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

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Integrated nutrient management of annual and perennial crops on sandy coastal plains of south-central coastal Vietnam

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Abstract

Integrated nutrient management (INM) is the use of available organic resources (manure, crop residues, biochar etc.) together with inorganic fertilisers to optimise crop nutrition. In low fertility sands, INM needs to consider the balanced supply of all limiting nutrients, not just nitrogen and phosphorus. Three field experiments were conducted on typical sands in the south-central coastal (SCC) region of Vietnam on annual and perennial crops to assess the value of applying available organic resources (manure, biochar) with inorganic fertilisers (including nitrogen, phosphorus and potassium (NPK), sulfur (S) and micronutrients) to optimise crop nutrition. Peanut responded positively to addition of S and micronutrients in addition to NPK. However, application of organic resources (manure, biochar) in combination with inorganic fertilisers further increased peanut yield significantly. Application of biochar increased mango productivity by 16%. By contrast, in cashew, there was limited benefit from increased rate of inorganic fertiliser, with or without biochar, possibly because of micronutrient deficiencies that were not treated with the fertiliser applied. Therefore, balanced rates of nutrients as inorganic fertilisers are required to achieve optimal productivity and nutrient use efficiency on sands. The integrated use of manure or biochar with balanced inorganic fertilisers was most effective in increasing peanut yield and significantly increased profit compared with either organic amendments or inorganic fertiliser alone.

Introduction

To meet the rising demand for food production, agriculture in Vietnam needs to expand production area, increase productivity per unit land area and/or intensify cropping systems. Expansion of land area for agriculture is restricted due to higher demand for development of urbanised and industrialised areas which offer better investment options for some areas of the coastal zones. Increasing productivity and intensifying cropping systems both require the use of higher inputs of nutrients and higher nutrient use efficiency. Higher fertiliser use may be constrained by the recent increase in fertiliser prices (FAO 2012). Farmers have limited revenue or resources to invest in fertilisers but may be able to make efficient use of on-farm organic resources (Hoang Thi Thai Hoa et al. 2015a). Many studies show that the combination of organic materials with inorganic fertilisers

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increases nutrient use efficiency, especially on sands (Pinitpaitoon et al. 2011).

Farmers have the option of utilising on-farm organic resources generated from manure, crop residues and/or biochar. There are examples in Vietnam where farmers under rice cropping had integrated on-farm available organic resources with inorganic fertilisers to minimise the cost of inputs and maximise the outputs through increased yields (Mutert et al. 1999). In addition, application of organic resources not only maintains the inherent soil fertility and return nutrients (e.g. magnesium, sulfur (S), zinc (Zn) etc.) that are either not available or too expensive in commercially available fertilisers, but also helps improve the buffering capacity of soil to hold nutrients and water that could be lost through leaching or run-off (Rasmussen and Collins 1991). Most farmers primarily use nitrogen (N) and phosphorus (P) fertilisers and, to a lesser extent, potassium (K) fertilisers. While such nutrient management practices may result in short-term yield gains, there will be a net negative effect on soil nutrient balance in the long term, which will lower the sustainability of these systems (Hoang Thi Thai Hoa et al. 2015a). Maintaining soil organic matter (OM) will also help to maintain positive K balances.

Although nutrient concentrations in manures from animals vary with animal type and on their feed intake, an average application of 5 tonnes/hectare (t/ha) would supply approximately 23 kg N, 9.6 kg P, 12.4 kg K and 1,000 kg of carbon (C) (Dierolf et al. 2001). Even though the nutrient requirement for crops (depending on crop type) is 4–5 times higher than what can be supplied through 5 t of manure, nonetheless the repeated application of 1 t of C from manure can also significantly improve the physical and chemical characteristics of the soils. Livestock in farming systems of south-central coastal (SCC) Vietnam generate on-farm available organic resources such as manures, which can be applied to the field.

Residues from commonly grown crops in Vietnam also contain substantial amounts of C, N, P, K and other nutrients and if returned to the soils can supply a similar amount of nutrients as that from a comparable amount of manure (Hoang Thi Thai Hoa et al. 2015a, b).

Biochar, a product synthesised by pyrolysis of organic matter, contains varying concentrations of nutrients such as N, P, K and S, depending upon the source of organic material. Most biochars prepared from chicken manure have a very high concentration of these nutrients (Hall and Bell 2015). Farmers in the SCC region make their own biochar from rice husk; however, they do not have the right technology or the resources to convert crop residues to biochar consistently and the concentration of nutrients in biochars may vary according to the method of preparation and the crop material used. Application of biochar to soil helps to reduce losses of nutrients by minimising erosion, improve water holding capacity, enhance soil microbial activity, increase soil pH, improve availability of P and increase fertiliser use efficiency (Glaser et al. 2002; Lehmann et al. 2003).

