruit is brought into the open air.

Poor translocation of calcium in the groundnut is of considerable practical im= portance. From the nutritional physiology point of view, two systems exists in one plant. The gynophores and developing fruit system functions virtually independently of the root system with regard to calcium nutrition. The necessity, however, of having a balanced nutrient supply available to both these systems has been stressed by numerous workers.

It is obvious that the process of calcium uptake by the fruit would be influenced by fluctuations in the moisture status of the topsoil. An adequate supply of calcium in the rooting zone is not necessarily a guarantee of an adequate calcium supply to the developing fruit.

THE EFFECT OF CALCIUM CARRIERS ON THE CHEMICAL COMPOSITION OF THE GROUNDNUT PLANT

The objective of this facet of the study was to determine the effect of calcium carriers on the overall nutritional status of the plant, and hence to explain variations in kernel yield and quality.

Nitrogen Fig. 5

Vegetative tissue

A highly significant increase in the nitrogen content of vegetative material sampled was observed with increasing amounts of calcium applied. The trend was consistent and linear, irrespective of calcium carrier used, the only exception being a slight decrease in nitrogen content (significant at the five per cent level) as a result of the G 1 treatment. This decrease might have been due to a dilution effect as a result of a marked growth response obtained as a result of the G 1 treatment.

The nitrogen content of untreated and gypsum-treated vegetative material was well below that of the DL and AL treated material. The pale yellow colour of foliage on the control and gypsum-treated plots was strikingly visible over most of the growing season, as illustrated in Plate 1. The yellowing of the foliage was uniform over the whole plant, and was not restricted to any particular part of the foliage. By contrast a dark green leaf colour was observed on all AL and DL treated plots, even at the lowest level of application.

The vegetative material obtained from untreated, AL 4, DL 4 and G 4 treatments had nitrogen contents of 1,73, 2,23, 2,28 and 1,96% respectively.

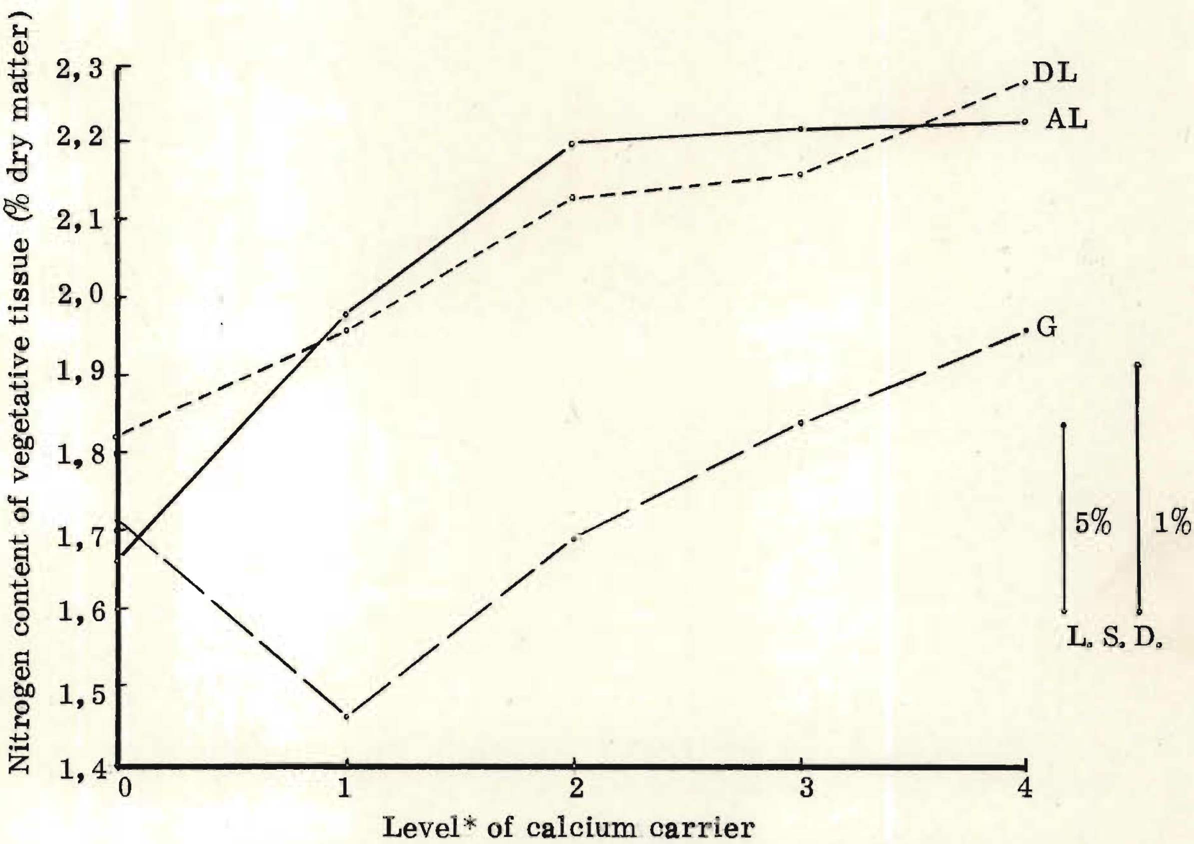

Fig. 5. Effect of calcium carrier treatment on nitrogen content of vegetative material

* See Table 2 (p. 9) for details

PLATE 1. The effect of calcium treatment on groundnut foliage colour. Yellow foliage indicates untreated or gypsum-treated plots

Crude protein content of the kernels Fig. 6

A highly significant increase in protein content of the kernels was obtained with increasing levels of AL and DL application, but a significant decrease in the rate of increase was observed at the higher levels of application. An increase in the crude protein content as a result of gypsum treatments was barely significant at the five per cent level. Kernels from the gypsum treatments had, on the average, a considerably lower crude protein content than either AL or DL treated kernels. There was no significant difference in crude protein content of kernels obtained from AL and DL treatments. The gypsum treatments never actually decreased the protein content of kernels, as obvious when compared with the crude protein content of kernels obtained from untreated plots.

The crude protein content of the kernels varied from 28,73% on untreated plots, to 33,43% on the DL 4 treatment.

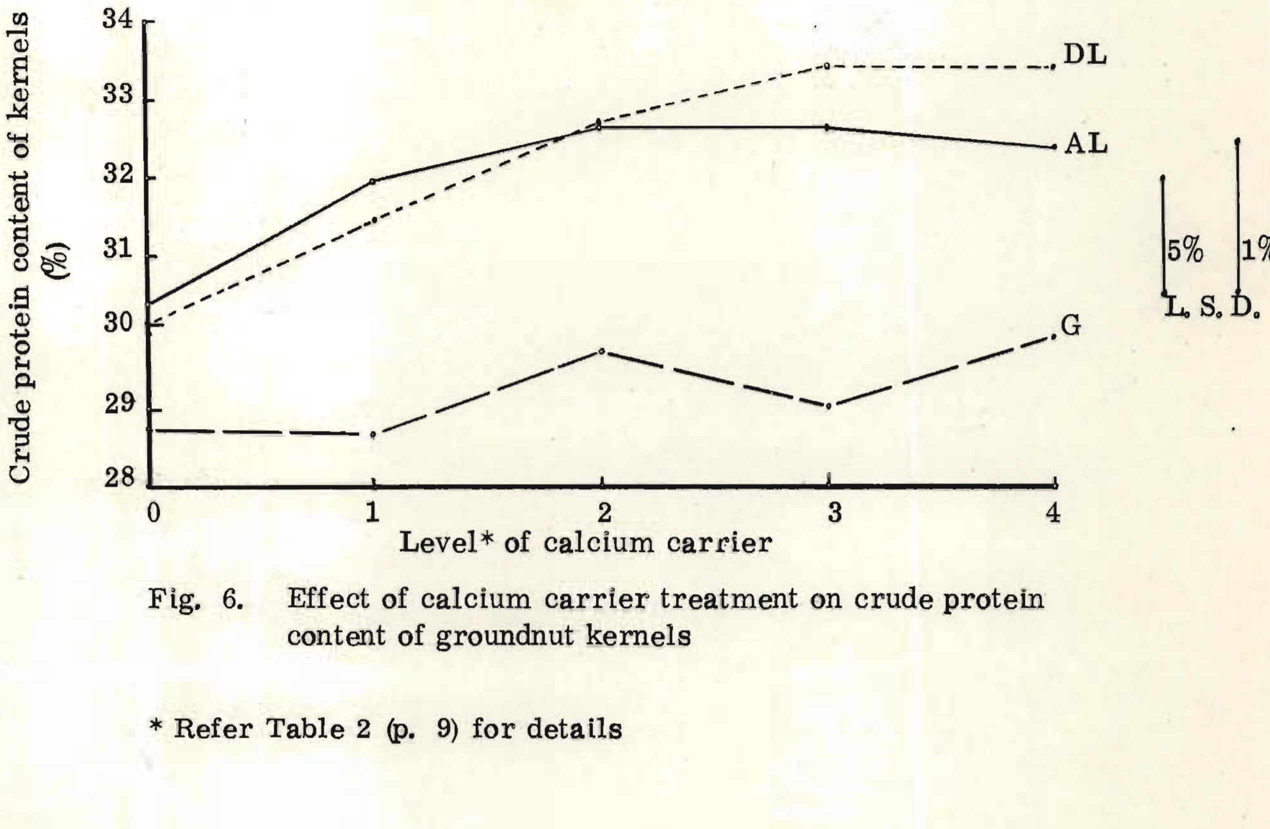

Fig. 6. Effect of calcium carrier treatment on crude protein content of groundnut kernels

* Refer Table 2 (p. 9) for details

Discussion

The treatment response pattern for vegetative material and kernels was very similar, a marked nitrogen deficiency being evident on all untreated and gypsum-treated plots. The latter produced the highest yield of well developed kernels and this would have increased the amount of nitrogen required by the plants. Brady, Reed & Colwell (1948) also reported a decreased nitrogen content in groundnut stems as a result of gypsum treatment. This might be expected because translocation of nitrogen from the foliage to the developing fruit would result in the nitrogen content of the stems being lowest in plants producing the highest yield of well developed kernels. The low nitrogen content of both foliage and kernels from the gypsum-treated plots would seem to indicate that the overall nitrogen nutrition of the plants was not satisfactory. There was no significant correlation between the nitrogen content of the vegetative material analysed and the crude protein content of the kernels.

A sulphur deficiency in soil is known to cause a yellowing of groundnut leaves (Burkhart & Collins, 1941; Hava, 1964), together with a reduction in the total ni= trogen uptake of the plants (Goldsworthy & Heathcote, 1963). Approximately 260 kg/ha sulphur was applied to the soil of the Dundee experiment as a "by-pro= duct" of the G 1 treatment. Between 5 and 10 kg sulphur per hectare has been sug= gested as required for normal growth of groundnuts (Gillier & Silvestre, 1969). It therefore appears unlikely that a sulphur deficiency could be the cause of abnor= mally low nitrogen content of the plant material on the gypsum-treated plots.

Reed & Brady (1948) also observed that groundnut plants to which agricultural lime was applied were definitely more robust and greener in colour than plants produced on untreated or gypsum-treated plots. An identical situation was ob= served in the Dundee experiment, as is evident from Plate 2. Mann (1935) reported that addition of lime to very acid soils (pH 4,5 and 5,3) resulted in an appreciable increase in nodulation in groundnuts, while gypsum reduced nodulation. Harris (1959)

PLATE 2. Effect of calcium treatment on groundnut foliage colour. Agricul= tural lime-treated plots in the background

attributed the light coloured condition of groundnut plants grown on acid soils to a nitrogen deficiency resulting from a reduction in activity of nitrogen fixing or= ganisms.

In view of the role of molybdenum as an essential element in the nitrogen fixation process (Anderson, 1956), a molybdenum deficiency on untreated control and gypsum-treated plots is suggested as the cause of poor colour and poor nitrogen status of both vegetative material and kernels. The soil on which this experiment was planted is known to be deficient in molybdenum at lower pH levels (Blamey, 1971). Applications of molybdenum to groundnuts have been reported to increase the nitro= gen content of foliage and kernels (Boswell, Anderson & Welch, 1967), and result in a darker green foliage and generally healthier appearing plants (Harris, 1959; Gillier, 1966). Increasing soil pH through liming would increase the availability of native as well as applied molybdenum (Parker, 1964). The pH range on untreated and gypsum-treated plots of the Dundee experiment was low enough to cause molyb= denum availability problems (refer Fig. 1, p. 16), and the expected improvement in leaf colour and nitrogen content of the plant (see Fig. 5, p. 29) was obtained with increasing pH.

A very marked increase in number of nodules per plant, as a result of molybdenum treatment of groundnut seed, was observed in an adjoining field experiment, but no kernel yield response was obtained as a result of this treatment. Increased kernel yields as a result of a molybdenum response are seldom obtained, even on soils known to be deficient in available molybdenum. It appears unlikely that a molybdenum deficiency, as a result of a low pH, could have been a limiting factor to kernel yield on the Dundee experiment. The increased nitrogen content of fo= liage on the gypsum-treated plots might possibly be attributed to the nutritional effect of sulphur.

Phosphorus

The calcium carrier treatments had no significant effect on the phosphorus content of the vegetative material analysed, of which the mean phosphorus content was only 0,12%. This is well below the 0,24% for Spanish-type groundnuts grown under adequate nutrient conditions (Hallock, Martens & Alexander, 1971). The poor phosphate status of the soil on the Dundee experimental area is to be noted in this respect.

It is of interest to note a consistent, significant positive correlation obtained between the phosphate and calcium content of the plant material analysed. This relationship, particularly significant in the case of gypsum treatments, is illustrated in Table 7.

TABLE 7. Effect of calcium carriers on correlation coefficients between calcium and phosphorus contents of groundnut vegetative material

Calcium carrier	r	t	Significance
Agricultural lime	0,544	2,428	*
Dolomitic lime	0,571	2,601	*
Gypsum	0,896	7,571	**

Potassium

Vegetative material

The mean potassium content of vegetative material over all treatments was 1,05%. Oram (1958) reported that 1% of leaf potassium was a critical level for groundnuts in Senegal. No response to applications of potassic fertilizer has yet been reported from groundnut experiments in Natal.

The applied calcium treatments had no significant effect on the potassium content of the vegetative material analysed.

Kernels Fig. 7

Increasing levels of calcium carrier resulted in a marked decrease in the potas= sium content of the kernels, on the average. This decrease in potassium content was particularly noticeable at lower levels of calcium application. At higher levels the magnitude of response decreased significantly, the overall response curve being quadratic.

Kernels produced on the gypsum-treated plots had a significantly lower potassium content than the DL and AL treated material, with no significant difference between the latter two treatments (see Table 8).

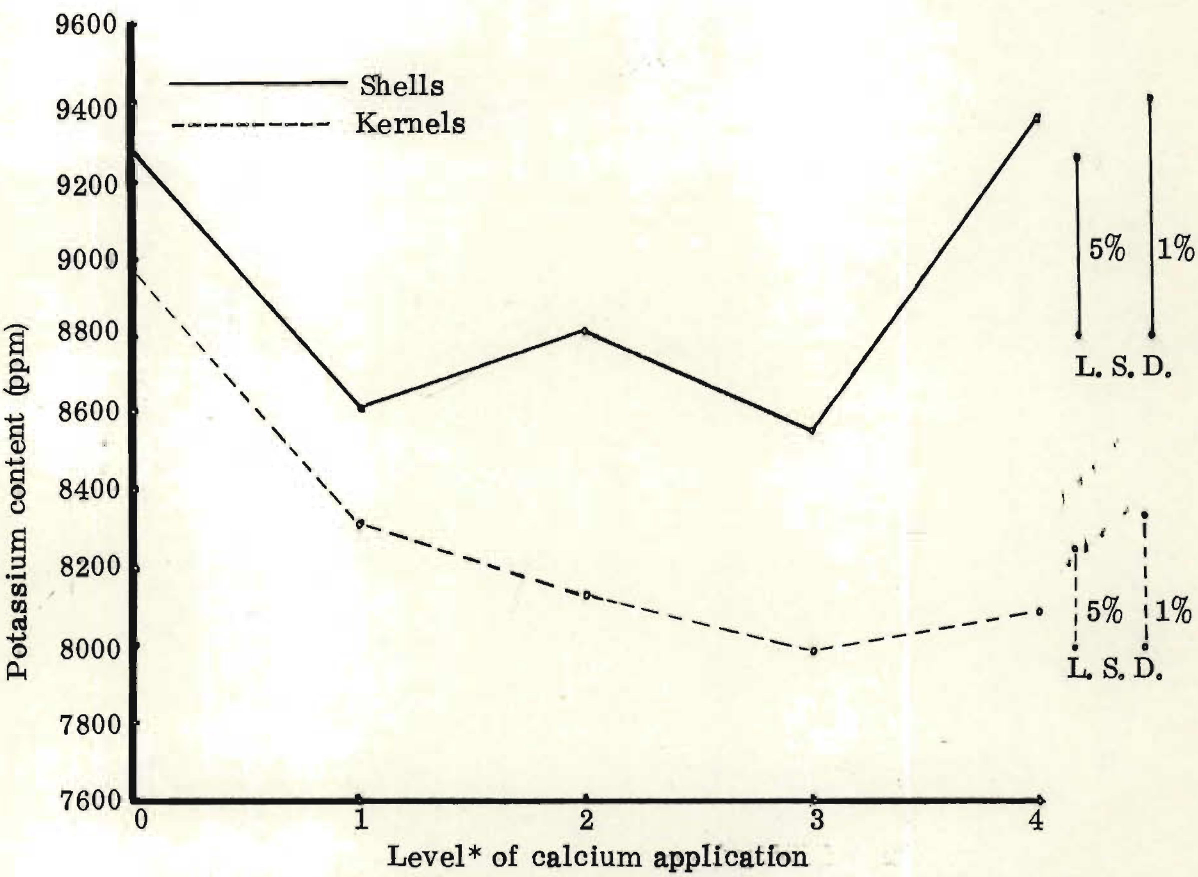

Fig. 7. Effect of calcium treatment on potassium content of groundnut kernels and shells

* Refer Table 2 (p. 9) for details

TABLE 8. Effect of calcium carrier treatment of the soil on potassium content of groundnut kernels and shells

Calcium carrier treatment	Potassium content of fruit	
	Shell	Kernel
	ppm	ppm
Agricultural lime - AL	9124	8333
Dolomitic lime - DL	9037	8417
Gypsum - G	8635	8151
Untreated control	9294	8988
L. S. D. (P = 0, 05)	392	220

The potassium content of kernels varied between 8900 ppm on untreated plots to 7900 ppm on the G 4 treatments.

Shells

Fig. 7 (p. 36)

The potassium content of the shells varied somewhat irregularly in relation to treatment applied. On the average a marked decrease in potassium content was ob= tained at the lower level of calcium application, but with higher levels of calcium application the potassium content of shells was restored to the original level. Shells produced on gypsum-treated plots had a significantly lower potassium content on the average (8635 ppm) than on the DL (9037 ppm) or AL (9124 ppm) treatments (see Table 8).

Discussion

Rogers (1948) observed that the calcium concentration in groundnut leaves is greatly affected by the ionic nature of the substrate on which the plants are grown. A lack of calcium and magnesium in the substrate was found to increase the potassium concen=

tration in the leaves to double that found in completely healthy ones. On the basis of this argument it is somewhat surprising to find no significant difference in potassium content of the vegetative material from treated and untreated plots in the Dundee experiment. In fact, a highly significant positive correlation between calcium and potassium contents of vegetative material was observed on the DL and gypsum-treated plots, as indicated in Table 9.

TABLE 9. Effect of calcium carriers on correlation coefficients between calcium and potassium contents of vegetative material

Calcium carrier	r	t	Significance
Agricultural lime	0,272	1,058	NS
Dolomitic lime	0,662	3,312	**
Gypsum	0,836	5,699	**

No significant correlation between potassium content of the soil and potassium content of plant material was observed. From data presented in Fig. 7 it is evident that the potassium content of shells and kernels was not increased under conditions of calcium deficiency in the fruiting zone, but rather that potassium uptake was decreased under conditions of favourable calcium supply. A similar observation was reported by Burkhart & Collins (1941). On this basis the fairly stable potassium concentration of the plant material would suggest that the roots were not subjected to calcium deficiency conditions. In the case of a deficiency condition in the rooting zone one would have ex= pected a decreased potassium content in the foliage with increasing applications of calcium. Increasing calcium concentrations with increasing depth in the soil profile, together with more favourable soil moisture conditions at greater depths, probably provided favourable conditions for calcium uptake by the roots.

No correlation between vegetative and kernel potassium, nor between shell and kernel potassium was observed.

Magnesium

Vegetative material

An increase in the exchangeable magnesium content of the soil was not accompanied by a similar increase in magnesium content of the plant material analysed. The mag= nesium content of plant samples obtained from gypsum-treated plots (0,34%) was slightly lower than that of the AL and DL treated plots (0,40 and 0,41% respec= tively). The average magnesium content of plant material from untreated plots was 0,37%, which compares favourably with the 0,35% for Spanish-type ground= nuts grown under adequate nutrient conditions (Hallock et al., 1971).

