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Sustainable and profitable crop and livestock systems in south-central coastal Vietnam

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Diagnosing multiple nutrient deficiencies that limit crop growth and yield on sands in south-central coastal Vietnam

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Abstract

Nutrient management for profitable and sustainable crop production depends on correct diagnosis of the full range of disorders that could potentially limit crop yield and grain or fruit quality. On sands, a suite of nutrient disorders can typically limit crop yield but the specific deficiencies can vary among types of sand. Hence, for site-specific nutrient management, there is a need for accurate diagnosis of the disorders. In the present study, the omission design—'All' nutrients, and without phosphorus (P), potassium (K), sulfur (S), boron (B), copper (Cu), zinc (Zn) and molybenum (Mo)—was used in five field experiments to determine limiting nutrients for peanut growth and yield on a range of the major sand types in south-central coastal (SCC) Vietnam. A modified double-pot experimental approach was also used to determine its accuracy in more rapid prediction of field nutrient deficiencies. In three field experiments in Phu Cat district, Binh Dinh province, irrigated peanut yield was depressed by K, S, B and Cu deficiency. In addition, omission of Zn depressed yield in one of those fields. Omission of Mo depressed shoot dry matter (DM) of peanut in the Cat Hanh site in 2011 but not seed yield. Double-pot experiments with maize as a test plant confirmed K, S, B and Cu deficiencies in Binh Dinh sands. By contrast, in sands in Ninh Thuan province, P, K, S, Cu and Zn were deficient for peanut yield at one field site while P, K, S, B, Cu and Zn were deficient at another. The results were supported by maize plant DM and shoot nutrient concentration responses in the double-pot experiment. We conclude that nutrient disorders vary among different sands, requiring careful diagnosis for each type of sand, but parent material best explains differences in the suite of nutrient deficiencies diagnosed in each. The modified double-pot experiment predicted the same deficiencies as the field experiments, suggesting it could be used as a diagnostic tool to assess the suite of nutrient limitations expected in different types of sands, whether in Vietnam or elsewhere. Multiple nutrient deficiencies in SCC Vietnam require further research to develop integrated nutrient management approaches to overcome these deficiencies and also minimise the cost of inputs.

Introduction

Sands in the coastal zone of Vietnam cover about 0.33 million hectares (ha) (Hoang Thi Thai Hoa et al. 2010), located mainly in the north and south-central regions. Only limited investigation of these soils has been carried out to develop evidence-based nutrient management practices for profitable and sustainable crop production. Present recommendations largely focus on balanced fertilisation with nitrogen (N), phosphorus (P) and potassium (K) which are applied to a range of field and tree crops common in the region (Hoang et al. 2009). However, multiple nutrient deficiencies, including micronutrients, are common on sands (Bell et al. 1990). Failure to diagnose the full range of deficiencies will limit the response to nutrients in fertilisers, produce low

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nutrient use efficiency of the supplied nutrients, and little or no profit from the fertiliser investment (Bell and Dell 2008). Moreover, in the coastal zone, where shallow aquifers occur under sands, there is a high risk of groundwater pollution from nutrients, such as nitrate-N (NO_3-N) and phosphate-P (PO_4-P) (Do Thi Thanh Truc et al. 2015) when there is low nutrient use efficiency for supplied fertiliser.

Low clay and high sand contents are the main defining characteristics of sands. Up to 18% clay is allowable in the Arenosols—the principal World Reference Base order for sand-rich profiles. Within the range 0–18% clay and 65–100% sand that occur in the Arenosols (FAO et al. 1998), large variation in soil properties is possible. Within sandy terrain, such as in Vietnam, significant variation in profile clay content can occur along topo-sequences (Bell et al. 2015). Differences in clay content and in clay mineral type can greatly alter the yield potential of rice and other crops. The parent material for sands can also vary and will undoubtedly influence the likelihood of particular nutrient deficiencies. The coastal sands in central Vietnam have been broadly divided into Red, Yellow and White dunal sands and Sandy marine soils (Vietnam Soil Association 1996). Within these geomorphic units, further subdivision of sands is recommended based on clay percentage, clay distribution with depth and pH of the soil (Bell et al. 2015). For example, the Red dunal sand has a basal strata of calcareous sands that is overlain by yellow sands with up to 60 m of red sand capping the dune (Bell et al. 2015). Soils associated with exposure of each of these strata will differ in their properties and accordingly may have distinctive influences on crop productivity.

Our investigations in Ninh Thuan, Phu Yen and Binh Dinh provinces of south-central coastal (SCC) Vietnam indicate that sands derive from in situ weathered granite, from colluvial sediments weathered from granite and from siliceous sediments reworked by aeolian and fluvial activity (Bell et al. 2015). Sandy alluvial deposits also occur in the coastal terrain of Ninh Thuan. In summary, sands comprise a diverse range of soils by variation in texture, parent material and pedological development, leading to considerable variation in physical and chemical properties. Hence, the type and severity of nutrient constraints need to be carefully defined for different types of sand profiles.

Nutrient management of sands is generally more complex than that of other soils because of the prevalence of multiple nutrient deficiencies. In addition, the low water holding capacity of the sands can limit root access to nutrients when topsoils dry out and with increased propensity of many nutrients to leach away (e.g. Bell and Seng 2007; Sitthaphanit et al. 2009). In north-eastern Thailand, apart from N and P deficiencies, K, sulfur (S), boron (B), molybdenum (Mo) and copper (Cu) are commonly deficient (Bell et al. 1990). However, not all these deficiencies occur on all sands and in all crops. For site-specific nutrient management of sands, accurate diagnosis is needed of the suite of disorders limiting crop production in a particular soil type.

Peanut (*Arachis hypogaea* L.) was chosen as the test crop for field studies to determine what range of nutrient disorders might limit yield and nut quality. Peanut is expanding as a cash crop in the SCC region, driven by market opportunities in China (Phan Thi Tam Giac and Mackay 2015). However, little research on its nutrient requirements in this region have been undertaken apart from a few studies on micronutrients and P deficiency (Nguyen Thi Dan and Thai Phien 1991; Le Thanh Bon 1996; Hoang Minh Tam et al. 2010; Nguyen Van Chien 2010). These studies tested only a few of the nutrients essential for peanut growth and doubt remains whether peanut crops achieved their potential yield on these sands.

The first aim of this study was to identify the nutrient constraints for yield of peanut on a range of sands in Phu Cat district, Binh Dinh province and Ninh Phuoc district, Ninh Thuan province. The second aim was to test the reliability of the double-pot technique developed by Janssen (1974, 1990) to rapidly assess nutrient constraints for plant growth of maize on a range of sands from Binh Dinh, Phu Yen and Ninh Thuan provinces. The ability to rapidly assess the nutrient supplying capacity of soils is an essential first step in developing a useful nutrient management system. The double-pot technique was assessed to confirm its reliability in predicting nutrient deficiencies found in peanut in the field experiments.

Materials and methods

Field experiments

Soil preparation and management

Omission experiments were conducted at five sites in Binh Dinh and Ninh Thuan provinces during 2010–12 on soils classified as sands or loamy sands based on surface texture (Table 1). Land was ploughed and later levelled by raking. All the experiments followed a complete randomised block design with four replicates. Each plot covered an area of 15 m². Dual Gold^R 960EC (S-Metolachlor (min. 98.3%) herbicide was used to control weeds by spraying the field after ploughing. Peanut (variety LDH 01) was chosen as the test crop at all sites to diagnose nutrient disorders that could limit growth and yield using an omission design (Bell et al. 1990). Two seeds/hole were placed manually at a distance of 20 cm with a row spacing of 25 cm to give a target density of 40 plants/m². Seeds were sown at a depth of 3–5 cm. The crop was regularly irrigated with bore water using a hose—a normal farming practice in this region—aimed at avoiding water stress to allow optimal crop growth. Pests and diseases were managed using various pesticides (Topsinm 70 wp, Anvil 5 SC, Cofidor, Admitox 750 wDG, Alimec USA 36 EC and Map – permethrin 50EC).