Numerous studies on integrated nutrient management (INM) using organic and inorganic fertilisers have shown benefits that include: increased growth, development and yield of crops (Prativa and Bhattarai 2011); increased abundance of micro-organisms and development of mycorrhizas under soybean–wheat rotation (Khaddar and Yadav 2006); and an improved benefit:cost ratio in addition to making farming more sustainable under a potato–mungbean–rice crop rotation system (Mollah et al. 2011).

This chapter focuses on the effectiveness of the INM approach using biochars and manures along with inorganic fertilisers on peanut and the tree crops, mango and cashew. The research also reflects on the economic benefits of using this approach.

Material and methods

Three experiments were conducted on sandy soils of Binh Dinh province in the SCC region using manure, biochar and inorganic fertilisers to examine the effect of these materials on the growth of peanut (two sites), cashew (one site) and mango (one site). Designs for the experiments varied between the annual and perennial crops as did the method of application.

Effect of biochar on yield of an established cashew orchard

The experiment was located at Xuan An village, Cat Tuong commune, Phu Cat district, Binh Dinh province. Six-year-old cashew trees in an orchard planted with grafted plants had a density of 200 plants/ha when the INM trial with biochar and inorganic fertiliser treatments was carried out. The trees had been regularly pruned and fertilised. Biochar was prepared using rice husk ('rice husk 1' in Table 2). The experiment was designed with two factors (biochar and inorganic/organic fertiliser) arranged in a randomised complete block design.

Each main plot of 1,600 m^2 had 16 plants that were split into four subplots each containing four trees in an area of 400 m^2. Observations were carried out on four central trees, one from each subplot: the remaining 12 trees acted as buffers to prevent the influence of other treatments.

The treatments were:

- biochar
  - B1 = no biochar
  - B2 = biochar applied once in 2009 at a rate of 40 kg/tree
- inorganic fertiliser NPK 16:16:8:13S and manure (applied annually from 2009 to 2012)
  - F1 = (0.31 kg N + 0.16 kg phosphorus pentoxide (P_2O_5) + 0.80 kg dipotassium oxide (K_2O) + 0.13 kg S)/tree + 30 kg manure/tree
  - F2 = (0.47 kg N + 0.32 kg P_2O_5 + 1.60 kg K_2O + 0.26 kg S)/tree + 30 kg manure/tree.

The combinations of treatments were: B1F1; B1F2; B2F1; B2F2—each replicated three times.

Effect of integrated nutrient management on peanut yield

For this experiment in the spring–winter season of 2012, two experimental sites were chosen on farmers' fields, both of which were located in Phu Kim village, Cat Trinh commune, Phu Cat district, Binh Dinh province. The soil was tilled and prepared at an appropriate moisture level before the plots were split for different treatments. At both sites, treatments were laid out following a split-plot randomised design and manure, biochar ('rice husk 2' in Table 2) and inorganic fertiliser were top-dressed, then incorporated to 10 cm depth. Each plot covered an area of 15 m^2. Peanut variety LDH 01 was used and seeds were planted 10 cm apart with one seed per hole inserted by hand at a depth of 2–3 cm. The distance between the rows was kept at 30 cm to give a plant density equivalent to 330,000 plants/ha.

The treatments were:

- organic fertiliser
  - N = none
  - B = 11.1 t biochar/ha
  - M = 10 t manure /ha
- inorganic fertilisers
  - T1 = NPK (30 N kg/ha + 90 P_2O_5 kg/ha + 60 K_2O kg/ha)
  - T2 = NPK + S (20 kg/ha)
  - T3 = NPK + S + micronutrients (2.4 kg/ha copper (Cu), 4.05 kg/ha zinc (Zn), 0.25 kg/ha boron (B), 0.54 kg/ha molybenum (Mo)).

The combinations of treatments were: MT1; MT2; MT3; BT1; BT2; BT3; NT1; NT2; NT3—each replicated four times.

Effect of biochar and inorganic fertilisers on mango yield and quality

The experimental site was located at Tan Hoa Nam village, Cat Hanh commune, Phu Cat district, Binh Dinh province. The experiment was laid out in a randomised complete block design. Each plot of approximately 680 m^2 consisted of 15–16 trees. The biochar used was 'rice husk 2' (Table 2). Observations and measurements of number of flowers, yield and fruit quality were carried out on the four central trees from each plot and the other 11–12 trees acted as a buffer to prevent the influence of other treatments on the measured trees.