Kernels

A highly significant increase in magnesium content of kernels was obtained as a result of increasing applications of all three calcium carriers, as indicated in Table 10. The rate of response was maintained over all levels of application, with

TABLE 10. Effect of level of calcium carrier application to the soil on magnesium content of the kernel

Level of calcium carrier	Magnesium content of the kernel
	ppm
0	2259
1	2340
2	2327
3	2431
4	2430
Mean	2357
L. S. D. (P = 0, 05)	111

no indication of a change in the rate of increase. The magnesium content of kernels from gypsum-treated plots was, on the average, significantly lower than that from either the AL or DL treatments (see Table 11).

TABLE 11. Effect of calcium carrier treatment of the soil on magnesium content of kernels and shells

Calcium carrier treatment	Magnesium content of the fruit	
	Shell	Kernel
	ppm	ppm
Agricultural lime - AL	1904	2388
Dolomitic lime - DL	2065	2422
Gypsum - G	1568	2263
Untreated control	1796	2259
L. S. D. (P = 0,05)	118	96

Shells

Fig. 8

The calcium carriers used differed considerably in their effect on the magnesium content of the shell (see Table 11). The magnesium content of shells from gypsum-treated plots was, on the average, considerably lower than that from either the AL or DL treated plots. The DL treatment resulted in a significantly higher shell magnesium content than the AL treatment did.

A significant increase in the magnesium content of the shells was observed with increasing levels of the AL and DL treatments, being significant in the case of the DL treatments and almost significant in the case of the AL treatments. Gypsum treatments resulted in an almost significant decrease in magnesium content of the shell, on the average.

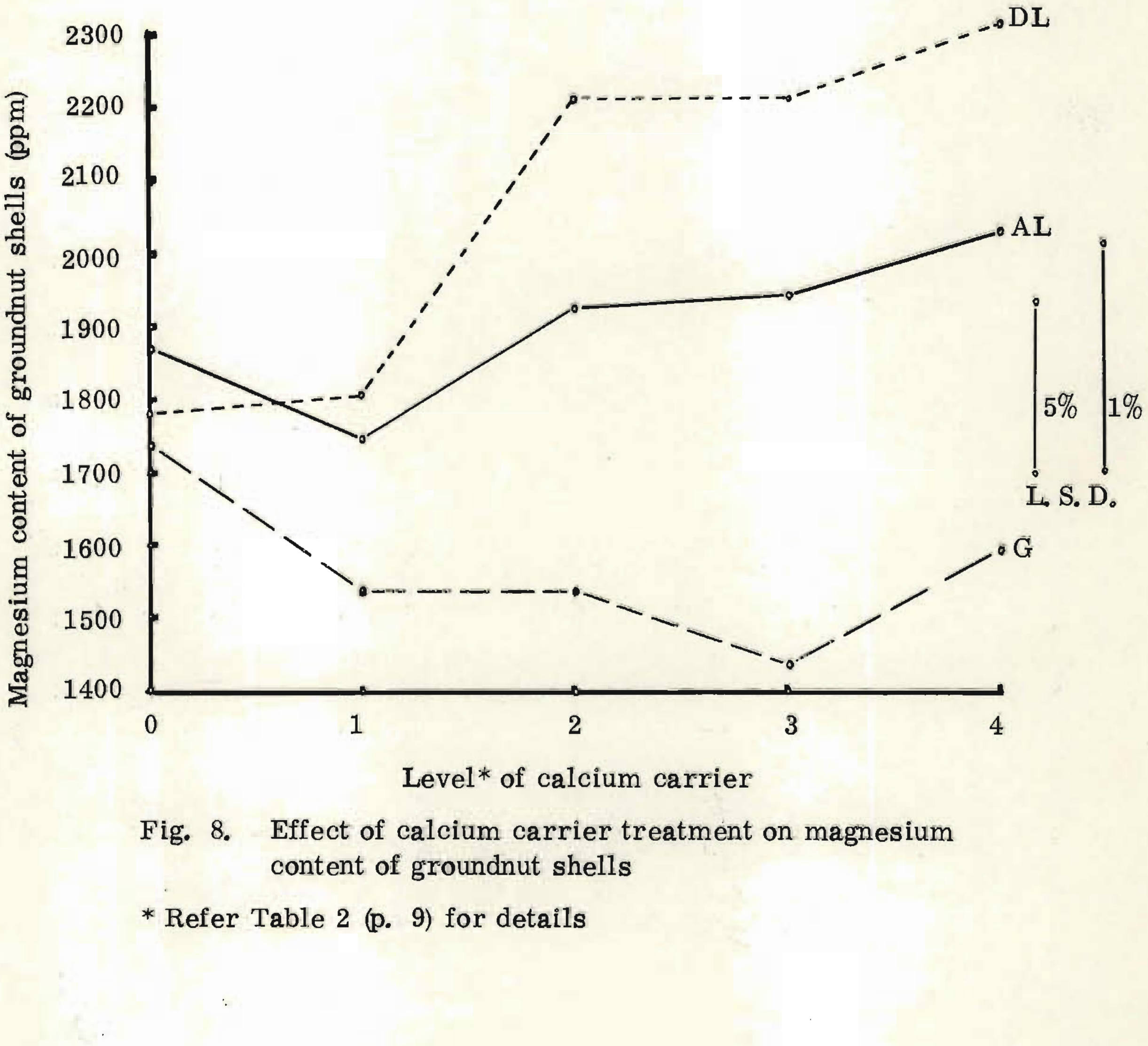

Fig. 8. Effect of calcium carrier treatment on magnesium content of groundnut shells

* Refer Table 2 (p. 9) for details

Discussion

The magnesium requirements of groundnuts are relatively low, and under the conditions of this experiment it would seem unlikely that magnesium deficiency was limiting yield. Even on untreated control plots the magnesium content of plant material was well above accepted critical levels. No significant correlation between the magnesium content of the soil and magnesium content of plant material was ob= served. A slightly stronger correlation between exchangeable magnesium in the soil and the composition of the fruit was observed (see Table 12), but was significant for only the gypsum treatment.

TABLE 12. Effect of calcium carriers on correlation coefficients between exchangeable magnesium content of the soil, and magnesium contents of kernels and shells

Calcium carrier	Kernel magnesium		Shell magnesium	
	r	Significance	r	Significance
Agricultural lime	0,450	NS	0,354	NS
Dolomitic lime	0,099	NS	0,497	NS
Gypsum	0,257	NS	0,656	**

Calcium

Vegetative material

Fig. 9 and 10

Notwithstanding their very marked effect on the exchangeable calcium content of the soil, calcium carrier treatments had little effect on the calcium content of vegetative material analysed. In fact, a negative (though not significant) relationship between soil and plant calcium was observed. In the case of gypsum treatments a significant quadratic response of calcium content of vegetative material was observed. Vegetative material from gypsum-treated plots had a significantly higher calcium content on the

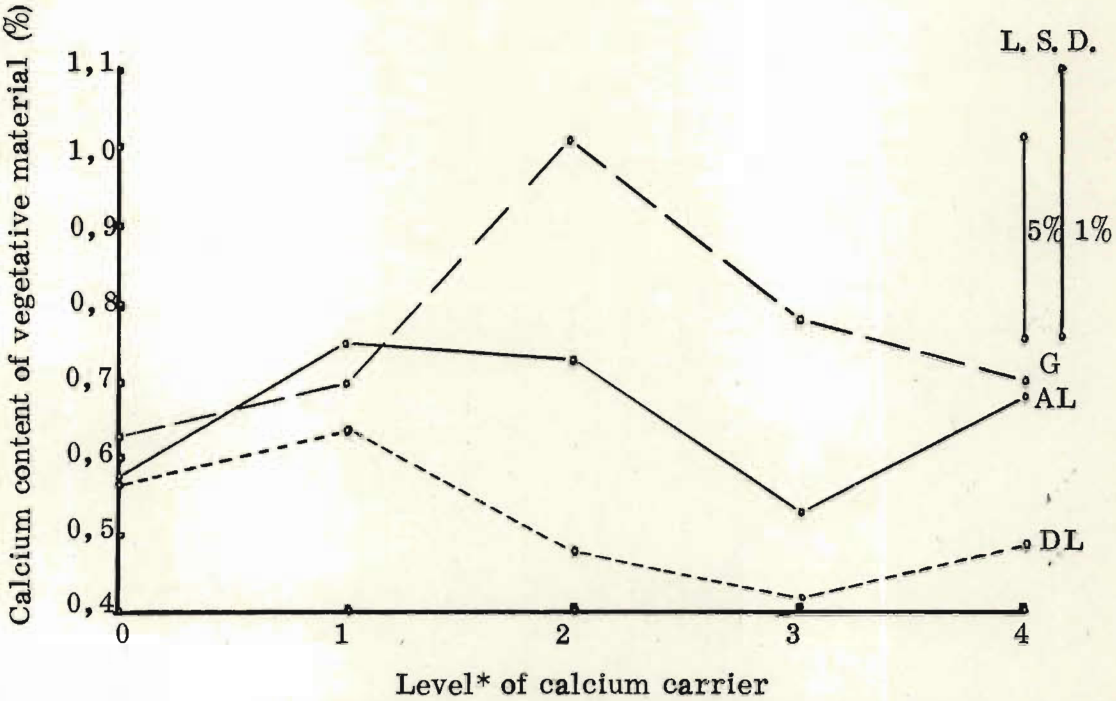

Fig. 9. Effect of calcium carrier treatment on calcium content of groundnut foliage

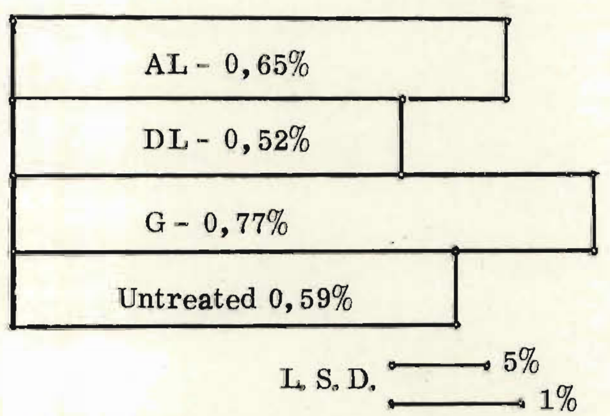

Fig. 10. Effect of calcium carrier on calcium content of groundnut foliage

* Refer Table 2 (p. 9) for details

average, than the DL treated material, and the calcium content in the case of AL treatments was intermediate. In general therefore, the calcium content of vegetative material was affected more pronounced by the type of calcium carrier than by the amount of calcium carrier.

The mean calcium contents of the vegetative material analysed were 0,65, 0,51, 0,77 and 0,59% for the AL, DL, gypsum-treated and untreated control plots respec= tively. The above figures are well below the approximately 1,25% calcium content for Spanish-type groundnuts grown under adequate nutrient conditions (Hallock et al., 1971).

Kernels

A linear increase in calcium content of groundnut kernels was observed with in= creasing levels of calcium carriers applied to the soil. This response pattern was consistent irrespective of calcium carrier used, as indicated in Table 13.

TABLE 13. Effect of level of calcium carrier application to the soil on calcium content of groundnut shells and kernels

Level of calcium carrier	Calcium content of the fruit	
	Shell	Kernel
	ppm	ppm
0	472	125
1	614	139
2	714	145
3	811	163
4	766	161
Mean	675	147
L. S. D. (P = 0,05)	84	17

The calcium content of kernels from gypsum-treated plots was consistently higher than that for the AL and DL treatments (see Table 14).

TABLE 14. Effect of calcium carrier on calcium content of the groundnut plant and fruit

Calcium carrier	Calcium content of plant material		
	Vegetative	Shell	Kernel
	%	ppm	ppm
Agricultural lime - AL	0,65	720	144
Dolomitic lime - DL	0,52	535	132
Gypsum - G	0,77	771	164
Untreated control	0,59	472	125
L.S.D. (P = 0,05)	0,13	73	15

The above results differ somewhat from those reported by Colwell, Brady & Piland (1945) who found the composition of kernels to be fairly constant, irrespective of treatment applied.

Shells Fig. 11

The calcium content of the shell was strongly influenced by the calcium carrier treatment applied to the soil and, on the average, a highly significant increase in calcium content of the shell followed on calcium applications to the soil. The rate of increase in calcium content of the shells was, however, not maintained and a statistically significant decrease in the rate of increase in calcium content was observed. This response pattern was similar for all three calcium carriers.

The calcium content of shells produced on gypsum-treated plots was significantly

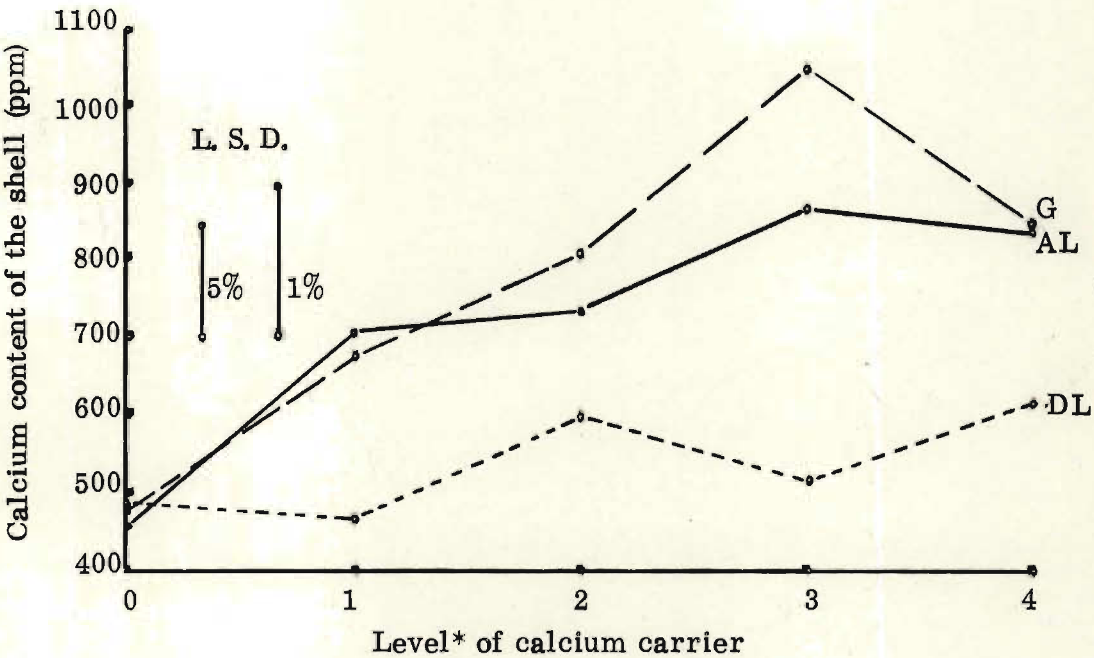

Fig. 11. Effect of calcium carrier treatment on calcium content of groundnut shells

* Refer Table 2 (p. 9) for details

higher than in the case of both AL and DL treatments. There was no significant difference in calcium content of shells from the latter two treatments.

Manganese

Vegetative material Fig. 12

A highly significant decrease in manganese content of the vegetative material sampled was observed with increasing amounts of calcium applied. This trend was consistent and linear, irrespective of calcium carrier used. There was no statis= tical significant difference in manganese content of vegetative material obtained from the three different calcium carrier treatments.

The mean manganese content of vegetative material from untreated plots was 342 ppm. Although considerably higher than the maximum of 140 ppm reported by Hallock et al. (1971), it is still well below the 1260 ppm reported by Gillier & Silvestre (1969 p. 117). The latter was reported to be toxic levels experienced under conditions of a very low soil pH. Although toxic levels of manganese could be expected at the low pH levels experienced on the Dundee expe= riment, leaching of these sandy soils probably would reduce the supply of available manganese. The minimum level of manganese in the analysed material was still well above the lower critical level of 10 ppm reported by Rich (1956, p. 355).

The marked decrease in manganese content of vegetative material observed over gypsum-treated plots indicates that soil pH level had a comparatively minor effect on manganese uptake. Rich (1956) found that soil pH could account for only 28% of the variance in manganese content of groundnut leaves. The higher the content of exchangeable calcium and magnesium, the lower plant manganese content was found to be. Rich (1956) explains the effect of calcium on manganese uptake to be due to depression of uptake by a similar cation.

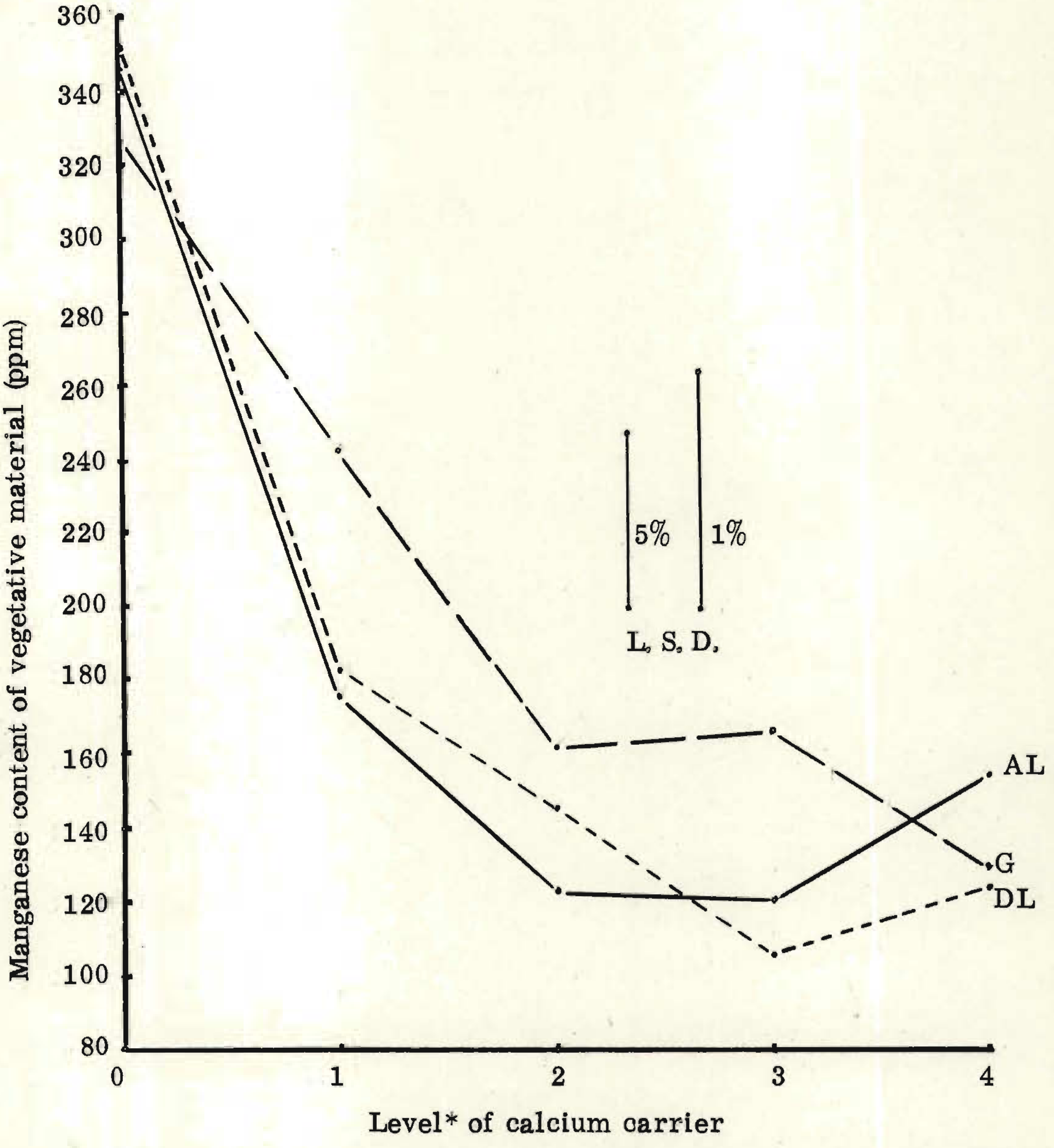

Fig. 12. Effect of calcium carrier treatment on manganese content of groundnut foliage

* Refer Table 2 (p. 9) for details

Summary

Apart from a marked improvement in the nitrogen status of the plant as a whole, the calcium carrier treatments had little influence on the chemical composition of the vegetative material analysed. A marked increase in nitrogen content of vege= tative material and kernels was, however, obtained as a result of the calcium carrier treatments applied. The AL and DL treatments were particularly effec= tive in this respect. It is suggested that increasing pH (as in the case of the AL and DL treatments) would lead to increased availability of molybdenum in the soil, with a resultant more efficient nitrogen fixation by nodule bacteria. The untreated and gypsum-treated plots had a significantly lower soil pH and at the same time a significantly lower nitrogen content in the vegetative material and kernels produced on these plots. A marked increase in nitrogen content was noted with increased levels of gypsum application.

The calcium carrier treatments applied had no effect on the phosphate status of the vegetative material analysed.

The potassium status of plant material was similarly unaffected, while no consistent response pattern was obtained as far as the potassium status of the shell was con= cerned. Groundnut kernels showed a very marked and consistent decrease in potas= sium content with increasing applications of calcium carriers. The magnesium con= tent of vegetative material was very insensitive to changes in exchangeable magne= sium content of the soil, whereas magnesium content of both shells and kernels was consistently increased as a result of these treatments.