The optimum rates of nutrients applied to soils were referred to as 'All' and included macro- (N, P, K and S) and micro- (Cu, B, zinc (Zn) and Mo) nutrients at rates, forms and methods of application outlined in Table 2. Rates of fertiliser application were based on recommendations for peanuts (Dierolf et al. 2001). The 'All' treatment was used as a benchmark to compare crop growth against other treatments in which specific elements were omitted.

All treatments received lime as calcium oxide (CaO) at 500 kg/ha, supplying 358 kg Ca/ha. Half of N, K and lime and all of P, S, Cu, Zn and Mo were broadcast on the soil surface and incorporated in the

Table 1. Location, year and physico-chemical properties of soils used for field experiments

Site no.	Location[a], year	Soil properties (0–10 cm)								
		Clay (%)	Silt (%)	Sand (%)	pH_{KCl}	Olsen P (mg/kg)	Org.C (%)	CEC (cmol/kg)	EC (dS/m)	Soil water, –0.1 bar (%)
1	Cat Hanh, 2010	9	3	88	4.30	5.2	0.45	1.80	0.008	7.1
2	Cat Hanh, 2011	2	3	95	6.98	33.1	0.43	1.80	0.041	4.7
3	Cat Trinh, 2011	2	4	94	4.40	35.9	0.51	2.4	0.024	6.5
4	An Hai, 2012	1	2	98	6.10	14.9	0.29	1.45	0.059	3.1
5	Phuoc Dinh, 2012	3	1	96	4.83	7.0	0.11	1.73	0.016	3.4

[a] Cat Hanh and Cat Trinh communes, Phu Cat district, Binh Dinh province; An Hai commune, Ninh Phuoc district, and Phuoc Dinh commune, Thuan Nam district, Ninh Thuan province

Note: pH_{KCl} = pH measured in 1M potassium chloride; Olsen P = extractable phosphorus; Org. C = organic carbon; CEC = cation exchange capacity; EC = electrical conductivity

Table 2. Fertiliser rates, forms and methods of application in the field experiments

Nutrient (element)	Amount applied (kg/ha)	Form of fertiliser	Method of application
Nitrogen	30 N	Urea: NH_2CONH_2	Broadcast
Phosphorus	40 P	Sodium dihydrogen phosphate: NaH_2PO_4	Broadcast
Potassium	50 K	Potassium choride: KCl	Broadcast
Sulfur	20 S	Calcium sulfate: $CaSO_4$	Broadcast
Boron	0.25 B	Boric acid: H_3BO_3	Foliar
Copper	2.39 Cu	Copper sulfate: $CuSO_4$	Broadcast
Molybdenum	0.543 Mo	Ammonium molybdate tetrahydrate: $(NH_4)_6Mo_7O_{24}.4H_2O$	Broadcast
Zinc	4.05 Zn	Zinc sulfate: $ZnSO_4$	Broadcast

soil to 8 cm depth before sowing: the remaining half of N, K and lime was broadcast at flowering stage. Boron was applied at 0.25 kg/ha as boric acid by dissolving in 500 litres (L) of water and sprayed on peanut foliage just before flowering.

Plant sampling and harvesting

Peanut shoots were harvested to measure dry matter (DM) at branching, flowering and maturity from a quadrat measuring 0.5 m^2 in an area representing 20 plants. Pod yield was measured at maturity by uprooting all the pods from the whole plot (15 m^2). Pods were sun-dried in the open and weighed to estimate pod yield. Other harvest data included number of pods/plant, number of well-rounded pods/plant, weight of 100 pods and weight of 100 nuts (kernels) from 10 plants/plot.

Soil and plant analysis

Soil pH was measured in 1 M potassium choride (KCl) in a soil to solution ratio of 1:5 using a pH meter (Mettle TOLEDO MP220). Electrical conductivity (EC) was measured in a soil to water ratio of 1:5 using a EC meter (Mettle TOLEDO FE30). Available P (Olsen P) was extracted using 0.5 M sodium bicarbonate ($NaHCO_3$) at pH 8.5 (Olsen et al. 1954). Organic carbon was determined by 1 N potassium dichromate ($K_2Cr_2O_7$) solution and 2.5 N sulfuric acid (H_2SO_4) (Walkley and Black 1934; Walkley 1947). Cation exchange capacity (CEC) was measured after extraction with 1 M ammonium acetate (NH_4OAc) at pH 7.0 (van Reeuwijk 2002). Soil particle size was measured according to Day (1965). Water holding capacity was determined using a pressure plate apparatus to de-saturate soil samples to –0.1 bar matric potential.

Plant samples, except N, were analysed for all the test nutrients using inductively coupled plasma (ICP) by an accredited laboratory (CSBP Limited, Western Australia). Nitrogen was analysed by the Kjeldahl method.

Double-pot experiment

Method, preparation and management

The double-pot method used here is a modified version of Janssen (1974, 1990) which involves growing the desired test plant (maize) in soil packed in a container and suspended above a pot containing nutrient solution, so that the plant roots can access nutrients from both the soil and from a nutrient solution. By selective omission of nutrients from the nutrient solution, the relative nutrient supply capacity of the soil can be easily assessed. This method differs from the original method of Janssen (1974) in the design of the apparatus and the nutrient solution used. Instead of the plant roots being able to grow through a gauze layer to the nutrient solution under the soil, the nutrient solution is supplied to the soil via a wick system.

The containers used were those used for food takeaway supplies. Dimensions of the upper container were 115 mm width × 40 mm height with a 6 mm hole pressed out in the centre of the base to accommodate the absorbent wick. The lower container was 115 mm width × 100 mm height. The cylindrical wicks were uncut cigarette filters measuring 7 mm × 125 mm. The wick was placed to touch the bottom of the lower container and to be approximately 5 mm below the surface of the soil placed in the upper container. Soils were collected in bulk from three sites representing field experimental sandy soils of Cat Hanh and Cat Trinh communes in Binh Dinh province (samples 1, 2 and 4), two soils from Ninh Thuan province, representing granite sand from An Hai (sample 3) and red sand from Phuoc Dinh (sample 5), and one representative sandy soil from Phu Yen province (sample 6). Soils used and their physico-chemical properties are presented in Table 3. Samples 1, 3, 4, 5 and 6 were collected at 0–20 cm depth, whereas sample 2 was taken from 20–40 cm depth from the same site as sample 1.

Each pot received 1 kg of the sandy soil as described in Table 3 after being passed through a 2 mm sieve. The pot was packed into the top container at a bulk density of 1.35 g/cm^3, and the lower container was filled with approximately 500 mL of distilled/deionised water. The wick absorbed nutrients and the water from the lower container via capillary action to supply to the soil in the upper container. Initially, the pot was left for several hours for the soil to moisten and equilibrate.

Six maize seedlings of similar size germinated earlier on wet tissue paper were planted in the pots containing soil placed above the container filled with water that was later replaced with the relevant nutrient solution. Nutrient solutions were topped up daily, or when required, and were replaced with fresh solution once per week. The nutrient solution treatments were randomised in replicate blocks and replicated three times.

Treatments

Seven treatments were tested for their impact on maize vegetative growth in the glasshouse (Table 4). These included a complete solution (All) and complete solution minus each of P, K, S, Cu, B and Zn+Mo. The pots were harvested 50 days after planting. Each plant top was cut at 3 mm above the soil surface to avoid contamination from the soil. The tops were dried at 70 °C for 48 hours and dry weights measured. The plant samples were ground to pass through a 2 mm sieve and total nutrient analysis was carried out for N, P, K, S, Cu, B, Zn and Mo.

