Improvement of Soil Productivity Through Legume-Based Cropping Systems in Indian Alfisols and Vertisols under Semi-arid Environments

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ABSTRACT

In the semi-arid tropics (SAT) of India, due to the uneven distribution of rainfall in the rainy season, crops grow under fluctuating soil moisture conditions. In the postrainy season, crops growing under decreasing soil moisture conditions are exposed to drought with the progression of growth. Poor physical conditions of soils such as surface sealing and Iow water-holding capacity of Alfisols and compaction of subsoil, Iow water infiltration and gas exchange rates of saturated Vertisols tend to enhance the effects of the fluctuations and decrease of the soil moisture. The Iow phosphorus fertility Ievel of Alfisols and Vertisols increases the susceptibility to drought by reducing the root growth of crops, especially cereals.

Pigeonpea and chickpea have long been cultivated as essential components of cropping systems in the Indian SAT. Recently we were able to confirm that the cultivation of those two legumes resulted in the increase of the productivity of Alfisols and Vertisols through the improvement of the soil physical conditions and root development of the succeeding crops, etc. Moreover in the case of pigeonpea the amount of available soil phosphorus was increased through a special Fe-P solubilizing mechanism. Improvement of the productivity of Alfisols and Vertisols of the Indian SAT through the cultivation of pigeonpea and chickpea will be discussed based on these findings.

Introduction

In the semi-arid tropics (SAT), soils are so diversified that 8 of the 10 orders in Soil Taxonomy (Soil Survey Staff, 1975) are found in this region (Table 1). Considering the climo-geomorphological history of the SAT (Budel, 1977), SAT soils can be classified into two groups. One group includes Alfisols and related soils such as Aridsols, Oxisols, and Ultisols. These soils were formed by essentially the same mechanism but differ in the rate of weathering depending upon the amount of precipitation. The area of Alfisols is 6.94 million km^2, accounting for 33% of the land area of the SAT. Soils related to Alfisols cover a total surface area of 7.6 million km^2 and account for 36% of the land area of the SAT. Another important soil type is Vertisols, which are relatively new soils derived from base-rich parent materials. The area of Vertisols is not as large as that of Alfisols, being 1.31 million km^2 and representing 6.3% of the land area of the SAT (Table 1).

Vertisols show uniform soil profiles which often extend to a depth of several meters. Vertisols are not as weathered as Alfisols and are rich in soil minerals. The dominant clay mineral is montmorillonite, which contributes to the high water-holding capacity of Vertisols. Because of deep profiles rich in minerals and high water-holding capacity, Vertisols are

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Table 1 Soils of the semi-arid tropics

Soil order	Area (million km²)			
	Africa	Latin America	Asia	Total
Alfisols	4.66	1.07	1.21	6.94
Aridsols	4.40	0.33	0.47	5.20
Entisols	2.55	0.17	—	2.72
Inceptisols	0.38	—	0.28	0.66
Mollisols	-	0.78	—	0.78
Oxisols	1.88	—	—	1.88
Ultisols	0.24	0.08	0.20	0.52
Vertisols	0.51	-	0.80	1.31
Others	—	0.70	0.23	0.93
Total	14.62	3.13	3.19	20.94

Source : Kampen and Burford, 1980.

recognized as among the most productive soils in the SAT.

Alfisols, which are more weathered than Vertisols, have a low water-holding capacity with kaolinite as the dominant clay mineral. Surface horizons of Alfisols are characterized by the lack of structural development (El-Swaify *et al.*, 1987). Thus, Alfisols are categorized as less productive soils than Vertisols in the SAT. However, in Alfisols, the clay content increases with depth and there is an argillic horizon which shows a moderate cation-exchange capacity and high water-holding capacity. Thus, Alfisols could also be categorized as deep and productive soils if plants growing on them could develop deep root systems. High P levels in the sub-soil layers were observed in an Alfisol field at ICRISAT Center, India (Fig. 1), and have been recorded in Brazil (Iwama and Nakagawa, 1988) and in other SAT soils (Mohr *et al.*, 1972).