Notwithstanding the very marked effect of calcium treatments on the exchangeable calcium content of the soil, the calcium status of the vegetative material was little affected. No translocation of calcium takes place between the plant and the developing fruit, and the calcium status of the fruit could therefore be expected to be a fairly reliable indication of the supply and availability of calcium in the fruiting zone. On the other hand, the solubility of the calcium carrier used together with the moisture status in the fruiting zone of the soil would have a very marked influence on the ef= ficiency of calcium uptake by the fruit. Unfavourable soil moisture conditions in the zone of fruit formation over the period of maximum calcium requirement is probably responsible for the poor correlation values presented in Table 15.

TABLE 15. Effect of calcium carriers on correlation coefficients between exchangeable calcium in the soil and calcium contents of the plant

Plant part	Treatment					
	AL		DL		G	
	r	Significance	r	Significance	r	Significance
Vegetative material	-0,27	NS	-0,66	**	-0,22	NS
Kernels	0,24	NS	0,01	NS	0,28	NS
Shells	0,35	NS	0,50	NS	0,66	**

In the case of both kernels and shells a fairly consistent increase in calcium content was obtained as a result of the calcium carrier treatment applied. The calcium car= rier used plays a very important role in determining the efficiency of calcium uptake by the developing fruit. The calcium content of the shell appears to provide a better indication than the kernels do, of the available calcium status of the soil in the fruiting zone.

A marked decrease in manganese content of vegetative material analysed was ob= served as a result of increasing levels of calcium application, irrespective of car= rier used. Although the manganese content level on untreated plots was high, both maximum and minimum levels experienced over all treatments were within accep= table limits.

As far as the possibility of leaf and/or plant analysis for the purpose of diagnosing nutrient deficiency conditions is concerned, analysis of vegetative material or kernels for nitrogen content appears to be of some value. At the same time the relationships between calcium and phosphate, and between calcium and potassium contents of the plant are of interest (see Tables 7, p. 35 and 9, p. 38).

EFFECT OF KERNEL DEVELOPMENT ON CHEMICAL COMPOSITION OF GROUNDNUT SHELLS

In order to obtain information on nutritional factors possibly involved in abnormal kernel development, pods in which various stages of kernel development had taken place were obtained, as follows:

(a) 100 two-cavity fruit in which none of the kernels had developed (the so-called "pops"). See Plate 3.
(b) 100 two-cavity fruit in which only one kernel had developed normally, and
(c) 100 two-cavity fruit in which both kernels had developed normally.

PLATE 3. Degree of kernel development in normal two-cavity groundnut pods. From left to right: normal, 1-kernelled and unfilled fruit ("pop")

The fruit were collected at random from the calcium carrier experiment and were not obtained from any specific treatment. The samples were shelled separately, milled and analysed for calcium, potassium and magnesium. Results obtained are presented in Table 16.

TABLE 16. Effect of kernel development on chemical composition of groundnut shells

Number of kernels in 2-cavity fruit	Chemical composition of shell			
	Ash	Calcium	Potassium	Magnesium
	%	ppm	ppm	ppm
no kernels	10,16	816	10 640	2 230
1 kernel	5,84	670	7 550	1 380
2 kernels	5,20	869	7 080	1 120
L. S. D. (P = 0,05)	2,51	130	629	145

Unfilled fruit ("pops") were associated with a marked increase in ash content compared with normally developed fruit. The empty pods had a high potassium and magnesium content in the shell, but the calcium content of the shell was affected less. Shells from normal fruit had the lowest ash, potassium and magnesium content, while 1-kernelled fruit were intermediate in composition.

It is surprising to find that there was little difference in calcium content of shells from normal and unfilled fruit, especially in view of the fact that applications of calcium usually have such a marked effect on shelling percentage. The poor cor= relation between calcium content of the soil and percentage "pops" in the crop is to be noted in this respect (see Table 19, p. 70).

EFFECT OF CALCIUM TREATMENT ON KERNEL YIELD

General

Changes in the calcium status of the soil appears to be the treatment most commonly associated with increased kernel yield and improved kernel quality. A liberal supply of calcium in a form available for uptake by the gynophore and developing fruit is essential for normal fruit development. The shallow fruiting zone, 0 to 15 cm from the surface of the sandy soils on which groundnuts are most often produced, is very susceptible to drying-out. A limited moisture supply in this zone could result in calcium starvation of the pod, even in a soil well supplied with calcium. Soil moisture is seldom limiting in the deeper rooting zone and the uptake of calcium by roots might proceed actively. Calcium taken up by the roots is not translocated to the fruit (Mizuno, 1965), and under the above conditions a poor correlation between calcium status of the vegetative portion of the plant and the fruit could be expected.

Soil moisture conditions, together with the solubility of the calcium supply in the soil, could therefore be expected to have a marked influence on the fruit and kernel development of the groundnut. The effect of calcium treatments on groundnut yield and quality should therefore be considered in relation to climatic conditions experienced over the growing season.

Kernel yield

1968/69 season

Fig. 13

The mean kernel yield over all treatments was 1709 kg/ha, which may be regarded as better than average for raingrown conditions.

Highly significant increases in yield were obtained with each successive application

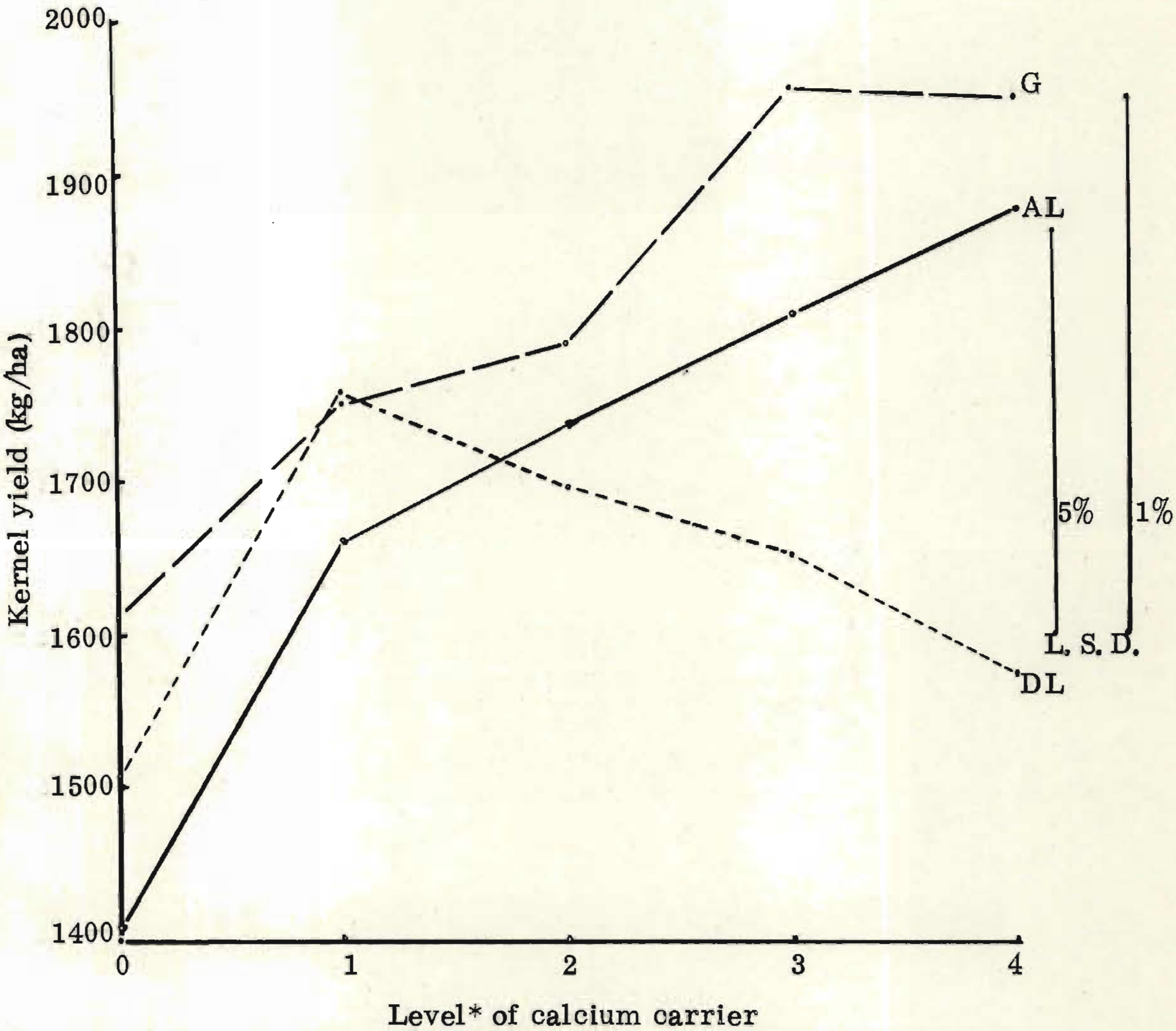

Fig. 13. Effect of calcium carrier treatment on groundnut kernel yield, 1968/69

* Refer Table 2 (p. 9) for details

of calcitic lime and gypsum. There was no indication of a change in the rate of in= crease in yield where these two calcium carriers were used. In the case of the DL treatment an increased yield, above the untreated control was obtained at the first level. At higher levels a consistent decrease in yield was obtained. The AL and DL treatments differed in their effect on the calcium and magnesium status of the soil. The lower exchangeable calcium content of the soil on DL treated plots (as shown in Fig. 3, p. 19 - as a result of the lower calcium content of the dolomitic lime) would lead one to expect lower yields compared with the same level of AL treated plots on this soil, which has a low calcium content. On this basis one would expect increased yields with higher levels of DL application (resulting in higher levels of calcium in the soil). Decreased yields were, however, obtained as a result of application of higher levels of dolomitic lime.

Strauss & Grizzard (1948) suggested that kernel yields would be decreased by applications of dolomitic limestone if the calcium saturation of the soil is relatively high and the K : Mg ratio relatively high. The decrease in yield at higher levels of DL treatment may therefore be due to a disturbance of the K : Mg balance in the soil. It is to be noted that the exchangeable magnesium content of the soil on the DL treated plots increased steadily above that on the AL plots as the level of application was increased.

The difference in kernel yield obtained from the different calcium carriers was not very great on the average. Highest yields were obtained from gypsum-treated plots, with mean yields from AL plots slightly (not significantly) lower. This yield superiority of the gypsum-treated plots was maintained over all levels of application. At the higher levels of application kernel yields on DL treated plots were significantly lower than on either AL or gypsum-treated plots.

Gypsum treatments were associated with a higher calcium content of the shell, higher shelling percentage (see Table 18, p. 67) and a lower percentage unfilled fruit (see Table 17, p. 65).

Variation in kernel yield response, with season Fig. 14 and 15

Considering yield data obtained over three successive seasons (1967/68 to 1969/70), as illustrated in Fig. 14, it is obvious that calcium as plant nutrient was a limiting factor to kernel yield over all three seasons. Increasing applications of calcium, irrespective of calcium carrier used, increased yields. The overall increase in yield, over the range of application levels, appeared to increase in magnitude from season to season.

The effect of calcium carrier on kernel yield varied from season to season, as is illustrated in Fig. 15. Yields from the AL and DL treatments remained consistent relative to each other, slightly higher yields always being obtained from the AL treated plots. The response to gypsum treatments varied considerably from season to season. The three growing seasons reported on differed considerably in amount of rainfall recorded. The total rainfall for the 1967/68, 1968/69 and 1969/70 seasons were 484, 542 and 646 mm respectively, all well below the 20-year annual average of 830 mm.

It is to be noted that yields obtained from gypsum-treated plots were never lower than that on the untreated control plots. The poor yield obtained from gypsum-treated plots over the 1969/70 season, relative to that obtained from the AL and DL treat= ments, could therefore not be attributed to an actual yield decreasing ("toxic") overall effect of gypsum. The beneficial effect of gypsum on kernel yield appears to be limited largely to seasons with a below-normal rainfall, as was observed by Colwell & Brady (1945).

The effect of gypsum on groundnut kernel yield is well documented. Typical of the numerous reports indicating a favourable yield response of large-seeded groundnuts as a result of gypsum applications are the data reported by Colwell & Brady (1945). Gypsum was found to excert a marked beneficial effect on yield and quality, particu= larly pronounced on soils low in calcium. Applications of dolomitic lime did not meet

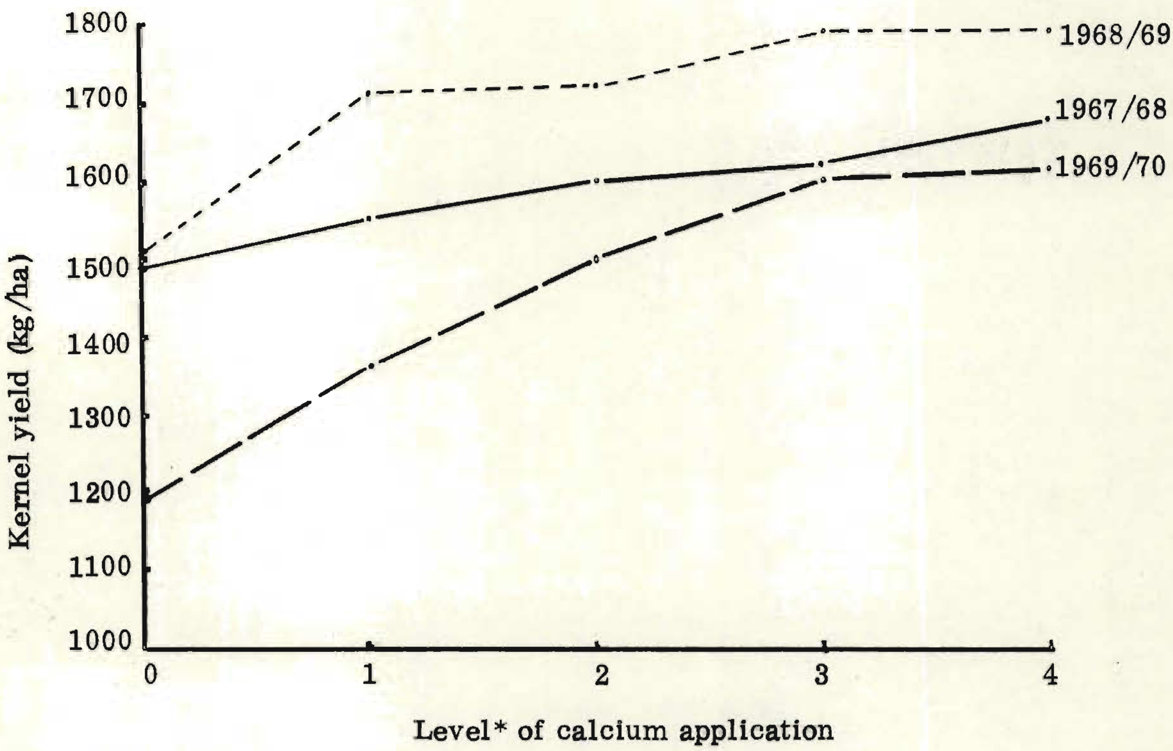

Fig. 14. Seasonal variation in kernel yield, as affected by level of calcium treatment applied to the soil

* Refer Table 2 (p. 9) for details

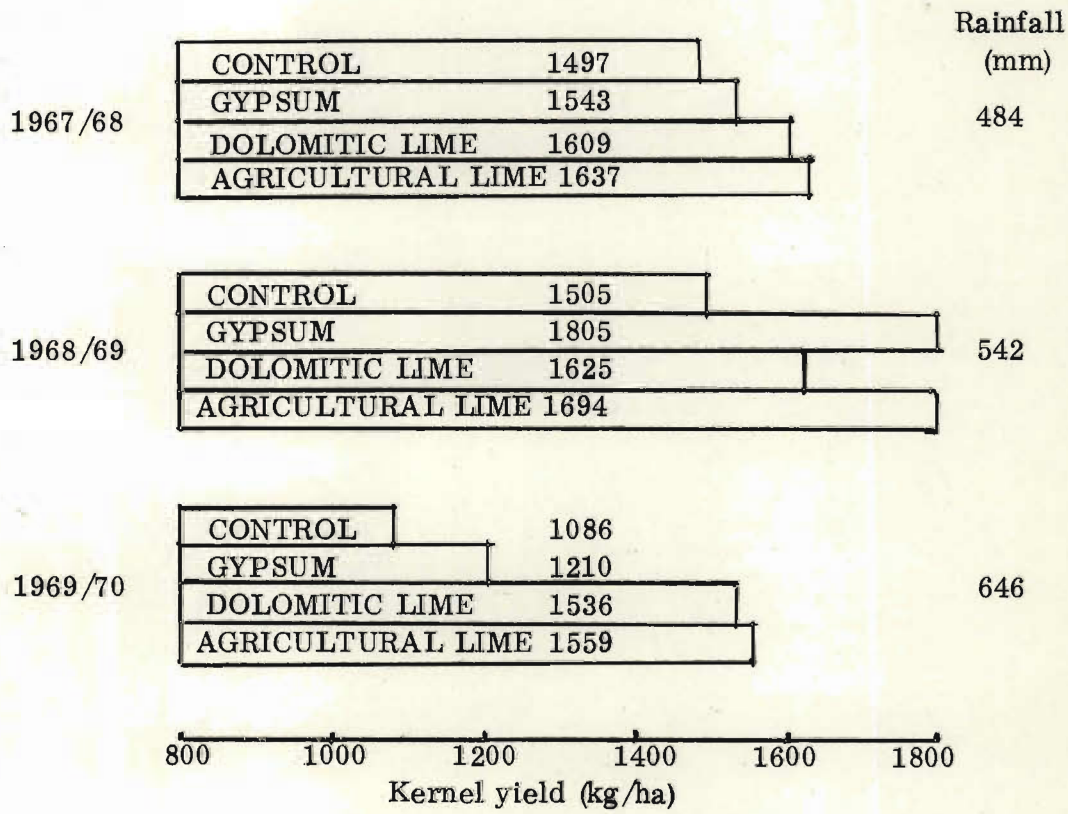

Fig. 15. Seasonal variation in kernel yield, as affected by calcium carrier used

the calcium requirements of the fruit on soils with a low calcium content. Even on a soil higher in calcium, it produced fruit of lower true shelling percentage than did gypsum. Gypsum proved far superior to limestone in this respect. The beneficial effect of gypsum was reported to be less pronounced on a soil of relatively high fertility level.

Middleton, Colwell, Brady & Schultz (1945) reported a favourable effect of gypsum on kernel yield and especially quality of a Spanish-type groundnut cultivar. Lime= stone applied in-the-row did not meet the calcium requirements of the developing fruit.

The advantage in dry seasons of higher-solubility calcium carriers such as gypsum lies largely in their capacity to ensure a continuous supply of available calcium. Even small amounts of moisture in the fruiting zone could release sufficient calcium to meet the requirements of the developing fruit.

The critical period as far as calcium supply in the fruiting zone is concerned was found by Mizuno (1965) to be the 10 to 30 days after the gynophore penetrates the ground. Calcium supplied during other periods had little effect on the development of normal seeds. The growth stage at which a temporary interruption of calcium uptake (as a result of insufficient moisture in the fruiting zone) occurs, would to a large extent determine the extent of damage to the developing fruit. Unfavourable soil moisture conditions in the fruiting zone over a relatively short period of time could therefore have a drastic effect on kernel yield and quality. It will be noted that over the 1968/69 season the critical 10 to 30 day period after gynophore penetration in the ground, corresponded with a very dry period (25th December, 1968 up to 26th January, 1969 - see Table 1 p. 8.

The higher yield obtained from gypsum-treated plots in the low-rainfall 1968/69 season could be attributed largely to more efficient calcium uptake by the developing fruit under unfavourable soil moisture conditions. The higher calcium content of gypsum-treated shells is evidence of a more efficient uptake of calcium by the fruit from gypsum-treated soil. A significant correlation between exchangeable calcium in the soil and calcium content of the fruit was obtained only in the case of gypsum (see Table 15, p. 50), indicating a more efficient flow of calcium from the soil to the fruit, in the case of gypsum treatments. On this basis it could be expected that gypsum would lose some of its advantages as calcium supplier over a season with normal rainfall (see Fig. 15, p. 59).

It would appear that there are factors other than just better solubility involved in the superior efficiency of gypsum as calcium carrier over seasons with a below normal rainfall. The effect of gypsum on the occurrence of unfilled fruit (see Table 17, p. 65) cannot be ascribed to a calcium factor only. This aspect will be pursued in Chapter III.

The comparatively low yields obtained from gypsum-treated plots in normal rainfall seasons have still to be explained. As was stated earlier, these poor yields could not be attributed to an actual yield-decreasing (toxic) effect of gypsum, since the yields obtained from gypsum-treated plots were no less than that obtained from untreated plots. Kernel yields obtained from untreated and gypsum-treated plots over the 1969/70 season were well below that obtained from the same plots over the 1968/69 season.

