CHAPTER 4

TOLERANCE OF GROUNDNUT GENOTYPES TO ACID SOILS

4.1 INTRODUCTION

The predominantly granitic sandy soils on which most of the groundnut crop in Zimbabwe is grown are highly leached, depleted of base nutrients and contain very low reserves of minerals that have the potential to weather and release the elements that are essential for plant growth (Vincent & Thomas, 1962; Nyamapfene, 1989). Most of the soils are acidic, and deficient in organic matter, calcium, magnesium, phosphorus and zinc (Grant, 1970, 1981; Mashiringwani, 1983; Tagwira *et al*., 1993). Thus, nearly all nutrients and lime have to be added in order to maintain fertility in these soils. Improved groundnut varieties with high yielding potential produce as little as 0.5 t ha^{-1} of kernels on these soils compared with 4.0 t ha^{-1} obtained on the heavier loamy and clayey soils (Hildebrand, 1996). These yield gaps are attributed mainly to limitations imposed by acid soil infertility, and to a lesser extent to limited water supply and to production constraints such as lack of disease and pest control. Nutrient stresses (both deficiencies and toxicities) are largely responsible for poor plant growth and lower nutrient use efficiency in acid soils (Foy, 1984; Fageria *et al*., 1990; Sumner *et al*., 1991; Foy, 1992; Baligar & Fageria, 1997; Baligar *et al*., 2001). Groundnut genotypes that are able to grow and produce well on acid soils can contribute towards improved crop productivity on acid soils of the resource poor farmers in the smallholder sector.

Since acid-soil infertility can involve both nutrient deficiencies (Ca, Mg, M, K S and N) and toxicities (Al and Mn), the tolerance of plants to soil acidity could be a function of an efficient uptake and utilisation of those nutrients that are deficient under acid-soil conditions and/or tolerance to Al and Mn toxicities. In this respect, tolerance can be defined as the ability of a plant to grow better, produce more dry matter, and develop fewer deficiency symptoms than another plant when grown at low or toxic levels of a mineral element (Clark, 1976). Alternatively, it can be defined as the ability of a genotype to produce a high yield in a soil that has a deficiency or

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toxicity of a particular element compared to a standard genotype (Graham, 1984). Other definitions of nutrient efficiency include efficiency of acquisition (plant nutrient content per available nutrient) or the efficiency with which a nutrient is used to produce biomass (plant biomass per plant nutrient content) or grain (grain yield per plant nutrient content). A nutrient-efficient genotype is also defined as one that is able to acquire nutrients from the growth medium and /or to incorporate or utilise them in the production of shoot and root biomass or seed, grain, fruit or forage (Blair, 1993; Baligar & Fageria, 1997; Baligar *et al.,* 2001).

The efficiency of nutrient utilisation (nutrient efficiency ratio - NER) is defined as the amount of dry mass produced per unit of mineral element present in the dry mass (Siddiqi & Glass, 1981; Glass, 1989). This parameter is a quantitative measurement of the efficiency with which plants convert primary resources (CO_2, H_2O and inorganic nutrients) into dry mass (Glass, 1989). Scientists have used the parameter to compare the efficiencies of nutrient utilisation among several crop species (Giordano, *et al.,* 1982; Woodend *et al.,* 1989; Behling *et al.,* 1989; Li & Gableman, 1990). Review papers, notably by Siddiqi & Glass (1981), Blair (1993), Gourley *et al.,* (1994) argue that the nutrient efficiency ratio might not have a sufficiently strong relationship to absolute yield. Siddiqi & Glass (1981) and Glass (1989) recommended that expression of utilisation efficiency should consider tissue concentration of the element rather than the absolute amount, and should be expressed as biomass per unit of tissue concentration. Accordingly, they deemed nutrient utilisation efficiency (NUE) a more appropriate measure of nutrient utilisation since growth depends on tissue nutrient concentration, and NUE takes into consideration tissue concentration rather than absolute amount. In that context, NUE is the amount of biomass produced per unit of tissue nutrient concentration, or in other words, a product of the efficiency ratio (NER) and biomass produced per plant (Siddiqi & Glass, 1981; Glass, 1989).

Given the prevalence of nutrient deficiency stresses in the low CEC sandy soils of Zimbabwe and the fact that the correction of nutrient deficiencies is a particular problem in the low-input cropping systems, groundnut genotypes tolerant to nutrient stress can be introduced to alleviate the limitations associated with nutrient deficiency. It is envisaged that productivity of groundnut in these soils can be improved by a combination of liming plus screening of genotypes for tolerance to acid stress. It should however be realised that the identification of a more efficient

genotype is at its best a temporary solution. As acidification continues, liming will ultimately be essential. Likewise, low soil fertility will need to be addressed in a sustainable manner.

The study objective was to examine genetic differences in groundnut for growth, productivity and efficiency of nutrient uptake and utilisation in an acid soil.

4.2 MATERIALS AND METHODS

Twelve advanced breeding lines of groundnut and three check lines (commercial cultivars Falcon, Jesa and Teal) were sown in separate plots on acid sandy soils during the 1999/2000 cropping season at Makoholi Experiment Station (MES) located in natural region IV (450 -600 mm rainfall) of Zimbabwe. The soils at MES are derived from granite and belong to the 5G (Fersiallitic order). They are moderately shallow greyish brown coarse-grained sands (particle size >0.02mm; silt + clay <15%), with low pH, low cation exchange capacity (CEC) and low amounts of cations (Thompson & Purves, 1981). Soil tests done before planting showed that the plots were uniform, and no differences were detected in soil pH, P, K, Ca or Mg among the plots. The chemical characteristics of the soil were pH ($CaCl_2$) 4.3, Al^{3+} 0.047 mg kg^{-1}, available P (Olsen) 11.9 mg kg^{-1}, available K 14 mg kg^{-1}, extractable Ca 72 mg kg^{-1}, extractable Mg 18 mg kg^{-1} and mineral N 11 mg kg^{-1}.

Dolomitic limestone at a rate of 600 kg ha^{-1} was disced into the soil a month before planting. A basal dressing of compound M (N_{10}:P_{10}:K_{10}) fertilizer at a rate of 360 kg ha^{-1} was applied prior to planting, while gypsum was broadcast on the row at 300 kg ha^{-1} at flowering. The 15 genotypes were in four replicates arranged in a randomised complete block design. Net plot size was seven rows of groundnut spaced 0.45m apart and 3m long. The groundnut genotypes were planted at 120 kg seed ha^{-1} on 24 November 1999. Fungicides (Mancozeb and Benomyl) were applied as required to minimise *Cercospora* infection. The crop was kept weed-free by hand hoeing throughout the growing season.

At peak flowering stage, soil and plant samples were taken for chemical analysis. Soil samples were taken from the middle of each plot and analysed for pH, Ca, Mg, K, P and N. Exchangeable cations were extracted with 1M ammonium acetate, and were analysed by atomic absorption

spectrometry (AAS). Phosphorus was extracted with bicarbonate using the Olsen method while soil pH was measured in calcium chloride. Samples of the youngest fully expanded leaves (YFEL) inclusive of blades and petioles were taken randomly from the inner seven rows of each plot for chemical analysis. The leaves were washed with distilled water and dried. The plant tissue samples (15g) were digested in 5:1 nitric acid:perchloric acid and nutrient concentrations (N, P, K, Ca, Mg, Fe, Zn, Mn and Cu) in the digest analysed using AAS. The Soil Productivity Research Laboratory (SPRL), Department of Research and Specialist Services, Zimbabwe conducted all chemical analyses.

