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Soil fertility management for groundnut in the lowveld of Mpumalanga and north coastal plain of KwaZulu-Natal provinces of South Africa

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ABSTRACT

Smallholder groundnut production contributes substantially to food security in Mpumalanga Lowveld (MLV) and in Manguzi, the northern coastal plain (NCP) of KwaZulu Natal (KZN), both of which are dominated by infertile structureless sandy soils. A study was conducted to obtain information on the chemical properties of the soils to guide fertilizer management for optimizing groundnut production on these soils. Soil samples were collected from representative sites in MLV and NCP, and analysed for pH, calcium (Ca), magnesium (Mg), potassium (K), phosphorous (P), zinc (Zn) and manganese (Mn) in the peg-zone (0-10 cm depth), root zone (10-40 cm depth) and subsoil (40-60 cm depth). The soils were largely acidic, with pH mostly falling below 5.5. The basic cation concentrations were generally low, and so were Zn and Mn concentrations. Nonetheless, with the exception of P and Mn, the soil concentrations of the other nutrients analysed were within ranges considered adequate for vegetative and reproductive growth of groundnut, though Zn was marginally so. General fertility management recommendations to inform agricultural extension are provided for groundnut production on the sandy soils based on the chemical analyses of the soils.

Keywords: Groundnut, soil chemical properties, soil fertility management, Lowveld of Mpumalanga, KwaZulu-Natal coastal plain

1. INTRODUCTION

Groundnut is the second most important crop grown by smallholder farmers in the Lowveld of Mpumalanga (Ncube *et al*., 2010) and in Manguzi on the NCP of KwaZulu-Natal (Phokane *et al*., 2019), where it plays an important role in food security and alleviation of protein-energy malnutrition as a functional food (Arya, Salve & Chauhan, 2016). The soils in Manguzi (Grundling 2011) and MLV (Mathews, 2010) are typically deep structureless sands. Whilst the soils are ideal for groundnut production on account of the ease with which the groundnut gynophores penetrate the soil to form pods, as well as the ease with which the pods can be harvested from the soil (Swanevelder, 1998), they are generally of low fertility, and therefore, highly susceptible to acidity due to their high leachability. Hence, crop production on them usually requires liming and fertilizer inputs. Currently, there is scanty information on the

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general chemical properties of the soils in MLV and the coastal plain of KwaZulu Natal to guide fertilizer management for the smallholder groundnut farmers in the absence of soil analysis. In this study, a soil chemical analysis was carried out for selected representative sites of sandy soils in MLV and Manguzi with the aim of assessing their nutrient status in relation to meeting the nutritional requirements for groundnut. The results of the study provide a basis for fertilizing the groundnut crop in the absence of a soil test.

2. DESCRIPTION OF THE STUDY AREAS

The climate of the area surveyed in MLV has warm to hot, moist to wet summers with dry, mild to cool winters. The average annual rainfall ranges from 600 to 800 mm, with 83% of the falls in the summer growing season from October to March (Paterson, 2012). The temperature varies from 18 to 35 ^{o}C during the summer season (Janila et al., 2013) and from 10 to 25 ^{o}C during winter (Paterson, 2012). The soils are structureless sandy loam (8% clay), and typically deep (900-1200 mm) and classified as Avalon series (Lengwati et al., 2020).

The climate of Manguzi in the northernmost part of the NCP of KZN is subtropical and receives summer rainfall, with a 30-year mean annual precipitation of approximately 580-963 mm (Mucina & Rutherford 2006; Matthews, 2007; Ramjeawon et al., 2020). The majority of the rainfall (60%) occurs during the summer months, between October and March, and is highly spatially and temporally variable (Ramjeawon et al., 2020). Mean daily temperatures vary from 21.0 °C to 32.1 °C in summer and 10.9 °C to 26.4 °C in winter (Ramjeawon et al., 2020). The soils majorly consist of deep Aeolian sands (Matthews, 2007).