Statistical analysis

Data were analysed using one-way analysis of variance (ANOVA) for each experiment. Treatment differences were examined by least significant differences at $p < 0.05$.

Table 3. Sampling location and physico-chemical properties of soils used for the double-pot experiment

Sample no.	Sampling site[a]	Clay (%)	Silt (%)	Sand (%)	pH $_{KCl}$	Olsen P (mg/kg)	Org. C (%)	CEC (cmol/kg)	EC (dS/m)	Soil water, –0.1 bar (%)
1	Cat Hanh	3	2	95	3.92	17.3	0.69	nd	0.08	4.4
2[b]	Cat Hanh	2	3	95	4.05	5.2	0.49	1.80	0.02	7.1
3	An Hai	3	3	94	5.30	1.5	0.30	2.20	0.03	7.8
4	Cat Trinh	2	4	94	4.40	35.9	0.51	2.40	0.02	6.5
5	Phuoc Dinh	2	3	95	5.04	3.8	0.12	1.88	0.01	3.4
6	Phu Yen	0	1	99	5.29	0.015	0.16	1.60	0.74	nd

[a] Cat Hanh and Cat Trinh communes, Binh Dinh province; An Hai and Phuoc Dinh communes, Ninh Thuan province; Phu Yen province (An Chan commune)

[b] This is the same site as sample 1, but taken at 20–40 cm depth

Note: pH_{KCl} = pH measured in 1M potassium chloride; Olsen P = extractable phosphorus; Org. C = organic carbon; CEC = cation exchange capacity; EC = electrical conductivity; nd = not detected

Table 4. Concentration of stock and nutrient solutions used in the double-pot experiment

Compound/salt used	Amount added (g/L stock solution)	Nutrient solution (mL/L)						
		All	–P	–K	–S	–Cu	–B	–Zn +Mo
Micronutrients								
Calcium nitrate tetrahydrate: $Ca(NO_3)_2.4H_2O$	236.1	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Potassium nitrate: KNO_3	101.1	1.0	2.0	–	2.0	2.0	2.0	2.0
Ammonium phosphate: $NH_4H_2PO_4$	115.0	2.0	–	2.0	–	2.0	2.0	2.0
Magnesium sulfate heptahydrate: $MgSO_4.7H_2O$	184.8	1.0	1.0	1.0	–	1.0	1.0	1.0
Potassium chloride: KCl	149.0	1.0	1.0	–	1.0	1.0	1.0	1.0
Potassium phosphate: KH_2PO_4	136.0	–	–	–	–	–	–	–
Calcium chloride: $CaCl_2.6H_2O$	109.5	–	–	–	–	–	–	–
Ammonium nitrate: NH_4NO_3	40.0	–	2.0	–	2.5	–	–	–
Ammonium chloride: NH_4Cl	106.8	–	–	1.0	–	–	–	–
Micronutrients								
Iron (Fe) sequestrene	64.360	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Manganese chloride: $MnCl_2.4H_2O$	2.969	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Zinc chloride: $ZnCl_2$	0.204	1.0	1.0	1.0	1.0	1.0	1.0	–
Copper chloride: $CuCl_2$	0.134	1.0	1.0	1.0	1.0	–	1.0	1.0
Boric acid: H_3BO_3	0.031	1.0	1.0	1.0	1.0	1.0	–	1.0
Ammonium molybdate tetrahydrate: $(NH_4)_6Mo_7O_{24}.4H_2O$	0.012	1.0	1.0	1.0	1.0	1.0	1.0	–

Note: N = nitrogen; P = phosphorus; K = potassium; S = sulfur; Cu = copper; Zn = zinc; B = boron; Mo = molybdenum

Results and discussion

Soil characteristics and effect of nutrient omission on peanut growth on farmers' fields

All the sites selected for nutrient omission field trials had >88% sand and low organic carbon (C) content. Most of the soils were acidic ($pH_{KCl} \leq 6.1$), except Cat Hanh–site 2 where the pH was neutral (Table 1). As a result of low clay and organic C content, the CEC and water holding capacity were also very low. Using the Soil Constraints and Management Practices (SCAMP) tool, lack of clay and organic C—common features of most sandy soils of SCC Vietnam—were identified to be the key constraints that limited crop productivity (Hoang Thi Thai Hoa et al. 2010; Bell et al. 2015). In addition, the acidic pH influences the availability of macro- and micronutrients to plants (Corey and Schulte 1973). Increase in soil pH reduces the availability of micronutrients, with the exception of Mo (under high pH conditions) (Gupta 1969). Legumes, such as peanuts, are especially sensitive and soil pH can greatly affect crop responses to Mo; however, there are genotypes and species that differ in their response to Mo (Gupta 1969; Adams 1997).

Micronutrient deficiencies in various crops have increased in prevalence principally because of intensive cropping, liming, leaching, modern high-yielding cultivars, and also due to loss of topsoil through erosion (Gupta et al. 2008). Decreased use of plant residues and animal manures that contain micronutrients (Bell and Dell 2008) and use of macronutrient fertilisers can also lead to micronutrient deficiencies.

Some of the levels of total micronutrients analysed in the soils used for double-pot omission experiments showed that the levels of nutrients in these soils were variable and very low (Table 5) compared with levels of these nutrients around the world (Gupta et. al. 2008). However, the total quantity of a micronutrient in a soil is generally not a good indicator of its availability to plants (McLaren et al. 1984), although total quantity does indicate the relative abundance of a particular element in a soil and its potential replenishing power (Bergeaux 1966).

Levels of Zn were lower than 10 mg/kg in these soils (Table 5), whereas most of the Zn levels reported by Gupta et al. (2008) ranged between 10 and 300 mg/kg. Levels of S were below the detection limit (Table 5). Lack of equipment capable of measuring nutrients at low levels is an impediment to appropriately analysing nutrients in the SCC region or elsewhere in Vietnam. Hence, building analytical capabilities and laboratory facilities to accurately measure low levels of these nutrients is fundamental to being able to make recommendations for crop production.

Effect of nutrient omission at different stages of peanut biomass and yield

Above-ground biomass at the flowering stage was highest (around 2 tonnes (t)/ha) at site 2 (Cat Hanh commune, 2011) compared with all the other sites, whereas site 5 (Phuoc Dinh commune, 2012) had the lowest (around 1 t/ha) biomass. Omission of K reduced biomass at flowering in all five locations. Omission of N and P decreased biomass on all sands except site 1 (Cat Hanh, 2010). Omission of S decreased biomass of all sands except site 1 and site 5. Among the micronutrients, omission of B depressed biomass in site 1 and site 4 (An Hai commune, 2012), omission of Cu depressed biomass on site 3 (Cat Trinh commune, 2011) and site 4, omission of Mo depressed biomass on site 1 and site 3 while omission of Zn depressed it on site 4 and site 5 (Figure 1).

