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Effect of Natural Phosphate Rock Enhanced Compost on Pearl Millet–Cowpea Cropping Systems

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Phosphorus (P) deficiency is considered as a major soil constraint to increased yields in tropical zones of Africa. Several methods have been tested to improve crop production but little information is available about the usage effect of phosphate rock (PR) and compost on mixed cropping of pearl millet (*Pennisetum glaucum* L. R. Br.) and cowpea (*Vigna unguiculata* L. Walp.). In this study, we investigated the effects of different PR application methods on pearl millet (millet) and cowpea cropping systems. This study was carried out at Senegal Agricultural Research Institute during the 2002 and 2003 rainy seasons, and comprised a sole millet, sole cowpea and millet–cowpea intercrop. Treatments were a control (Cont), 3 tons ha^{-1} of compost (Com), 3 tons ha^{-1} of phospho–compost (P–Com) and 3 tons ha^{-1} of compost plus Taiba Natural Phosphate (T–Com), replicated 4 times in a randomized complete block design.

In sole millet, P–Com significantly increased the total dry weight compared to the control. Although P–Com was beneficial for intercrop millet, its increased yields through T–Com were more significant, giving evidence of the beneficial effect of mixed cropping on the usage of local phosphate rock directly applied to soil. In contrast, such a beneficial effect was not observed for cowpea which was likely not P limited growth. However, although sole crops gave higher yields, the Land Equivalent Ratios (LERs) over the two years indicated a greater advantage of applying treatments in the millet–cowpea intercrops except for P–Com (LER=0.93) which appeared to be more effective in sole cropping systems.

Keywords: Phospho–compost, LER, millet–cowpea intercrop, Sole crop, Taiba Natural Phosphate

INTRODUCTION

Pearl millet (*Pennisetum glaucum* L. R. Br.) is widely cultivated in the semi–arid environment of Senegal. It is often associated with cowpea (*Vigna unguiculata* L. Walp.), which contains about 22% protein in grains and constitutes an important component of food security for farmers and urban people. The crop residues from cowpea also constitute an important source of livestock feed especially in the dry savannas of West African Semiarid Tropics. However, growth and productivity of these crops are limited by temporally and spatially erratic rainfall and poor soil fertility (Davis–Carter, 1989). The decrease in soil fertility in the tropical area of Senegal is related to low nutrient replenishment (Badiane, 1993), depleting soil organic matter and mineral elements, particularly phosphorus (P) which is one of the major elements required by all living organisms. Under these conditions, productivity levels of both cereals and legumes are too low to sustain food production requirements. Although organic amendments such as crop residue, manure, or compost are essential in the sustainability of cropping systems (Cambardella *et al.*, 2003), they cannot prevent nutrient mining. The addition of only organic amendments corresponds in most cases to a recycling process, which does not compensate for nutrients exported through crop products. Therefore, the use of external inputs such as inorganic plant nutrients or local sources of P such as phosphate rock (PR) are essential to maintain or improve soil productivity. Zapata (2003) suggested the application of local PR rather than the costly P fertilizers to increase plants P uptake. Such application of PR can avoid traditional acidification processes for water–soluble P fertilizers. Furthermore, because of their extremely variable and complex chemical composition, PRs are also sources of several nutrients other than P required for plant growth. In the case of Senegal, the main local PR of Taiba (Taiba Natural Phosphate = TNP) has been used by crop producers to increase soil productivity. However, not beneficial results are often obtained, due to little known scientific information about the agronomic effectiveness of TNP and its usage strategies. On another hand, mixed intercropping is known to be an age–old, widespread practice in the warmer climates of the world, especially the tropics (Willey, 1979). Fujita *et al.* (1990) indicated the importance of mixed cropping system for increasing soil nitrogen. As a result, the nutritional advantage of mixed cropping and the positive effect of organic amendments such as compost are thought to be more beneficial for soil productivity when combined with PR. For our knowledge, few studies have dealt with the

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mixed cropping system of millet and cowpea and the usage methods of TNP in the tropical area of Senegal. Hence, we conducted this study to (1) investigate the effects of different PR applications (PR blended with compost or separately applied to soil with compost) on millet and cowpea growth and (2) examine the impact of the cropping system (sole and intercrop, millet and cowpea) on the agronomic effectiveness of the P application method. We examined the findings from this study through the calculation of the LER to better understand the opportunity in achieving yields of millet and cowpea with P based PR fertilization and mixed cropping.