Groundnut yields have been reported to be decreased by high concentrations of soluble manganese (Anon., 1966). Although the low soil pH levels experienced on this ex= periment would suggest the possibility of increased solubility and uptake of man= ganese (Snider, 1943; Fried & Peech, 1946), especially on untreated and gypsum-treated plots, manganese content of vegetative material analysed was not unduly high (see Fig. 12, p. 48).

Gypsum-treatments were as effective as the AL or DL treatments in reducing the manganese content of vegetative material, although having very little effect on soil pH. Although limited information is available on critical levels of manganese for groundnuts, it would appear unlikely that manganese toxicity could have been a serious yield-limiting factor under the conditions of this experiment. It might, how= ever, be that the pattern of manganese uptake over a season with normal or above normal rainfall (1969/70) is different from that illustrated in Fig. 12. Such a situation could be expected, since under conditions of high soil moisture (poor aeration) an increase in soluble manganous ions as a result of reduction from manganic to manganous manganese occurs (Bradfield, Badjer & Oskamp, 1934). This would lead to increased uptake of manganese by plants, resulting in manganese toxicity.

EFFECT OF CALCIUM CARRIERS ON KERNEL DEVELOPMENT

General

The role of calcium in decreasing the number of unfilled ovarian cavities and increasing fruit and kernel size has been well documented (Mehlich & Reed, 1947; Brady, Reed & Colwell, 1948; Harris, 1949; Mizuno, 1965). Normal sporogenesis, embrio sac development and fertilization provide no basis for predicting the occurrence of later seed failures which give rise to the shrivelled seeds and the empty pod characteristics of the so-called "pop" condition. When a young seed fails during the gynophore stage, the portion of the ovule containing it also fails to grow. Failures of the seed after underground pod enlargement has begun does not seem to inhibit completion of pod development (Gregory, Smith & Yarbrough, 1951). In the case of unfilled ovarian cavities normal shell growth occurs and the undeveloped ovules can be seen with the naked eye.

Effect of calcium treatment on percentage unfilled two-cavity fruit Fig. 16

The percentage unfilled two-cavity fruit (no kernels at all in a normally formed two-cavity sized fruit) obtained from individual plots over the whole experiment varied between 1 and 64% depending on treatment applied.

There appears to be no correlation between the exchangeable calcium content of the soil and the occurrence of unfilled fruit. The level of calcium applied had, in the case of the AL and DL treated plots, very little effect on the percentage unfilled fruit. It is of interest to note that the lower levels of calcium application consistently decreased the percentage unfilled fruit. It would therefore appear that a relatively small amount of calcium is required to ensure normal fruit fill, but that an additional factor, apart from amount of calcium applied, played a role in the case of the gypsum treatments.

The percentage unfilled fruit was markedly affected by the calcium carrier used (see

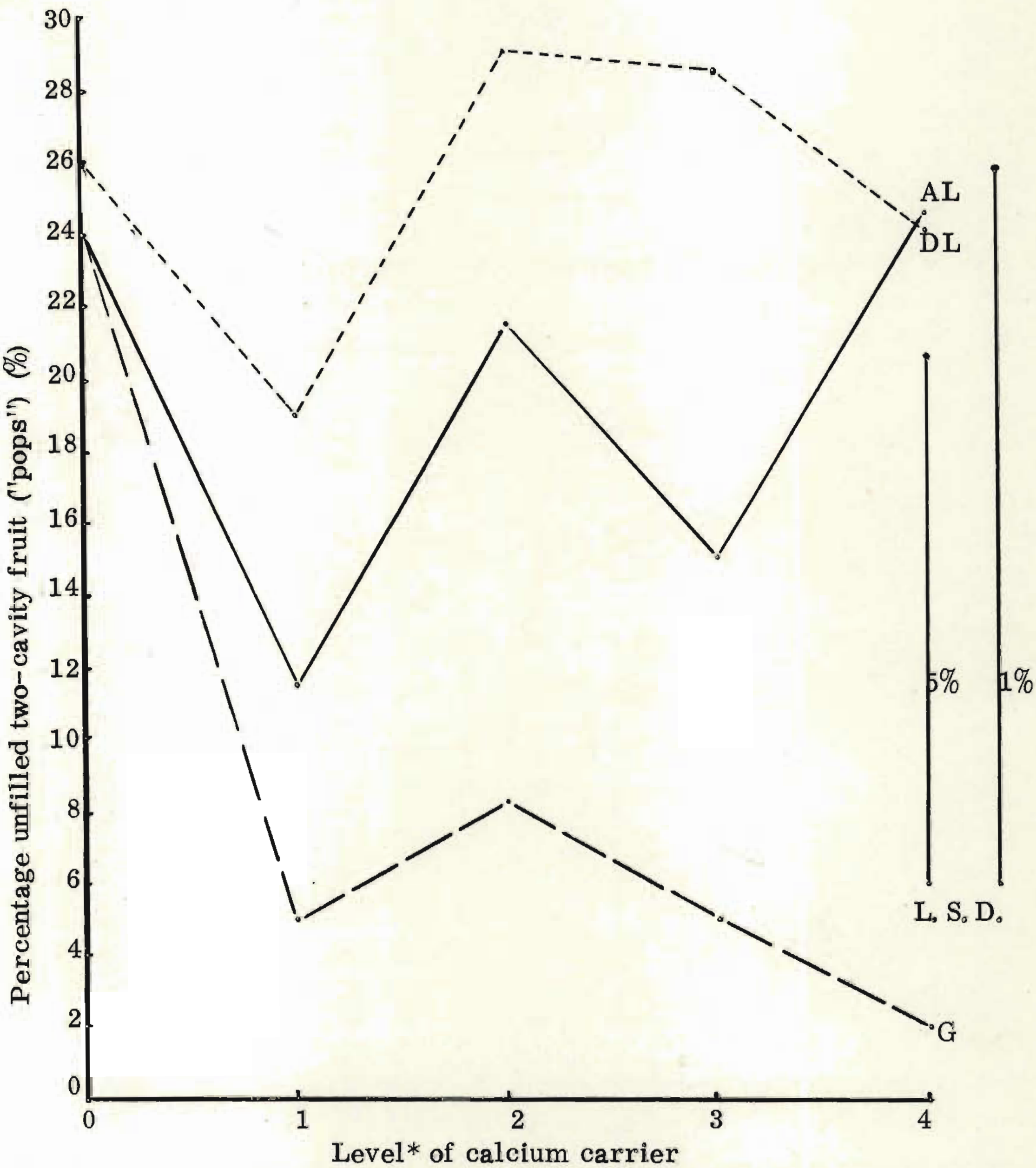

Fig. 16. Effect of calcium carrier treatment on percentage unfilled fruit ("pops")

* Refer Table 2 (p. 9) for details

Table 17), gypsum being the only calcium carrier having a marked influence in decreasing the percentage unfilled fruit.

TABLE 17. Effect of calcium carrier on percentage unfilled, 1- and 2-kernelled fruit

Calcium carrier	Unfilled fruit	1-Kernelled fruit	2-Kernelled fruit
	%	%	%
Agricultural lime - AL	19,3	10,8	69,7
Dolomitic lime - DL	25,3	11,7	63,0
Gypsum - G	8,9	7,0	84,3
Untreated control	24,7	14,8	60,5
L. S. D. (P = 0,05)	7,4	2,8	8,5

A highly significant decrease in percentage empty fruit was obtained wherever gypsum was applied. The mean percentage empty fruit on gypsum-treated plots was 8,9%, as against the 19,3% for AL and 25,3% for DL treatments.

Effect of calcium treatment on percentage ovarian cavities filled Fig. 17

A random sample of 100 fully developed two-cavity fruit was obtained from each plot. Each sample was shelled separately and the number of kernels obtained, counted. The effect of calcium carrier treatment on percentage ovarian cavities filled is given in Fig. 17.

Except for an almost significant increase in percentage ovarian cavities filled as a result of the AL 1 and DL 1 treatments, applications of calcitic and dolomitic lime had little effect in this respect. A highly significant increase in percentage ovarian cavities filled was obtained as a result of gypsum-treatments. A high per=

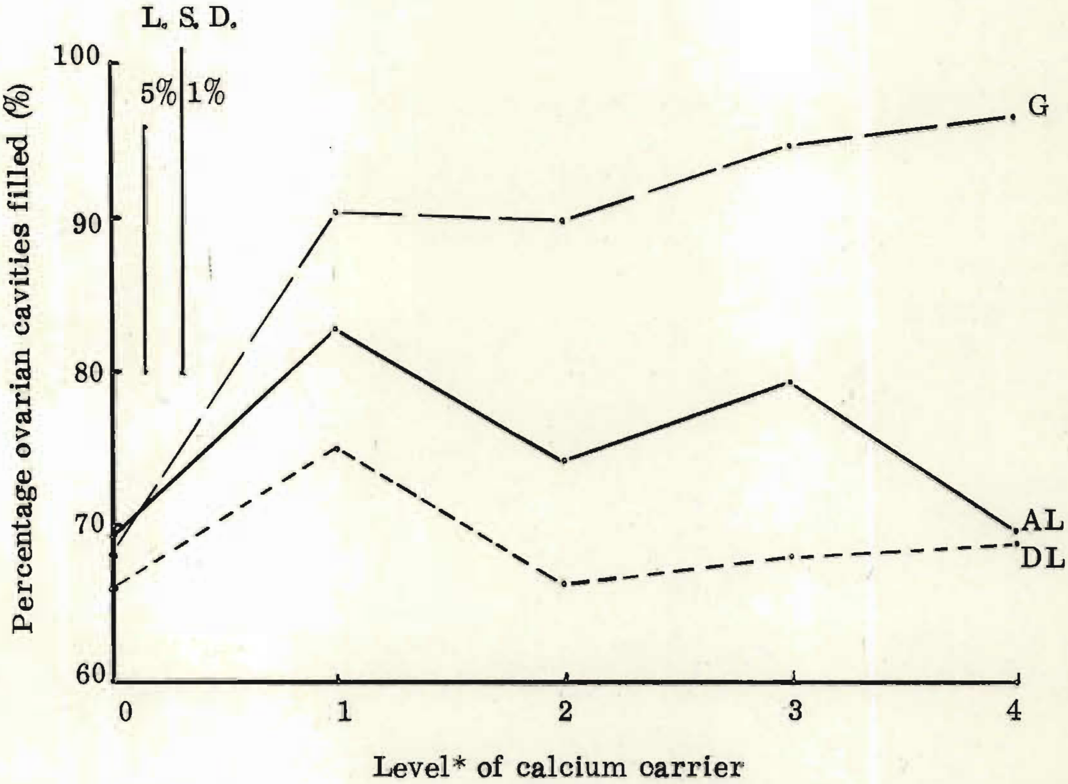

Fig. 17. Effect of calcium carrier treatment on percentage ovarian cavities filled in 100 two-cavity groundnut fruit

* Refer Table 2 (p. 9) for details

centage ovarian cavities filled was maintained over all levels of gypsum application, although the maximum increment was obtained as a result of the G 1 treatment.

The mean percentage ovarian cavities filled on the untreated control, AL, DL and gypsum-treated plots was 67,9, 75,1, 68,9 and 87,8% respectively.

Shelling percentage

A highly significant increase in shelling percentage was obtained from all calcium carrier treatments (see Table 18).

TABLE 18. Effect of calcium carrier treatment on groundnut shelling percentage

Calcium carrier	Level of calcium carrier					Mean
	0	1	2	3	4	
	%	%	%	%	%	%
Agricultural lime	61,8	67,5	67,6	70,5	67,5	67,0
Dolomitic lime	62,0	66,1	65,8	64,0	62,2	64,0
Gypsum	64,4	70,1	71,6	72,0	71,5	69,9
Means	62,7	67,9	68,3	68,8	67,1	67,0

L. S. D. - Calcium carrier 2,0 (P = 0,05)
2,7 (P = 0,01)

L. S. D. - Level of calcium carrier
2,3 (P = 0,05)
3,1 (P = 0,01)

L. S. D. - Body of table 4,0 (P = 0,05)
5,4 (P = 0,01)

This increase in shelling percentage was, however, largely limited to the lower levels of calcium application, the response curve having a very marked quadratic nature. An increased shelling percentage was obtained up to an exchangeable soil calcium level of 0,55 me 100^{-1} g soil.

From Table 18 highly significant differences in the effect of the different calcium carriers on shelling percentage was also evident. The highest shelling percentage was obtained on gypsum-treated plots, a significantly lower shelling percentage on all AL treated plots, and the lowest shelling percentage from the DL treatments. Brady, Reed & Colwell (1948) reported that a high magnesium treatment in a nutrient culture experiment gave a percentage pod fill (shelling percentage) significantly lower than the corresponding value for a high-calcium treatment.

Discussion

An inadequate supply of calcium is generally claimed to be the most important cause of unfilled ovarian cavities in the groundnut fruit (Reed & Brady, 1948; Goldsworthy & Heathcote, 1963; Anon., 1969). Comparing the data for percentage ovarian cavities filled, percentage gynophores developing fruit and percentage two-cavity fruits, Reed and Brady (1948) observed that of the above three measurements the latter two are the least sensitive to variations in calcium supply. With insufficient calcium some gynophores will develop shells and these may finally be present as two-cavity sized shells, but they will not fill and the percentage ovarian cavities filled will reflect this insufficiency of calcium.

Goldsworthy and Heathcote (1963) claimed that it is the nutrient action of calcium which is an effective remedy for the "pop" condition, and not the secondary effects of lime on pH or of gypsum as a source of sulphur. A 40% reduction in the number of "pops" over an untreated control was experienced following on an application of gypsum in Zambia (Anon., 1969). Middleton et al. (1945) reported a 19% increase in the percentage ovarian cavities filled in a Spanish-type cultivar, as a result of similar treatment.

A higher K : Ca ratio in the kernels, pods and haulms of plants producing a large percentage unfilled fruit was reported by Brown (1965). There is some evidence that there may be a threshold value of the ratio,

$$\frac{\text{Exchangeable potassium in the soil (me } 100^{-1} \text{ g soil)}}{\text{Exchangeable calcium in the soil (me } 100^{-1} \text{ g soil)}},$$

above which "pops" are likely to occur. A provisional value of 0,20 for this ratio was given by Brown (1965). In the case of a large-seeded type a soil calcium content of 0,60% has been reported as the critical level for the occurrence of "pops" (Brown, 1965). From a study of data presented in Fig. 3 (p. 19) and Fig. 16 (p. 64) it is obvious that level of exchangeable calcium was not a limiting factor causing a large percentage "pops" in the AL and DL treatments, because increasing levels of soil calcium from these two treatments did not result in a decrease in percentage unfilled fruit.

The nutritional status of the plant with regard to potassium has been reported to have an effect on the percentage ovarian cavities filled and shelling percentage (Anon., 1944; Colwell & Brady, 1945). High concentrations of potassium in the rooting zone, especially under conditions of limited calcium supply, was reported to result in a lowered shelling percentage and a decreased percentage fruit fill. This situation could occur where drought conditions limit the uptake of calcium from the fruiting zone by the gynophore and fruit, whereas the uptake of potassium could still take place <u>via</u> the roots, from lower soil depths where soil moisture conditions would still be favourable. In the presence of a supply of available calcium in the fruiting zone, high concentrations of potassium in the rooting zone apparently had no affect on fruit filling (Brady, Reed & Colwell, 1948).

In order to obtain information on the relationship between various plant and soil characteristics and the occurrence of unfilled fruit, a series of correlation studies were undertaken, using data from the Dundee experiment. The results obtained from these correlation studies are presented in Tables 19 and 20.

TABLE 19. Correlation coefficients between the percentage unfilled fruit of groundnuts (produced with different calcium carriers) and the chemical composition of soil and plant

Composition attribute	Treatment					
	AL		DL		G	
	r		r		r	
1 Exchangeable Ca in the soil	0,206	NS	0,295	NS	-0,234	NS
2 Exchangeable Mg in the soil	0,305	NS	0,160	NS	0,262	NS
3 Exchangeable K in the soil	-0,266	NS	-0,114	NS	0,243	NS
4 $\frac{1}{2}$	-0,203	NS	0,048	NS	-0,243	NS
5 $\frac{1}{3}$	0,496	NS	0,391	NS	-0,308	NS
6 $\frac{1}{2 \times 3}$	0,214	NS	0,155	NS	-0,358	NS
7 Calcium content of the shell	0,057	NS	0,089	NS	-0,014	NS
8 Potassium content of the shell	0,018	NS	-0,164	NS	-0,188	NS
9 Magnesium content of the shell	0,463	NS	0,213	NS	0,122	NS

Note: A random sample of shells from each plot was chemically analysed. This sample would have included shells from 0-, 1- and 2-kernelled fruit.

TABLE 20. Correlation coefficients between shelling percentage of groundnuts (produced with different calcium carriers) and the chemical composition of soil and plant

Composition attribute	Treatment					
	AL		DL		G	
	r		r		r	
1 Exchangeable Ca in the soil	0,024	NS	-0,456	NS	0,415	NS
2 Exchangeable Mg in the soil	0,194	NS	-0,353	NS	-0,086	NS
3 Exchangeable K in the soil	0,416	NS	0,189	NS	0,034	NS
4 $\frac{1}{2}$	-0,410	NS	-0,098	NS	0,487	NS
5 $\frac{1}{3}$	-0,454	NS	-0,553	*	0,407	NS
6 $\frac{1}{2 \times 3}$	-0,672	**	-0,150	NS	0,551	*
7 Calcium content of the kernel	0,618	**	0,422	NS	0,246	NS
8 Magnesium content of the kernel	0,538	*	0,177	NS	0,091	NS
9 Potassium content of the kernel	0,321	NS	0,496	NS	-0,584	*
10 $\frac{7}{8}$	0,404	NS	0,550	*	0,596	*
11 $\frac{7}{9}$	0,526	*	0,511	*	0,618	**
12 $\frac{7}{8 \times 9}$	0,528	*	0,621	**	0,659	**

No correlation could be found between percentage unfilled fruit and calcium, potassium or magnesium content of either soil or plant. The marked effect of gypsum on the occurrence of unfilled fruit (see Table 17, p. 65) must therefore be ascribed to a factor other than those mentioned above. Shelling percentage data (Table 20) also reveal a poor correlation with calcium, potassium and magnesium content of the soil, but a better correlation begins to emerge where these three constituents are con= sidered in relation to each other (Table 20, sections 4, 5 and 6). It should be noted, however, that a negative correlation was obtained in the case of AL and DL treat= ments, in contrast to the positive correlation obtained in the case of gypsum treat= ments.

No relationship between chemical composition of the shell (as far as calcium, potassium and magnesium was concerned) and shelling percentage was observed. The concentrations of these three elements in relation to each other in the case of kernels was, however, fairly well correlated with shelling percentage (refer especially section 12 in Table 20). A high proportion calcium to potassium and magnesium is correlated with a high shelling percentage.

A very marked seasonal effect was noted in the occurrence of abnormally high percentages unfilled fruit on field experiments throughout Natal. It would appear that a large-scale occurrence of the "pop" condition is mostly associated with a season of below-normal rainfall. A high percentage unfilled pods was obtained from field experiments in the 1968/69 season, followed by a virtually complete absence of "pops" in the 1969/70 season. The growth stage of the plant at which such mois= ture deficiency conditions occur would determine the intensity of the "pop" con= dition. An interruption in the process of calcium uptake over the critical period of calcium requirement would result in abnormally low fruit fill. The stage of growth at which the interruption of calcium uptake takes place would therefore determine the extent of the "pop" condition, and the occurrence of unfilled pods would vary from season to season.

<u>Kernel size</u> Fig. 18

Kernel size was expressed as number of kernels per ounce (28,35 g), as well as the percentage kernels (by weight) riding screens of a set of standard ground= nut grading sieves.