The treatments were:

- organic fertiliser
  - N = no biochar
  - B = biochar applied at a rate of 50 kg/tree
- inorganic fertilisers
  - T1 = NPK (0.49 kg N + 0.25 kg P_2O_5 + 0.38 kg K_2O)/tree
  - T2 = NPK + S (0.49 kg N + 0.25 kg P_2O_5 + 0.38 kg K_2O + 0.16 kg S)/tree
  - T3 = NPK + S + micronutrients (0.49 kg N + 0.25 kg P_2O_5 + 0.38 kg K_2O + 0.16 kg S + 10.9 g Cu + 2.5 g Mo + 18.4 g Zn + 1.1 g B)/tree

The combinations of treatments were: NT1, NT2, NT3, BT1, BT2, BT3, each replicated four times.

Chemical analysis

All the chemical analysis methods were as described in Bell et al. (2015).

Results and discussion

Soil and biochar characteristics

Most soils were acidic with pH values at or below 5.5 (measured in 1 M KCl), but the very low levels of exchangeable aluminium pose no risk of toxicity to crops (Bell et al. 2015). Low organic carbon levels (<0.5%) and clay contents (2–3%) were found in all soils (Table 1), a common feature for the majority of sandy soils in SCC Vietnam. Low cation exchange capacity and water holding capacity values of these sites are constraints that can lead to low water and nutrient use efficiency.

Incorporation of manure, crop residues and/or composted manure in soils has been practised by farmers in the SCC region to boost crop productivity (Hoang Thi Thai Hoa et al. 2015b). Farmers have recently started to produce biochar from crop residues (rice, peanut, cassava etc.) since biochars have been shown to boost crop production. However, the ability to increase production depends on the levels of nutrients in the biochars, which are highly variable and depend upon processing and the type and source of raw material used for pyrolysis (Table 2). Most biochars have neutral to high pH and can help improve soils of this region as most of them are acidic. In addition, biochars may be able to supply nutrients like P, K, S and Zn which are deficient in these soils (Hoang Minh Tam et al. 2015).

Effect of biochar on cashew yield, soil moisture retention and profitability

The experiment was carried out on a 6-year-old established cashew orchard with application of 40 kg of biochar per tree in a circle at a radius of 1.5 m from the trunk in 2009. Cashew growth and yield were assessed each year till 2012 to determine the

Table 1. Physico-chemical properties of soils (0–20 cm) at the four experimental sites in Phu Cat district, Binh Dinh province

Crop	pH_{H_2O} (1:5)	pH_{KCl} (1:5)	EC (dS/m)	Org. C (%)	Olsen P (mg/kg)	Exch. Al^{3+} (cmol/kg)	CEC (cmol/kg)	Clay (%)	Silt (%)	Sand (%)	Soil water	
											–0.1 bar (%)	–0.33 bar (%)
Cashew	5.2	4.40	0.01	0.31	2	0.09	1.28	2	3	95	7.1	1.5
Mango	6.4	5.51	0.04	0.32	17	0.16	1.93	2	5	93	4.4	2.4
Peanut	6.1	5.23	0.04	0.09	42	0.03	3.12	3	9	88	5.2	2.7
Peanut	5.6	5.44	0.18	0.11	60	0.02	1.72	2	2	96	4.2	2.3

Note: pH_{H_2O} = pH measured in water; pH_{KCl} = pH measured in 1 M potassium chloride; EC = electrical conductivity; Org. C = organic carbon; Olsen P = extractable phosphorus; Exch. Al^{3+} = exchangeable aluminium cations; CEC = cation exchange capacity

Table 2. Chemical properties and nutrient levels in biochar from various sources

Biochar characteristic	Biochar source material			
	Wheat straw[a]	Chicken manure[a]	Rice husk 1[b]	Rice husk 2[c]
pH (1:5 H_2O)	8.39	7.69	8.60	7.40
Electrical conductivity (dS/m)	9.18	5.19	1.20	1.50
Water holding capacity (g/g)	287	180	NT	NT
Total nitrogen (%)	2.24	2.04	0.55	1.00
Cation exchange capacity (cmol/kg)	23.7	18.1	21.0	27.0
Potassium (mg/kg)	33,700	13,800	6,500	NT
Phosphorus (mg/kg)	4,150	11,600	720	4,840
Sulfur (mg/kg)	2,040	3,650	49	NT
Zinc (mg/kg)	54	334	14	NT
Calcium (mg/kg)	5,540	26,200	1,000	NT