3. MATERIALS AND METHODS

3.1. Soil sampling sites

Five and six sites, not less than 2 km apart, were sampled in MLV and Manguzi, respectively. The five sites in MLV were Lowveld Agricultural College farm (LVAF) -25.440278, 30.982500, Malekutu (-25.369167, 31.271667), Numbi -25.148889, 31.183611, Luphisa -25.436944, 30.973056 and Masoyi -25.159722, 31.158889]. In Manguzi, the six sites were KwaMazambane (-26.930017, 32.781462), Ekuhluphekeni -26.965920, 32.765527, Thandizwe (-26.975483, 32.723929), Nsukumbili -27.035640, 32.697573, Ndlondlweni (-27.143905, 32.552688) and Mabhudu (-27.213716, 32.548059). The sites in Manguzi were representative of the sandy soil in the northern (Maputaland) coastal area of KwaZulu-Natal.

3.2. Soil sampling and processing

At each of the pit sites, four holes were randomly sampled 10 meters apart. In recognition of separate nutrient requirements in the root and peg-zone of groundnut (Zharare, Blamey & Asher, 2009; Zharare, Asher & Blamey, 2011), three soil samples were obtained per sampling hole at depths 0-10 cm (peg-zone), 10-40 cm (root-zone) and 40-60 cm (subsoil) using an auger.

The soils from the three depths were mixed separately in buckets at each of the pit sites, and a composite soil sample of each of the sampling depth was taken for chemical analysis.

The soil samples were air-dried at room temperature, crushed between rubber belts on a soil crusher, and passed through a 1 mm sieve. Those materials that could not be crushed were discarded.

3.3. Determination of pH and mineral nutrient concentrations

The chemical analyses included the pH, macronutrients calcium (Ca), magnesium (Mg), potassium (K), phosphorous (P) and micronutrients manganese (Mn) and zink (Zn). The soil pH was measured in 1M KCl in a soil solution ratio of 1:1.25 following a standard procedure described by Pansu and Gautheyrou (2006). The macro- and micronutrients were extracted from 2.5 g of each ml sample in 25 ml of Mehlich 3 solution (Mehlich 1984). The resultant suspension was stirred at 400 r.p.m. for 10 min on a stirrer and filtered using Whatman No.1 paper. Five ml of the filtrate was diluted with 20 mL of 0.0356 M $SrCl_2$, and the concentrations of Ca and Mg in the filtrate were determined by atomic absorption spectrometry (AAS). Potassium concentration was determined by AAS from 5 mL of the filtrate after dilution with 20 mL de-ionised water. Phosphorus concentration was determined from 2 ml of the filtrate using a molybdenum blue procedure as modified by (Hunter, 1974). The micro-nutrients Zn, Cu and Mn were determined by AAS from the undiluted filtrate.

4. RESULTS AND DISCUSSION

Generally, the soils in MLV and Manguzi were strongly acidic (Table 1). With the exception of Luphisa in MLV, which had soil pH above 6.0, the pH values in the peg zone, the root zone in the subsoil at all other sites were less than 5.5, the lower limit in the pH range 5.5-6.5 considered optimal for groundnut (Kumar *et al.*, 2019). The soils, therefore, require liming to raise the pH to between 5.5. and 6.5. Lower pH values adversely affect groundnut root growth and the uptake of P and boron (B), as well as causing Al toxicity (Fageria and Zimmermann 1998). In addition, low pH in the peg-zone adversely affects pod development and filling (Murata, Zharare & Hammes, 2013), as well as nodulation and nitrogen fixation processes (Maccio, Fabra & Castro, 2002). To raise the pH from 4.5 to 6.5 in a depth of 30 cm in sandy soil generally needs in excess of 5 t lime ha^{-1} (Roy *et al.*, 2006). However, due to the low exchange capacity of the soil, and hence poor buffering capacity to pH changes, liming done at any one time should not exceed 500 kg ha^{-1} on sandy soil. High rates of lime can precipitate trace elements such as Mn, Zn and iron (Fe), making them unavailable to plants (Fageria & Zimmermann, 1998). In the absence of a soil test, groundnut production in the soils at MPL (topsoil pH range 4.3 to 6.2) and Manguzi (topsoil pH range 4.8 to 5.1) would benefit from splitting lime application of between 900 kg and 1.5 t ha^{-1} at 3 to 6 month before planting for a period of up to 3 years. It should also be taken into cognisance that Mupangwa and Tagwitra (2005) determined from a multi-location field study that the optimum calcitic lime application rate on granitic sandy soils in Zimbabwe is 200 kg ha^{-1}. This was adequate to counteract soil acidity and to supply the Ca needed in the peg zone for proper groundnut fructification and pod filling.