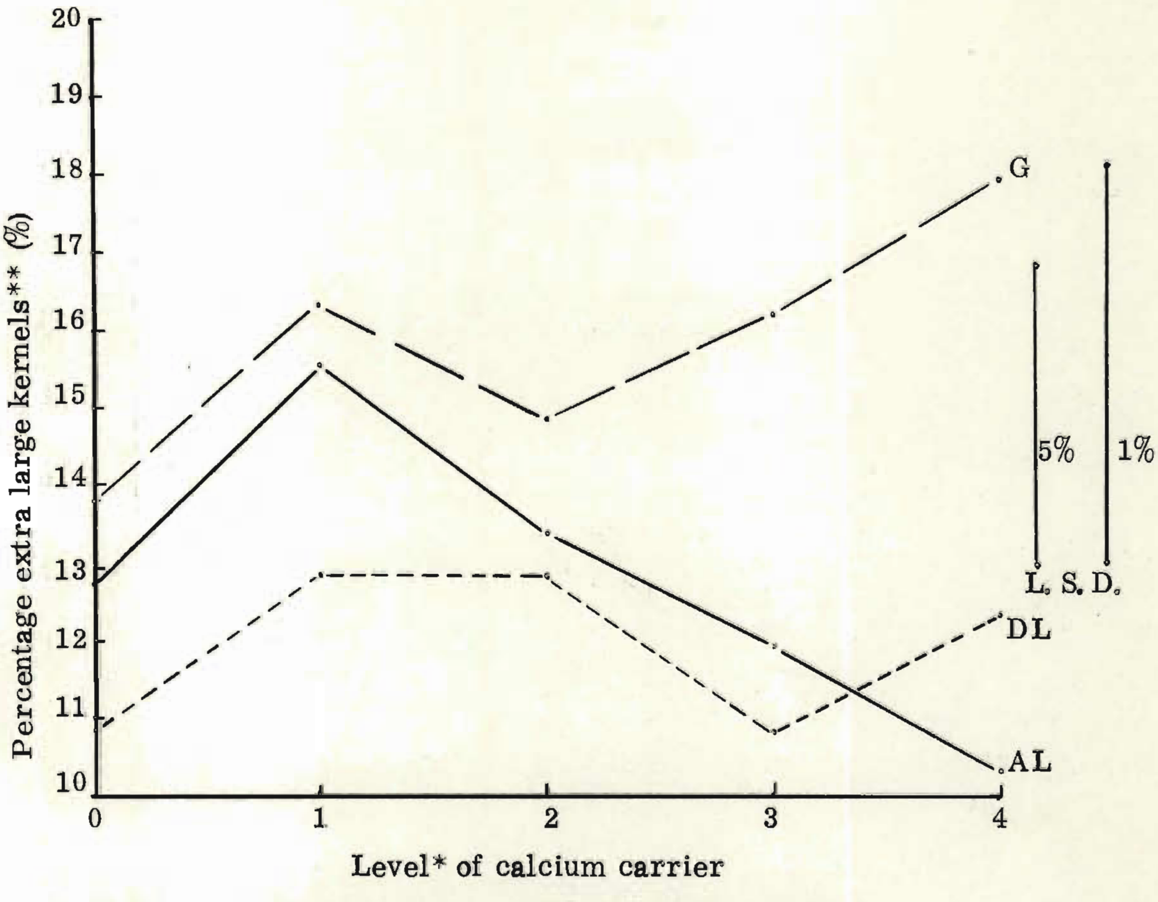

Fig. 18. Effect of calcium carrier treatment on the percentage extra large kernels in the crop

* Refer Table 2 (p. 9) for details

** Extra large kernels - kernels riding a standard 20 x 7,50 mm grading screen

The applied calcium treatments had no effect on the number of kernels per ounce.

The calcium carrier used, however, had an effect on kernel size, measured by means of grading sieves. Only in the case of kernels not passing through the 20 x 7,50 mm grading screen (the ELK kernel size grouping) did the level of calcium application have a significant effect. In the case of the AL treatments an almost sig= nificant increase in percentage extra large kernels was obtained as a result of the AL 1 treatment, followed by a consistent and significant decrease in percentage ELK with higher levels of application. The DL treatments had no significant effect on the percentage ELK. In the case of gypsum treatments a consistent increase in percentage ELK was obtained, even at the higher levels of application.

The highest percentages of ELK, LK, and MK kernels were all obtained from gypsum-treated plots (see Table 21).

TABLE 21. Effect of calcium carrier on groundnut kernel size

Calcium carrier	Kernel size distribution		
	E. L. K. *	L. K. *	M. K. *
	%	%	%
Agricultural lime - AL	12,79	33,21	25,62
Dolomitic lime - DL	11,96	32,36	23,40
Gypsum - G	15,82	40,05	26,02
Untreated control	12,45	32,25	24,18
L. S. D. (P = 0,05)	1,93	3,86	1,90

*Note on kernel size notation:

E. L. K. - Extra large kernels, riding a standard 20 x 7,50 mm grading screen

L. K. - Large kernels, riding a 20 x 6,75 mm screen

M. K. - Medium sized kernels, riding a 20 x 6,00 mm screen

There were no significant difference in kernel size distribution between the AL and DL treatments, although the DL treatments consistently gave the lowest percentages ELK, LK, and MK kernels.

Calcium as plant nutrient appeared to have a relatively minor effect on kernel size and the effect of gypsum cannot be explained in terms of purely a calcium nutritional effect because of the dissimilar effects of the AL and DL treatments.

<u>Oil content of the kernels</u> Fig. 19

In view of the known fact that plump kernels contain a higher percentage oil than shrivelled ones, oil content determinations were made on kernels of uniform plump= ness. Kernels riding the 20 x 6,00 mm grading screen were used for this purpose.

Increasing rates of application of the various calcium carriers resulted in a sig= nificant decrease in oil content, on the average. This decrease in oil content was, however, largely due to the effect of the AL and DL treatments. A marked decrease in oil content was obtained at increasing levels of AL and DL. The gypsum treat= ments had no significant effect in this respect, although a tendency to increase oil content was noted. The oil content of kernels produced on the gypsum-treated plots was significantly higher than that on the AL or DL treated plots, on the average.

The mean oil content of kernels from the untreated, AL, DL and gypsum-treated plots was 44,4, 42,8, 42,1 and 46,2% respectively. The effect of calcium carrier on oil content was of considerably greater magnitude than the amount of calcium applied. A similar response pattern was observed in the case of kernel size data, and it is doubtfull whether changes in oil content could be attributed to a direct treatment effect. It appears more likely that the basis of selection for plump kernels was not fine enough, especially in view of the very marked effects of applied treat= ments on percentage ELK. These large kernels would contain a higher percentage oil, and the changes in oil content observed might have been a secondary effect of

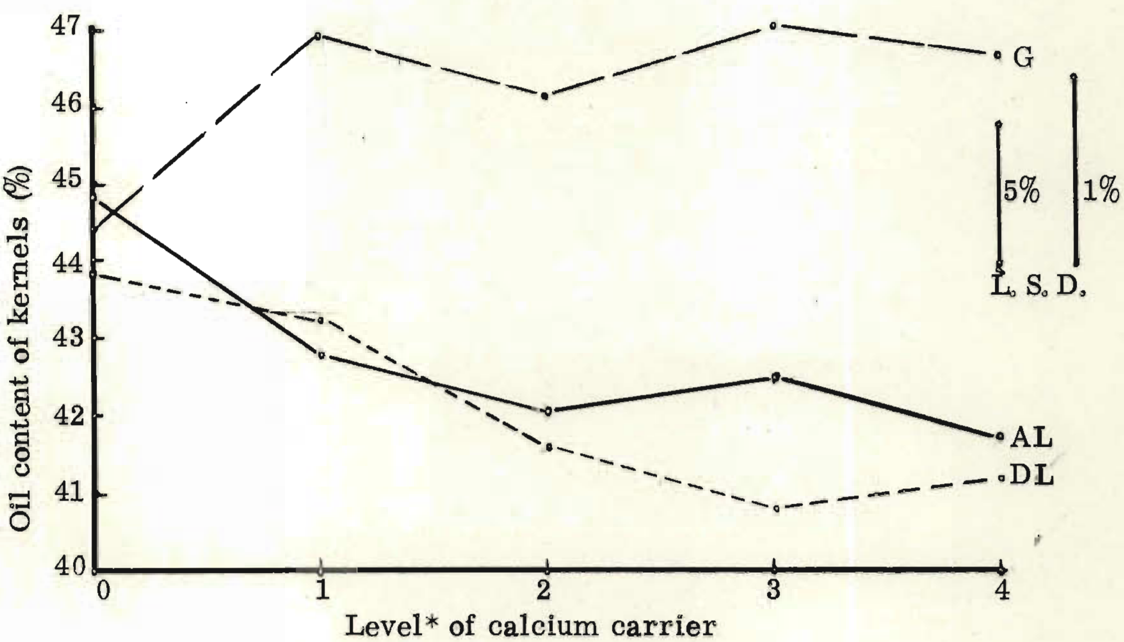

Fig. 19. Effect of calcium carrier treatment on oil content of groundnut kernels

* Refer Table 2 (p. 9) for details

the increased percentage of large kernels.

Summary

The percentage ovarian cavities filled in the groundnut fruit varies markedly from season to season. A high percentage unfilled fruit ("pops") and a low percentage ovarian cavities filled is usually associated with a season with below normal rain= fall. Increasing levels of calcium had little effect in improving any of the above abnormalities. No correlation was observed between the exchangeable calcium, potassium or magnesium content of the soil and the occurrence of unfilled ovarian cavities.

Hence the marked effect of gypsum treatments in highly significantly increasing the percentage of ovarian cavities filled must be ascribed to a mechanism other than just improved levels of calcium in the soil.

Shelling percentage was increased by increasing levels of calcium carrier applica= tion. Poor correlations between shelling percentage and exchangeable calcium, potassium and magnesium content of the soil were observed. The ratio of calcium to potassium and magnesium in the kernels is generally closely associated with shelling percentage. This ratio in the kernels could be altered as a result of an interrupted uptake of calcium by the fruit during temporary drought conditions in the zone of fruit formation.

The calcium carrier treatments had relatively little effect on kernel size. Only in the case of the ELK kernel size grouping did the treatments have a significant ef= fect. The percentage ELK kernels was increased by applications of gypsum, de= creased by increasing applications of AL and hardly affected by applications of DL. It would appear that a factor other than just the amount of calcium applied was responsible for these effects.

The oil content of kernels riding a 20 x 6,00 mm grading screen was little af= fected by the amount of calcium applied, while the oil content of kernels from gypsum-treated plots was significantly higher than that on AL or DL treated plots. These changes in oil content are probably a result of changes in kernel size, rather than a change in oil concentration.

A SUGGESTED LIMING PROGRAMME FOR SPANISH-TYPE GROUNDNUTS ON AN AVALON MEDIUM SANDY LOAM SOIL

Groundnuts are usually grown in rotation with other crops, and its nutritional requirements should be considered in relation to the requirements of the other crop or crops in the rotation. It should be kept in mind that the groundnut plant is an extremely efficient feeder", utilizing plant nutrients at levels in the soil consider= ably below critical levels for most other crops (York & Colwell, 1951; Scarsbrook & Cope, 1956). Visible nutrient deficiency symptoms are seldom observed under field conditions, and the groundnut plant must be regarded as very adaptable nutritionally.

The requirements for a successful liming programme for groundnuts on an Avalon medium sandy loam soil are twofold, viz. the attainment of a favourable soil pH and secondly the provision of an adequate supply of available calcium in the fruiting zone.

Although groundnuts are more tolerant to the toxic conditions associated with a low soil pH than most other crops, increased kernel yields were observed on limed plots (in comparison with gypsum-treated plots), especially over seasons with an average or above-average rainfall. Based on soil pH data obtained from groundnut fields in Northern Natal (Table 4, p. 18) and kernel yield data, presented in Fig. 15 (p. 59), it would appear that approximately 25% of the fields sampled have a pH comparable to that on the untreated or gypsum-treated plots of the Dundee experi= ment and would produce reduced yields in seasons with normal or above-normal rainfall.

The availability of molybdenum is known to be unsatisfactory at a soil pH below 5,5. On this basis molybdenum deficiency conditions (and hence inefficient nitrogen fixation) could be expected on most of the Northern Natal groundnut producing soils unless pH is adjusted by liming. This is important because most of these soils are known to have a very unsatisfactory nitrogen status.

The calcium status of the Avalon medium sandy loam soils sampled is generally very unsatisfactory for groundnut production and linear increases in kernel yield were obtained by applications of either agricultural or dolomitic lime on the Dundee experiment. The highest level of exchangeable soil calcium attained on these treat= ments was 1,45 me 100^{-1} g soil and achieved on about only 27% of the fields sampled in Northern Natal. A calcium deficiency must therefore be regarded as a serious limiting factor to groundnut yields on the majority of Avalon medium sandy loam soils.

The provision of a supply of readily available calcium in the zone of fruit formation is an important requirement for satisfactory kernel yield and quality. These factors become critical in the sandy topsoil of the Avalon medium sandy loam soils upon their drying out, to which they are very susceptible. A more soluble calcium carrier such as gypsum, or a finely ground limestone, in the zone of fruit formation would meet this requirement for readily available calcium, and their beneficial effect would be more evident in drier seasons. The supply and solubility of the calcium carrier in the zone of fruit formation would to a large extent determine the severity of "drought damage" in the groundnut fruit. The common recommendation that lime be applied to the crop preceding groundnuts in the rotation might lead to calcium starvation of the groundnut fruit over seasons with a below normal rainfall, since most of the previously applied lime would have moved out of the zone of fruit formation as a result of leaching and cultivation.

Preference should be given to the use of superphosphate (containing a considerable amount of gypsum) rather than double superphosphate. In view of the danger of creating nutritional imbalances in these poorly buffered soils, it would appear necessary that the calcium status of the soil should further be improved by the use of neutral calcium salts such as gypsum, in addition to the normally used liming materials. In view of the problems associated with temporary moisture shortages in the zone of fruit formation, gypsum should be broadcast and worked in shallowly at planting time. The spreading of gypsum over the rows at flowering time might coincide with a temporary drought period, and result in insufficient movement of calcium into the zone of fruit formation. The applications of gypsum would also provide the sulphur requirements of the crop.

On the basis of the magnesium status of the soils sampled from the Dundee experi= ment, it appears unlikely that this element would be limiting to groundnut yields on the same soil in Northern Natal. Furthermore decreased kernel yields were ob= tained at high levels of magnesium in the soil. The use of dolomitic lime would therefore be unwarranted as a rule.

The suggested programme would result in an increased nitrogen content of vegetative tissue and kernels, as a result of more efficient functioning of nitrogen fixing bac= teria. The phosphate, calcium and potassium content of the vegetative tissue would remain more or less unaffected. With regard to the kernels, the calcium and mag= nesium content would increase and the potassium content decrease with increasing amounts of available calcium and magnesium in the soil.

In view of the adaptability of the groundnut plant to variations in nutritional status of the soil, it would be dangerous to suggest an optimum pH or soil calcium level on the basis of the requirements of the groundnut alone. A high degree of saturation of the exchange complex with calcium might lead to potassium or magnesium defi= ciencies in sensitive crops such as maize or sunflower.

The suggested optimum pH range for groundnuts of between 5,8 and 6,2 (Perry, 1963) produced satisfactory groundnut yields on the Dundee experiment station, but serious zinc deficiency symptoms have been observed in maize at Dundee within this pH range. The Avalon medium sandy loam must, however, be regarded as in= herently deficient in zinc for requirements of maize, and zinc applications would in any case be required for high maize yields.

The level of exchangeable calcium in the soil should be increased to a level of 1,45 me 100^{-1} g soil (the highest level attained in the Dundee experiment) provided soil pH is not increased above the recommended levels. The less easily leached lime-supplied calcium should be supplemented with readily available gypsum-cal= cium in such a way as to prevent an excessively high pH, but at the same time buil= ding up the level of available calcium in the soil.

The relationship between calcium and boron in plant metabolism suggests interesting possibilities as far as the calcium requirements of groundnuts are concerned. In Chapter III the theory is suggested that an adequate level of soluble boron in the plant would lead to a higher level of efficiency of the calcium in the plant. If the level of soluble boron in the plant could be kept at a sufficiently high level over drought periods, the efficiency of calcium accummulated in the plant over the ear= lier stages of the growing season, might be sufficiently high to tide the plant over periods of temporary calcium deficiency. In this way the necessity for high rates of application of gypsum might be overcome.

Increasing levels of gypsum in the soil would result in an increased percentage large kernels being produced. Since these large kernels would contain a higher percentage oil, an increased oil yield per hectare would be obtained.

CHAPTER III

STUDIES ON THE OCCURRENCE, CAUSE AND CONTROL OF HOLLOW HEART AND BLACK PLUMULE DAMAGE IN GROUNDNUT KERNELS

INTRODUCTION

Numerous workers have reported on "concealed" or "hidden" damage in groundnut kernels (Harris & Gilman, 1957). Under these terms any damage or defect of the shelled kernel which adversely affects quality and which cannot be detected without splitting the kernels are included. Wilson (1947) and Long (1951, p. 284) mentioned three different types of interior damage, two of which seemed to be associated with organisms, while the third appeared to be physiological in nature. Subsequently two distinct forms of internal damage that are physiological in nature have been identified and are known as "hollow heart" and "black plumule".

Hollow Heart

Several workers (Harris & Gilman, 1957; Cox, 1962; Cox & Reid, 1964; Harris & Brolman, 1966a) emphasized the effect of boron on the internal condition of the groundnut kernel. Harris & Gilman (1957) suggested the term "hollow heart" for symptoms in the kernel caused by a boron deficiency. The condition is described as a knurled, hollow, off-coloured area in the cotyledon. The depression in the center of the cotyledon may vary from very shallow and slightly coloured to deep and black according to the severity of the deficiency condition. In severe cases the plumule may be affected, and is then pointed, poorly developed or even completely destroyed.

The hollow heart deficiency condition has been practically eliminated by applying boron, both in nutrient culture and field experiments (Cox & Reid, 1964; Harris, 1968).

PLATE 4. Hollow heart damage in groundnut kernels, indicating from left to right respectively slight, medium, severe and very severe damage

Black plumule

The earliest report on discoloured embryos in groundnut kernels was made by Harris and Gilman (1957). Hartley and Bailey (1959) described kernels that are normal in appearance except for the plumule which may vary in colour through various shades from light yellowish tan to dark brown. Harris and Brolman (1963) found that applications of agricultural lime corrected this dark plumule condition.

Hollow heart and black plumule damage in groundnut kernels was first observed in Natal during the 1967/68 season. These symptoms occurred on a large scale during the 1968/69 season, and an intensive study of these phenomena was made during this period. Material was obtained from groundnut field experiments throughout the Natal Region, and the kernels, split by hand, were examined for the two forms of damage.

PLATE 5. Black plumule damage in groundnut kernels

The results reported here were obtained from a number of different field ex= periments, all laid out on an Avalon medium sandy loam soil, the majority of which were not designed specifically for the study of hollow heart and black plumule in groundnuts. Details on these experiments are given only where relevant to the results. The cultivar "Nelson Spanish" was used in all these trials, unles other= wise stated.

FACTORS DETERMINING THE INTENSITY OF OCCURRENCE OF HOLLOW HEART AND BLACK PLUMULE IN GROUNDNUT KERNELS

Climate

Since only relatively small quantities of boron are required by plants, the margin between sufficiency and deficiency is small and the balance is readily disturbed. As a result climatic factors, especially rainfall, can cause marked seasonal fluctuations in boron supply, especially since soluble borates are easily leached. The occurrence of a boron deficiency may therefore be expected to be erratic and rather unpredictable.

The marked seasonal variation in intensity of occurrence of hollow heart and black plumule damage in groundnut kernels, observed in experiments conducted in Natal, is indicated by the data presented in Table 22.

TABLE 22. The occurrence of black plumule and hollow heart damage on specific plots over a number of growing seasons*

Season	Rainfall	Treatment				
	mm	Untreated	DL1	DL2	DL3	DL4
		Percentage black plumule kernels				
1967/68	484	22	16	2	30	6
1968/69	542	42	27	36	44	32
1969/70	646	0	0	1	0	1
		Percentage hollow heart kernels				
1967/68	484	38	10	24	22	28
1968/69	542	23	24	29	55	58
1969/70	646	4	4	4	12	12

*Data obtained from the experiment described in Chapter II

A number of workers have indicated that the incidence of boron deficiency symptoms in plants is closely correlated with the occurrence of drought conditions (Brown & King, 1940; Schuster & Stephenson, 1940; Hobbs & Bertramson, 1950; Stinson, 1953). Whilst total boron may be concentrated in either the surface or lower horizon of the soil, depending on how the soil was formed, the water soluble (available) boron is usually concentrated in the surface horizons of well drained soils (Anon., 1960). Thus it is claimed that when soils are dry and nutrient uptake from the surface horizons is restricted, plants might be unable to absorb sufficient boron from the lower soil horizons, and so become deficient. The fact that, in the Dundee field experiment applications of gypsum could clear boron deficiency symptoms in groundnut kernels (see Fig. 22, p. 93), even over a very dry season such as 1968/69, indicates that the above theory does not explain the whole situation.

Fertilizer practices

General

Fig. 20 and 21

In order to obtain preliminary information on the effect of trace elements on the occurrence of hollow heart and black plumule in groundnuts, an observational trial was laid out on an Avalon medium sandy loam soil on the Dundee Research Station in 1968. The treatments applied are summarised in Table 23 and data on the incidence of hollow heart and black plumule on these plots are presented in Figures 20 and 21.