At physiological maturity, all groundnut plants in the net plot were counted and harvested by hand and separated into aboveground plant parts and pods. The aboveground parts were dried in the oven at 60^0C for 48 hours and the dry weight recorded. The pods were sun-dried to 10% moisture and the dry weight recorded. Genotype performance was evaluated in terms of production of aboveground biomass, pod and kernel yield, kernel nutrient composition and efficiency of nutrient uptake and utilisation. The measures of nutrient efficiency used in this study to assess differences between genotypes were shoot dry mass (SDM), kernel yield, nutrient efficiency ratio (NER) and nutrient use efficiency (NUE). The NER was defined as production of shoot dry mass or harvestable product (kernels) per unit of nutrient absorbed (nutrient accumulation), that is, the amount of dry mass (g) produced for each 1g of a nutrient absorbed and accumulated in the dry mass (Siddiqi & Glass, 1981; Gerloff & Gableman, 1983; Gourley *et al.,* 1994). The total amount of nutrient absorbed (nutrient accumulation) was obtained by multiplying dry mass by nutrient concentration in the tissue. Nutrient efficiency ratio was calculated as dry mass yield divided by the amount of nutrient accumulation. In this context the ratio defines the efficiency with which plants recover nutrients from the soil. The NUE was defined as production of shoot dry mass or kernels per nutrient concentration, i.e. units of dry mass produced per unit nutrient concentration in the dry mass (Siddiqi & Glass, 1981; Glass, 1989). Since nutrient concentration is the inverse of the NER, then NUE is the product of NER and dry mass produced per plant. It quantifies dry mass production by plants at a given nutrient concentration.

The results were analysed as randomized complete block designs with four replicates using the General Linear Models (GLM) procedure of the Statistical System (SAS Institute Inc. Cary, NC, USA 1996 Copyright). Differences among treatments were determined with Duncan's multiple range test, and differences at the $P \leqq 0.05$ level of significance are reported. In addition, data on kernel yield and some of its parameters were subjected to regression analysis.

4.3 RESULTS AND DISCUSSION

Soil tests at peak flowering showed that the pH ($CaCl_2$) was 4.9, available P (Olsen) 18.4 mg kg^{-1}, available K 20 mg kg^{-1}, extractable Ca 103 mg kg^{-1}, extractable Mg 25 mg kg^{-1} and mineral N 14 mg kg^{-1}. Total rainfall received for the season was 826.6 mm, with 51.5 mm received in November, 144.5 mm in December, 171 mm in January, 400.5 mm in February, and 59.1 mm in March.

4.3.1 YIELD AND YIELD COMPONENTS

Differences in shoot dry mass were highly significant among the genotypes (Table 4.1). The advanced breeding line 106/96 produced the highest shoot dry mass (12.69 g $plant^{-1}$), while the lowest (7.70 g $plant^{-1}$) was produced by line 316/5/3. Shoot dry mass of the three check cultivars was generally high, ranging from 10.69 to 11.25 g $plant^{-1.}$

In terms of yield potential, at least six of the breeding lines performed as good as the check cultivars (Table 4.1). The highest kernel yield of 1124 kg ha^{-1} produced by line 106/96 was 85.2% higher than that produced by the lowest yielder (line 262/8/2). Line 106/96 was also characterised by the highest shelling percentage (76.7%) and the largest seed size (0.52 g). Genotypes with the highest yields tended to have larger seeds, and *vice versa*. This denotes a positive relationship between seed size and kernel yield, and the correlation analysis showed a highly significant correlation between the two parameters (Table 4.8).

Table 4.1 Pod and kernel yield, shelling %, shoot dry mass and seed size of groundnut genotypes

Genotype	Pod yield (kg ha^{-1})	Kernel yield (kg ha^{-1})	Shelling %	Shoot dry mass (g plant^{-1})	Kernel size (g seed^{-1})
262/8/2	939	607	64.6	9.06	0.295
297/7/16	1 366	877	64.2	8.75	0.432
303B/7/5	1 197	738	61.7	9.34	0.318
309/8/2	1 163	722	62.0	9.58	0.299
316/5/3	1 107	675	61.0	7.70	0.300
328/5/7	965	658	68.2	9.13	0.393
328/5/12	1 309	834	63.7	9.03	0.298
338/5/2	1 289	886	68.7	10.52	0.321
19/82	1 006	649	64.5	8.54	0.325
418/93	1 351	923	68.4	11.20	0.464
95/96	1 383	930	67.2	12.46	0.363
106/96	1 466	1124	76.7	12.69	0.521
TEAL	1 214	796	65.6	10.69	0.344
JESA	1 174	733	62.4	11.25	0.314
FALCON	1 017	717	70.5	10.97	0.321
Mean	**1 196**	**791**	**66.0**	**10.06**	**0.354**
LSD$_{(0.05)}$	**119**	**90.4**	**5.93**	**2.06**	**0.03**

The four lines with the highest shoot dry mass (106/96, 95/96, 418/93 and 338/5/2) also produced the highest pod and kernel yields. This suggests a positive relationship between vegetative growth and kernel yield, which is contrary to the contention that abundant vegetative growth is detrimental to groundnut fruit load. The correlation analysis, in fact, showed no significant correlation between kernel or pod yield with shoot dry mass (Table 4.8). It has, however, been established in other legumes and cereals that grain yield is positively correlated with dry mass yield (Snyder & Carlson, 1984). Fageria *et al.* (2001) also established a positive relationship between biomass yield and grain yield in common bean, where they observed a highly significant and positive correlation between the two parameters.

4.3.2 N, P, K, CA AND MG CONCENTRATIONS IN THE LEAVES

Leaf analysis is important for determining the nutritional health of plants. For groundnut, chemical analyses of the leaves (YFEL) performed at flowering are considered suitable for judging the nutrient status of the plants during vegetative growth (Smith *et al.,* 1994). In this respect, the established nutrient sufficiency levels in groundnut YFEL are 3 to 4.5% N, 0.2 to 0.5% P, 1.7 to 3.0% K, 1.25 to 2.0% Ca and 0.3 to 0.8% Mg (Gascho & Davis, 1994). The elemental concentrations in groundnut YFEL sampled in this study are given in Table 4.2. Leaf N concentrations of 3.0% to 3.9% were in sufficient quantities in all genotypes, and no significant differences in N content were detected among the genotypes. The highest N concentrations were observed in the YFEL of line 338/5/2 whereas the N concentrations of the check cultivars were intermediate. Phosphorus concentrations in the YFEL of all the lines were also within the range considered sufficient for optimal vegetative growth of groundnut and varied among the lines from 0.28 to 0.48% (Table 4.2). Six of the lines had significantly higher P concentrations than line 328/5/12, which had the lowest P content (0.28%).

Values for K concentrations were not significantly different among genotypes, and ranged from 0.87 to 1.33%, while those for Ca concentrations ranged from 0.81 to 1.32%. Potassium was severely deficient in all genotypes while Ca was deficient in all but three genotypes, suggesting possible yield limitations due to deficiency of the two elements. Overall, the three check cultivars had lower K and Ca concentrations compared to the breeding lines, and cultivar Jesa had the lowest K and Ca concentrations among all the genotypes. Magnesium concentrations ranged from deficiency (0.23%) in line 309/8/2 to sufficiency (0.40%) in lines 95/96 and 328/517, and were adequate in most genotypes. Lines 95/96 and 328/5/7 had significantly higher Mg concentrations (0.40%) than the other genotypes.