Table 5. Total nutrient levels in some of the soil samples from south-central coastal Vietnam collected for the double-pot experiment

Sample no.	Sampling site	Copper (mg/kg)	Zinc (mg/kg)	Sulfur (mg/kg)	Boron (mg/kg)
1	Cat Hanh	2.53	8.58	bdl	7.05
2	Cat Hanh	3.25	5.63	bdl	2.89
3	An Hai	1.38	9.75	bdl	3.71
4	Cat Trinh	1.00	6.18	bdl	2.87
5	Phuoc Dinh	1.44	3.80	bdl	21.5
6	Phu Yen	1.45	4.63	bdl	7.97

Note: bdl = below detection limit; see Table 3 for other properties of these samples

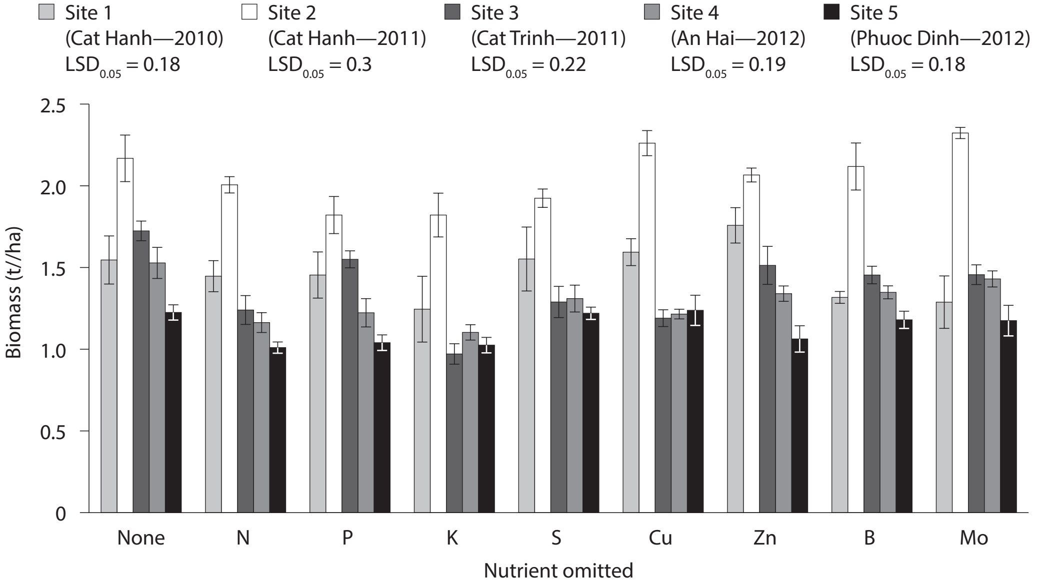

Figure 1. Effects of nutrient omission on above-ground biomass (t/ha) of peanut at the flowering stage. Note: N = nitrogen; P = phosphorus; K = potassium; S = sulfur; Cu = copper; Zn = zinc; B = boron; Mo = molybdenum; $\text{LSD}_{0.05}$ = least significant difference at $p < 0.05$

Biomass at the harvest stage more than doubled at all sites compared with biomass at flowering (Figure 2). Omission of N, P, K and S significantly decreased peanut growth at sites 2, 4 and 5. By contrast, at site 1, only Mo omission depressed above-ground biomass, and at site 3, N, P and K omission depressed above-ground biomass. While Zn omission depressed above-ground biomass in sites 2, 4 and 5, Cu omission depressed biomass at site 5 as did omission of Mo at site 2. At site 1, omission of Cu or B gave an increase in biomass which was significantly higher than all other sites and treatments, including where all nutrients (All) were applied (Figure 2). Plant residue, especially of peanut due to its high protein content, is used as feed for animals or as compost in the SCC region and hence is an important component of the peanut plant that contributes to farming income (Hoang Thi Thai Hoa et al. 2015). Hence, higher above-ground biomass in addition to higher pod yields would be an added advantage for farmers in this region.

With all the nutrients applied to peanut, the pod yield varied between 2.3 and 4.1 t/ha among the five field experimental sites (Figure 3), even though all the soils were sands or loamy sands and were sown during the main peanut-growing season. However, higher peanut yields of more than 6 t/ha are achievable (Middleton 1980). Differences in yields can be attributed to the type of parent material from which the soils were derived and their variable levels of total nutrients, which have the potential of replenishing a particular nutrient (Bergeaux 1966). Site 2 had the highest peanut pod yield of all the five sites (Figure 3), which may be attributed to the neutral pH and high levels of P in the soil (Table 1). In addition, the differential yield responses following fertiliser application can be attributed to differences in residual soil fertility status (Giller and Cadisch 1995; Palm et al. 2001; Koné et al. 2008).

Poor yield at site 1 was mainly because of the drought in 2010 that affected most of the crops in Binh Dinh province, even where all the nutrients were applied. Drought stress has an adverse influence on water relations, mineral nutrition, metabolism, growth and yield of peanut (Suther and Patel 1992). Levels of P were also low at this site and may have contributed to restricted yields.

Apart from different irrigation and rainfall regimes, distribution of clay with depth and other variable characteristics down the profile, as shown by Bell et al. (2015), could also have influenced the growth and yield of peanut. The rate of nutrient leaching, such as B, down the sandy profiles (e.g. Sitthaphanit et al. 2009) during field preparation and sowing may have also limited peanut growth later in the crop cycle. However, despite the differences in maximum yield at each site, strong responses of yield were obtained to omission of selected elements, including micronutrients. For example, omission of K and S depressed peanut pod yield at all sites (Figure 3). Omission of Cu and B decreased pod yield at the three sites in Binh Dinh (sites 1–3), while Cu, B and Zn deficiency reduced pod yield at Ninh Thuan (site 4/An Hai) and Cu and Zn deficiency reduced pod yield at Ninh Thuan (site 5/Phuoc Dinh). Deficiency of P limited pod yield at both sites in Ninh Thuan (sites 4 and 5), which can be attributed to low levels of P found in these soils (Table 1). Surprisingly, absence of Mo gave an increase in pod yield at site 1 which contrasts with the decrease in shoot above-ground biomass (Figure 2). One possible explanation is that 'All' produces excessive vegetative above-ground biomass that inhibits pod growth, while the reduced above-ground biomass in 'All – Mo' may decrease the sink strength of the shoots relative to pods. Lower levels of nutrients such as P and Mo can also affect nodulation and nitrogen fixation, especially when soils are acidic, particularly below pH 5.5 (Angelini et al. 2003).

Effect of nutrient omission on peanut pod quantity and quality

Hollow pods (known as 'pops') and/or a blackened plumule inside the seed or nut (known as 'black heart') are indications of poor quality resulting from calcium (Ca) deficiency (Singh and Basu 2005). Poor germination has also been observed where Ca concentration in peanut seeds is below 400 mg/kg. However, since lime was applied to all the experimental fields before sowing, it is assumed that the amount of Ca would have been sufficient to prevent internal defects in the seed and poor germination. Phosphorus and S both contribute to oil synthesis, nodulation and pod yield, all of which reflect peanut quality (Singh and Basu 2005); however, pod quality and quantity were both most affected in the absence of Zn (All – Zn) at site 1 (Table 6). The weight of nuts was depressed by the omission of most of the elements in comparison to the treatment where all nutrients were applied; in particular, Zn, P, Cu and S.

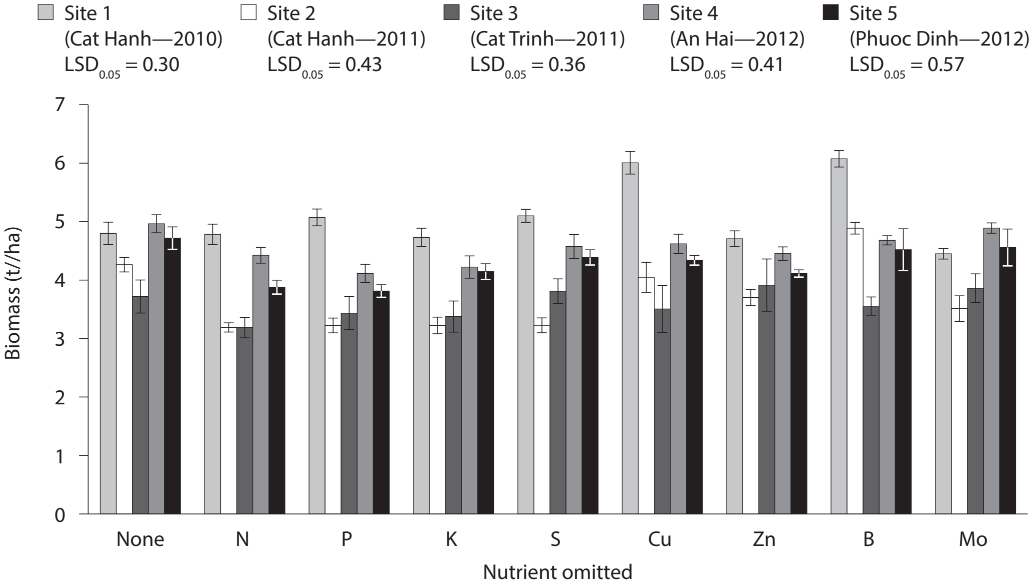

Figure 2. Effects of nutrient omission on above-ground biomass (t/ha) of peanut at the harvest stage.
Note: N = nitrogen; P = phosphorus; K = potassium; S = sulfur; Cu = copper; Zn = zinc; B = boron; Mo = molybdenum; $LSD_{0.05}$ = least significant difference at $p < 0.05$