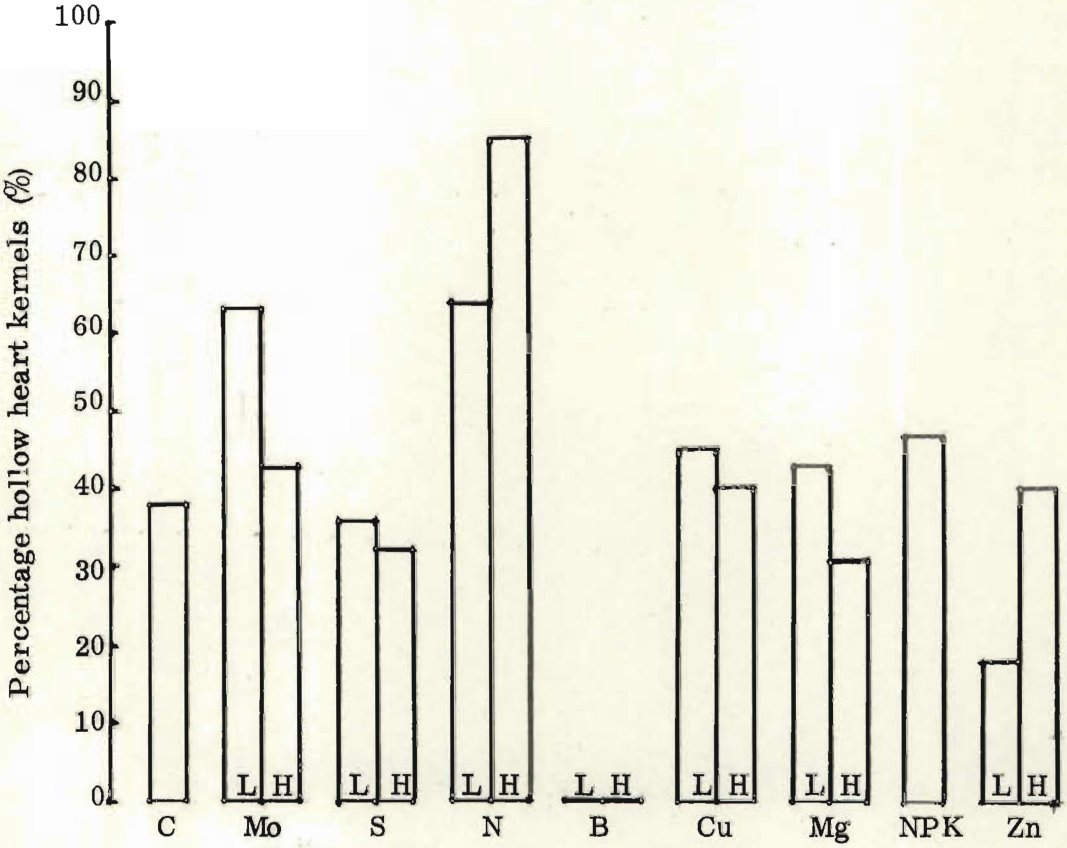

Fig. 20. The effect of different plant nutrient applications to the soil on the occurrence of hollow heart damage in groundnut kernels

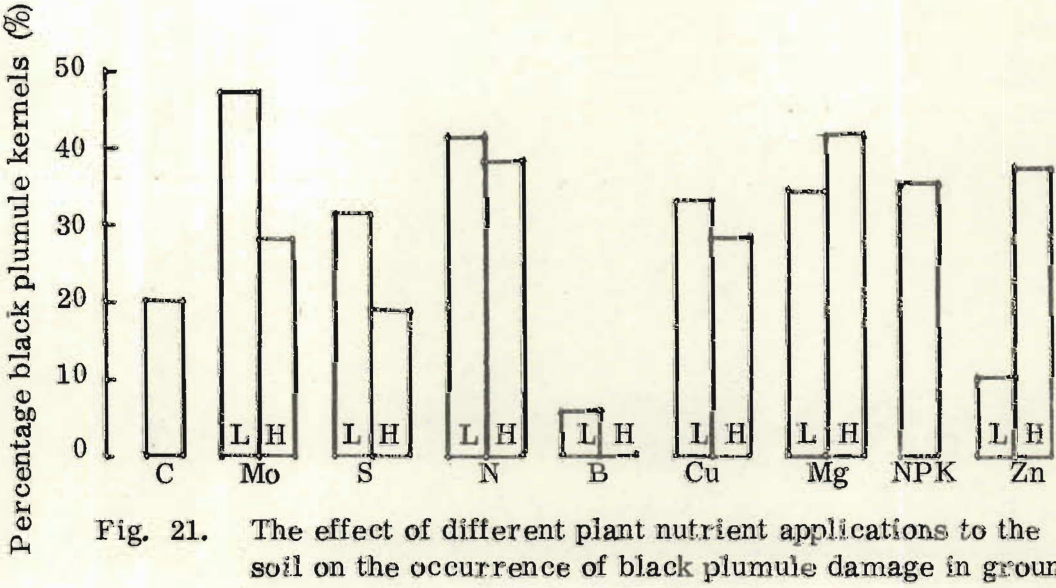

Fig. 21. The effect of different plant nutrient applications to the soil on the occurrence of black plumule damage in groundnut kernels

TABLE 23. Nutrient treatments applied to observational trial, Dundee Research Station, 1968/69

Code	Plant nutrient applied	Carrier used	Amount applied
C	Untreated control	-	-
Mo L Mo H	Molybdenum	$Na\ Mo\ O_4 . 2H_2O$	260 g/ha 520 g/ha
S L S H	Sulphur	Flowers of sulphur	63 kg/ha 126 kg/ha
N L N H	Nitrogen	Urea (46% N)	105 kg/ha 210 kg/ha
B L B H	Boron	Borax	13 kg/ha 26 kg/ha
Cu L Cu H	Copper	$Cu\ SO_4$	26 kg/ha 52 kg/ha
Mg L Mg H	Magnesium	$Mg_2\ SO_4$	52 kg/ha 104 kg/ha
NPK	Mixture (6,3% N, 9,4% P, 6,3% K)		530 kg/ha
Zn L Zn H	Zinc	$Zn\ SO_4$	26 kg/ha 52 kg/ha

Although a biometrical analysis of the results was not possible, it was obvious that applications of borax were effective in eliminating hollow heart and markedly reduced black plumule damage (especially at the higher level of application).

It is of interest to note that the incidence of both hollow heart and black plumule ap= peared to be markedly increased by applications of nitrogenous fertilizer (urea) and the lower level of sodium molybdate. The lower level of zinc-sulphate, on the other hand, appeared to decrease the frequency of occurrence of both hollow heart and black plumule.

Nitrogen, phosphate and potash

The occurrence of hollow heart and black plumule was investigated in various biometrically designed fertilizer trials laid out on the Dundee research station. Confirmation of frequency of hollow heart being increased by applications of urea (46% N) was obtained from two separate field experiments, the results of which are presented in Table 24.

TABLE 24. Effect of nitrogenous fertilizer application on occurrence of hollow heart and black plumule in groundnuts

	Level of N applied	Hollow heart	Black plumule
	kg/ha	%	%
Experiment N Dd 3/6/1 (1968/69)	0	10,5	16,3
	80	31,6	29,6
	$N_1 - N_0$	21,1**	13,3**
Experiment N Dd 3/6/2 (1968/69)	0	9,7	21,5
	80	16,9	30,1
	160	22,2	28,9
	$N_1 - N_0$	7,2**	NS
	$N_2 - N_1$	5,3*	NS

* Significant at the 5% level
** Significant at the 1% level

The percentage black plumule was increased in one of these experiments (refer Table 24).

The effect of superphosphate was less clear. It had no effect on hollow heart damage when applied by itself. Increasing applications of superphosphate in the presence of dolomitic lime, however, resulted in a marked increase in hollow heart damage. This response pattern was observed on both above experiments. Applications of superphosphate did not affect the frequency of occurrence of black plumule damage at all, despite its high calcium content.

The effect of applications of potassium chloride on hollow heart damage was variable. A highly significant increase in frequency of black plumule damage was observed in one field experiment following on the application of 52 kg/ha potassium chloride (50% K). As shown in Table 28 (p.111) the ratio kernel Ca : kernel K is generally well correlated with the intensity of black plumule damage.

<u>Lime and gypsum treatments</u> Fig. 22 and 23

Kernel samples were taken from the Dundee experiment described in Chapter II in order to determine the effect of calcium carrier treatments on the occurrence of hollow heart and black plumule damage. The data presented in Figures 22 and 23 were obtained over the 1968/69 season.

Increasing levels of calcium application in the form of agricultural and dolomitic lime, had no statistically significant effect on the occurrence of either form of internal damage. Increasing the calcium content of the kernels from an average of 125 ppm to 145 ppm in the case of the AL treatment actually resulted in an increased percentage black plumule kernels, despite the fact that black plumule is generally regarded as a calcium deficiency symptom.

Applications of gypsum resulted in a highly significant decrease in percentage hollow heart and black plumule damage. In the case of gypsum treatments an average calcium content of the kernels at 180 ppm was associated with approximately 7% black

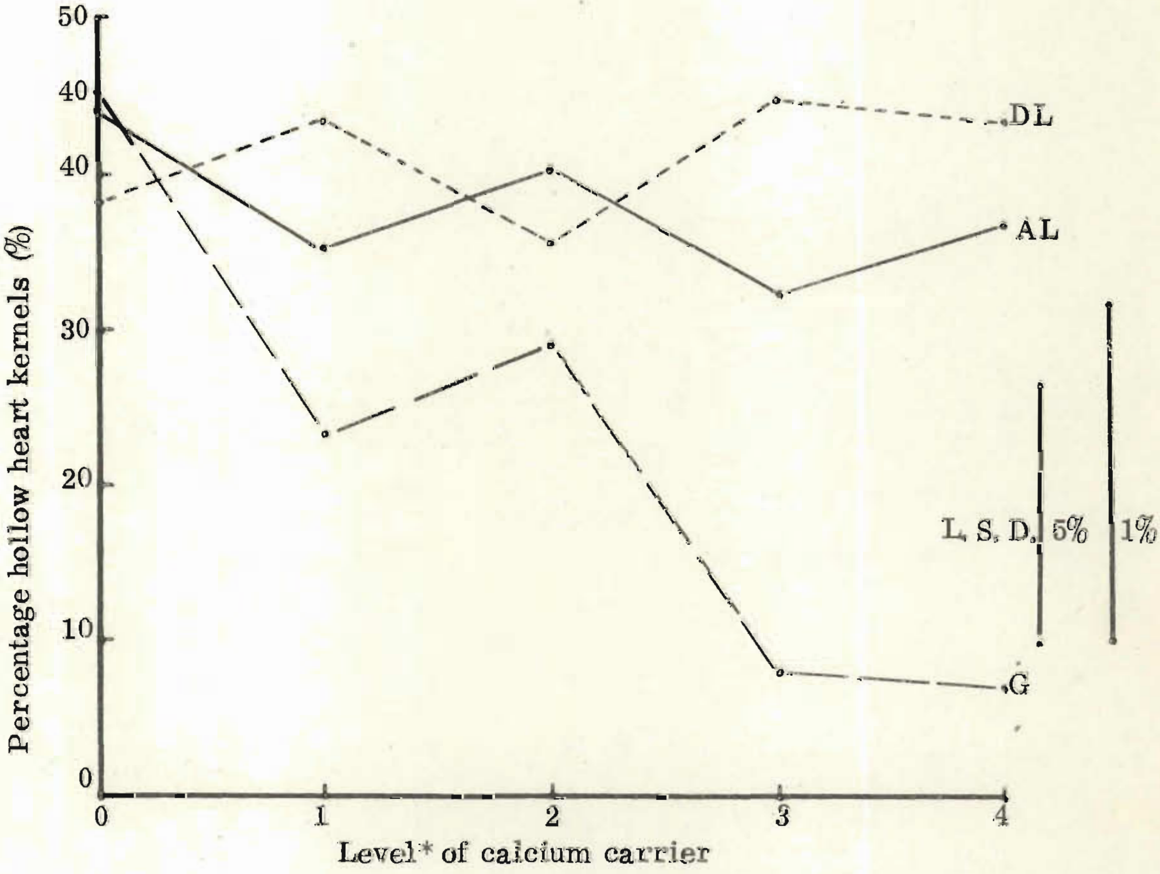

Fig. 22. Effect of calcium carrier treatment on percentage hollow heart kernels

* Refer Table 2 (p. 9) for details

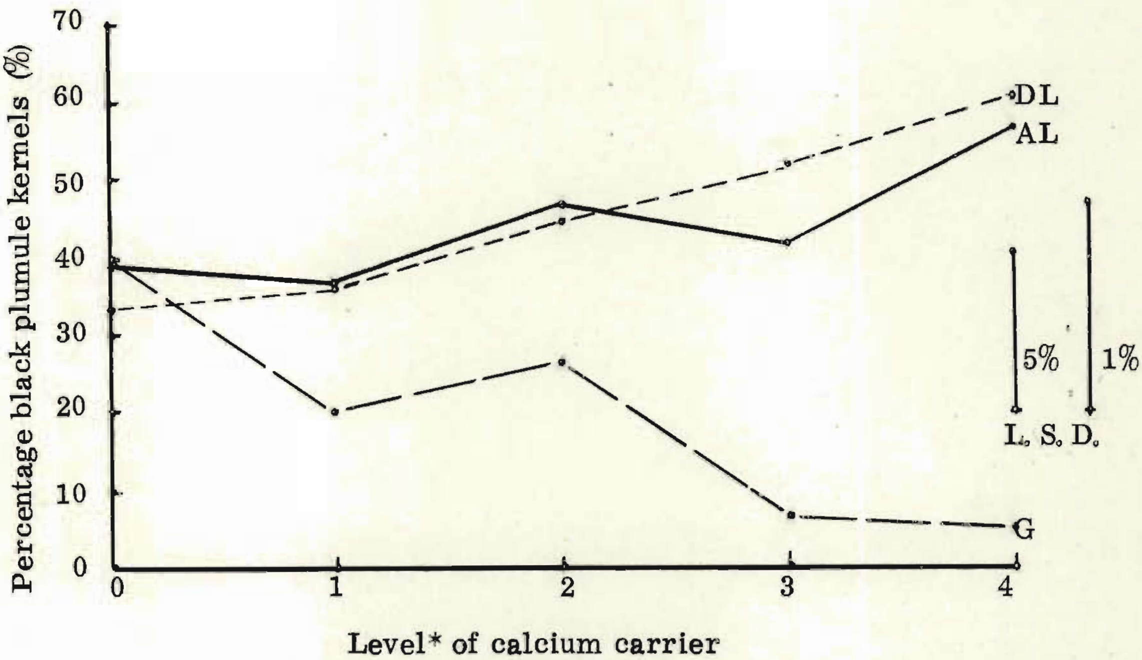

Fig. 23. Effect of calcium carrier treatment on percentage black plumule kernels

* Refer Table 2 (p. 9) for details

plumule kernels, compared with 41% black plumule kernels associated with 169 ppm calcium in the case of the AL treatments. The average percentage hollow heart and black plumule kernels (over all levels of application) in the case of untreated, AL, DL and gypsum-treated plots are presented in Table 25.

TABLE 25. Effect of calcium carrier on percentages of hollow heart and black plumule kernels

Calcium carrier	Hollow heart kernels	Black plumule kernels
	%	%
Untreated control	42,6	37,3
Agricultural lime - AL	37,8	44,0
Dolomitic lime - DL	41,0	45,3
Gypsum	22,5	19,8
L. S. D. (P = 0,05)	8,1	10,0
(P = 0,01)	10,8	13,5

It is to be noted that the percentage hollow heart and black plumule kernels in the case of gypsum-treated plots appears to be unduly high. The significant reductions in both forms of concealed damage were only obtained at the higher levels of gypsum appli= cation, as indicated in Fig. 22.

The extent of concealed damage experienced in this experiment over the 1968/69 season was the most severe yet reported in literature. The most severe damage noted on any single plot of the above experiment was 64% hollow heart and 90% black plumule damaged kernels.

The calcium carriers used were analysed for the presence of boron as impurity, but no detectable amounts were observed in any of them.

It would appear that the gypsum-treatments in some way affected the availability of boron in the soil.

Cultural practices

Cultivar

Figures 24 and 25

Kernels obtained from the cultivars used in a groundnut yield trial (experiment N Dd 3/3 - 1968/69) were examined to determine the sensitivity of various cul= tivars to hollow heart and black plumule damage. The cultivars examined were mostly small-seeded Spanish-types suitable for production under dryland conditions.

A very marked difference in frequency of occurrence of both forms of internal damage was noted amongst cultivars. The order of response of cultivars differed in respect of hollow heart and black plumule damage. A low percentage hollow heart damage was, for example, observed in Natal Common (the cultivar generally produced in Natal). It was, however, more susceptible to black plumule damage than most other cultivars. Nelson Spanish, the cultivar mostly used in the local groundnut research programme, ranked high in respect of susceptibility to both forms of damage. No significant correlation between any particular cultivar characteristic and the oc= currence of hollow heart or black plumule damage could be established.

Carver and Hull (1945), Bledsoe, Harris and Clark (1945), and Harris and Gilman (1957) reported differences in response of groundnut cultivars to applications of boron, while various workers (Gore, 1941; West, 1942; Sellschop, 1962) have reported pronounced differences between groundnut cultivars in their calcium requirements.