The deficient Ca and K levels in the leaves could be a reflection of the low concentrations of these nutrients in the soil solution. Foy (1974) classified the problems associated with Ca deficiency into two categories namely, (a) inability to absorb Ca from soils low in Ca levels or with low ratios of Ca opposed to other cations and (b) inadequate distribution of Ca to actively growing tissues after absorption. Thus the low Ca levels in leaf tissue could be a result of either

(a) or (b) or a combination of both. Calcium translocation, rather than uptake, is usually the primary determining factor in the final Ca content of plant tissue according to Kirkby & Pilbeam (1984).

Table 4.2 Nutrient concentrations (%) in groundnut leaf dry mass (YFEL sampled at peak flowering)

Genotype	N	P	K	Ca	Mg
268/8/2	3.7	0.42	1.19	1.32	0.33
297/7/16	3.4	0.34	0.98	1.03	0.28
303B/7/5	3.6	0.42	1.02	1.01	0.29
309/8/2	3.7	0.31	0.85	1.03	0.23
316/5/3	3.0	0.36	1.11	1.06	0.35
328/5/7	3.2	0.40	1.16	1.26	0.40
328/5/12	3.7	0.28	0.95	1.03	0.29
338/5/2	3.9	0.48	1.07	0.99	0.32
19/82	3.5	0.44	1.08	0.94	0.31
418/93	3.4	0.36	1.06	0.95	0.32
95/96	3.7	0.46	1.33	1.28	0.40
106/96	3.7	0.42	1.10	0.96	0.28
TEAL	3.3	0.37	0.91	1.00	0.26
JESA	3.7	0.33	0.87	0.81	0.27
FALCON	3.5	0.39	1.18	0.90	0.34
Mean	**3.5**	**0.39**	**1.06**	**1.04**	**0.31**
LSD $_{(0.05)}$	**0.56**	**0.13**	**0.34**	**0.36**	**0.09**

4.3.3 N, P, K, CA AND MG CONCENTRATIONS IN KERNELS

Healthy, mature groundnut kernels typically contain 0.14 to 0.47 % P, 0.62 to 0.89% K, 0.038 to 0.088% Ca, and 0.16 to 0.20% Mg (Adams *et al.,* 1993; Savage & Keenan, 1994). The kernel nutrient concentrations observed in our study are given in Table 4.3. Significant differences were observed for kernel N concentration among the genotypes. Two of the lines had N concentrations higher than the cultivar Jesa (4.12% N) while seven of the lines had N concentrations higher than the cultivar Falcon (3.70% N). The P concentrations were in the

sufficient ranges for all genotypes, with significant differences in the P concentrations that ranged from 0.27 to 0.45%. The K concentrations were in the sufficient ranges in all the genotypes, and ranged from 0.6% to 0.96%. There were no significant differences in the K concentrations between the genotypes. The kernel Ca concentrations, which ranged between 0.019 – 0.038 % among the lines, were extremely low, with the highest concentration of 0.038 % falling within the lower end of the range 0.038-0.041% found to be adequate for maximum germination of four groundnut cultivars by Adams *et al.* (1993). The Ca concentrations differed among genotypes, and were highest in the check cultivars (0.028 - 0.038%). Magnesium content was generally adequate in all genotypes, but differed significantly between genotypes, and was highest in line 95/96 (0.21%) and lowest in line 303B/7/5 (0.14%).

Even though the concentrations of K and Mg appeared deficient in the leaves in most of the lines, the concentrations of these two nutrients, as well as those for P and N in the kernels were generally within the normal ranges expected for groundnut. Thus, Ca was the only deficient nutrient in the kernels. It has been observed that groundnut pods appear to be poor absorbers of Ca (Cox *et al.,* 1982); hence the unusually high soil Ca requirements within the pod environment (Cox *et al,* 1982; Hodges *et al.,* 1993). The Ca deficient status of the kernels in the present study could be a reflection of the low Ca status of the soil, as well as the antagonistic relationship between Ca and Mg or K. The variability in kernel Ca concentration could be a direct consequence of differences in Ca uptake by the pods, or differences in Ca amounts that can be imported from the roots (Beringer & Taha, 1976). Since Ca in the xylem sap is translocated upward in the transport system and is neither mobile in the phloem nor redistributed within the plant (because of formation of ion complexes as oxalate or other insoluble forms or binding to the cell wall), it is unavailable for transport (Ferguson, 1979). Variability in pod Ca concentration in snap beans was attributed to differences in transport of Ca via root pressure (Quintana *et al.,* 1997), or to differences in direct Ca uptake (Quintana *et al.,* 1999).

Table 4.3 Nutrient concentrations (% DM) in groundnut kernels

Genotype	N	P	K	Ca	Mg
262/8/2	3.53	0.269	0.658	0.026	0.148
297/7/16	4.12	0.374	0.819	0.028	0.188
303B/7/5	3.84	0.294	0.630	0.024	0.140
309/8/2	4.01	0.341	0.600	0.023	0.149
316/5/3	4.05	0.397	0.735	0.028	0.170
328/5/7	3.83	0.356	0.750	0.029	0.164
328/5/12	3.70	0.302	0.655	0.024	0.153
338/5/2	4.46	0.452	0.705	0.019	0.159
19/82	4.20	0.365	0.793	0.028	0.183
418/93	3.37	0.348	0.815	0.024	0.176
95/96	5.02	0.361	0.833	0.029	0.214
106/96	4.32	0.302	0.956	0.022	0.178
TEAL	3.96	0.324	0.636	0.028	0.175
JESA	4.12	0.357	0.739	0.038	0.184
FALCON	3.70	0.445	0.739	0.032	0.175
Mean	**4.02**	**0.353**	**0.737**	**0.027**	**0.170**
$LSD_{(5\%)}$	**0.06**	**0.12**	**0.031**	**0.015**	**0.02**

4.3.4 NUTRIENT RELATIONSHIPS IN THE LEAVES AND KERNELS

Correlation analysis data for leaf and kernel nutrient relationships are presented in Table 4.4. The leaf nutrient relationships show that the N concentrations were negatively correlated with Ca, Mg and K concentrations. A negative correlation between N and Ca was observed by Kawasaki (1995) who reported that N from NH_4 inhibited Ca absorption by barley, maize and tomato. There were positive and significant correlation coefficients between the P, Ca, Mg, and K concentrations in the leaves, suggesting synergistic uptake interactions among these nutrients. The synergism between nutrients could be explained by interdependence of the nutrients in plant metabolism. Nonetheless, synergistic relationships among nutrients (e.g. Ca, Mg and K) are usually a common phenomenon when the nutrients are present at low concentrations (Marschner, 1995; Fageria, 2001), as was the case with the soils being investigated. In this study, the correlations between Ca and other nutrients were stronger with K and Mg than with P.