Site 2 not only had a higher overall pod yield than other sands (Figure 3), but also had a higher number of well-rounded pods/plant and higher weight of nuts (Tables 6–10). Number of pods/plant and number of well-rounded pods/plant were most affected where K was omitted. Weight of nuts was highest where all nutrients were applied, reflecting the significance of balancing all the nutrients for optimum seed growth. Neutral pH of the soil at site 2 may have also enhanced nutrient uptake and, hence, peanut growth.

In general, site 3 had fewer pods/plant and well-rounded pods/plant compared with the other four

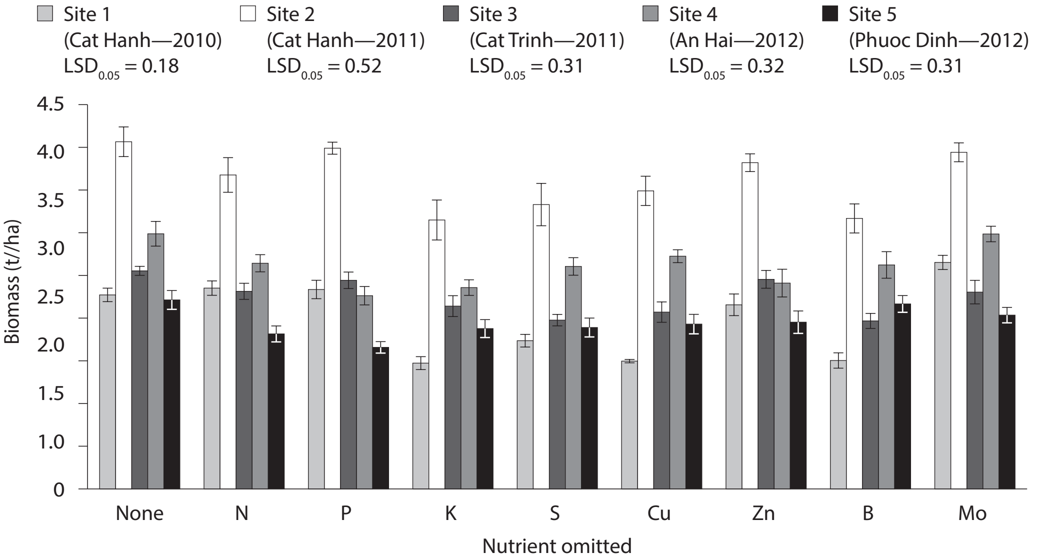

Figure 3. Effects of nutrient omission on pod yield (t/ha) of peanut at harvest. Note: N = nitrogen; P = phosphorus; K = potassium; S = sulfur; Cu = copper; Zn = zinc; B = boron; Mo = molybdenum; $LSD_{0.05}$ = least significant difference at $p < 0.05$

Table 6. Effects of nutrient omission on pod quantity and quality of peanut at site 1 (Cat Hanh commune, Binh Dinh province, 2010)

Treatment	No. of pods/ plant	No. of well-rounded pods/plant	Weight of 100 pods (g)	Weight of 100 nuts (g)
All	12.7	7.1	124	64.5
All minus N	13.1	6.3	119	60.3
All minus P	13.4	7.7	117	55.8
All minus K	11.2	6.0	103	63.6
All minus S	12.4	7.8	111	58.9
All minus Cu	13.4	6.6	104	57.0
All minus Zn	9.9	5.7	109	54.3
All minus B	12.0	6.8	106	61.1
All minus Mo	12.0	5.8	127	59.6
$LSD_{0.05}$	1.01	1.10	NS	3.32

Note: values are means of four replicates; N = nitrogen; P = phosphorus; K = potassium; S = sulfur; Cu = copper; Zn = zinc; B = boron; Mo = molybdenum; $LSD_{0.05}$ = least significant difference at $p < 0.05$; NS = not significant sites, especially the other Binh Dinh location sites 1 and 2. Only omission of N and Cu decreased pods per plant (Table 8). The decrease in overall yield could be explained by the reduced numbers of well-rounded pods, where omission of K, S, Cu and B decreased these by 14–27% ($p < 0.05$). Omission of P had no impact on quality or quantity as the level of P in the soils at this site was more than adequate (Table 1).

Numbers of pods/plant and well-rounded pods/plant, and weight of pods and nuts were all higher at site 4 than at site 5. This is a reflection of the soil quality at site 4, where the pH is less acidic and there were higher P and organic C levels (Table 1). Omission of P and K decreased the number of pods/plant and well-rounded pods/plant at site 4 (Table 9), whereas at site 5, omission of N and P decreased both number of pods/plant and well-rounded pods/plant while omission of K depressed only well-rounded pods/plant (Table 10). Weights of pods and nuts were not significantly different among treatments at these sites with the exception of decreased 100 nut weight in the 'All minus K' treatment at site 4 (Table 9).

Table 7. Effects of nutrient omission on pod quantity and quality of peanut at site 2 (Cat Hanh commune, Binh Dinh province, 2011)

Treatment	No. of pods/ plant	No. of well-rounded pods/plant	Weight of 100 pods (g)	Weight of 100 nuts (g)
All	12.5	9.8	153	66.1
All minus N	12.7	9.1	160	62.2
All minus P	12.6	9.5	151	63.3
All minus K	9.9	7.5	159	63.7
All minus S	11.9	8.9	157	62.9
All minus Cu	11.1	9.0	155	60.1
All minus Zn	11.2	9.3	156	62.0
All minus B	11.8	8.6	153	59.3
All minus Mo	11.3	9.7	159	64.3
$LSD_{0.05}$	1.48	1.22	8.90	2.33

Note: values are means of four replicates; N = nitrogen; P = phosphorus; K = potassium; S = sulfur; Cu = copper; Zn = zinc; B = boron; Mo = molybdenum; $LSD_{0.05}$ = least significant difference at $p < 0.05$

Table 8. Effects of nutrient omission on pod quantity and quality of peanut at site 3 (Cat Trinh commune, Binh Dinh province, 2011)

Treatment	No. of pods/ plant	No. of well-rounded pods/plant	Weight of 100 pods (g)	Weight of 100 nuts (g)
All	8.8	6.8	137	58.3
All minus N	7.5	5.8	143	58.6
All minus P	8.4	6.7	141	61.4
All minus K	9.2	5.7	142	61.2
All minus S	8.7	5.0	138	63.8
All minus Cu	7.8	5.2	138	59.3
All minus Zn	9.2	6.7	133	61.8
All minus B	8.7	5.5	139	56.3
All minus Mo	9.1	6.1	136	60.4
$LSD_{0.05}$	1.0	0.8	6.8	4.3

Note: values are means of four replicates; N = nitrogen; P = phosphorus; K = potassium; S = sulfur; Cu = copper; Zn = zinc; B = boron; Mo = molybdenum; $LSD_{0.05}$ = least significant difference at $p < 0.05$

Table 9. Effects of nutrient omission on pod quantity and quality of peanut at site 4 (An Hai commune, Ninh Thuan province, 2012)