[a] Source: Hall and Bell (2015)
[b] Rice husk biochar produced in the Philippines (data supplied by Peter Slavich), used in the cashew experiment
[c] Rice husk biochar produced by the Agricultural Science Institute for Southern Central Coast of Vietnam (ASISOV), used in the peanut and mango experiments
Note: NT = not tested

short- and long-term effects of biochar. The application of biochar had positive effects on growth, development and cashew yield (Figure 1). Cashew yield increased significantly each year from the time of application of biochar in 2009 till 2011 and thereafter stabilised in 2012. In the first year, cashew yield increased from 1,130 kg/ha where no biochar was applied (treatment B1F2) to 1,477 kg/ha where 40 kg of biochar was applied in addition to the inorganic and organic (manure) fertiliser (B2F2) (Figure 1a).

In 2011 alone, increased fertiliser rate increased cashew yield, without an additional effect from biochar (Figure 1c). Biochar treatments (B2F2 and B2F1), regardless of the level of fertiliser, increased cashew yield by 200–400 kg/ha in 3 of 4 years. In 2011, biochar increased cashew yield only with the lower fertiliser rate.

Soil moisture levels over a 4-month period (January to April) in the dry season of 2010 under cashew trees with biochar treament (B2) were lower within the active root zone (0–60 cm) than without biochar (B1) (Figure 2). The lower soil water storage at 0–60 cm depth with biochar may be because: (1) the measured root zone (60 cm) of cashew trees may not correspond to the active root zone; (2) shallow groundwater levels at this site could have

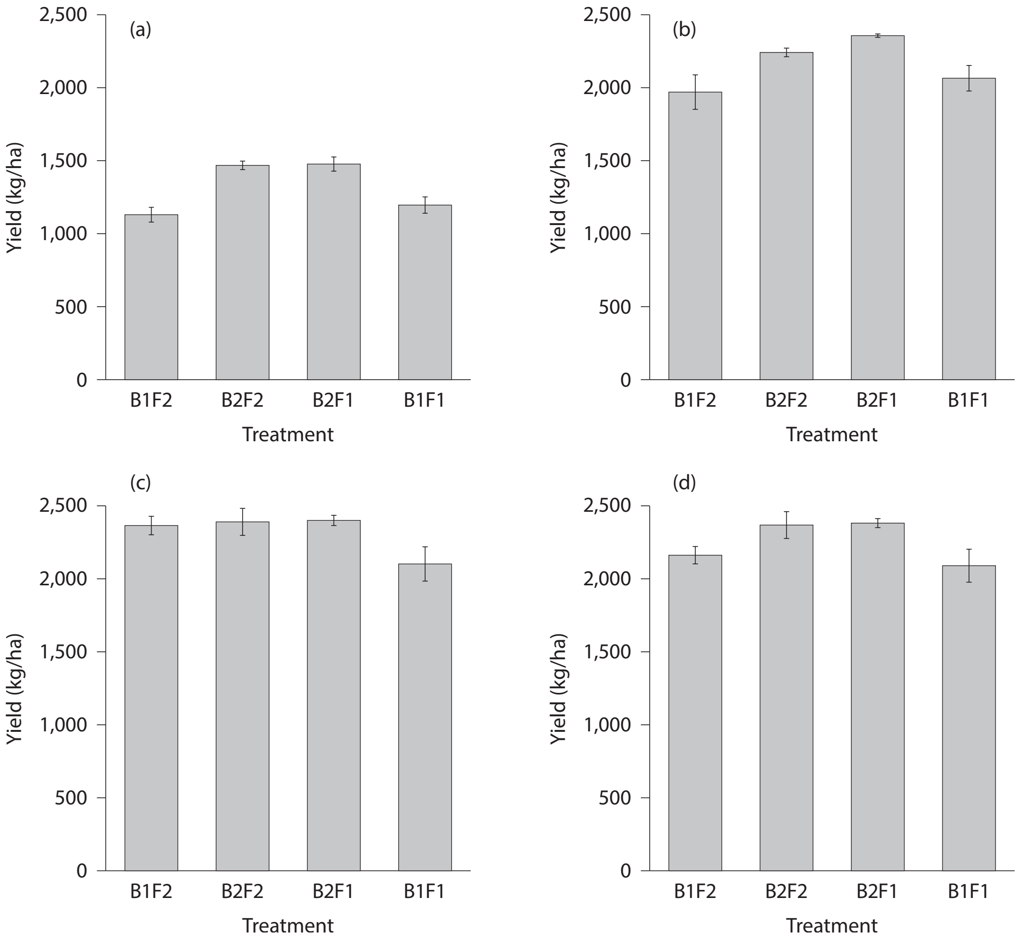

Figure 1. Effect of biochar on cashew yield in (a) 2009, (b) 2010, (c) 2011 and (d) 2012. Note: B1 = no biochar; B2 = biochar applied once (40 kg/tree) in 2009; F1 = 1 kg NPK fertiliser + 320 g urea + 30 kg manure/tree; F2 = as for F1, but with 2 kg NPK

met the moisture requirement of cashew for growth; (3) biochar influenced water storage in only the 20 cm deep ring of soil around the trunk where it was incorporated rather than the entire active root zone; and/or (4) water uptake may have been faster due to increased cashew growth with biochar, which depleted soil water storage.