Unlike in the leaves, correlations between the nutrient concentrations in the kernels were generally weak (Table 4.4). Only those correlations between the concentrations of Ca and P, and between Mg and the concentrations of N, K and P in the kernels were significant. Negative but non-significant correlations were observed between Ca concentration and those of N and K, and between N and K concentrations. Antagonistic interactions between Ca^{2+}, $Mg^{2+,}$ K^{+} and N^{+} were expected, because of competitive inhibition in the uptake of these nutrients that occurs because of having ions with similar sizes, geometry of coordination, and electronic configuration (Fageria, 2001). Nevertheless, other factors could be involved in determining the interactions between these nutrients since there were differences in the interactions of the same nutrients between the leaves and the kernels.

Table 4.4 Nutrient relationships in leaves and kernels of groundnut

Relationship	Correlation coefficient (r)	
	Leaves	**Kernels**
N vs Ca	-0.266***	-0.022ns
P vs Ca	0.417***	0.721***
K vs Ca	0.692***	-0.204ns
Mg vs Ca	0.721***	0.020ns
N vs Mg	-0.360***	0.320***
P vs Mg	0.429***	0.242*
K vs Mg	0.852***	0.393***
N vs P	-0.085ns	0.193ns
N vs K	-0.403***	-0.131ns
P vs K	0.565***	0.172ns

4.3.5 NUTRIENT UPTAKE BY LEAVES AND KERNELS

In order to evaluate genotypic variation in nutrient accumulation, the uptake (content) of nutrients was calculated as nutrient concentration in tissue x dry mass. This was used as an estimate of nutrient removal from the soil. Nutrient uptake has been advocated as a valuable index of nutrient efficiency since it is closely related to growth and nutrient concentration (Glass, 1989). Considerable variation in uptake of N, P, K, Ca and Mg by the genotypes was observed (Table 4.5). In the leaves, uptake of the five nutrients was highest in lines 106/96 and 95/96, which were

the highest producers of shoot dry mass. Despite the better shoot growth in the check cultivars, their nutrient uptake levels were not significantly better than some of the breeding lines with poorer shoot growth. The lines that produced the lowest shoot DM did not necessarily remove the least amount of nutrients from the soil. This can be attributed to differences in nutrient concentrations and dry mass production. Line 316/5/3 with the lowest shoot dry mass had higher concentrations of P, K, Ca and Mg compared to the mean concentrations of these nutrients in the check cultivars.

In the kernels, significant differences in uptake of N, P, K, Ca and Mg by the genotypes were observed (Table 4.5). Overall, nutrient removal was highest in the line with the highest kernel yield (line 106/96) and lowest in line 262/8/2 - the line with the lowest kernel yield. With the exception of N, nutrient uptake by the check lines was higher than in at least five of the breeding lines for each of the nutrients.

Table 4.5 Nutrient uptake (kg ha^{-1}) in shoots and kernels of groundnut genotypes.

Genotype	Uptake in shoots					Uptake in kernels				
	N	**P**	**K**	**Ca**	**Mg**	**N**	**P**	**K**	**Ca**	**Mg**
262/8/2	100	11	31	35	9	21	1.61	3.49	0.16	0.89
297/7/16	89	9	25	26	7	36	3.39	7.05	0.25	1.62
303B/7/5	99	12	29	28	8	29	2.12	4.51	0.15	1.02
309/8/2	104	8	24	29	6	29	2.51	4.33	0.15	1.08
316/5/3	69	8	25	24	8	27	2.68	4.98	0.18	1.15
328/5/7	87	11	31	34	11	25	2.49	4.94	0.19	1.07
328/5/12	97	8	28	30	8	32	2.65	5.31	0.22	1.27
338/5/2	121	15	33	31	10	39	3.92	6.28	0.17	1.41
19/82	88	11	27	23	8	27	2.24	5.13	0.16	1.18
418/93	113	12	34	30	10	31	3.22	7.49	0.23	1.63
95/96	135	17	49	47	15	48	3.10	6.52	0.30	1.98
106/96	139	16	42	36	11	49	3.30	9.61	0.25	2.04
TEAL	105	12	29	32	8	31	2.54	5.07	0.22	1.38
JESA	122	11	30	28	9	30	2.65	5.33	0.29	1.33
FALCON	111	13	39	29	11	27	3.29	5.14	0.25	1.23
MEAN	**105**	**12**	**32**	**31**	**9**	**32**	**2.78**	**5.67**	**0.20**	**1.35**
LSD $_{(5\%)}$	**8.05**	**1.28**	**3.31**	**3.39**	**0.94**	**5.94**	**0.15**	**1.31**	**0.02**	**0.07**

4.3.6 RELATIONSHIPS BETWEEN NUTRIENT UPTAKE, NUTRIENT CONCENTRATIONS, YIELD AND YIELD PARAMETERS

Nutrient concentrations (N, P, K, Ca and Mg) in the leaves were generally not correlated with pod or kernel yield, seed size or shoot dry mass (Table 4.6). In the kernels, Ca and P concentrations were not correlated with yield and shoot dry mass, whereas N and K showed significant correlations with pod and kernel yields. Magnesium and K concentrations showed significant correlations with seed size and shoot dry mass. The lack of correlations between leaf nutrient concentrations and yield support the observation by Gascho & Davis (1994) that the final groundnut kernel yield and quality do not generally relate well to leaf composition during growth due to restricted downward phloem movement of nutrients from the above-ground plant parts to the developing pods. Both leaf and kernel Ca concentrations were weakly correlated with pod or kernel yield, suggesting that factors other than Ca nutrition were also involved. The poor correlation between leaf Ca and kernel yield was expected, since root-absorbed Ca is of little value to underground developing pods of groundnut, owing to the limited translocation of root-absorbed Ca to the pods (Bledsoe *et al.,* 1949; Skelton & Shear, 1971; Chahal & Virmani, 1973). The lack of correlations between leaf and kernel Ca concentrations appears to support this point.

Nutrient uptake (N, P, K, Ca and Mg) in the leaves was positively and significantly correlated with shoot dry mass, whereas only N uptake was significantly correlated with pod and kernel yield (Table 4.6). Only the uptake of N and P were significantly correlated with seed size. Correlations between nutrient uptake in the kernels and yield, shoot dry mass and seed size were generally significant (Table 4.6). With the exception of N and Mg, nutrient uptake in the kernels was not correlated with shoot dry mass. In a solution culture study, Fageria & Baligar (1989) noted that the shoot nutrient concentrations in five crop species were negatively correlated with dry mass, whereas uptake was significantly and positively correlated, implying that nutrient uptake can be used as a reliable indicator of nutrient use efficiency of genotypes.

Table 4.6 Correlation coefficients between yields, nutrient concentration and uptake in leaves and kernels of groundnut genotypes.