Treatment	No. of pods/ plant	No. of well-rounded pods/plant	Weight of 100 pods (g)	Weight of 100 nuts (g)
All	10.6	9.3	164	58.5
All minus N	9.6	8.3	162	57.6
All minus P	8.8	7.4	160	57.2
All minus K	8.9	7.2	159	55.8
All minus S	9.6	8.3	160	56.8
All minus Cu	9.7	8.4	161	58.6
All minus Zn	9.3	8.1	161	57.3
All minus B	10.1	8.6	163	57.7
All minus Mo	10.4	8.9	163	58.5
$LSD_{0.05}$	1.9	1.3	NS	2.7

Note: values are means of four replicates; N = nitrogen; P = phosphorus; K = potassium; S = sulfur; Cu = copper; Zn = zinc; B = boron; Mo = molybdenum; $LSD_{0.05}$ = least significant difference at $p < 0.05$

Table 10. Effects of nutrient omission on pod quantity and quality of peanut at site 5 (Phuoc Dinh commune, Ninh Thuan province, 2012)

Treatment	No. of pods/ plant	No. of well-rounded pods/plant	Weight of 100 pods (g)	Weight of 100 nuts (g)
All	9.1	7.6	162	56.6
All minus N	6.9	5.7	162	56.2
All minus P	6.6	5.2	159	55.7
All minus K	7.9	6.3	157	54.1
All minus S	8.3	6.9	161	56.4
All minus Cu	7.7	6.4	161	56.8
All minus Zn	7.3	6.1	161	55.3
All minus B	8.2	6.9	161	56.8
All minus Mo	7.9	6.5	162	55.5
$LSD_{0.05}$	1.9	1.1	NS	NS

Note: values are means of four replicates; N = nitrogen; P = phosphorus; K = potassium; S = sulfur; Cu = copper; Zn = zinc; B = boron; Mo = molybdenum; $LSD_{0.05}$ = least significant difference at $p < 0.05$

Soil characteristics and effect of nutrient omission on maize growth in double-pot trials

The double-pot experiment was carried out to assess its potential to identify nutrient deficiencies that could occur in sandy soils of SCC Vietnam. Maize was chosen as the test crop because of its responsiveness to nutrient deficiencies within a relatively short growing period.

Sandy soils for the double-pot experiment were collected to determine whether it could confirm the effects of nutrient omission from the peanut field trials and to examine additional sands not studied in the field (from Phu Yen province). All the soils were sandy, acidic and had low organic C, CEC and water holding capacity. Soil P levels varied between 0.02 and 36 mg/kg, which are considered low to adequate. Sample 6 (Phu Yen) had the lowest clay and P levels compared with the other soils (Table 3).

Dry matter yield of maize

Sample 6 had the highest DM yield per plant among all the soils, followed by samples 4 and 5 (Figure 4). All other soils had nearly half the biomass. In general, omission of K from the nutrient solution had the most significant effect on DM yield of maize compared with all other nutrients (Figure 4). All the sands assessed, due to low clay content, supplied limited K for crop growth (Bell et al. 2015). Omission of P depressed DM on all sands, except sample 2. Surprisingly, the P content of soils (Table 3) was not clearly related to the P limitation of maize growth in the 'All minus P' treatment. Omission of S depressed maize DM yield in all six sands. The most profound impact of S was observed in soils from Ninh Thuan and Phu Yen provinces—samples 3, 5 and 6.

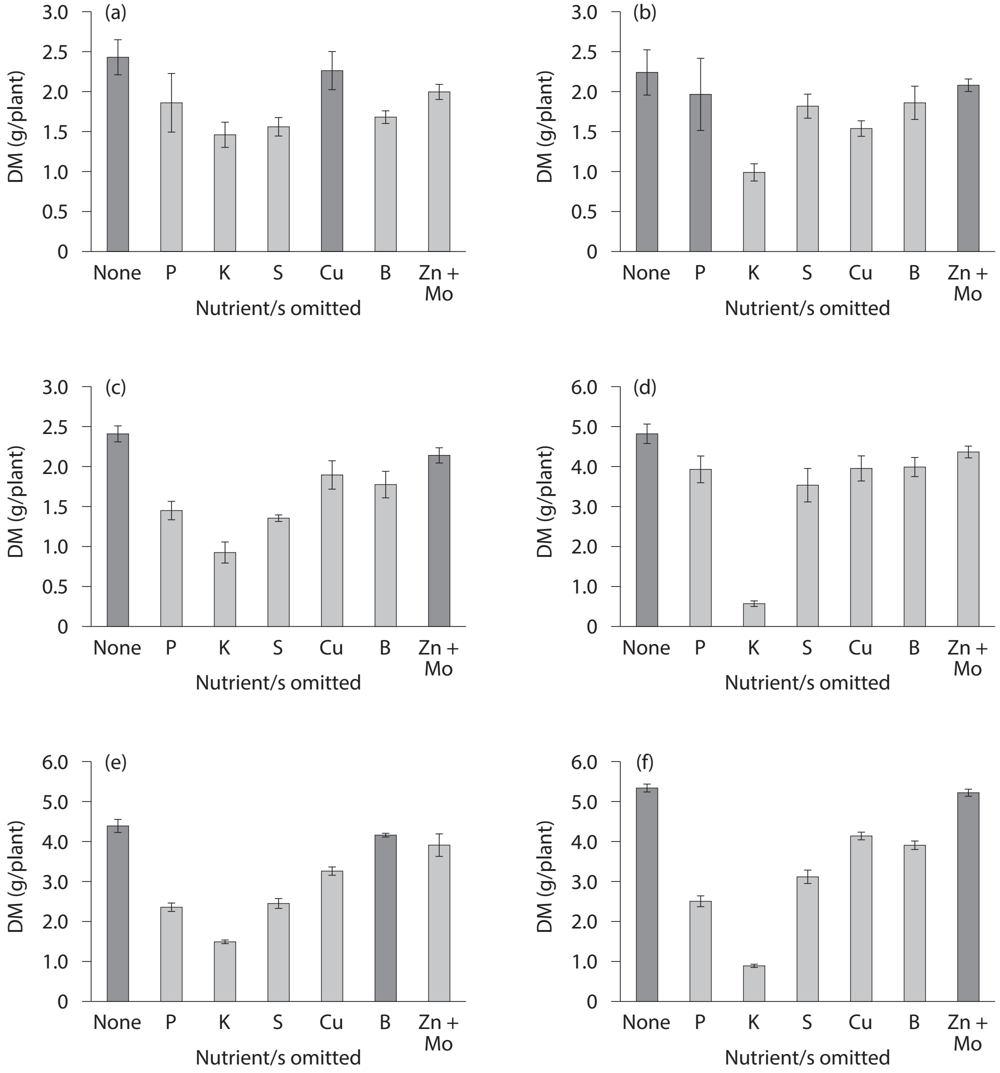

Figure 4. Effect of all nutrients or the omission of nutrients from solution on the dry matter (DM) of maize shoots harvested after 50 days using the double-pot technique with soil from (a) sample 1, Cat Hanh, 0–20 cm; (b) sample 2, Cat Hanh, 20–40 cm; (c) sample 3, An Hai; (d) sample 4, Cat Trinh; (e) sample 5, Phuoc Dinh; and (f) sample 6, Phu Yen. Note: for each sample, the bars with lighter shading were significantly ($p < 0.05$: least significant difference = 0.31) decreased relative to the 'All' treatment; P = phosphorus; K = potassium; S = sulfur; Cu = copper; B = boron; Zn+Mo = zinc + molybdenum

Omission of Cu depressed maize DM except in sample 1. By contrast, in sample 2, where soil had been collected from 20–40 cm depth from the same site as sample 1, maize DM was depressed by Cu omission (Figure 4b). Boron deficiency depressed maize DM on all sands except sample 5. In samples 1, 2, 4 and 5, omission of Zn+Mo depressed maize DM but the magnitude of the decrease was in the range 10–20% (Figure 4).