MATERIALS AND METHODS

Soil analysis of the experimental site

This study was carried out at the experimental field station of the Senegal Agricultural Research Institute (ISRA) at Bambey (16º30'–16º28'N, 15º44'–15º42'W). The soil was described as a ferruginous soil (Maignien, 1965) and classified as a Lixisol (Food Agriculture Organization, 1998). From 9 locations of the experimental site, soil was collected at 0–20 and 20–40 cm depth to make two composite soil samples. Samples were air–dried, sieved (<2 mm) and thoroughly mixed. They were digested by following the H_2O_2–H_2SO_4 digestion procedure of Ohyama *et al.* (1991). Total N, K and P were then determined by the indophenol, flame photometry and ascorbic acid methods, respectively. The pHH_20 was determined by a glass electrode method (soil: water ratio is 1:2.5). Chemical properties of the soil are summarized in Table 1. The soil had a moderate total N and K content, low total and available P and low CEC.

Analysis of Taiba Natural Phosphate and compost properties

Total P_2O_5, citric acid soluble P_2O_5 and water soluble P_2O_5 of TNP were measured by the method of Official Methods of Analysis of Fertilizer (NIAES, 1992). Total P_2O_5 was extracted from TNP with a combination of concentrated HCl and HNO_3 at 250 °C. De–ionized water and 2% citric acid solution were used for water and citric acid soluble P–fractions extraction, respectively. HCl extracted P, NH_4F extracted P and NaOH extracted P were determined by the ascorbic acid method of Murphy and Riley (1962) or Bray and Kurtz (1945).

The two types of compost (compost and phospho–compost) used in this experiment were analyzed for their content in total phosphorus by the vanadomolybdate (Hanson, 1950) method. P(%) in compost, phospho–compost and TNP was then calculated and used to deduce the amount of P (kg ha^{-1}) in Cont, Com, P–Com and T–Com (Table 2). T–Com total P corresponded to the sum amount of P supplied through compost and TNP (375 kg h^{a-1}) application.

Plant materials

This study was carried out using pearl millet (*Pennisetum glaucum* L. R. Br.) cv. Souna3 and cowpea (*Vigna unguiculata* L. Walp.) cv. Melakh. These varieties of millet and cowpea were developed by the Senegal Agricultural Research Institute. Millet cv. Souna3 has a growth cycle of 90 days and grows with rainfall levels ranging from 380 mm to 460 mm and is photoperiod sensitive. Cowpea cv. Melakh has a growth cycle of 60 days.

Experimental design

The experiment included three cropping systems corresponding to sole millet, sole cowpea and millet–cowpea intercrops. Each cropping system had a total of four treatments, laid out in a randomized complete block design. Treatments consisted of a control (Cont)

Table 2. Result of total P content (%P) in Com, P–Com and T–Com and the deducted corresponding amount (kg ha^{-1}) in treatments

Treatments	2002		2003	
	%P	kg ha^{-1}	%P	kg ha^{-1}
Cont	0.00	0.00	0.00	0.00
Com	0.34	10.20	0.25	7.50
P–Com	1.00	30.00	0.80	24.00
T–Com	16.70	71.80	16.60	69.10

Cont=control, Com=compost, P–Com=phospho–compost, T–Com=direct application of TNP (Taiba Natural Phosphate) and compost to the soil. P (kg ha^{-1}) corresponds to the content in 3 tons ha^{-1} Com or P–Com. *P (kg ha^{-1})=(%P × 3 tons ha^{-1})/100*. P (kg ha^{-1}) in T–Com=P amount in Com + P amount in TNP. As TNP contains 37.64% P_2O_5, 141.15 kg P_2O_5 ha^{-1} (=61.58 kg P ha^{-1}) were supplied through 375 kg ha^{-1} TNP. *%P=% P_2O_5 × 0.4363*. In control, there was no P application.