	POD YIELD	KERNEL YIELD	SEED SIZE	SDM	POD YIELD	KERNEL YIELD	SEED SIZE	SDM
	NUTRIENT CONCENTRATION							
	IN THE LEAVES				IN THE KERNELS			
Ca	0.037ns	0.022ns	0.044ns	0.007ns	-0.012ns	-0.012ns	-0.118	-0.051ns
Mg	0.003ns	0.026ns	0.072ns	0.037ns	0.010ns	0.100ns	0.265**	0.307**
N	0.296**	0.300**	0.031ns	0.041ns	0.281**	0.266**	0.015ns	0.174ns
P	-0.182ns	-0.160ns	0.135ns	0.076ns	-0.046ns	-0.033ns	-0.124ns	0.047ns
K	-0.113ns	-0.057ns	0.082ns	0.081ns	-0.308**	-0.244*	0.226*	0.269**
	NUTRIENT UPTAKE							
Ca	0.106ns	0.131ns	0.142ns	0.593***	0.606***	0.616***	0.213*	0.137ns
Mg	0.106ns	0.157ns	0.188ns	0.665***	0.858***	0.935***	0.504***	0.284**
N	0.281**	0.341***	0.218*	0.877***	0.897***	0.937***	0.394***	0.231*
P	-0.064ns	-0.013ns	0.238*	0.626***	0.746***	0.770***	0.293**	0.152ns
K	0.011ns	0.091ns	0.199ns	0.690***	-0.100ns	-0.104ns	-0.082ns	-0.108ns

*** Correlation is significant at the 0.01 level (2-tailed). ** Correlation is significant at the 0.05 level

* Correlation is significant at the 0.10 level ns - Correlation is not significant.

4.3.7 NUTRIENT EFFICIENCY RATIO AND NUTRIENT USE EFFICIENCY IN SHOOT PRODUCTION

Differences in nutrient efficiency ratio (NER) were significant for all nutrients (Table 4. 7). For vegetative growth, the highest Ca efficiency ratio (CaER) of 138 g shoot dry mass per g Ca was recorded for cultivar Jesa whereas the lowest (77) was recorded for line 262/8/2. Line 106/96 that produced the highest shoot dry mass had a CaER of 105. The efficiency ratio of Mg (MgER) varied between 251 and 475 g shoot dry mass per g Mg. The N efficiency ratio (N-ER) ranged from 26 to 33 g shoot dry mass per g N, while the P efficiency ratio (PER) ranged from 219 to 399 g shoot dry mass per g P. Variations in the efficiency ratio of K (KER) ranged from 77 to 129 g shoot dry mass per g K. The highest or lowest nutrient efficiency ratios were not confined to specific genotypes.

Nutrient use efficiency (NUE) in vegetative growth significantly differed among genotypes

(Table 4.7). The Ca use efficiency (CaUE) values were highest (1521 g shoot dry mass per g Ca concentration) for cultivar Jesa and lowest (699) for line 262/8/2. The Mg use efficiency (MgUE) values ranged between 2266 and 4538 g shoot dry mass per g Mg concentration, while those in N (N-UE) ranged between 247 and 346 g shoot dry mass per g N concentration. Phosphorus use efficiency (PUE) ranged from 2040 to 3715 g shoot dry mass per g P concentration while K use efficiency (KUE) ranged from 742 to 1410 g shoot dry mass per g K concentration. Overall, the greatest variation in nutrient use efficiency was observed for Ca while the least variation was observed for N. Cultivar Jesa had the highest NUE values for most of the nutrients.

Genotypes that produced the highest shoot dry mass were not necessarily the ones that had the highest NER values and *vice versa*. The correlation analyses showed a weak and negative correlation between shoot dry mass and NER (Table 4.9). Nutrient use efficiency and shoot dry mass were positively related, and the correlation analysis showed a highly significant and positive correlation between the two (Table 4.9). However, care should be taken not to attach too much importance on this positive correlation, since the calculation of NUE as NER x dry mass implicitly should result in a positive correlation between NUE and dry mass.

4.3.8 NUTRIENT EFFICIENCY RATIO AND NUTRIENT USE EFFICIENCY IN KERNEL DM PRODUCTION

While kernel dry mass yields of the genotypes differed by as much as 57%, differences in their NER and NUE were even more pronounced (Table 4.7). With the exception of Ca, the nutrient efficiency ratios (g kernel DM per g nutrient) tended to be highest in genotypes that generally had the lowest kernel yields, while genotypes with the highest kernel yields generally had low NERs. While all the twelve breeding lines had higher CaER values than the check varieties, the values were highest in the lines that had the highest kernel yields (lines 106/96 and 338/5/2), and low in those lines that generally had the lowest kernel yields. Variations in nutrient use efficiency (NUE) for kernel production were of a greater magnitude than the NER (Table 4.7). The genotype that produced the highest kernel yield (line 106/96) was the most efficient in utilisation of all nutrients. Cultivars Jesa and Falcon were the least efficient in utilisation of Ca and P,

respectively. Overall, genotypes with the highest yields were the most efficient in nutrient use and *vice versa.*

High NERs in lines with the lowest kernel yields imply a negative relationship between NER and kernel yield. However, the suggested negative relationship was not demonstrated by the correlation analysis that showed positive but weak correlations between NER and kernel yield, with only the correlation between kernel yield and MgER negative (Table 4.9). Genotypes that produced the highest kernel yield generally had the highest NUE values, an indication of a positive relationship between nutrient efficiency and yields in groundnut. The correlation analysis confirmed this relationship, with highly significant and positive correlations being observed between pod yield, kernel yield and seed size with NUE. As already indicated, this positive correlation should be expected because of the factors included in the estimation of NUE.

4.3.9 RANKING OF GENOTYPES ACCORDING TO NER AND NUE

When the genotypes were ranked according to nutrient efficiency ratio with respect to shoot dry mass production, the check cultivar Jesa and line 328/5/12 ranked first in overall NUE, whereas the breeding line 106/96 which produced the highest shoot dry mass ranked 11th (Table 4.8). The ranking of genotypes for NUE was similar to that for NER for Jesa, Teal, lines 328/5/7 and 418/93, but differed from that for NER for the rest of the genotypes (Table 4.8). As regards kernel dry mass production, the rankings showed that line 106/96 with the highest kernel yield ranked eighth in NER and first in NUE (Table 4.8). Line 262/8/2 which produced the lowest kernel yield was ranked second in NER and tenth in NUE. The check cultivars ranked between 6 and 12, irrespective of the nutrient efficiency parameter used.

The study has demonstrated that there are considerable variations in NER and NUE in groundnut genotypes. With regard to kernel dry mass production, greater variation was recorded for nutrient use efficiency (NUE) than for nutrient efficiency ratio (NER), and the reverse trend was observed with respect to shoot dry mass production. Lesser variation in NER than in NUE was also observed in barley (Siddiqi & Glass, 1981) and in wheat (Woodend *et al.* (1989).

Table 4.7 Nutrient efficiency ratio (NER) and nutrient use efficiency (NUE) of groundnut genotypes