Nutrient concentration in maize shoots after treatment

In general, the lowest concentrations of each nutrient were found in the treatments where that particular nutrient was omitted and the highest in the treatment where all nutrients were applied (Table 11). However, there were substantially different concentrations among soils both with the 'All' treatment and those with the omission of specific elements from solutions applied in the double-pot experiment.

Table 11. Effect of all nutrients (All) and omission of selected elements on concentrations of macro- and micronutrients in shoots of maize

Soil type and treatment	Macronutrient (%)				Micronutrient (mg/kg)			
	N	P	K	S	Cu	B	Zn	Mo
Sample 1: sandy soil on granite from Cat Hanh commune (0–20 cm)								
All	1.33 g–l	0.15 a	1.83 kl	0.38 a	18.9 ef	17.8 hi	92.5 a	1.3 def
All minus P	1.27 h–m	**0.04 ijk**	2.51 bcd	0.27 bc	14.1 p–u	9.2 op	87.9 b	1.6 ab
All minus K	2.10 a	0.07 efg	**1.00 p**	0.30 b	15.1 k–p	6.5 rs	78.9 e	1.1 klm
All minus S	1.40 d–i	0.14 ab	2.51 bcd	**0.17 fgh**	14.6 m–r	8.5 pq	52.6 l	1.4 bcd
All minus Cu	1.43 c–h	0.14 abc	2.26 efg	0.18 efg	**12.8 tuv**	15.3 j	50.5 mn	1.2 jkl
All minus B	1.26 i–m	0.12 bcd	2.44 cd	0.18 efg	18.8 ef	**3.5 vw**	60.5 j	1.1 mno
All minus Zn+Mo	1.30 h–m	0.12 bcd	1.40 n	0.19 def	18.3 efg	11.6 lm	**40.9 rst**	**1.0 no**
Sample 2: sandy soil on granite from Cat Hanh commune (20–40 cm)								
All	1.29 h–m	0.08 ef	2.47 bcd	0.29 b	16.9 g–j	12.3 l	83.2 c	1.3 jkl
All minus P	1.21 klm	**0.03 jk**	2.53 bcd	0.20 def	12.1 v	7.7 qr	80.6 d	1.3 ghi
All minus K	1.25 i–m	0.06 ghi	**0.71 q**	0.23 cd	14.2 o–t	5.1 tu	77.5 f	1.2 hij
All minus S	1.26 i–m	0.09 e	1.61 m	**0.09 k**	13.3 r–v	6.6 rs	47.4 p	1.2 jkl
All minus Cu	1.37 f–k	0.11 d	1.98 ijk	0.11 jk	**10.1 w**	3.3 vw	56.0 k	1.1 mno
All minus B	1.20 lm	0.04 ijk	1.29 no	0.16 f–i	13.9 p–u	**1.9 x**	62.6 i	1.1 mno
All minus Zn+Mo	1.16 m	0.04 jk	2.49 bcd	0.13 h–k	12.7 uv	10.7 mn	**40.4 st**	**1.0 pq**
Sample 3: sandy soil on granite from An Hai commune, Ninh Thuan province (0–20 cm)								
All	1.33 g–l	0.12 bcd	2.48 bcd	0.18 efg	18.9 ef	17.8 hi	40.4 st	1.4 bcd
All minus P	1.25 i–m	**0.04 jk**	0.89 pq	0.17 efg	14.3 n–s	10.1 no	30.9 w	1.4 bcd
All minus K	1.21 klm	0.04 ijk	**0.87 pq**	0.20 def	13.8 p–u	6.6 rs	44.3 q	1.2 mno
All minus S	1.40 d–i	0.07 fg	0.73 q	**0.13 h–k**	15.9 i–m	11.9 l	30.1 w	1.1 mno
All minus Cu	1.18 lm	0.04 hij	0.87 pq	0.12 ijk	**12.9 s–v**	8.7 pq	37.8 u	1.6 a
All minus B	1.34 g–l	0.04 hij	2.18 gh	0.14 g–j	15.6 j–n	**6.0 st**	36.5 v	1.4 efg
All minus Zn+Mo	1.32 g–m	0.09 e	2.41 cde	0.16 f–i	17.2 ghi	14.4 jk	**23.6 y**	**1.0 klm**
Sample 4: sand from omission experiment on peanut in Cat Trinh commune (0–20 cm)								
All	1.65 b	0.12 cd	2.57 bc	0.14 g–j	18.6 ef	26.3 c	48.9 o	1.4 bcd
All minus P	1.48 c–g	**0.03 jk**	2.42 cde	0.13 h–k	15.7 j–n	21.2 e	45.3 q	1.3 ijk
All minus K	1.43 c–h	0.04 ijk	**0.98 p**	0.12 ijk	13.5 q–v	18.2 ghi	40.3 st	1.2 jkl
All minus S	1.26 i–m	0.04 ijk	2.63 b	**0.10 jk**	15.8 i–m	20.3 ef	48.9 o	1.1 mno
All minus Cu	1.23 j–m	0.04 ijk	2.47 bcd	0.13 h–k	**16.8 hij**	19.0 gh	41.5 rs	1.2 lmn
All minus B	1.55 bcd	0.04 hij	2.38 def	0.13 h–k	14.9 l–q	**10.2 no**	50.9 m	1.5 bc
All minus Zn+Mo	1.48 c–g	0.07 fg	2.43 cde	0.11 jk	16.1 i–l	17.2 i	**34.0 v**	**1.0 op**

continued

Table 11. (cont'd) Effect of all nutrients (All) and omission of selected elements on concentrations of macro- and micronutrients in shoots of maize

Soil type and treatment	Macronutrient (%)				Micronutrient (mg/kg)			
	N	P	K	S	Cu	B	Zn	Mo
Sample 5: red sandy soil from Phuoc Dinh commune, Ninh Thuan province (0–20 cm)								
All	1.67 b	0.06 ghi	2.49 bcd	0.23 cd	26.2 b	13.9 k	68.3 g	1.5 def
All minus P	1.65 b	**0.02 k**	1.92 jkl	0.12 ijk	13.3 r–v	4.3 uv	67.5 gh	1.5 cde
All minus K	1.41 d–i	0.04 hij	**0.84 pq**	0.22 de	15.5 j–o	2.4 wx	66.7 h	2.0 op
All minus S	1.43 c–h	0.04 ijk	1.22 o	**0.12 ijk**	16.3 ijk	4.9 tu	61.2 ij	1.4 fgh
All minus Cu	1.47 c–g	0.03 jk	2.03 hij	0.14 g–j	**13.1 s–v**	4.9 tu	61.6 ij	1.4 fgh
All minus B	1.59 bc	0.03 jk	2.22 fg	0.14 g–j	25.5 b	**1.9 x**	49.3 no	1.1 klm
All minus Zn+Mo	1.37 f–k	0.03 jk	2.14 ghi	0.13 h–k	19.6 de	5.4 stu	**41.9 r**	**1.1 mno**
Sample 6: sandy soil from Phu Yen province (0–20 cm)								
All	1.53 b–f	0.06 gh	2.95 a	0.17 fgh	28.5 a	32.4 a	60.3 j	1.2 jkl
All minus P	1.27 h–m	**0.02 k**	2.46 bcd	0.13 h–k	23.4 c	24.2 d	55.9 k	1.2 lmn
All minus K	1.41 d–i	0.04 jk	**0.85 pq**	0.11 jk	20.4 d	20.3 ef	50.1 mno	1.1 mno
All minus S	1.37 f–k	0.04 ijk	1.36 bc	**0.09 k**	22.3 c	19.4 fg	56.9 k	0.9 pq
All minus Cu	1.38 e–j	0.04 ijk	2.22 fg	0.10 jk	**18.1 fgh**	29.8 b	28.4 x	0.9 no
All minus B	1.54 b–e	0.03 jk	2.03 hij	0.16 f–i	22.5 c	**23.8 d**	39.6 t	1.2 jkl
All minus Zn+Mo	1.48 c–g	0.04 jk	1.79 l	0.11 jk	26.8 b	28.7 b	**23.2 y**	**0.9 q**
LSD$_{0.05}$	0.16	0.04	0.22	0.05	1.43	1.25	1.38	0.1