Table 1. Soil properties of the experimental site

Depth (cm)	pH		Total N	Total K	Total P	Available P[a]	Exchangeable cations[b]				CEC[c]
							Na	K	Ca	Mg	
	H_2O	KCl	g kg^{-1} soil		mg kg^{-1} soil		mg kg^{-1} soil				cmolc kg^{-1}
0–20	6.11	5.22	0.35	0.28	105	26.3	38.5	55.5	812	ND	16.11
20–40	6.18	5.26	0.30	0.28	114	22.7	31.7	46.3	1113	ND	19.31

[a] Bray 2 method (Bray and Kurtz 1945)
[b,c] Ammonium acetate based shaking extraction, followed by atomic absorption spectrometer for Exchangeable cations and indophenol method for CEC. ND: Not detectable.

with no P application, 3 tons ha^{-1} compost (Com), 3 tons ha^{-1} phospho–compost (P–Com) and 3 tons ha^{-1} of compost combined with a direct application of 375 kg ha^{-1} TNP (T–Com). Compost was made with millet straw residues and farm yard manure. Phospho–compost (P–Com) was produced same as compost in the exception that 375 kg ha^{-1} of TNP was added during the composting process. TNP was therefore supplied in two different methods; after a preliminary transformation through P–Com and a direct application to soil with compost through T–Com. Moreover, a basal fertilization with N (urea) and K (KCl) was carried out at rates of 20 kg N ha^{-1} and 15 kg K ha^{-1} in sole cowpea, 41 kg N and 10.5 kg K per ha in sole millet and millet–cowpea intercrop. The rate of fertilizer in intercrop cowpea was with the same as that of millet which was the main crop. In all trials, plot size was 8.5 m × 12.3 m with row spacing and plant spacing of 1 m × 1 m in sole millet and 0.5 m × 0.5 m in sole cowpea. In intercrop plots, two millet rows were sown with 1.5 m spacing and two cowpea rows were sown with 0.5 m spacing between the millet rows. Plant spacing within a row was 50 cm for both millet and cowpea in the intercrop.

Field management

This study was a 2 year experiment, carried out during the rainy season periods of 2002 and 2003 (from July to October). Sole millet and sole cowpea stands were rotated each year, while millet–cowpea intercrop was maintained in the same stand. Just before the beginning of each rainy season (June), the field area was plowed, divided into plots and Com, P–Com and T–Com incorporated to a depth of 15 cm. The seed sowing was performed 1 day after the first rain (8 July on 2002 and 23 July on 2003) at 3 seeds per hill for cowpea and more than 10 seeds for millet. However, millet was thinned to 5–6 plants per hill at 10 days after sowing (DAS). The basal fertilizers (N and K) were broadcast and incorporated into the soil, 2 weeks after sowing and the plots were maintained weed–free throughout plant growth. All the other operations were as per farmer practice, including disease and insect protection measures.