GENOTYPE	NER (mg shoot dry mass / mg nutrient in shoot DM)					NER (mg kernel dry mass / mg nutrient in kernel DM)				
	N	P	K	Ca	Mg	N	P	K	Ca	Mg
262/8/2	28	244	86	77	314	29	376	153	4274	679
297/7/16	29	292	105	102	376	24	278	123	4484	540
303B/7/5	28	244	103	102	361	27	369	161	5210	720
309/8/2	27	334	119	100	440	25	314	167	5179	675
316/5/3	33	278	95	96	290	25	265	136	4123	590
328/5/7	32	251	89	80	251	27	299	134	3915	611
328/5/12	27	399	128	126	475	27	337	154	4013	656
338/5/2	26	219	94	101	313	22	228	142	5360	632
19/82	29	238	96	109	333	24	289	127	4106	548
418/93	29	317	101	115	331	30	314	125	4783	570
95/96	27	231	77	81	254	20	288	139	4425	469
106/96	27	253	94	105	358	23	335	124	5350	571
Teal	30	274	112	102	395	26	318	157	3607	573
Jesa	28	306	129	138	410	25	305	136	2790	545
Falcon	29	280	86	113	296	27	228	136	3681	573
MEAN	**29**	**277**	**101**	**103**	**346**	**25**	**303**	**141**	**4353**	**597**
LSD$_{(0.05)}$	**1.06**	**26.46**	**9.40**	**9.59**	**37.59**	**1.26**	**26.36**	**7.47**	**547.70**	**23.92**
	NUE (g shoot dry mass / g nutrient in shoot DM)					NUE (g kernel dry mass / g nutrient in kernel DM)				
	N	P	K	Ca	Mg	N	P	K	Ca	Mg
262/8/2	251	2201	799	699	2871	59	779	312	8771	1392
297/7/16	255	2566	930	910	3336	72	799	371	12448	1615
303B/7/5	262	2262	946	944	3335	64	948	411	14384	1814
309/8/2	262	3281	1149	976	4289	60	749	408	13757	1633
316/5/3	256	2150	742	734	2279	56	607	309	9524	1346
328/5/7	287	2312	819	725	2266	60	612	297	8656	1370
328/5/12	250	3276	1023	1019	3650	75	925	454	11465	1889
338/5/2	273	2352	994	1072	3303	67	697	423	15945	1880
19/82	247	2040	827	945	2861	54	676	279	9851	1204
418/93	331	3715	1169	1345	3812	94	972	391	14657	1775
95/96	341	2865	953	1003	3157	62	976	483	12443	1472
106/96	346	3202	1172	1325	4510	87	1309	503	20679	2125
Teal	324	2920	1203	1094	4245	69	869	424	9801	1550
Jesa	312	3431	1410	1521	4538	61	745	342	6553	1360
Falcon	325	3046	935	1241	3269	65	535	340	7920	1414
MEAN	**288**	**2775**	**1005**	**1037**	**3448**	**67**	**813**	**383**	**11790**	**1589**
LSD $_{(0.05)}$	**20.67**	**300.48**	**97.72**	**115.73**	**356.51**	**7.31**	**122.7**	**51.88**	**2220**	**180.83**

Table 4.8 Ranking Genotypes according to NER and NUE

GENOTYPE	NER IN SDM PRODUCTION					Overall	NER IN KERNEL DM PRODUCTION					Overall
	N	P	K	Ca	Mg		N	P	K	Ca	Mg	
262/8/2	9	11	14	15	10	**13**	2	1	5	8	2	**2**
297/7/16	6	5	5	8	5	**5**	12	12	15	6	14	**15**
303B/7/5	8	12	6	7	6	**7**	6	2	2	3	1	**1**
309/8/2	12	2	3	11	2	**6**	8	6	1	4	3	**3**
316/5/3	1	7	9	12	13	**10**	9	13	10	9	7	**10**
328/5/7	2	10	12	14	15	**12**	5	9	11	12	6	**11**
328/5/12	13	1	2	2	1	**1**	4	3	4	11	4	**4**
338/5/2	15	15	10	10	11	**14**	14	14	6	1	5	**7**
19/82	7	13	8	5	8	**9**	11	10	12	10	12	**12**
418/93	4	3	7	3	9	**3**	1	7	13	5	11	**5**
95/96	11	14	15	13	14	**15**	15	11	7	7	15	**12**
106/96	14	9	11	6	7	**11**	13	4	14	2	10	**8**
Teal	3	8	4	9	4	**4**	7	5	3	14	9	**6**
Jesa	10	4	1	1	3	**1**	10	8	9	15	13	**12**
Falcon	5	6	13	4	12	**8**	3	15	8	13	8	**9**
	NUE in SDM production					**Overall**	**NUE IN KERNEL DM PRODUCTION**					**Overall**
	N	**P**	**K**	**Ca**	**Mg**		**N**	**P**	**K**	**Ca**	**Mg**	
262/8/2	13	13	14	15	12	**14**	13	8	12	12	11	**10**
297/7/16	12	9	11	12	7	**11**	4	7	9	6	7	**7**
303B/7/5	9	12	9	11	8	**10**	8	4	6	4	4	**4**
309/8/2	10	3	5	9	3	**5**	11	9	7	5	6	**9**
316/5/3	11	14	15	13	14	**14**	14	14	13	11	14	**14**
328/5/7	7	11	13	14	15	**12**	12	13	14	13	12	**13**
328/5/12	14	4	6	7	6	**7**	3	5	3	8	2	**3**
338/5/2	8	10	7	6	9	**9**	6	11	5	2	3	**5**
19/82	15	15	12	10	13	**13**	15	12	15	9	15	**14**
418/93	3	1	4	2	5	**3**	1	3	8	3	5	**2**
95/96	2	8	8	8	11	**7**	9	2	2	7	9	**6**
106/96	1	5	3	3	2	**2**	2	1	1	1	1	**1**
Teal	5	7	2	5	4	**4**	5	6	4	10	8	**7**
Jesa	6	2	1	1	1	**1**	10	10	10	15	13	**12**
Falcon	4	6	10	4	10	**6**	7	15	11	14	10	**11**

Variation in nutrient efficiency has been attributed to differences in absorption, translocation, shoot demand, dry matter production per unit of nutrient absorbed in addition to environmental interactions and genetic variability (Duncan & Baligar, 1990; Baligar & Fageria, 1997). Genotypic differences in nutrient efficiency are related to differences in efficiency in acquisition by the roots, or in utilization by the plant, or both. With regard to N, P, K and Mg, higher nutrient use efficiencies may be related to better use of stored nutrients, or by better retranslocation between organs (Clark, 1976; Marschner, 1995).

Calcium efficiency may differ depending on binding stage of Ca, transport rate to the apical meristem or differences in functional requirement within the tissue (Marschner, 1989). Differences in Ca efficiency have been reported in maize (Baligar *et al.,* 1997) and tomatoes (English & Maynard, 1981; Giordano *et al.,* 1982; Li and Gableman, 1990). Many of the differences in Ca efficiency have been linked to differences in root nutrient acquisition capacity, transport and utilization by the plant (Marschner, 1989). Similarly, in the present study, the observed differences in CaER and CaUE among the groundnut lines can possibly be explained in terms of differences in their abilities to absorb Ca and to utilise it after absorption. With tomato lines grown in nutrient solution, Giordano *et al.,* (1982) found that a Ca-efficient line removed 68% more Ca from the solution than an inefficient one. Furthermore, two tomato lines with similar total Ca uptake had different CaER, indicating that the more efficient line produced more dry mass per unit of Ca tissue than the inefficient cultivar. In the present study, the check lines Jesa and Falcon had the highest kernel Ca concentrations, but had the lowest CaER values, indicating a superior Ca uptake that was not matched by efficient utilisation of the Ca. Also, lines 106/96 and Falcon had identical Ca uptake in the kernels, but Falcon showed a much higher CaER than 106/96, and this can only be explained by a better Ca utilisation by Falcon.