Biochar application significantly increased input costs in 2009 and resulted in lower returns in comparison to where no biochar was applied (Table 3). In 2010, as a result of a significant increase in the yield of cashew nuts, the net profits increased compared with 2009 by over Vietnamese dong (VND)21 million as a result of the fertiliser application alone and VND30 million with biochar application. Cashew yields again increased in 2011, further increasing net profit margins. Profits declined in 2012 as a result of low cashew nut prices. The net profit where biochar was applied clearly showed higher returns than no-biochar treatments after the year of initial application. The net profits with biochar exceeded those without biochar by VND6.2 million/ha, VND5.1 million/ha and VND6.2 million/ha in 2010, 2011 and 2012, respectively. Over the 4 years of the trial, the overall net profit increased by VND15 million/ha, averaging 3.8 million/ha/year from biochar application.

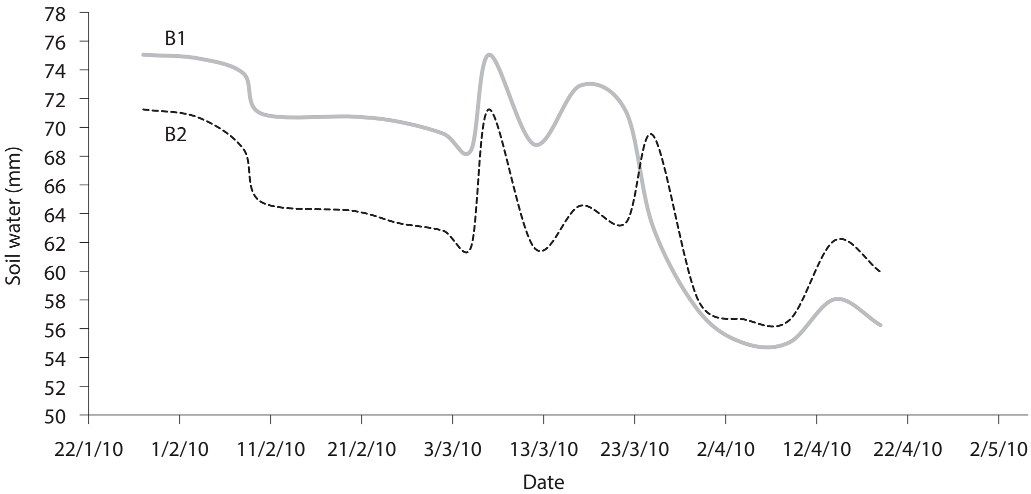

Figure 2. Soil water storage (in mm to 60 cm depth) in 2010 with biochar (B2) and without biochar (B1)

Table 3. Economic evaluation of fertiliser and biochar use for cashew production (VND million)

	2009		2010		2011		2012		Average over 4 years	
	B1	B2	B1	B2	B1	B2	B1	B2	B1	B2
Input costs	11.8	19.8	13.6	13.6	15.2	15.2	17.1	17.1	14.4	16.4
Materials	4.6	12.2	6.4	6.4	7.1	7.1	8.0	8.0	6.5	8.4
Labour	7.2	7.6	7.2	7.2	8.1	8.1	9.1	9.1	7.9	8.0
Output (cashew nut income)	20.9	26.5	44.4	50.6	71.5	76.6	53.2	59.4	47.5	53.3
Net profit	9.1	6.7	30.8	37.0	56.3	61.4	36.1	42.3	33.1	36.9

Note: B1 = without biochar; B2 = with biochar

Effect of integrated nutrient management on peanut yield and profitability

With the application of inorganic NPK fertiliser alone, peanut yields at the two sites were over 3 t/ha (Figure 3), which was higher than the average peanut yield in Vietnam (General Statistics Office 2012). Addition of S with NPK increased peanut yields at site 1 but not at site 2. However, S plus the micronutrients (B, Cu, Mo and Zn) increased peanut yield at both sites relative to NPK or NPK plus S alone. Application of either manure or biochar together with NPK increased the yield of peanuts by 18.5% and 21.1%, respectively, reaching approximately 4 t/ha (Figure 3). The highest yields were obtained when either biochar or manure were applied together with NPK plus S and micronutrients. This indicates that the highest yield of peanut could be achieved with supply of all limiting nutrients plus the organic amendment. The positive effects of manure or biochar, S and micronutrients were additive, indicating that the biochar and manure were not simply replacing nutrients supplied by inorganic fertiliser.