Stage of maturity

Cox and Reid (1964) reported that a comparison between very immature, immature

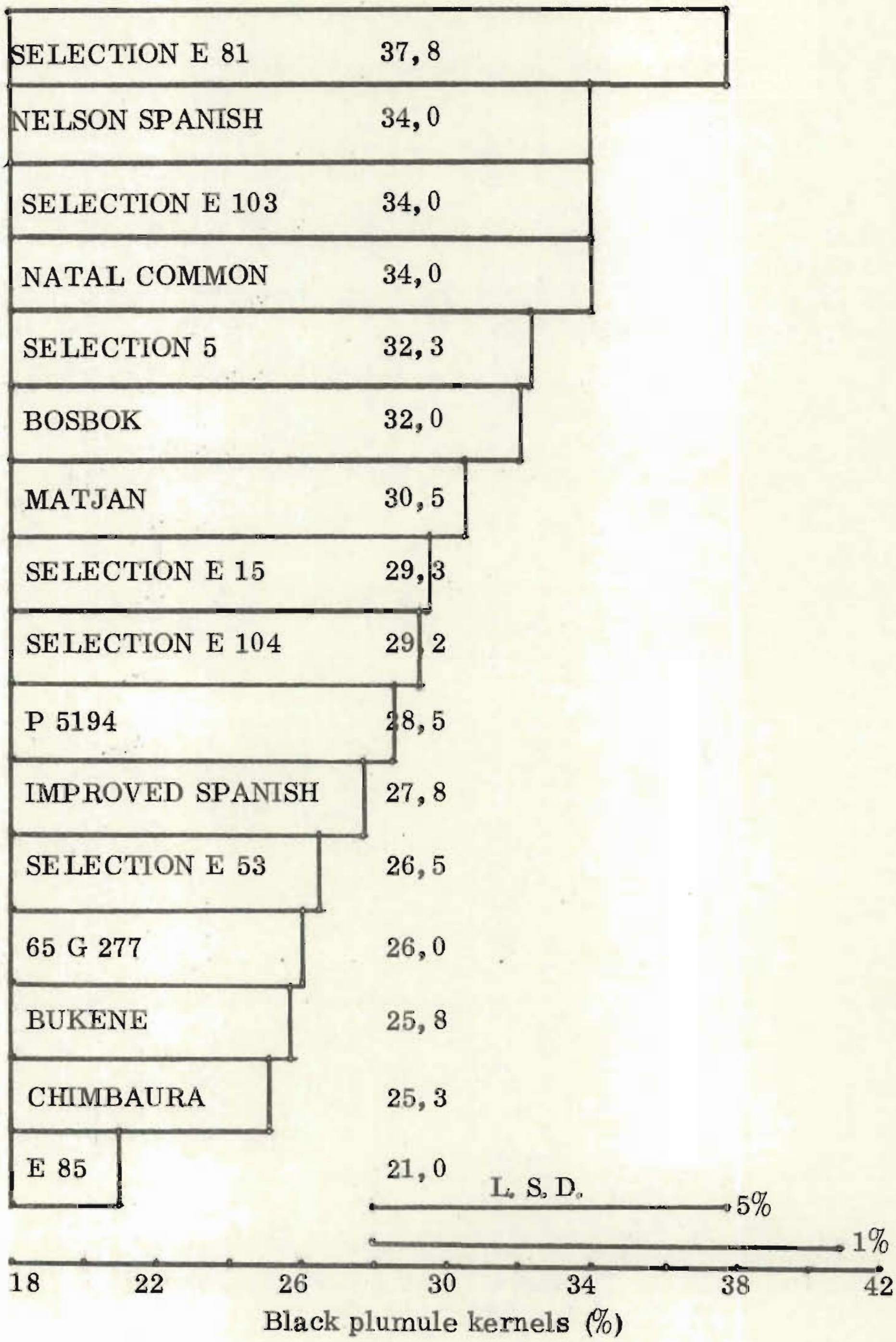

Fig. 24. Occurrence of black plumule in different groundnut cultivars

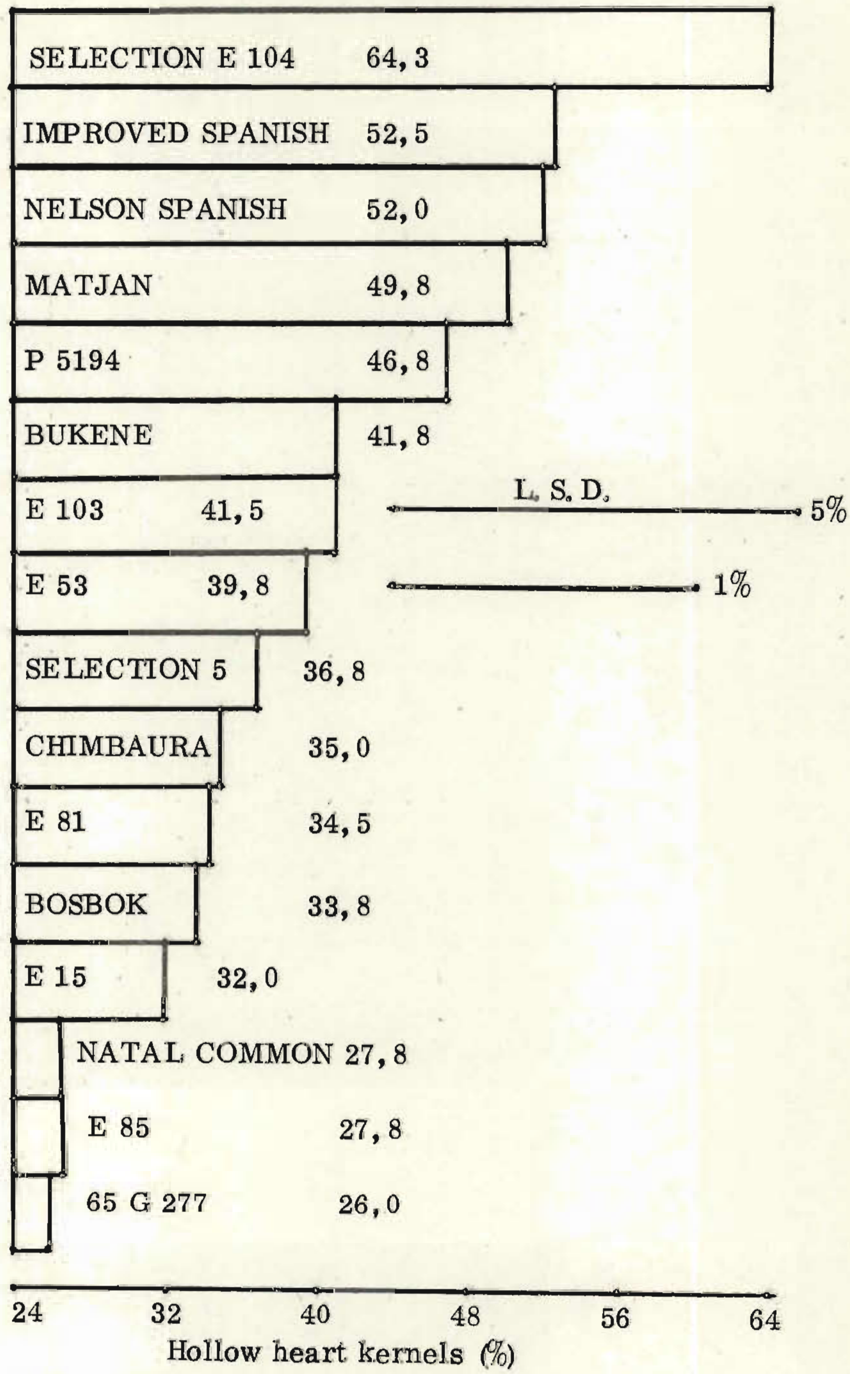

Fig. 25. Occurrence of hollow heart in different groundnut cultivars

and mature kernels of the NC 4X cultivar revealed 3,1, 10,1 and 20,1% black plumule and 3,3, 3,2 and 3,6% hollow heart respectively. A similar determination was carried out in an experiment conducted on the Dundee experiment station over the 1968/69 season. The three Spanish-type and one Valencia cultivar used were harvested at weekly intervals beginning 112 days after planting.

Harvesting dates had no statistically significant effect on the occurrence of either hollow heart or black plumule damage. Being early-maturing it is possible that these cultivars were at a later stage of maturity at the time of the earliest harvest, in comparison with the maturity groupings used by Cox and Reid.

Leafspot control

The prevention of leafspot diseases (mainly Cercospora personata and C. arachidicola) by means of a fortnightly treatment with a fungicide (Dithane M 45) had no effect on the occurrence of either form of damage, even though these treatments resulted in a highly significant increase in hay yield.

Plant population density

The intensity of occurrence of hollow heart and black plumule damage was investi= gated in a plant population density - fertilizer trial (experiment N Dd 3/6/2) at Dundee in 1968/69 and the results obtained are presented in Table 26.

TABLE 26. Effect of plant espacement and level of dolomitic lime application on the occurrence of hollow heart damage in groundnut kernels

Amount of dolomitic lime		Plant espacement 76 x 15 cm	38 x 7,6 cm
kg/ha		%	%
0		13,5	21,3
260		14,6	15,6
	Mean	18,5	14,0
	L. S. D. (P = 0,05)	3,9	

A significantly higher percentage hollow heart damaged kernels was observed at the higher plant population density but an application of 260 kg/ha dolomitic lime decreased the percentage hollow heart kernels very significantly. None of the above treatments affected the percentage black plumule kernels.

Summary

Although the occurrence of black plumule and hollow heart damage in groundnut kernels seems to be closely associated with the occurrence of drought conditions, intensification of production through increasing use of fertilizer and high plant population densities could be expected to make the occurrence of these forms of internal damage more common. A change-over to improved cultivars could also be expected to bring about changes in the pattern of occurrence.

Application of agricultural and dolomitic lime had little effect on the occurrence of these deficiency symptoms, in spite of the fact that these treatments resulted in a marked increase in soil pH and calcium content of the soil and the fruit. Applications of gypsum resulted in highly significant decreases in the occurrence of both hollow heart and black plumule damage.

Applications of borax at a rate of 26 kg/ha virtually eliminated both forms of damage.

EFFECT OF SOME SOIL CHEMICAL FACTORS ON HOLLOW HEART AND BLACK PLUMULE IN GROUNDNUTS

Calcium, potassium and magnesium content of the soil

As reported in the previous section, additions of agricultural and dolomitic lime to an Avalon medium sandy loam soil had little effect on the occurrence of hollow heart and black plumule damage in groundnut kernels. From a study of data presented in Table 27 it is clear that there is no obvious relationship between the calcium status of the soil and the occurrence of either hollow heart and black plumule. It will be noted that a highly significant increase in the exchangeable calcium content of the soil in the case of the AL and DL treatments had very little effect on the occurrence of hollow heart and black plumule damage in kernels.

TABLE 27. Correlation coefficients between chemical composition of the soil and occurrence of black plumule and hollow heart in groundnut kernels

Soil attribute	Treatment					
	AL		DL		G	
			BLACK PLUMULE			
	r		r		r	
1 Exchangeable Ca	0,334	NS	0,554	*	-0,592	*
2 Exchangeable Mg	0,238	NS	0,452	NS	0,250	NS
3 Exchangeable K	-0,238	NS	-0,011	NS	0,018	NS
4 $\frac{1}{2}$	0,209	NS	-0,036	NS	-0,597	*
5 $\frac{1}{3}$	0,655	**	0,539	*	-0,599	**
6 $\frac{1}{2 \times 3}$	0,452	NS	-0,018	NS	-0,654	**

Table 27 (continued)

Soil attribute	Treatment					
	AL		DL		G	
			HOLLOW HEART			
	r		r		r	
7 Exchangeable Ca	0,353	NS	0,266	NS	-0,573	*
8 Exchangeable Mg	0,118	NS	0,118	NS	-0,573	*
9 Exchangeable K	-0,079	NS	-0,172	NS	-0,010	NS
10 $\frac{7}{8}$	0,585	*	0,251	NS	-0,626	**
11 $\frac{7}{9}$	0,461	NS	0,377	NS	-0,579	**
12 $\frac{7}{8 \times 9}$	0,424	NS	0,295	NS	-0,674	**

The marked reduction of hollow heart and black plumule in gypsum treatments (refer Figures 22 and 23, pages 93 and 94) could therefore hardly be ascribed to its action as calcium carrier. However, being a more soluble calcium carrier it could have supplied calcium at a critical growth stage when other calcium carriers, due to lower solubility, were more or less inactive. This possibility will be discussed later. It is of interest to note that the incidences of both hollow heart and black plumule were significantly negatively correlated in the gypsum treatments with both the exchangeable calcium content of the soil and the frequence of damaged kernels. In the case of AL and DL treatments a positive (though not significant) relationship was observed.

The potassium and magnesium status of the soil had little direct influence on the occurrence of hollow heart and black plumule in the kernels. The strongest corre= lation observed was between the ratio

$$\frac{\text{Exchangeable calcium in the soil (me } 100^{-1} \text{ g soil)}}{\text{Exchangeable potassium in the soil (me } 100^{-1} \text{ g soil)}},$$

and the percentage hollow heart kernels. This correlation was highly significant and negative in the case of the gypsum treatments, but non-significantly positive for the AL and DL treatments.

<u>Boron status of the soil</u> Fig. 26

Water soluble boron appears to be a better measure of available soil boron than acid soluble or total boron (Berger & Truog, 1940; Berger, 1949), and is generally well correlated with plant response. This fraction of soil boron is considered to be the form available for uptake by the plant (Smith & Anderson, 1955).

The water soluble boron content of the soil was determined on all plots of the Dundee experiment described in Chapter II. The available boron was extracted by refluxing with hot water according to the method of Berger & Truog (1944). The boron con= tent of the extract was then determined by the method of Dible, Truog and Berger (1954) incorporating minor modifications. The results obtained are presented in Fig. 26.

The mean water soluble boron content of the soil on untreated plots was 0,218 ppm at the end of the 1968/69 season. This level of available boron must be regarded as barely sufficient for normal growth, because boron deficiency symptoms fre= quently occur when the available boron content on sandy and light textured soils fall below 0,2 ppm (Anon., 1960). Winsor (1952) found the available boron content of a soil to be at a maximum in a wet summer, decreasing markedly in a dry sum= mer. The organic matter content of the Avalon medium sandy loam soils are very low, with an average carbon content of 0,61% (a C : N ratio of 14 : 1). Since the available boron supply in the soil is very closely dependent on the organic matter fraction in the soil (Wallace, 1951), a boron deficient condition could be expected.

The calcium carrier treatments had little effect on the water soluble boron content of the soil. A slight decrease in available boron was noted on the AL and DL treated

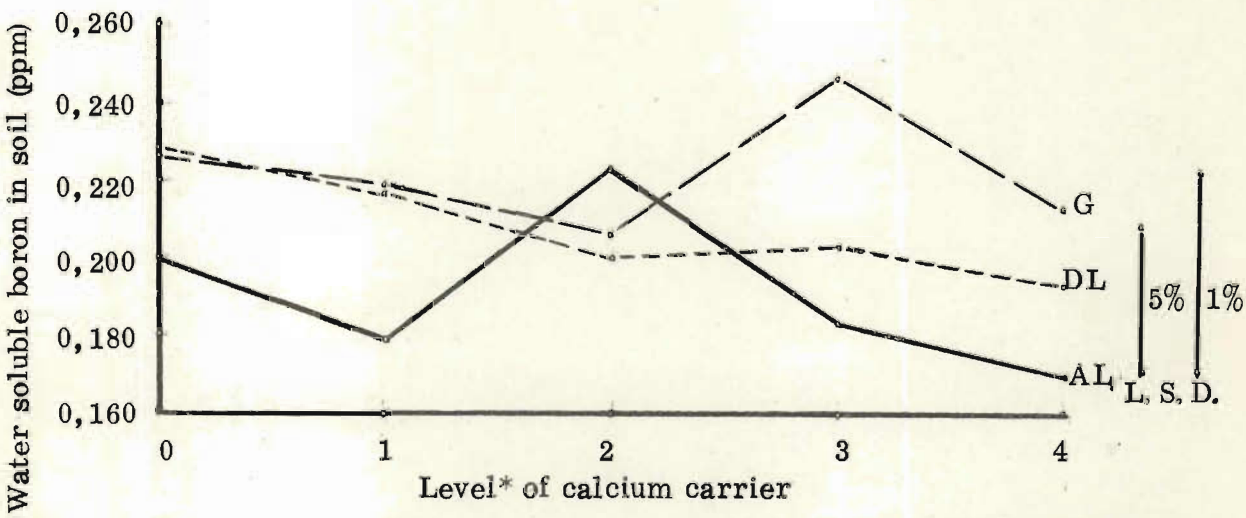

Fig. 26. Effect of calcium carrier treatment on water soluble boron content of an Avalon medium sandy loam soil

* Refer Table 2 (p. 9) for details

plots, in agreement with the generally reported phenomenon of decreased availability of boron on limed soils (Naftel, 1937). The difference in available boron resulting from the different treatments was, however, not significant.

The higher levels of boron associated with the G 3 and G 4 treatments corresponds with the lower levels of hollow heart and black plumule damage observed in the field experiment.

Summary

The calcium, potassium and magnesium content of the soil appears to be of little value for predicting the intensity of occurrence of hollow heart and black plumule damage under the conditions of the Dundee experiment. It appeared that the action of gypsum in reducing both these forms of internal damage was caused by a factor other than its calcium supplying power.

The available boron content (water soluble boron) of the Avalon medium sandy loam is low enough to predict that boron deficiency conditions will occur on this soil, especially during dry seasons. The calcium carrier treatments had relatively little effect on the available boron status of the soil. A more favourable boron status was obtained at the higher levels of gypsum application, although not significantly better than on untreated control plots.

FIXATION OF BORON IN THE SOIL

General

It is well known that boron applied to soils in irrigation water is adsorbed or "fixed" to a variable extent, and that an equilibrium exists between adsorbed and dissolved boron (Hatcher & Bower, 1958; Biggar & Fireman, 1960; Hingston, 1964). Since plants respond to dissolved boron only (Hatcher, Blair & Bower, 1959), adsorption of boron could result in boron deficiency symptoms appearing in the plant.

Possible causes of boron fixation

Overliming

Naftel (1937), Midgley and Dunkley (1940) and Wolf (1940) showed overliming to be a possible cause of boron fixation and the occurrence of boron deficiency conditions. Overliming injury has also been associated with a decreased boron content in the plant (Muhr, 1940). A study of results obtained from experiments conducted at Dundee indicates that overliming had in none of these trials been a factor contributing to the occurrence of black plumule or hollow heart. An increase in soil pH from 4,9 to 6,2 (Fig. 1, p. 16) was not accompanied by a significant increase in either form of damage (Fig. 22 and 23, pages 93 and 94). The highest pH attained was probably still too low to result in "overliming injury". Bingham, Elseewi and Oertli (1970) reported boron absorption by excised barley roots to be non-cumulative, rapid and unaffected by pH variations of the substrate in the acid range. However, increases in pH above 7 resulted in sharp reductions in boron absorption. Both forms of damage occurred equally severe on unlimed plots.

Soil moisture conditions

Boron fixation as a result of particular microclimatic condition in the soil must be considered, especially in view of the numerous reports indicating a close association between climate and the intensity of boron deficiency symptoms. Crops on the same field, subjected to identical treatment, often show very different intensities of boron deficiency in two successive seasons (see Table 22, p. 86).

Parks (1944) subjected soil samples to wetting and drying treatments, simulating conditions expected to occur in soils over a dry period. These treatments were car= ried out at different drying temperatures and in the absence and presence of dif= ferent liming materials. Fixation of added boron varied from none to almost com= plete fixation with the increase in the number of drying cycles. Bigger and Fireman (1960) reported similar results. Parks observed native extractable boron to remain the same or even increase after a number of drying cycles.

The effect of variable soil moisture conditions on the degree of boron fixation in an Avalon medium sandy loam soil was examined as follows.

Airdry soil samples obtained from the AL 4, G 4 and untreated plots of the experiment described in Chapter II were kept in polythene containers and moistened to field capacity. Deionised water (tested boron-free) was used for this purpose. These samples were kept at F. M. C. for 24-hours, and the following treatments then applied:

1. Samples kept at F. M. C. for 24-hours.
2. Samples dried in a forced-draught oven for 2 hours (constant weight was at= tained after 2 hours of drying), rewetted to F. M. C., dried for a further 2 hours and the water soluble boron in the soil extracted in boiling water (Berger and Truog, 1944). This treatment is called two wet-dry cycles.

3. Samples subjected to four wet-dry cycles (as described above), and available boron determined.
4. Samples subjected to six wet-dry cycles.
5. Samples subjected to eight wet-dry cycles.

The above 5 wetting-drying treatments were done on soil samples obtained from the AL 4, G 4 and untreated plots. Each treatment was replicated four times. The drying treatments were carried out at a temperature of $50^{o}C$, the samples for treatment 1 being kept at room temperature. After the hot water extraction of boron from these samples, the total boron in the extract was determined according to the method of Dible, Truog and Berger (1954).

The results obtained from this experiment are presented in Fig. 27.

The wetting and drying treatments resulted in a marked decrease in water soluble boron content of soil from untreated and lime-treated plots. No decrease, on the average, was obtained in the case of the gypsum-treated plots.

From the results of the abovementioned experiment it would appear that gypsum-treatment of the Avalon medium sandy loam soil prevented the fixation of boron into an unavailable form. This fixation process appears to be associated with seasons in which periods of soil moisture stress occur. Very little hollow heart and black plumule damage occurs in a season with normal or above normal rainfall.

A number of workers have reported on the effect of sulphur or the sulphate-ion on boron availability in soils. Cook and Millar (1939) found that the application of sulphur in lowering soil pH from 7,5 to 6,2 liberated boron by an amount equal to the application of 11,2 kg/ha borax. Wolf (1940) reported the boron content of plants growing on soils receiving moderate applications of gypsum to be greater than that of plants grown on untreated soil. It is of interest to note reports by Wear (1956) on the effect of $CaCO_3$, Na_2CO_3 and $CaSO_4$ on the uptake of zinc by sorghum. The up=

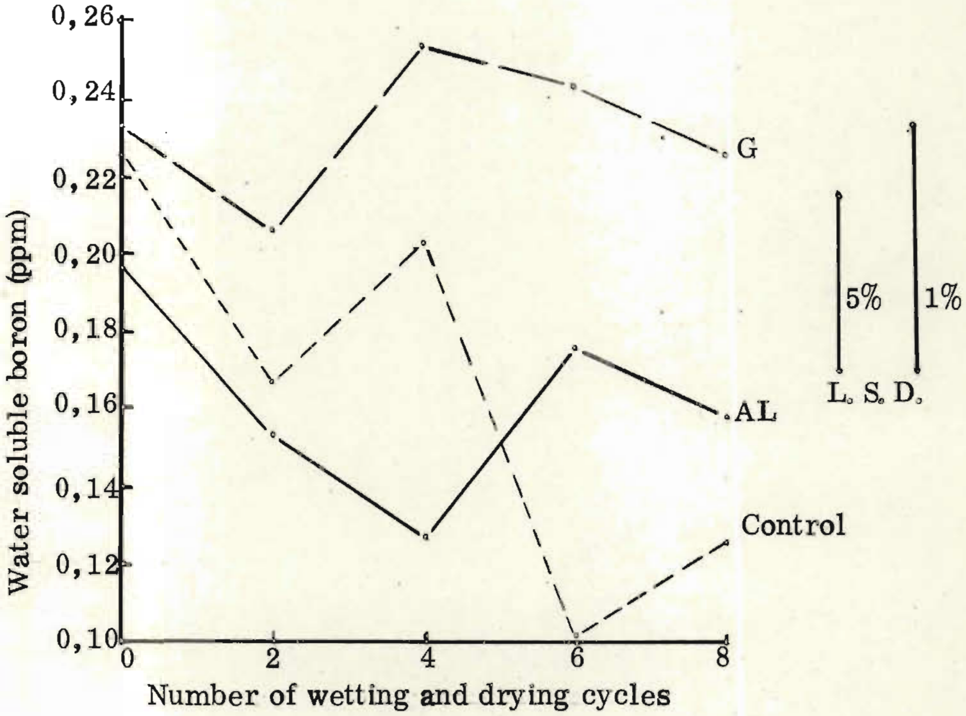

Fig. 27. Effect of wetting and drying treatments on water soluble boron in an Avalon medium sandy loam soil

G - Soil samples from G 4 plots
AL - Soil samples from AL 4 plots
Control - Soil samples from untreated plots

take of zinc decreased where $CaCO_3$ and Na_2CO_3 was supplied, while an increased zinc uptake was observed following on an application of $CaSO_4$.

Mechanism of boron fixation

The mechanism of boron fixation in the soil is not yet clear. Hatcher, Bower and Clark (1967) concluded that $Al(OH)_3$ and similar hydroxy aluminium materials are the major soil constituents causing boron retention by soils. Moreover, it is postulated that lime-induced boron deficiency in plants is caused by decreases in boron concentration in the soil solution resulting from additional adsorption by the $Al(OH)_3$ precipitated by liming.

Results obtained from the Dundee experiments support the generally held theory that the fixation process is mainly chemical in nature.

Summary

The supply of boron in the soil available for uptake by the groundnut plant is decreased over drought periods. Since the available boron supply in an Avalon medium sandy loam soil is at the best of times barely sufficient for normal growth, this "fixation" of boron over a dry period results in the appearance of boron deficiency symptoms. The nature of this fixation process is not understood. Overliming did not play a role under the conditions of the experiment reported on but the application of gypsum prevented the fixation of boron under these conditions of desiccation.

THE RELATIONSHIP BETWEEN THE CHEMICAL COMPOSITION OF THE GROUNDNUT KERNEL AND THE OCCURRENCE OF HOLLOW HEART AND BLACK PLUMULE DAMAGE

Suggestions have been made from time to time over a period of years that the symptoms of boron deficiency and toxicity are tremendously influenced by quan= titative relationships in the plant between boron and the metallic cations, espe= cially calcium and potassium (Shive, 1945).