Table 4.9 Correlation coefficients between yields and nutrient efficiency in groundnut

	SEED SIZE	POD YIELD	KERNEL YIELD	SHOOT DRY MASS
Seed size	1.000	0.399***	0.477***	0.229*
Pod yield	0.399***	1.000	0.961***	0.136ns
Kernel yield	0.477***	0.961***	1.000	0.201ns
Shoot dry mass (SDM)	0.229*	0.136ns	0.201ns	1.000
CaER in SDM	-0.070ns	-0.027ns	-0.017ns	-0.028ns
MgER " "	-0.094ns	-0.008ns	-0.024ns	-0.162ns
NER " "	-0.044ns	0.310**	0.312***	-0.077ns
PER " "	-0.142ns	0.135	0.129ns	-0.096ns
KER " "	-0.101ns	0.064ns	0.017ns	-0.161ns
CaER in Kernel yield	0.191ns	0.092ns	0.101ns	0.070ns
MgER in " "	-0.252ns	0.021ns	-0.076ns	-0.290ns
NER " " "	0.008ns	-0.274**	0.252**	-0.153ns
PER " "	0.127ns	0.082ns*	0.049ns	-0.087ns
KER " "	-0.254ns	0.371***	0.289**	-0.188ns
CaUE in SDM	0.105ns	0.056ns	0.104ns	.587***
MgUE	0.069ns	0.063ns	0.092ns	.518***
NUE	0.179ns	-0.051ns	0.005ns	0.868***
PUE	0.019ns	0.215ns	0.251**	0.569***
KUE	0.068ns	0.141ns	0.141ns	0.546***
CaUE in KDM	0.403***	0.611***	0.663***	0.129ns
MgUE	0.371***	0.931***	0.919***	0.080ns
NUE	0.508***	0.855***	0.891***	0.133ns
PUE	0.448***	0.769***	0.793***	0.128ns
KUE	0.295**	0.932***	0.937***	0.116ns

***, **, *, - Correlation is significant at the 0.01, 0.05, 0.10 level (2-tailed). ns Correlation is not significant

4.3.10 CLASSIFICATION OF GENOTYPES INTO EFFICIENT AND INEFFICIENT GROUPS

Four categories of genotypes with respect to NUE were identified using a method similar to that used by Fageria & Baligar (1999) to characterize wheat genotypes.

a) *Efficient and responsive genotypes.* These are genotypes that produced above average shoot dry mass or kernel yields and had above average NUE.

b) *Efficient and non-responsive genotypes.* These are genotypes that produced more than average yield but NUE was below average.

c) *Non-efficient and responsive genotypes.* These are genotypes that produced below average yield but NUE was above average.

d) *Non-efficient and non-responsive genotypes.* Those genotypes that produced below average yield and NUE was also below average.

Classification of the groundnut genotypes with regards to shoot dry mass production is shown in Figure 4.1. The check cultivars Teal and Jesa, and lines 106/96 and 418/93 were consistently classified as efficient and responsive to all the five nutrients, whereas lines with the least shoot dry mass (316/5/3 and 19/82) were consistently in the non-efficient and non-responsive group for all nutrients but K. No genotypes were classified in groups (c) and (d) for K, implying that all the genotypes were efficient in K utilisation, though some were not responsive to K application. The majority of genotypes were classified either in group (a) or (d).

Pertaining to kernel DM production, classification of the genotypes is shown in Figure 4.2. Check cultivars Falcon and Jesa, and the lines that produced the lowest kernel yields (262/8/2, 316/5/3, 19/82 and 328/5/7) were in the non-efficient and non-responsive group for all the five nutrients. Cultivar Teal was efficient in utilization of all five nutrients, but was not responsive to applied N, K, and Mg. Lines that produced the highest kernel yields (106/96, 95/96 and 418/93) were consistently in the efficient and responsive group for all five nutrients. Similar to shoot dry mass production, the genotypes were mainly classified either in group (a) or (d).

In summary, when the genotypes were categorized according to the four efficiency parameters (kernel yield, shoot dry mass, NER and NUE), line 106/96 ranked second, whereas line 418/93

that produced the third highest kernel yield ranked first. These two lines were also classified as efficient and responsive genotypes, and are thus the most desirable since they can yield well at low nutrient supply. The commercial cultivar Teal ranked fourth, and was classified as efficient and responsive to Ca and P, and efficient and non-responsive to Mg, N and K. This means that the cultivar can be grown in P and Ca deficient soils and produce good yields. It can also be grown in soils low in N, K and Mg and still produce above average yields. Cultivars Jesa and Falcon ranked fifth and tenth respectively, and were classified as non-efficient and non-responsive to N, P, K, Ca, and Mg.

4.4 CONCLUSIONS

The evaluated genotypes differed in yield, NER and NUE when grown on an acid sandy soil. The differences were more pronounced in kernel than in shoot dry mass yield. Since nutrient uptake, concentration and growth are intricately interwoven, genotypic differences in nutrient acquisition and utilization will ultimately result in differences in productivity. Several lines had pod and kernel yields superior to those observed in the best of the commercial cultivars used in this study, and this translated into superior NUE for most of the lines. Of particular note were breeding lines 106/96 and 418/93 that produced shoot and kernel DM yields and had higher NUE and NER values than the mean of the 15 genotypes. Release of these two lines for commercial production is most likely to improve groundnut productivity on acid sandy soils of Zimbabwe.

The differences in nutrient use efficiency between the efficient and inefficient genotypes were large enough to postulate that success in increasing groundnut yields on acid soils could be achieved by screening genotypes for tolerance to soil acidity in low fertility soils. Adaptation of plants to acid soils requires highly efficient uptake and/or utilization of nutrients, particularly Ca, Mg and P (Marschner, 1995), therefore identification of genotypes with greater tolerance to low soil levels of these nutrients, coupled with the ability to produce reasonable yields when grown on such soils, could go a long way in improving groundnut productivity on acid soils. The genotypes that were able to extract more nutrients from the soils generally produced high yields and were classified as efficient and responsive. This implies that they can be expected to perform well in acid soils where Ca, Mg and P are limiting, although this will inadvertently hasten the

depletion of the already scarce nutrients. The ideal genotype would be one that produces high yields with as little nutrients as possible, i.e. one with high nutrient utilization efficiency.

The most appropriate parameter for assessing the suitability of genotypes for acid soils is nutrient use efficiency, with the other parameters assisting in accurate characterization of the genotypes. With respect to groundnut productivity, Ca use efficiency would be the most reliable parameter for separating efficient from inefficient genotypes. It should, however, be mentioned that although use of nutrient efficient genotypes to increase crop production appears to be an attractive and feasible approach, on its own it might not be an adequate prescription for sustainable crop productivity on acid soils. It needs to be augmented with judicious use of lime and fertilizers.