Application of 11.1 t/ha biochar in combination with inorganic fertilisers (BT3) gave the highest net profit increase (VND15.53 million) for peanut production compared with application of complete inorganic fertiliser without biochar (NT3; Table 4). This was followed by the other two biochar treatments that increased profit by VND15.0 million (BT2 compared with NT2) and VND12.3 million (BT1 compared with NT1). Application of manure in combination with inorganic fertilisers also increased net profits compared with the equivalent inorganic fertiliser treatment on its own. As with biochar, greatest profit was gained from the combination of manure with the complete fertiliser treatment (MT3). Even though the cost of manure (VND5.0 million)

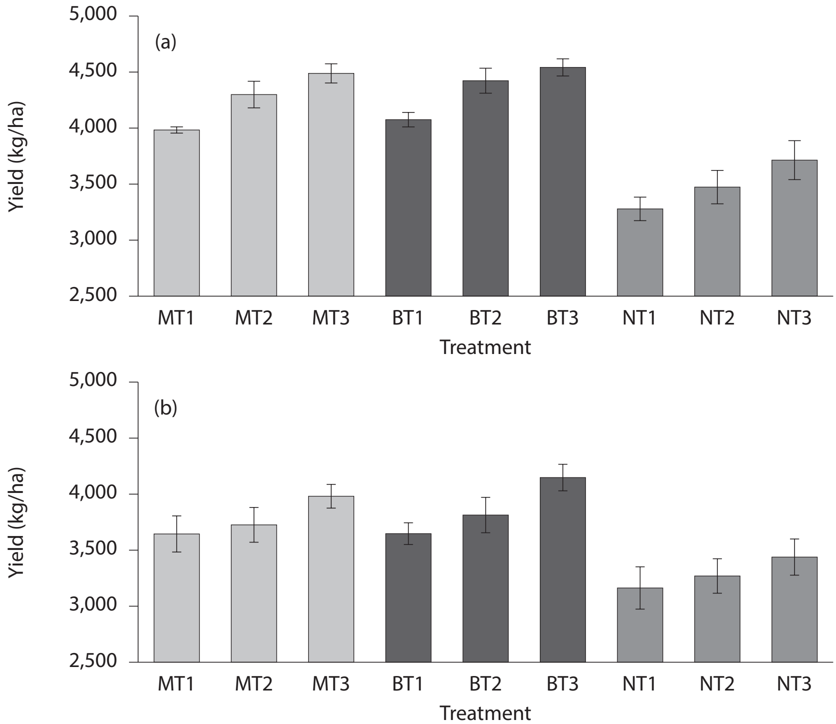

Figure 3. Effect of manure, biochar and inorganic fertilisers on peanut yield at Phu Cat (a) site 1 and (b) site 2. Note: for treatments, N = no organic fertiliser; B = 11.1 t biochar/ha; M =10 t manure/ha; T1 = nitrogen–phosphorus–potassium (NPK) (30:90:60 kg/ha); T2 = NPK + sulfur (S) (20 kg/ha); T3 = NPK + S + micronutrients (2.4 copper, 4.05 zinc, 0.25 boron, 0.54 molybdenum kg/ha)

and biochar (VND3.7 million) are significant, the increase in profit margins due to the increase in yield compensated for the investments made in manure and biochar application.

Although the cost of biochar application was high (VND3.7 million for 11.1 t/ha), given the long-term effect of biochar (at least 4 years) on yields as shown for cashew (Figure 1), it represents a lower annual cost than other forms of fertilisation. The cost of manure (VND5 million for 10 t/ha) is higher than for biochar; however, long-term effects of manure were not investigated.

The increase in productivity of peanut as a result of adding manure or biochar could be attributed to a range of factors but further research is needed to define the mechanisms responsible. The addition of biochar to the soil was shown elsewhere to: reduce nitrogen losses from leaching; increase water holding capacity; increase the soil microbial population; increase soil pH; increase K content; and increase fertiliser use efficiency (Glaser et al. 2002; Lehmann et al. 2003).