Data collection and statistical analysis

In a sole millet plot, a harvest area of 20 m^2 corresponding to 20 hills was investigated, while in sole cowpea plots, the harvest area was 14 m^2 and corresponded to 56 hills. In intercrop plots, the harvesting area was 20 m^2 and contained 56 hills of cowpea and 24 hills of millet. Therefore, the corresponding densities in sole millet, intercrop millet, sole cowpea and intercrop cowpea were respectively 10,000; 12,000; 40,000 and 28,000 hills ha^{-1}. Based on its shorter cycle and its progressive maturity, cowpea was harvested each 2 weeks, starting from 12 September in 2002 and 23 September in 2003. However, millet was harvested at one time on 3 October in 2002 and on 12 October in 2003. After harvesting, the total dry weight (aerial part, i.e. shoot + grains) was air–dried to a constant weight and the yield each plot was recorded. Treatment effects over the 2 year experiment were assessed by analysis of variance (ANOVA) using Genstat for Windows version 5 (Rothamsted Research, Harpenden, Hertfordshire, England). A two–way ANOVA of the two years was carried out to evaluate the year × treatment interaction. A significance of this interaction indicates a variation of yields over the two years. In this case, treatment effects are yearly discussed according to the one–way ANOVA. If the interaction is not significant, yields are considered to be stable over years and the discussion is based on the combined analysis (two–way ANOVA) over the two years. Mean separation was performed using the least significant difference (LSD) at P=0.05 whenever a significant difference ANOVA (P<0.05) result occurred. The mean dry matter (yield) of cowpea and millet in both sole and intercrop systems was used to calculate the Land Equivalent Ratio (LER) of each treatment using the following formula: LER = (Intercrop millet yield/sole millet yield) + (Intercrop cowpea yield/sole cowpea yield). The LER represents the relative land area required for a sole crop to produce the yields achieved in intercropping (International Rice Research Institute 1974). In other words, the LER is calculated to indicate whether a treatment presents more advantage in a sole or an intercrop system, indicating the most beneficial cultural system. Based on the P content in Com, P–Com and TNP, the level of P in treatments was calculated and a linear regression of crop yields in function of the P level in treatments carried out.

RESULTS AND DISCUSSION

Effect of P application method on millet growth

In sole millet, the two–way ANOVA revealed a significance (P<0.05) of the year × treatment interaction, indicating that yields were not stable and varied over the two years. Therefore, sole millet responses to P application method in 2002 and 2003 were separated, and the one–way ANOVA showed that total dry weight (TDW) was significantly correlated to treatments (2002, P=0.029; 2003, P=0.003). In 2002, there was no significant difference in sole millet TDW between Cont, Com and T–Com, but P–Com significantly increased the TDW (Table 3) and that about 1.5–fold over the control. Sole millet TDW in 2003 was, however, significantly improved by both P–Com and T–Com 1.54 and 1.51–fold, respectively, over the control. Therefore, although P–Com was beneficial in both 2002 and 2003 for sole millet, T–Com showed a positive effect only in 2003. No beneficial effect was recorded for Com in either 2002 or 2003 compared to the control. For intercrop millet, the two–way ANOVA was used as the year × treatment interaction was not significant (P=0.82; data not shown). There was a significant increase (P=0.001) of intercrop millet TDW for all Com, P–Com and T–Com 1.32, 1.5 and 1.87–fold, respectively, over the control (Table 3). Furthermore, yields increases through T–Com were significantly higher than that of Com and P–Com. These results clearly indicated the ability of

Table 3. Mean yields of sole millet (separated analysis of 2002 and 2003) and intercrop millet (combined analysis of 2002 and 2003)

Treatments	Mean Yield[y] (kg ha^{-1})		
	Sole millet 2002	Sole millet 2003	Intercrop millet
Cont	3800 a	5856 a	2897 a
Com	4725 ab	7331 a	3848 b
P–Com	5725 b	9063 b	4348 b
T–Com	3919 a	8869 b	5421 c
$P_{0.05}$	0.029	0.003	0.001
$LSD_{0.05}$	1266	1519	820

In a column means followed by the same letters are not significantly different by LSD (*P<0.05*). [y] Average of four replications (original replications data are not shown). Sole millet results in 2002 are separated from that of 2003, based on the significance (data not shown) of the year × treatment. Intercrop millet results are combined based on the non significance of the year × treatment interaction. Cont=control, Com=compost, P–Com=phospho–compost, T–Com=direct application of TNP and compost to the soil.