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The basic cations concentrations of the soils were also generally low, and so were Zn and Mn, the only micronutrients analysed (Table 1). The concentrations of the basic cations were lower, but the concentrations of the micronutrients Zn and Mn were higher in MLV compared to the Manguzi soils (Table 1), which probably reflected differences in the management of the soils in the two areas.

TABLE 1: Variations in soil pH, P, K, Ca, Mg, Mn and Zn levels down the soil profile at five sites in MLV and six sites in Manguzi.

Sampling Sites	Soil depth (cm)	Soil pH (KCl scale)	P	K	Ca	Mg	Mn	Zn
			(mg kg^{-1})					
	Mpumalanga lowveld sites							
MLACF	0-10	4.3	41.2	106.2	445	96.7	4.2	26.1
	10-40	5.4	30	78.6	408	106.2	2.4	20.7
	40-60	5.2	13.2	73.6	409	104	1.4	3.4
	Site mean	**5.0**	**28.1**	**86.1**	**420.7**	**102.2**	**2.7**	**16.7**
Malekutu Site mean	0-10	5.0	23	72	238	43	6.3	4.4
	10-40	5.2	27.2	76	308	69	4.3	3.8
	40-60	4.5	5.7	78	232	69	5.3	0.5
	Site mean	**4.9**	**18.6**	**75.3**	**259.3**	**60.3**	**5.3**	**2.9**
Numbi	0-10	4.7	29.5	107	287	54	8.5	7.2
	10-40	4.8	27.3	81.7	342	67.7	5.7	10.6
	40-60	4.5	19.7	108.3	356	68.3	7	1.5
	Site mean	**4.7**	**25.5**	**99.0**	**328.3**	**63.2**	**7**	**6.4**
Luphisa	0-10	6.3	44.5	62	325	69.5	4	9.7
	10-40	6.4	60	76	326	79.5	3	10.2
	40-60	6.2	77	256	330	136	2	1.9
	Site mean	**6.3**	**60.1**	**131.3**	**327.0**	**95.0**	**3**	**7.3**
Masoyi	0-10	4.5	2	22	136	28	24	0.4
	10-40	4.3	4	52	168	46	4.5	0.8
	40-60	4.8	7	83	309	116	5	0.4
	Site mean	**4.5**	**4.3**	**52.3**	**204.3**	**63.3**	**11.2**	**0.5**
		Manguzi sites						
KwaMazambane	0-10	5.1	15.7	167	1218	156	8	3.4
	10-40	4.8	9	86	443	104	3.3	1.0
	40-60	4.5	9.7	119	485	124	5	2.7
	Site mean	**4.8**	**11.5**	**124**	**715**	**128**	**5.4**	**2.4**
Ekuhluphekeni	0-10	5.3	13.7	200	560	166	6.3	2.4
	10-40	4.7	12.7	188	348	110	3.3	2.8
	40-60	4.6	12.7	140	247	90	5	2.8
	Site mean	**4.9**	**13.0**	**176**	**385**	**122**	**4.9**	**2.7**