Concentrations of P, K, S and Cu in peanut leaves did not necessarily increase where these nutrients were applied in inorganic fertiliser or with the organic amendments. Higher levels of K were observed where biochar was applied compared with treatments without biochar (Table 5). Biochars may contain high levels of nutrients like P, K, S and Zn; however, the levels of most of these nutrients were not determined for the 'rice husk 2' biochar used for peanut and mango experiments and besides may vary with method of processing and raw material used (Table 2).

Table 4. Economic evaluation of manure and biochar use for peanut production in 2012

Treatment[a]	Material costs (VND '000/ha)	Yield (t/ha)	Total revenue (VND '000/ha)	Net profit (VND '000/ha)
MT1	32.97	3.81 ± 0.10	95.25	62.28
MT2	33.48	4.01 ± 0.14	100.32	66.84
MT3	34.50	4.23 ± 0.11	105.85	71.35
BT1	31.67	3.86 ± 0.10	96.52	64.85
BT2	32.18	4.11 ± 0.15	102.97	70.79
BT3	33.20	4.34 ± 0.10	108.62	75.43
NT1	27.97	3.22 ± 0.10	80.52	52.55
NT2	28.48	3.37 ± 0.11	84.27	55.79
NT3	29.50	3.58 ± 0.12	89.40	59.90

[a] N = no organic fertiliser; B = 11.1 t biochar/ha; M = 10 t manure/ha; T1 = nitrogen–phosphorus–potassium (NPK) (30:90:60 kg/ha); T2 = NPK + sulfur (S) (20 kg/ha); T3 = NPK + S + micronutrients (2.4 copper, 4.05 zinc, 0.25 boron, 0.54 molybdenum kg/ha)

Table 5. Effect of fertiliser on the levels of nutrients in peanut leaves at flowering stage at site 1

Treatment[a]	Nitrogen (%)	Phosphorus (%)	Potassium (%)	Sulfur (%)	Copper (mg/kg)	Zinc (mg/kg)	Boron (mg/kg)
MT1	4.74	0.37	2.38	0.28	4.09	31.2	28.2
MT2	4.93	0.38	2.41	0.31	3.49	30.4	29.5
MT3	5.06	0.41	2.50	0.30	3.60	35.0	54.1
BT1	5.04	0.41	2.67	0.29	4.17	36.6	30.8
BT2	5.06	0.41	2.77	0.30	3.67	34.0	32.3
BT3	4.96	0.40	2.67	0.32	4.86	39.4	57.8
NT1	4.84	0.40	2.29	0.30	4.05	35.9	29.0
NT2	4.98	0.42	2.59	0.33	4.60	38.2	30.8
NT3	5.03	0.41	2.43	0.32	4.03	38.6	57.3

[a] N = no organic fertiliser; B = 11.1 t biochar/ha; M = 10 t manure/ha; T1 = nitrogen–phosphorus–potassium (NPK) (30:90:60 kg/ha); T2 = NPK + sulfur (S) (20 kg/ha); T3 = NPK + S + micronutrients (2.4 copper, 4.05 zinc, 0.25 boron, 0.54 molybdenum kg/ha)

Effect of biochar and inorganic fertilisers on mango yield and quality

Biochar significantly improved flowering and yield; however, the proportion of good-quality fruits (type 1) was not significantly altered by biochar application (Table 6). The inorganic fertiliser treatments had no significant effects on mango yield. The biochar and nutrient treatments were applied in November 2011 to 6-year-old mango trees. Mango trees normally achieve maximum flowering and fruiting when they are 8 years of age or older, hence it would be useful to assess response of older mango trees to biochar and inorganic fertiliser on sands.

General discussion

Multiple nutrient deficiencies on sands were identified by Hoang Minh Tam et al. (2015). The present results for peanut support the requirement for S in addition to micronutrients for maximum production of peanut on two sands in the Phu Cat district of Binh Dinh province. While the specific micronutrient deficiencies were not diagnosed in the present peanut experiment, the omission experiments in Phu Cat suggest that B and Cu were deficient (Hoang Minh Tam et al. 2015). However, the suite of micronutrient deficiencies varied in other sands, especially those from Ninh Thaun province (Hoang Minh Tam et al. 2015). Hence, it is critically important to have an accurate means of diagnosing the deficiencies on sands so that appropriate treatments can be applied. While field experiments can give a definitive diagnosis, they are costly and time consuming to run. Plant analysis can be used to diagnose nutrient deficiencies but depends on access to laboratories that are able to reliably determine low concentrations of micronutrients. Soil tests may give a general indication of deficiency risk but are generally not considered very accurate for predicting micronutrient deficiencies (Bell and Dell 2008). The double-pot approach appeared to predict the same deficiencies identified in the field and may be a suitable approach for SCC Vietnam (Hoang Minh Tam et al. 2015).