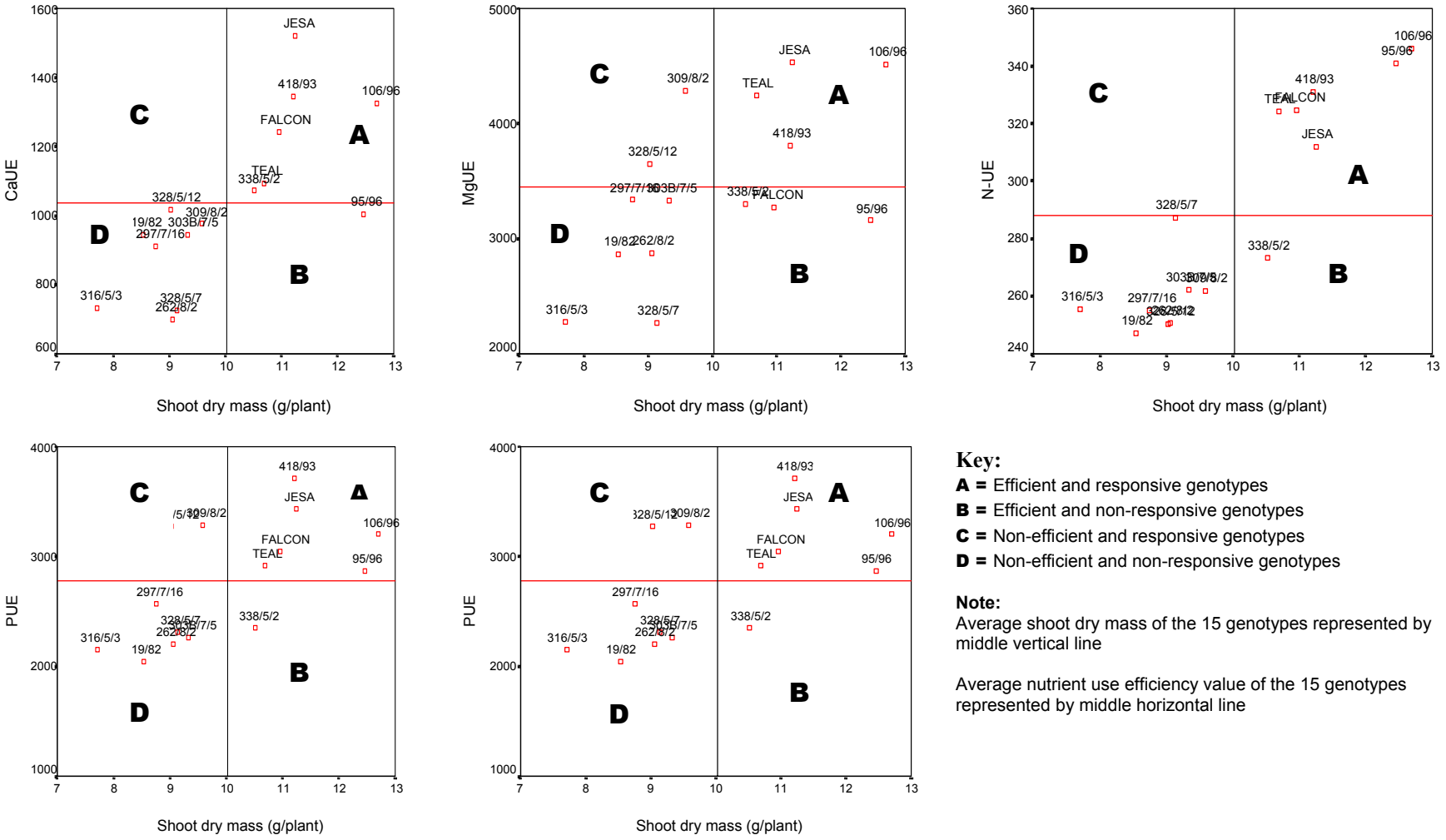
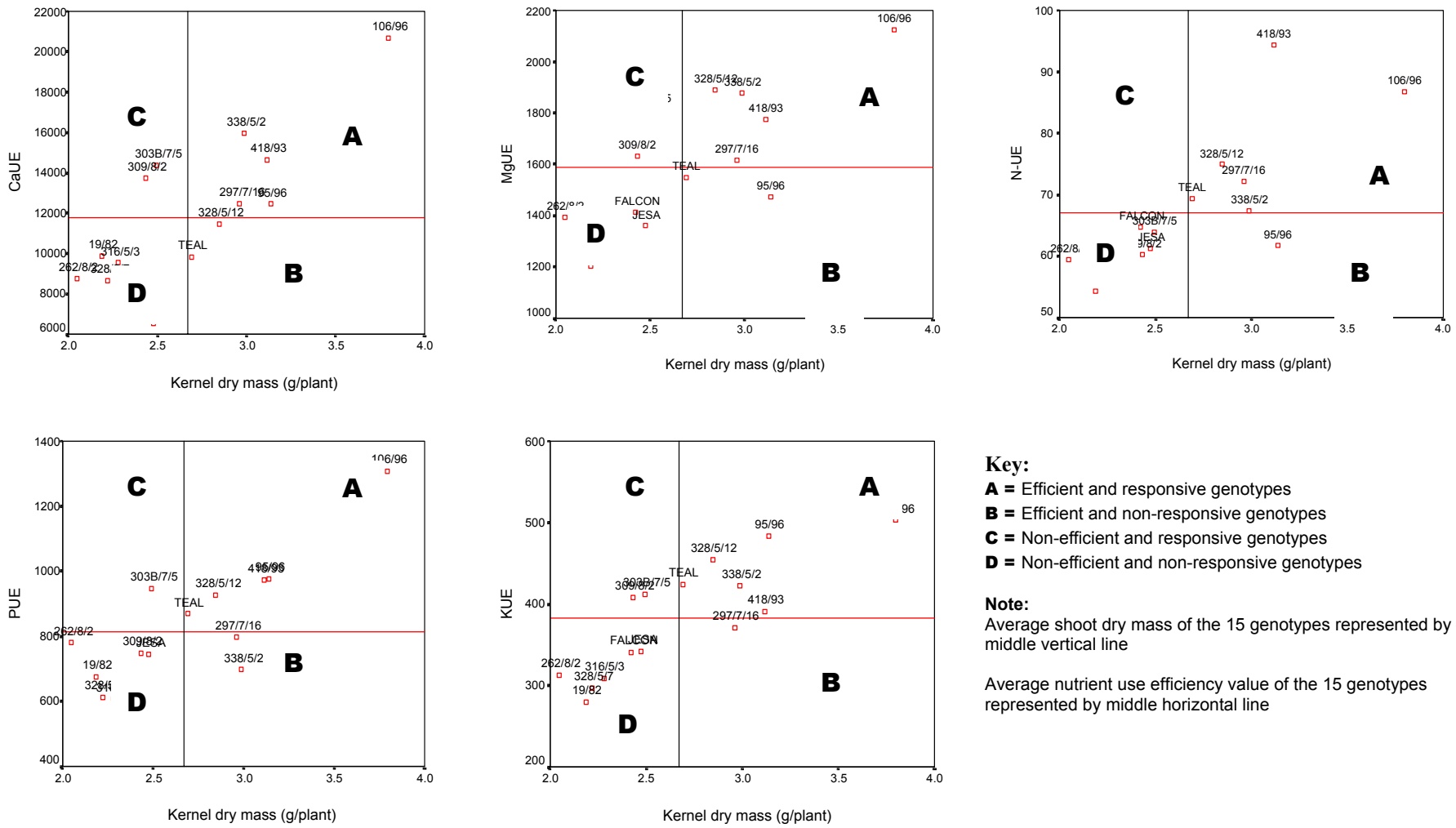


Figure 4.1 Classification of groundnut genotypes for nutrient use efficiency (g SDM / g nutrient concentration in SDM)



Key:

A = Efficient and responsive genotypes

B = Efficient and non-responsive genotypes

C = Non-efficient and responsive genotypes

D = Non-efficient and non-responsive genotypes

Note:

Average shoot dry mass of the 15 genotypes represented by middle vertical line

Average nutrient use efficiency value of the 15 genotypes represented by middle horizontal line

Figure 4.2 Classification of groundnut genotypes for nutrient use efficiency (g kernel dry mass / g nutrient concentration in kernel dry mass)