Note: values are the average of three replicates; averages followed by the same letter for an element are not significantly different; N = nitrogen; P = phosphorus; K = potassium; S = sulfur; Cu = copper; B = boron; Zn = zinc; Mo = molybdenum; LSD$_{0.05}$ = least significant difference at $p < 0.05$

The leaf N concentrations in this study were ≤2.1% (Table 11), which is low. Sufficiency ranges of N for maize are 2.7–4.0 % (Steinhilber and Salak 2010). According to Reuter et al. (1997), critical shoot N concentrations at the eight-leaf stage could be as high as 3.7%. Plant analysis data (Table 11) show that the effects of the 'All' treatment and lack of P, K, Cu, Zn, B and Mo on the leaf N concentration were not large. The results in Table 11 also show very low P concentrations in maize. Self and Soltanpour (2010) classified P concentration in the whole plant from seedling to sixth leaf stage and fully expanded leaf prior to tasseling as: 0.22% (critical level), 0.22–0.25% (low), 0.25–0.50% (sufficient). From the data compiled by Reuter et al. (1997), the critical P concentration in shoots up to 45 days or 30 cm height is 0.29%. The shoot N and P concentrations indicate that the double-pot solutions did not supply adequate N and P for maize. Nevertheless, shoot P concentrations varied among the sands and highest P concentrations were in the 'All' treatment, with the exception of sample 2, and lowest without P application in all the soils tested. The growth responses to omitting P varied with individual soil types, signifying the importance of residual P levels in the sands which ranged between 0.02 and 35.9 mg/kg (Table 3).

The mean leaf K concentration in maize plants where K was omitted varied between 0.71 and 1.00% in the six soils investigated (Table 11). The range of sufficient K concentrations in cereals in young shoots, 5–8 cm above the soil surface, is 3.5–5.5% dry weight (Barker and Pilbeam 2007). According to other findings, the K sufficiency range for maize in the whole plant at seedling stage (<40 cm or six-leaf stage) is 1.5–4.0% (Reuter et al. 1997; Schwab et al. 2007). Based on these concentrations, maize in the 'All' treatment had marginal to adequate concentrations while omission of K in all sands induced a severe K deficiency.

Critical values of S in young maize shoots (<10-leaf or <45 days) range from 0.10 to 0.25% (Reuter et al. 1997; Osman 2013), indicating that the 'All' treatment supplied adequate S to maize in sands but was probably marginal in some, such as sample 4. When S was omitted in the double-pot experiment, shoot S concentrations were below the critical value for all the soils except sample 1), indicating deficiency. This is consistent with depressed shoot dry matter. However, even though maize in sample 1 had apparently adequate S, the concentrations were depressed compared to the 'All' treatment and growth was depressed.

Omission of Cu depressed maize growth in all sands except sample 1. However, Cu concentrations were above the critical range of 2.3–3.7 mg/kg (Osman 2013) when Cu was omitted (Table 11). In this case, the shoot growth response in the double-pot experiment was a more definitive indicator of Cu deficiency than shoot Cu analysis. In contrast, where B was omitted, B concentrations were within or below the critical range (3–5 mg/kg; Osman 2013) in samples 1, 2 and 5. However, in sample 5, shoot dry matter was not depressed, while in samples 4 and 6, it was depressed, despite having higher shoot B concentrations. Hence, the shoot B analysis was not always a reliable predictor of shoot DM response to omission of B.

Omission of Zn+Mo decreased both Zn and Mo concentrations in maize shoots but values remained well above critical concentrations for young maize shoots reported by Reuter et al. (1997). Moreover, there was no evidence of lower Zn or Mo concentrations in shoots on the samples where maize DM was depressed. However, in samples 4 and 5, omission of Mo+Zn depressed shoot N concentrations compared with the 'All' treatment. This is consistent with Mo deficiency which inhibits nitrate reductase enzyme and hence protein synthesis (Bell and Dell 2008).

General discussion

Multiple nutrient deficiencies were identified in all sands in field and double-pot experiments. This is a distinctive property of low fertility sands and requires a different approach to nutrient management than on other soils (Bell et al. 1990; Bell and Dell 2008). Whereas most other soils express one, two or three deficiencies of mostly macronutrients (generally N combined with P and/or K), on sands S and micronutrient deficiencies are also common.

The primary task for nutrient management in each sand type is to accurately predict the deficiencies that will limit crop production so that effective treatments can be developed. The double-pot experiment predicted deficiencies that were also identified in the field experiments. While correction of deficiency in the field is the most authoritative evidence, field experiments are costly and time consuming and hence only limited numbers can be afforded. Hence an accurate, low-cost approach such as the double-pot method can be used for screening large numbers of sands for potential deficiences. As shown in the present study, there would be merit in screening subsoils as well as topsoils since different deficiencies can be identified. Given the unreliable results from plant analysis in confirming deficiencies, and low reliability of soil testing in general for predicting micronutrient deficiencies (Bell and Dell 2008), the double-pot method is the recommended approach to follow.

When multiple nutrient deficiencies are diagnosed, the task of establishing suitable fertiliser programs can be time consuming. Recommended fertiliser practices involve a consideration of rate, timing, form and method of application (IPNI 2015). This experimentation needs to be conducted in the field, and repeated over several years and sites to establish reliable practices that can be recommended. Practices might need to be adjusted according to plant species, particularly between annual crops and perennial crops. However, some of this type of research has been conducted on sands in Thailand and could be assessed in SCC Vietnam as a first approximation of requirements for annual crops (Bell et al. 1990). Progress towards defining effective supply of S and micronutrients is reported by Hoang Vinh et al. (2015).

In addition to the supply of inorganic fertilisers to correct multiple nutrient deficiencies on sands, integrated nutrient management (INM) approaches are generally most effective. Organic resources such as manure or crop residues are presently used by farmers on sands in SCC Vietnam (Hoang Thi Thai Hoa et al. 2015). These could be used to increase the nutrient and moisture retention capacity of sands to enhance water and nutrient use efficiencies. Further evidence of the value of INM involving the use of biochar in addition to manure is reported by Hoang Vinh et al. (2015).

Conclusions

In field experiments in this study, multiple nutrient deficiencies were evident in each of the five sands examined. While the three sands in Phu Cat district of Binh Dinh province expressed deficiencies of K, S, B and Cu for peanut pod yield, a different suite of deficiencies was limiting peanut yield on each of the two sands in Ninh Thuan province (N, P, K, S, B, Cu, Zn at one site and N, P, K, S, Cu, Zn at the other). Parent material may be a predictor of which deficiencies will occur on particular types of sands; however, the DM response of the maize test crop using the double-pot experimental approach was a suitable predictor. The double-pot experiment also identified P, K, S, Cu, B, Zn and Mo deficiencies: the actual suite of deficiencies, however, varied among sands as in the field experiments.

The double-pot technique described and evaluated here appears to be a valuable diagnostic tool to predict the nutrient supplying capacity of a range of nutrients in sands, including micronutrients. Its simple design and low cost make it ideal for large-scale screening of soils, especially where access to analytical facilities for accurate soil and plant analysis, of micronutrients in particular, is limited.

Preliminary research on correction of multiple nutrient deficiencies in sands of SCC Vietnam, including INM practices, are reported by Hoang Vinh et al. (2015).

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