P–Com to increase millet yields independently to the period (1.5–fold in 2002 and 1.54–fold in 2003) and the cropping system (same increase rank in sole millet and intercrop millet). The positive effect of P–Com obtained from the mixing of crop residues and natural phosphate rock on plant growth was reported by Bangar *et al.* (1985). They found a high level of available P in P–Com using the 32P isotope dilution method and stated that the effectiveness of P–Com was as equal to that of superphosphate. Although we didn't measure the P availability in our treatments, the positive effect of P–Com in both sole and intercrop millet was likely due to an increased available P. Sekhar and Aery (2001) indicated that co–composting of PR with organic matter converts a part of P_2O_5 into available forms. Rajan and Watkinson (1992) also reported a high water–soluble and citric–soluble P content in P–Com that should easily stimulate root growth and facilitate greater exploitation of P enriched soil. However, T–Com had a more positive effect for millet when it was intercropped with cowpea. This result indicated that the millet–cowpea intercrop may have increased the availability of TNP when directly applied to soil with compost. This positive effect was likely related to the presence of the cowpea which presumably enhanced the low solubility of TNP through enzymatic reactions. Ae *et al.* (1990) reported greater PR availability when applied in pigeon pea–sorghum intercrop. The cereal–legume positive effect on directly applied PR may also arise from the improvement of soil biological and physical properties and the ability of legumes to solubilize occluded phosphorus and highly insoluble calcium–bound phosphorus by roots exudates such as phosphatases (Tarafdar and Claaseen, 1998). The effectiveness of PR depends on its chemical and mineralogical composition, soil factors, and the crop to be grown (Khasawneh and Doll, 1978, Sidibe–Diarra *et al.* 2004). TNP contained 376.4 g kg^{-1} total P_2O_5 with water soluble and citric acid soluble P_2O_5 values of 7.32 and 185.2 g kg^{-1}, respectively. HCl, NH4F, and NaOH extracted P_2O_5 fractions of TNP were 5.13, 5.11 and 0.03%, suggesting that the remaining portion could correspond to the occluded phosphorus which is one of the four main groups of inorganic phosphates (Chang and Jackson, 1957). Moreover, as TNP has a relatively high citric acid soluble P_2O_5 (18.5%), organic acids secretion through leguminous roots could improve its availability for crops uptake. It is interesting to note that T–Com also increased significantly sole millet growth in 2003 experiment, which received more rains (715.5 mm) than did the 2002 (316.44 mm) experiment. This result may indicate that the positive effect of TNP also depends on the climatic conditions such as the amount of rain which may increase its solubility and availability. Fe, Al and Ca ions of the soil are responsible for fixing phosphate ions, and freshly precipitated phosphate salts of these ions (in the soil) are slowly available to the plants and upon aging, availability of P is further reduced. Therefore the non positive effect of TNP in 2002 (Table 3), may have been related to a low dissolution and precipitation in soil, reducing PR availability to sole millet. This could be one of the reasons for many conflicting results related to the application of PR. In another hand, although the same amount of TNP (375 kg ha^{-1}) was used to make P–Com and T–Com, results in Table 2 revealed a higher total P in T–Com than in P–Com, indicating a likely loss of TNP

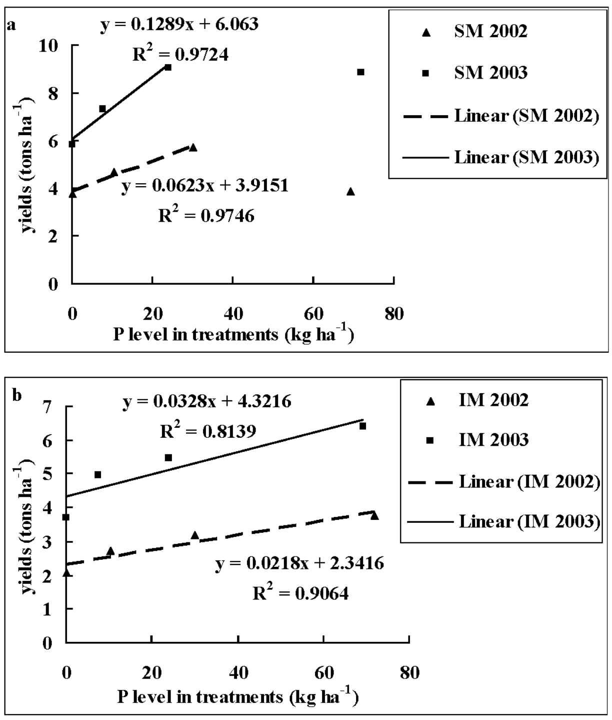

Fig. 1. Effect of P level in treatments on sole millet (a) and intercrop millet (b) yields in 2002 and 2003. Each point is the mean of four replications. P (kg ha^{-1}) is the amount of P in treatments: Cont, Com, P–Com and T–Com respectively. SM=Sole millet, IM=Intercrop Millet. Points linked by a line are positively correlated. In sole millet, the two last points are outliers excluded from the linear regression.