The relationship between the calcium, potassium and magnesium status of the ker= nel, and the occurrence of hollow heart and black plumule damage is set out in Table 28.

TABLE 28. Correlation coefficients between nutrient attributes of kernels and the occurrence of hollow heart and black plumule

Kernel attribute	Treatment					
	AL		DL		G	
			HOLLOW HEART			
	r		r		r	
1 Ca-content	-0,207	NS	-0,291	NS	-0,651	**
2 Mg-content	-0,292	NS	-0,082	NS	-0,358	NS
3 K-content	0,346	NS	0,423	NS	0,519	*
4 $\frac{1}{2}$	-0,086	NS	-0,393	NS	-0,638	**
5 $\frac{1}{3}$	-0,241	NS	-0,356	NS	-0,693	**
6 $\frac{1}{2 \times 3}$	-0,198	NS	-0,478	NS	-0,678	**
			BLACK PLUMULE			
	r		r		r	
1 Ca-content	-0,453	NS	-0,471	NS	-0,694	**
2 Mg-content	-0,408	NS	-0,192	NS	-0,282	NS
3 K-content	0,641	**	0,363	NS	0,697	**
4 $\frac{1}{2}$	-0,436	NS	-0,585	*	-0,712	**
5 $\frac{1}{3}$	-0,512	*	-0,491	NS	-0,750	**
6 $\frac{1}{2 \times 3}$	-0,539	*	-0,573	*	-0,773	**

The chemical composition of the kernel in terms of the above three elements is poorly correlated with the occurrence of both forms of internal damage, unless considered in relation to the calcium carrier used. In the case of gypsum treatments a consis= tent significant relationship between the calcium and potassium content of the kernel and percentage internally damaged kernels was observed.

The magnesium content of the kernel appears to have little effect on the occurrence of internal damage. An increased potassium content of the kernel was closely asso= ciated with an increased percentage internal damage. Reeve and Shive (1944) repor= ted boron deficiency symptoms to be strongly intensified with increasing concen= trations of potassium in the plant.

An increased calcium content of the kernel was generally associated with a decrease in percentage black plumule kernels. Overall the ratio of calcium to potassium and magnesium in the kernel is well correlated with the occurrence of black plumule damage. In the case of hollow heart this ratio is of value on gypsum-treated material only.

In general the response pattern observed indicates that the relationship between gypsum-applications and internal damage is due to factors other than just the calcium-supplying power of gypsum. In order to obtain further information on the action of gypsum, the total boron content of kernels obtained from untreated plots and plots treated with agricultural lime and gypsum was determined. Results ob= tained from these determinations are given in Table 29.

TABLE 29. Effect of calcium treatment on boron content of groundnut kernels

Calcium treatment	Hollow heart kernels	Black plumule kernels	Boron content of kernels
	%	%	ppm
L 0	32	59	9,8
L 1	14	21	9,0
L 2	50	50	7,1
L 3	51	41	6,6
L 4	48	27	7,8
G 0	46	60	8,1
G 1	31	45	10,2
G 2	39	45	9,9
G 3	1	4	13,9
G 4	6	6	12,6
Mean boron content of AL-treated kernels			7,6
Mean boron content of gypsum-treated kernels			11,6
Mean boron content kernels from control			9,0
L. S. D. (P = 0,05)			1,43

The mean total boron content of kernels obtained from untreated plots was 9 ppm. This figure can be compared with the 12,25 ppm reported by Hallock *et al.* (1971) for kernels produced under nutrient sufficient conditions. Applications of agricultural lime resulted in a marked decrease in the boron content of the kernels, while the gypsum-treatments had the opposite effect. Since no boron-impurity could be detected in any of the calcium carriers used, it would appear that the gypsum-treatments resulted in an increased uptake of boron by the plant. The higher percentage available boron in the soil on gypsum-treated plots is illustrated in Fig. 27 (p. 109).

From the data reported in Table 29 it would appear that the critical level of boron in the kernel, as far as hollow heart damage is concerned, is between 10,2 and 13,9 ppm (see treatments G 1 and G 4 respectively). Gillier (1969) reported a boron content of 11,6 and 13,2 ppm in groundnut kernels to be associated with well developed and just visible hollow heart damage respectively. Cox and Reid (1964) reported values of 13,1 and 6,3 ppm for the boron content of normal and deficient groundnut kernels.

The very close relationship between boron content of the kernels and the occurrence of black plumule damage is of interest. The critical values of boron in terms of hol= low heart damage seems to hold for black plumule damage as well.

THE IMPORTANCE OF THE CALCIUM - BORON INTERRELATIONSHIP IN PLANT NUTRITION, WITH SPECIAL REFERENCE TO GROUNDNUTS

Hollow heart and black plumule damage in groundnuts often, but not always, occur in the same kernel. Furthermore, Cox and Reid (1964) reported that the occurrence of both hollow heart and black plumule could be reduced by applications of either cal= cium (in the form of gypsum), or boron. Boron, however, was more effective than gypsum in reducing the percentage hollow heart, whereas the application of gypsum was more effective than boron in reducing the percentage plumule damage. In view of the differential reduction in the amount of the two forms of damage as result of the application of gypsum and borax, it was concluded that the two forms of damage occur independently. Since the calcium and boron treatments consistently reduced both forms of damage and affected the levels of these elements in the kernel, Cox and Reid (1964) suggested that the relation between the amount of damage and the concentration of these nutrients in the kernel may best be expressed as a nutritional association.

There are often striking similarities between the symptoms of calcium and boron deficiency in plants, which have led to frequent suggestions of an interdependence of their metabolism. The earliest investigators to suggest an association between calcium and boron were Brenchley and Warington (1927). Later work by Warington (1934) with _Vicia faba_, in which the actual amount of calcium absorbed was deter= mined, showed that the presence of boron does indeed result in a very considerable increase in the amount of calcium absorbed by the plants. Similar results were ob= served by Hill and Grant (1935), and Purvis and Davidson (1948).

Work by Marsh and Shive (1941) brought out further interesting aspects of the role of calcium and boron in plant nutrition. The _total_ calcium content of maize plants was found to be independent of the amount of boron supplied. The _soluble_ calcium content of the plants, on the other hand, was found to be closely correlated with the soluble boron content and the total boron content of the plant, and also with the boron content of the medium. Burkhart and Collins (1941) reported the lack of boron in groundnut leaves to result in a soluble calcium concentration one-half that of com= pletely healthy leaves. Thus soluble boron acts directly or indirectly to maintain cal= cium in the soluble and therefore active state.

Brown and Ambler (1969) found the concentration of Ca^{45} to be higher in the root sap of boron deficient plants but more Ca^{45} was transported to the tops of boron sufficient plants, suggesting that boron may play a role in calcium transport and utilization.

It is suggested that the proportional part of the total calcium in the plant which is maintained in the soluble, active state in which it can be translocated from points of supply to centers of metabolic activity, is not determined by the total calcium content of the plant, but simply by the supply of available boron in the corresponding tissues, which in turn is determined by the boron concentration in the nutrient sub= strate. This peculiar property of boron, by which calcium is rendered mobile and active is not confined to organic substrates. The principle has been utilized in in= dustrial procedures to eliminate calcium in the soluble form from complex organic as well as inorganic systems in which it occurs as an impurity (Shive, 1945).

The following theory is suggested to explain the occurrence of hollow heart and black plumule in groundnut kernels.

If at any stage in the growth cycle of the plant boron becomes deficient, so that a deficiency of active (soluble) boron occurs in the plant, such a deficiency would rapidly destroy the potential metabolic possibilities of calcium in the plant, even when calcium is present in adequate concentrations in both tissues and soil (as was the case in the AL and DL treatments of the experiment reported on in Chapter II). Under such conditions both boron and calcium deficiency symptoms would occur in the plant (hollow heart and black plumule respectively) in the case of groundnuts.

Where boron is maintained in adequate concentration in the plant and calcium is ex= cluded from the nutrient substrate, calcium deficiency symptoms (black plumule) would not manifest themselves untill the calcium previously acquired by the plant becomes inadequate in quantity to maintain the growth status of the plant. This would require a relatively long period of time in the presence of an adequate supply of active boron, since the calcium already in the plant would function quite effi= ciently, being kept in a soluble and therefore active state. This situation was pro= bably experienced in the case of the boron applications to a calcium deficient soil, as illustrated in Fig. 20 and 21 (p. 88 and 89).

York (1949) in a moisture-boron study with groundnuts, reported increased kernel yields and increased shelling percentages as a result of boron applications only when the crop was grown in air-dry soil. Under such conditions the uptake of cal= cium by the developing fruit would be very limited, and the effect of boron appli= cations would then be to "activate" reserve supplies of less soluble calcium in the plant.

THE EFFECT OF CALCIUM CARRIER TREATMENT OF THE SOIL ON THE VIABILITY OF GROUNDNUT SEED PRODUCED

Seed deficient in calcium and boron have been reported to be poor planting stock (Harris & Brolman, 1963). Reid and York (1950) indicated that groundnuts failed to develop beyond the seedling stage in the absence of calcium in the growth medium. The low calcium content of groundnut seed, together with the relative immobility of calcium in the plant has been suggested as reasons for this phenomenon.

Higgins and Bailey (1959) suggested that seed with dark plumules (black plumule) were not satisfactory for planting, and Hartley and Bailey (1959) indicated that plants from such seed did not develop normally. A condition causing browning of the plumules, reported by Hartley and Bailey (1959), was also experienced in the Dundee experiments, and was classified as black plumule. Hartley and Bailey reported this abnormality to continue for some time to affect the ability of the epicotyl to utilize the food in the cotyledons.

The effect of a high percentage black plumule and hollow heart damage on seed viability was examined in two separate experiments at Dundee in the 1969/70 season. In the first experiment hand shelled seed obtained from plots producing (i) a large percentage hollow heart (but relatively little black plumule), (ii) a large percentage black plumule (but otherwise normal) and (iii) normal seed was planted in containers in order to evaluate germination potential of the seed. The result ob= tained in this observational trial is illustrated in Plate 6. A very marked difference in rate of germination was observed, the above-ground appearance of hollow heart and black plumule damaged seed being very much delayed when compared with nor= mal seed (the control section on Plate 6). The typical seedling deformities described by Hartley and Bailey (1959) and Harris and Brolman (1966b) were observed. Nu= merous plants with the "stub leaf" or "crinkled leaf" condition were observed in seedlings derived from seed collected on both the "hollow heart" and "black plumule" plots. Seedlings from the control plot were generally free from abnorma=

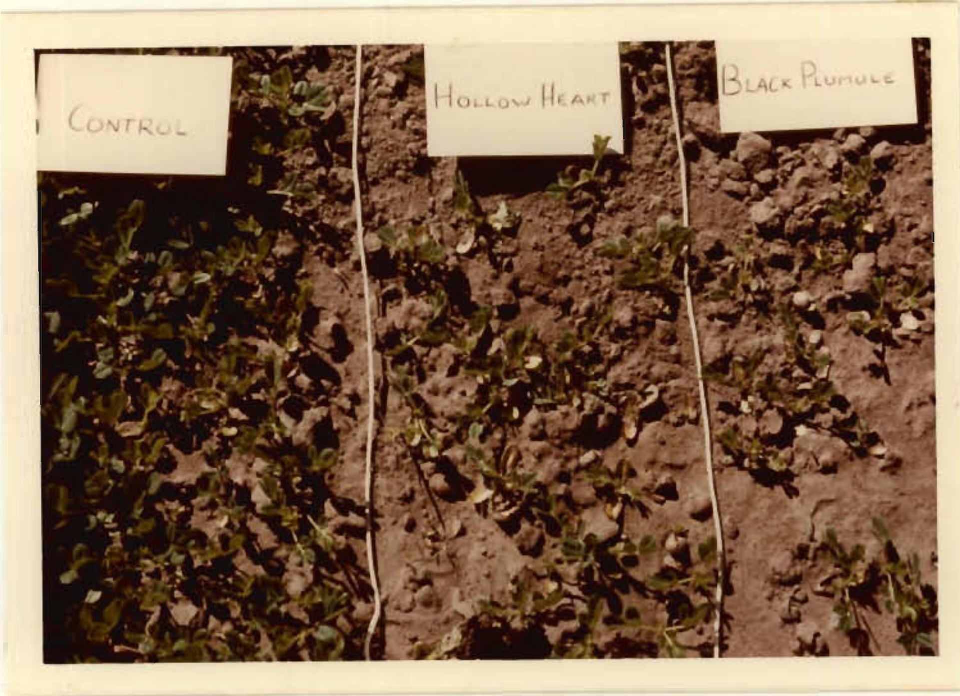

PLATE 6. Rate of seedling emergence as affected by physiological status of the seed (See text for explanation)

lities. On many of the affected seedlings the petioles were stunted or failed to grow, and in extreme cases there was no epicotyl growth even though root and hypocotyl were normal. Various degrees of epicotyl damage, including seedlings with normal hypocotyl and root, whose cotyledons emerged without epicotyls, were observed. Seedlings with less extreme abnormalities subsequently produced normal leaves, but many of these were low in vigour during the first few weeks after germination, as was observed by the above workers.

Typical seedling abnormalities observed are illustrated in Plate 7. It is of interest that many of these abnormalities are very similar to that experienced in the case of early stages of herbicide damage. It was not possible to associate any particular form of damage specifically with either hollow heart or black plumule.

PLATE 7. Typical seedling abnormalities as a result of hollow heart and black plumule damage in groundnut seed. Normal seedling on the left

In a second trial hand-shelled seed obtained from each plot of the experiment des= cribed in Chapter II was planted in a field trial. Only seed riding a standard 20 x 6 mm groundnut grading screen was used. The seed was thoroughly treated with a sulphur-based seed protectant (Thiram) before planting in ideal seedbed and soil moisture conditions. Counts were made to determine the number of seed= lings visible 10, 18 and 22 days after planting respectively. The results of this trial are presented in Table 30.

TABLE 30. Effect of calcium carrier treatment under which the seed was produced, on rate of seedling emergence

(a) Effect of calcium carrier

Calcium carrier	Percentage seedlings visible*		
	Days after planting		
	10	18	22
	%	%	%
Agricultural lime	64,5	86,1	85,7
Dolomitic lime	61,3	82,8	82,1
Gypsum	62,4	88,9	89,1
Untreated control	58,1	81,9	83,0
L. S. D. (P = 0,05)	1,6	0,1	0,1

(b) Effect of level of calcium carrier

Level of calcium	Percentage seedlings visible*		
	Days after planting		
	10	18	22
	%	%	%
0	58,1	81,9	83,0
1	65,6	85,1	84,3
2	62,9	86,7	82,7
3	62,1	87,9	87,7
4	64,9	88,1	90,2
Mean	62,7	85,9	85,6
L. S. D. (P = 0,05)	1,4	0,1	0,1

* Total number of seeds planted per plot - 216

Considering the high percentage internally damaged kernels, together with the severe damage caused by these deficiency conditions, a surprisingly high germination percentage was obtained. The fact that only plump seed was used probably contributed to the high germination percentage. Where one or both of these two forms of abnor= mality occur in small seed, the embryo is often completely destroyed. Seedlings emerged earlier and more uniformly from seed produced on gypsum-treated plots than from seed produced on either the AL or DL treated plots. The calcium content of the seed used had little effect on the rate of emergence.

The effect of the actual presence of black plumule and hollow heart damage in ground= nut seed on seedling emergence was not determined because their presence cannot be determined without the seed being split (and thus becoming of no value as seed).

A SUGGESTED EXPLANATION FOR THE ROLE OF GYPSUM IN GROUNDNUT NUTRITION

Gypsum is extensively used as "a source of readily available calcium" for the production of high quality groundnuts. This practise has, however, never been fol= lowed in South-Africa, probably because the Spanish-type cultivars produced are known to have a relatively low calcium requirement and yield and quality responses to applications of gypsum are therefore to be expected under critical conditions only. Such conditions occurred in Natal in the 1968/69 season when the favourable response to applications of gypsum were experienced.

The effect of gypsum applications on the total boron content of the kernels necessitates a reappraisal of the role of gypsum in the results reported in Chapter II. In some way applications of gypsum appear to prevent the fixation of boron into a form unavailable to the plant over a dry period. This results in a more-or-less normal boron content of kernels produced on gypsum-treated plots, in comparison with the abnormally low boron content of the kernels on untreated and AL treated plots.

A boron deficiency in groundnuts is characterised by a decreased shelling percentage, a decreased percentage ovarian cavities filled and an increased percentage of hollow heart kernels (Harris, 1968). These abnormalities are typical "drought damage" symptoms. Under conditions of moisture stress, soil boron appears to become fixed into an unavailable form, resulting in a boron deficiency condition in the plant, ac= companied by the typical boron ("drought") deficiency symptoms.

Applications of gypsum could under these conditions have a dual effect.

Firstly, because of its higher solubility it could contribute a supply of available calcium even under unfavourable soil moisture conditions. Under these conditions agricultural and dolomitic lime would have little effect as a result of low solubility. Gypsum treatments would under these conditions result in an increased calcium up=

take by the developing fruit, as indicated in Table 14 (p. 45). The low calcium content of the Avalon medium sandy loam soil on which the experiment was planted would be limiting to groundnut yields (see Fig. 14, p. 58) and an increased calcium uptake as a result of the gypsum treatment would therefore lead to an increased ker= nel yield.

Secondly applications of gypsum appear to result in normal uptake by the plant of boron over seasons with a below normal rainfall, thus preventing the typical boron deficiency symptoms commonly experienced under drought conditions. It would ap= pear that the well known beneficial effects of gypsum treatments on groundnut yield and quality might be to a large extent due to the creation of more favourable boron nutritional conditions in the plant. The poor correlations obtained between calcium content of both the soil and plant in the case of AL and DL treatments, with charac= teristics such as percentage unfilled fruit, percentage ovarian cavities filled and shelling percentage, appears to lend support to the theory that the favourable effect of gypsum must have been due to its effect on the boron nutrition of the plant.

Hollow heart damage (boron deficiency) would be prevented through the direct action of gypsum in the prevention of boron fixation. Black plumule damage (calcium defi= ciency) would be partly prevented through increased calcium uptake from the more soluble calcium supply (ex gypsum). At the same time the more favourable boron status of the plant (as a result of gypsum treatments preventing boron fixation) would ensure the calcium in the plant to be physiologically active and thereby preventing the calcium deficiency symptoms from occurring.

HOLLOW HEART AND BLACK PLUMULE IN GROUNDNUTS - A SUMMARY OF FINDINGS TOGETHER WITH PRACTICAL SUGGESTIONS

Hollow heart and black plumule in groundnut kernels are symptoms of a nutritional deficiency condition associated with an imbalance of calcium and boron in the plant. A below optimum level of available boron in the soil would result in the appearance of hollow heart, and possibly at a later stage also black plumule. It is suggested that an adequate supply of boron is required to keep calcium in a physiologically active ("soluble") state in the plant, and a lack of boron could result in the appearance of calcium deficiency symptoms due to "inactivation" of calcium in the plant.

The calcium content of the groundnut kernel is poorly correlated with the occurrence of black plumule damage. The ratio of calcium to potassium and magnesium in the kernel is positively correlated with the occurrence of black plumule damage. A boron content of the kernel of between 10 and 14 ppm appears to be the critical level for occurrence of both black plumule and hollow heart damage. The exchangeable calcium, potassium and magnesium content of the soil appears to be of little value for the purpose of predicting hollow heart or black plumule damage.

The occurrence of hollow heart and black plumule is generally associated with the occurrence of drought periods. Under conditions of moisture stress, boron in the soil becomes "fixed" into a form unavailable for uptake by the plant. At the same time the uptake of calcium by the developing fruit would be interrupted because of insufficient moisture in the zone of fruit formation. The occurrence of black plumule as a result of decreased calcium uptake would therefore be aggravated by a boron deficiency condition. Applications of boron would prevent the appearance of both black plumule and hollow heart damage.

Applications of gypsum (in the region of 4000 kg/ha) results in a marked decrease in hollow heart and black plumule damage. This treatment appears to prevent the fixation of boron over a drought period, resulting in increased levels of boron in the plant. At the same time the provision of a supply of calcium in a readily available (more soluble) form would decrease black plumule damage.

It is suggested that the very high applications of gypsum common to groundnut pro= duction in the United States could be reduced considerably if supplemented with applications of boron, thereby increasing the efficiency of calcium in the plant.

The level of available boron in the Avalon medium sandy loam on which the Dundee experiment was planted is inherently low even under favourable moisture conditions. Intensification of crop production would lead to increased occurrence of boron deficiency. These deficiencies would be aggravated by applications of fertilizer such as urea or potassium chloride. A change-over to improved cultivars would often result in a different pattern of occurrence of hollow heart and black plumule damage.

Considerable practical problems are experienced with the application of the small amounts of boron required for groundnut production. The mixing of the required amount of boron with the seed protectant or the marketing of boron-treated fer= tilizer should receive attention. Critical levels of boron in the soil in relation to the requirements and sensitivity to boron toxicity of groundnuts and its associated crops, should be determined.

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