Current fertilisers used by farmers in SCC Vietnam supply N and/or P or N, P and K. However, the present results indicate the need for balanced fertiliser that supplies all the limiting nutrients. Balanced fertiliser can be designed by mixing two or more fertilisers to provide the recommended rates and proportions of nutrients; however, suitable S and micronutrient fertilisers may not be available in local markets. This suggests the need for engagement with fertiliser suppliers, manufacturers and blenders to ensure the most suitable balanced fertilisers are available in areas of sandy soils. This may involve the development of fertilisers specifically designed for crops on sands only.

Strong yield responses were obtained in peanut from balanced supply of inorganic fertilisers. By contrast with cashew, there was no response to increased rates of NPKS fertiliser, possibly because

Table 6. Effect of integrated nutrient management, biochar and fertiliser, on mango yield

Treatment[a]	Flowering ratio[b] (%)	Yield (kg/tree)	Yield (g/m^2 of canopy surface area)	Fruit quality[c]	
				Type I (%)	Type II (%)
BT1	19.4	9.4	523	71.1	28.9
BT2	27.5	8.5	524	73.4	26.6
BT3	26.7	10.0	572	74.1	25.9
NT1	18.0	7.4	406	73.2	26.8
NT2	21.9	8.0	458	75.7	24.3
NT3	21.2	8.6	459	72.2	27.8
CV (%)		14.7	11.1		
$LSD_{0.05}$		1.92	81.8		

[a] N = no biochar; B = biochar applied (50 kg/tree); T1: nitrogen–phosphorus–potassium (NPK) (1.26 kg di-ammonium phosphate (DAP) + 0.5 kg urea + 0.73 kg KCl/tree); T2: NPK + sulfur (S): (1.26 kg DAP + 0.5 kg urea + 0.86 kg K_2SO_4)/tree; T3: NPK + S + micronutrients (27 g $CuSO_4$ + 4.5 g $(NH_4)6Mo_7O_{24}.4H_2O$ + 45 g $ZnSO_4$ + 6.5 g H_3BO_3)/tree)

[b] Flowering ratio: flowering branches as a % of total branches per tree

[c] Type 1 = fruits with no defects; type 2 = fruits with visible defects which sell at one-third the price of type 1 fruits

Note: CV = coefficient of variation; $LSD_{0.05}$ = least significant difference at $p < 0.05$

growth remained limited by deficiencies of micronutrients. However, regardless of the inorganic fertiliser treatment, there were additive effects of manure or biochar on peanut yield. There is evidence from studies in Thailand that response to inorganic fertilisers on sands can be improved by combining with supply of organic amendments (Bell and Seng 2007). This may be related to improved soil water storage, slowed release of nutrients to match with crop demand, decreased nutrient leaching or increased total supply of one or more limiting nutrients. A range of organic resources are presently applied by farmers in SCC Vietnam to sands (Hoang Thi Thai Hoa et al. 2015a). This practice should be supported and encouraged. However, further research is needed to determine the main processes by which applying organic materials improve crop yield on sands. The variable composition of organic amendments makes it difficult to simply predict the effects expected. If organic amendments are primarily supplying nutrients then the nutrient composition of the materials, such as reported by Hoang Thi Thai Hoa et al. (2015a), is important. Biochar is a new organic material that could be used in SCC Vietnam. However, it is necessary to regulate the quality of biochar to provide greater confidence to farmers in the profitability and reliability of its use. Addition of biochar and/or manure has the potential to build soil carbon, increase soil pH and build resilience in the sands of SCC Vietnam. Longer term studies on sands in the region would be valuable to quantify the range of soil improvement benefits that can be achieved with biochar and the other organic amendments.

Conclusions

In general, use of biochar and/or manure in combination with inorganic fertilisers had positive effects on peanut yields. Application of biochar under cashew trees seemed to have a long-term positive effect even though the cost of the initial application cost was high. Costs of biochar were more than recovered by increased yields over the 4-year period of the cashew trial. Application of biochar increased productivity by 13% in cashew and economic returns over 4 years averaged VND3.8 million/ha/year. Application of biochar increased mango productivity by 16%; however, the trees were only 6 years old and their yield was still below potential. By contrast, in cashew, there was limited benefits from increased rates of inorganic NPK fertiliser, with or without biochar, possibly because other limitations such as micronutrient deficiencies were not treated.

The integrated use of manure or biochar with balanced inorganic fertilisers was most effective in increasing peanut yield and significantly increased profit compared with either organic amendments or inorganic fertiliser alone.

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