during co–composting. Because, TNP was not added to Com, its P content was lower than those of P–Com and T–Com (Table 2). The linear regression based on the total P in treatments showed a positive correlation (R^2>0.97) between sole millet yields and P level (Fig. 1a) in treatments, at the range 0 to maximum 30 kg P ha^{-1} corresponding to the P level in P–Com, while a negative correlation was found between the P level in T–Com and sole millet yields, particularly in 2002. For intercrop millet (Fig. 1b), there was a positive correlation between yields and P level (R^2>0.80) at the range 0 to 71 kg P ha^{-1} corresponding to that of T–Com. These results suggested that millet response was not dependant of total P as there was no difference between P–Com and T–Com effect on sole system, albeit T–Com had a much higher total P. However, the millet–cowpea intercrop might have increased the availability of P in T–Com as previously described.

Effect of P application method on cowpea growth

In both sole and intercrop cowpea, the year x treatment interaction (P>0.05; data not shown) was not significant. The combined analysis showed a significant increase (P=0.001) of sole cowpea TDW over the control, for Com, P–com and T–Com (Table 4). However, there was no significant difference among the effectiveness of Com, P–Com and T–Com, suggesting that in sole cowpea, there was no beneficial effect of applying natural phosphate through P–Com or directly to soil through T–Com. This point could be explained if available P in Com was sufficient for the needs of cowpea. Smyth and Cravo (1990) reported a low cowpea critical P level of 8 mg kg^{-1} soil in a Brazilian oxisol. However, this was in contradiction to other reports (Bationo *et al.*, 2002; Israel, 1987) where P deficiency was considered to be the most limiting soil factor for cowpea production. Phosphorus was reported to enhance nodule formation (Somado *et al.*, 2003), as well as increase the efficiency of the rhizobium–plant symbiosis and, therefore, increase nitrogen fixation (Israel, 1987). In contrast to sole cowpea, no significant difference (P=0.92) was observed among the treatments effectiveness in intercrop cowpea (Table 4). The high degree of probability level indicated that intercrop cowpea did not respond to the treatments. The benefit of applying TNP through P–Com and T–Com in millet–cowpea intercrop was more evident for millet. Fujita *et al.* (1990) reported a potential transfer of the fixed nitrogen by leguminous plants to the associated crops. Moreover, due to its deeper and larger root surface area (Rachie and Majmudar, 1980), intercrop millet may have better access to nutrients and water in case of competition with intercrop cowpea. The negative correlation between cowpea yields and P level in treatments (Fig. 2) indicated that cowpea growth did not seem to be dependent to the P application method, compared to millet.

Table 4. Mean yields of sole and intercrop cowpea over 2 years experiment (2002 and 2003): combined analysis

Treatments	Yield[y] (kg ha^{-1})	
	Sole cowpea	Intercrop cowpea
Cont	1847 a	1046
Com	2744 b	1173
P–Com	2717 b	1016
T–Com	2963 b	1091
$P_{0.05}$	0.001	0.92
$LSD_{0.05}$	403	–

In a column means followed by the same letters are not significantly different by LSD ($P<0.05$). [y]Average of four replications over two years (original replications data are not shown). The year × treatment interaction is not significant (data not shown), the combined analysis is thus considered. Cont=control, Com=compost, P–Com=phospho–compost, T–Com=direct application of TNP and compost to the soil.