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Thandizwe	0-10	5.1	12	154	1277	155	12	4.3
	10-40	4.8	7	72	481	108	3	1.1
	40-60	4.5	6	100	497	128	4.7	1.0
	Site mean	**4.8**	**8.3**	**108.7**	**751.7**	**130**	**6.6**	**2.1**
Nsukumbili	0-10	5.2	5.7	168	396	120	4.3	3.0
	10-40	4.5	4	131	309	118	2.7	1.7
	40-60	4.3	9.3	123	282	70	3.7	2
	Site mean	**4.7**	**6.3**	**140.7**	**329**	**102.7**	**3.6**	**2.2**
Ndlondlweni	0-10	4.8	8	126	1007	144	14.3	2.7
	10-40	4.6	5.7	74	347	83	3.7	1.1
	40-60	4.4	7	94	465	110	3.3	0.8
	Site mean	**4.6**	**6.9**	**98**	**606**	**112**	**7.1**	**1.5**
Mabhudu	0-10	5.4	4	187	406	111	3.3	0.7
	10-40	4.3	2.3	100	173	91	1.3	0.6
	40-60	4.3	4	84	252	73	2.3	0.7
	Site mean	**4.7**	**3.4**	**123.7**	**277**	**91.7**	**2.3**	**0.7**

Any consideration of soil fertility for groundnut production has to take into account the stratified distribution of Ca, Mg, K and Zn down the soil profile. This is because the availability of these nutrients in the different soil layers of the soil profile affects the productivity of groundnut differently (Wolt and Adam, 1979, Zharare *et al*., 1993; Zharare, Blamey & Asher, 2009; Zharare, Asher & Blamey, 2011; Kumar *et al*., 2019). Because of the development of its fruit underground, groundnut has, on the one hand, relatively high demand for Ca in the peg-zone for successful pod development compared with that required in the root zone for its vegetative growth (Wolt and Adam, 1979; Cox *et al*., 1982; Zharare, Blamey & Asher, 2009; Zharare, Asher & Blamey, 2009). On the other hand, the soil Mg and K concentrations in the root-zone should be relatively low to minimize the inhibition of these nutrients on pod Ca uptake from the peg-zone (Brady and Colwell 1945; Zharare, Asher & Blamey, 2011). When they are in excess of Ca in the peg-zone, pop production increases (Brady and Colwell 1945; Cox *et al*., 1982). In the current study, peg-zone Ca concentration ranged from 136 to 445 mg kg^{--1} of soil in MLV and from 173 to 1218 mg kg^{-1} in Manguzi (Table 1). These values were above 100 mg kg^{-1} of soil Ca level considered adequate for proper groundnut pod development in South Africa (Swanevelder, 1998). Hartzog and Adams (1973) also reported that a soil Ca concentration of 100 mg kg^{-1} was regarded as sufficient for groundnut production for the runner type groundnut, and there was no need for gypsum application, but soils with Ca concentration below 87.5 mg kg^{-1} needed gypsum application. With the current study, there are no sites falling below 87.5 mg kg^{-1} (Table 1). Thus, gypsum application is not necessary in these soils, especially for Valencia and Spanish types of groundnut, which require less Ca in the peg-zone than do Virginia groundnut (Cox *et al*., 1982). However, since there is a need to apply lime in both locations, its application will add more Ca to the soil.