Evaluation of Land Equivalent Ratios (LERs)

The treatment based LERs calculated per year and their averages over the two year–experiment are shown are shown in Table 5. In 2002, except for T–Com (LER=1.31), all the other LERs were less that 1 indicating a greater advantage of sole cropping systems on the effectiveness of the corresponding treatments. However, all LERs were over 1 in 2003 and treatments appeared to be more effective when applied to the millet–cowpea intercrop system. When the average LERs over the two years were considered, the millet–cowpea intercrop remained the cropping system with the highest LERs

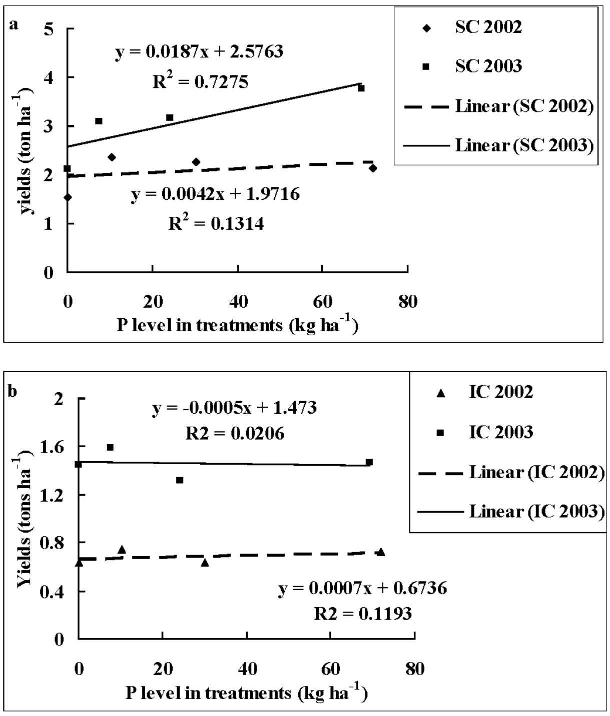

Fig. 2. Effect of P level in treatments on sole cowpea (a) and intercrop cowpea (b) yields in 2002 and 2003. Each point is the mean of four replications. P (kg ha^{-1}) is the amount of P in treatments: Cont, Com, P–Com and T–Com respectively. SC=Sole Cowpea, IC=Intercrop Cowpea. Points linked by a line are not positively correlated.

Table 5. Land Equivalent Ratio of treatments over two years experiment (2002 and 2003)

Treatment	year	Mean yields[a] (kg ha^{-1})				Partial LER	Combined LER
		Intercrop millet	Sole millet	Intercrop cowpea	Sole cowpea		
Cont	2002	2080	3800	640	1560	0.96	1.14
	2003	3714	5856	1456	2134	1.32	
Com	2002	2733	4725	756	2381	0.90	1.04
	2003	4964	7331	1590	3107	1.19	
P–Com	2002	3197	5725	640	2263	0.84	0.93
	2003	5500	9063	1322	3170	1.02	
T–Com	2002	3801	3919	733	2149	1.31	1.21
	2003	6413	8869	1473	3777	1.11	

[a] Average of four replications for each treatment in 2002 and 2003.
Cont=control, Com=compost, P–Com=phospho–compost, T–Com=direct application of TNP and compost to the soil. Treatments partial LERs (per year) were calculated and the averages over the two years deducted.

(superior to 1), indicating an advantage of the intercrop for all treatments, except for P–Com (LER<1) which presented more advantage when applied in sole crops. Jensen (1996) related the benefit of intercrop systems to flexibility, profit maximization, risk minimization, soil conservation and maintenance, weed control, and nutritional advantages. In conclusion, both P–Com and T–Com could be suggested as suitable P application methods in sole millet and millet–cowpea intercrop systems. However, T–Com may provide a greater benefit when it is applied in intercrop systems. For sole cowpea, only Com could be enough for suitable yields. However, further studies focused on the analysis of plant components using ^{15}N and ^{32}P to could clarify the contribution of phosphorus and nitrogen nutrients derived from the Com, P–Com and T–Com on millet and cowpea growth. Evaluating treatments effect on cowpea N_2 fixation may help understand the cause of no response of the intercrop cowpea. Isotopic analyses of soil samples would also enable to evaluate the treatments effect on soil fertility.

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