Wolt and Adams (1979) determined that 0.25 is the critical Ca:(Ca+Mg+K) ratio for maximising pod filling while only a ratio of 0.1 was required for maximizing vegetative growth of groundnut. In the present study, the Ca/(Ca+Mg+K) ratios in the peg- and root zones were above 0.60 at all the sites tested, with a majority of the sites falling in the range of 0.7 to 0.9 (Table 2). Thus, the ratios were substantially above the critical values for maximal pod filling and vegetative growth, which further confirmed that Ca deficiency is not anticipated to limit groundnut yields in both Manguzi and MLV. As for the other macro-nutrients nutrients analysed; generally, 40 to 88 mg kg^{-1} of K (Hanlon, Kidder & Mcneal, 1990), 10 to 30 mg kg^{-1} of Mg (Hodges, Gascho & Kidder 1994) and 8 to 10 mg kg^{-1} of P (Singh, Basu & Singh, 2004) in the soil are considered adequate for healthy vegetative growth of groundnut. In the current study, the root zone concentrations of Mg ranged from 46 to 106.2 mg/kg, K ranged from 52 to 81.7 mg/kg, and P ranged from 4 to 30 mg/kg in MLV. In Manguzi, the soil concentrations of Mg ranged from 83 to 118 mg/kg, K from 72 to 188 mg/kg and P from 2.3 to 12.7 mg/kg. From these data, K was marginally sufficient, while P was either marginally sufficient or lower than the optimal range for groundnut. Based on the data, both Manguzi and MPLV soils require an application of K at a rate of between 25 and 45 kg K2O ha^{-1} (Singh, Basu & Singh, 2004), with the higher rate being recommended for MPLV, which has lower sufficient K levels (Table 1).

The deficiency of P was severe in Manguzi soils, whereas in MLV, the P levels were largely adequate by a high margin compared to the index levels (8 to 10 mg kg^{-1}) for healthy growth of groundnut, except at Masoyi. However, because of the acidic nature of the soils, the availability of P could be low due to fixation by iron (Fe) and aluminium (Al) oxides (Penn and Camberato, 2019). Liming the soil to between 5.5 and 6.5 will release P from fixation, making it more available to plants. Care is, however, needed not to over lime the soils as it would cause precipitation of P by Ca, thus making it unavailable to plants (Penn and Camberato, 2019). In the absence of a soil test, groundnut production in Manguzi could benefit from an application of 30-40 kg P_2O_5 ha^{-1} (Singh, Basu & Singh, 2004), whereas the soil in MPLV requires lower P application rates for maintenance. It is best to apply P as a broadcast basal application at planting. However, if there is no sufficient amount for broadcasting, it can be dolloped in the planting hole below the seed but not in contact with the seed. This will also reduce the fixation of P by the soil compared to broadcasting.

Magnesium tended to be more in the peg-zone than in the root-zone and subsoil at Manguzi, but in MLV, the Mg concentration was higher in the root-zone. The higher Mg concentration in the peg-zone in Manguzi might negatively affect the development of the pods since Mg suppresses Ca and Zn uptake by groundnut pod from the peg-zone (Zharare *et al.*, 1993; Zharare, Asher & Blamey, 2011), and both of these nutrients are required in the peg-zone for proper pod development (Zharare *et al.*, 1993). Furthermore, the omission of Mg in the pod culture solution was shown by Zharare *et al.* (1993) to improve groundnut pod and seed development.

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Hence, the need to carefully balance the Ca, Zn and Mg nutrition of groundnut in the peg-zone. Therefore, when correcting the low soil pH in both MLV and Manguzi, it would be advisable to use calcitic lime with no Mg rather than dolomitic lime, which contains Mg, since the soils have adequate Mg.

Although groundnut requires Zn in the peg-zone for pod development (Zharare *et al.*, 1993), the concentration required in the peg-zone to satisfy the requirements for pod development has not yet been determined. Nonetheless, groundnut is said to require about 0.5 mg kg^{-1} to 1.0 mg Zn kg^{-1} of soil (Hanlon, Kidder & Mcneal, 1990, Plank. 1989). In the present study, the Zn level in the peg-zone varied from 0.4 to 26.1 mg kg^{-1} in MLV and 0.7 to 4.3 mg kg^{-1} in Manguzi. In the root zone, the levels of Zn ranged from 0.6 to 2.8 mg kg^{-1} in Manguzi. With the exception of one site (MLVACF) in MLV, the levels are substantially higher than the critical soil Zn level (0.5 to 1.0 mg kg-1 soil) required for optimal groundnut production under soil pH 5.5 to 7.0. Therefore, substantial groundnut yield suppression from Zn deficiency is not expected in both MLV and Manguzi. However, liming the soils to correct the low pH generally prevalent in these soils is expected to induce Zn deficiency at some of the sites with low Zn concentration as both high pH (Fageria and Zimmermann, 1998) and Ca (Baker 1978) suppress Zn uptake by plants. Consequently, it might be prudent to apply between 2-4 kg Zn ha^{-1} as ZnSO4 or equivalent as ZnO (Singh *et al.*, 2004) to accompany liming in order to offset yield losses through pH- and Ca-induced Zn deficiency, especially when large amounts of lime are applied.

TABLE 2: The Ca: (Ca+Mg+K) concentration ratios in the 0 -10 cm soil depth and 10-40 cm soil depth at 6 sites in Manguzi and 5 sites in MLV.

Sampling sites in Manguzi (NCP of KZN)	Soil depth (cm)	Ca:(Ca+Mg+K) Ratio		Sampling sites in MLV	Soil depth (cm)	Ca:(Ca+Mg+K) Ratio
KwaMazambane	0-10	0.89		LVACF	0-10	0.82
	10-40	0.81			10-40	0.79
Ekuhluphekeni	0-10	0.77		Malekutu	0-10	0.85
	10-40	0.76			10-40	0.82
Thandizwe	0-10	0.89		Numbi	0-10	0.84
	10-40	0.82			10-40	0.83
Nsukumbili	0-10	0.77		Luphisa	0-10	0.82
	10-40	0.72			10-40	0.80
Ndlondlweni	0-10	0.87		Masoyi	0-10	0.83
	10-40	0.81			10-40	0.79
Mabhudu	0-10	0.79				
	10-40	0.66				

Generally, Mn toxicity is the main problem encountered in acid sandy soils with pH values in the range of 4.5 to 5.0 because of its high solubility under acidic conditions. However, even though the soils in MLV and Manguzi are acidic, the soil Mn concentrations ranging from 4 to 24 mg kg^{-1} in MLV and from 3 to 14 mg kg-1 in Manguzi are too low to cause toxicity in groundnut. Rather, Mn deficiency might be expected in both locations. The critical soil Mn concentration for groundnut is 3 to 7 mg kg^{-1} in soil with a pH between 5.5 and 7.0 (Hanlon, Kidder & Mcneal,1990; Plank, 1989). This range is similar to the mean site range 2.3 to 7.1 mg kg^{-1} obtained in the acidic soil in MLV and Manguzi, except for Masoyi in MLV, which had a mean Mn concentration of 11.2 mg kg^{-1}. Manganese solubility and availability to plants decrease with increasing soil pH. Thus, raising the soil pH above 5.5 will exacerbate Mn deficiency on these soils. Consequently, it will be necessary to also apply Mn when liming the soils. In the absence of a soil test, an application from 1 to 4 kg Mn ha^{-1} as $MnSO_4$, MnO_2, $MnCO_3$, or $MnCl_2$ (Sing *et al.*, 2004) is herein recommended along with fertilizer depending on the amount of lime applied.

5. CONCLUSIONS AND RECOMMENDATIONS

The sandy soils on which groundnut is being grown by smallholder farmers in MPLV and Manguzi were found to be acidic and low in Ca, Mg, K, P, Zn and Mn concentrations. However, Ca, Mg and K were present in concentrations that are adequate for groundnut production. Therefore, the soils do not need the application of these nutrients apart from maintenance dressings. The P and Mn concentrations were in the deficient ranges, and the soil Zn concentration was marginal for groundnut. Thus, P, Mn and Zn could limit groundnut yields in MPLV and Manguzi. To optimize groundnut productivity on these acidic soils, lime should be applied at low rates of 200 to 500 kg/ha. This should be done with calcitic lime accompanied with applications of P, Mn and Zn to prevent lime-exacerbated deficiencies of these nutrients.

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