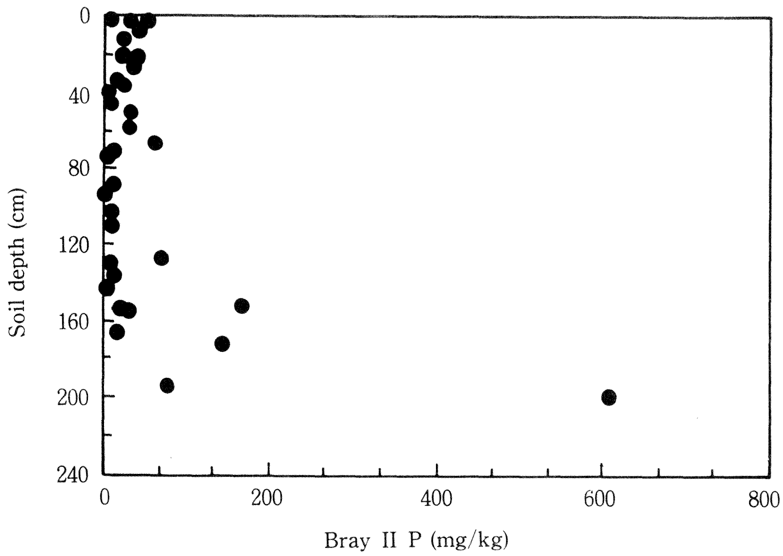


Fig. 1 Changes in available P (Bray II) with soil depth of an Alfisol field at ICRISAT Center.

Thus, better utilization of entire soil profiles with a deep root system would be a means of increasing and stabilizing crop production in both Alfisols and Vertisols. Factors preventing root penetration deep into the profile are poor soil aeration in both Alfisols and Vertisols, and the formation of surface crusts and existence of murrum layers in Alfisols.

It has recently been reported that pigeonpea (*Cajanus cajan* L. Millsp.) and chickpea (*Cicer arietinum* L.), which are grain legumes widely cultivated in the Indian SAT, are endowed with unique mechanisms for the uptake of relatively insoluble phosphorus (P) in soils which other plants can hardly utilize (Ae *et al.*, 1991 a, b). These unique mechanisms are also recognized to affect their root behaviour. Pigeonpea and chickpea have also been found to improve soil physical conditions and increase the productivity of succeeding crops. In this paper, we analyze the root activities of pigeonpea and chickpea in Vertisols and Alfisols and discuss the beneficial effects of the cultivation of these legumes on the growth of other crops.

Puptake mechanisms of chickpea and pigeonpea

It has been recognized that chickpea and pigeonpea are crops less responsive to P application (Saxena, 1980 and Johansen, 1990). To confirm this observation, we compared the responses of chickpea and pigeonpea to P application with that of sorghum in an Alfisol and a Vertisol field with low P fertility at ICRISAT Center. Phosphorus contents of the two soils are indicated in Table 2.

Table 2 PH and phosphorus contents (mg/kg) of Alfisol and Vertisol at ICRISAT Center (field and pot experiments)

Parameter	Alfisol	Vertisol
pH (H_2O)	6.0	8.1
Total P	122.0	153.0
Ca-P	3.8	52.8
Al-P	8.1	18.1
Fe-P	51.3	77.4
Olsen's P ($NaHCO_3$ extraction)	4.3	0.7

Sorghum showed a moderate response to P application in the Vertisol and a large response in the Alfisol (Fig. 2). Chickpea did not respond to P application in the Vertisol, but did so in the Alfisol.

A sizable fraction of the inorganic P in Vertisols is associated with Ca (Table 2). Calcium-bound P (Ca-P) in Vertisols is considered to be a sparingly soluble compound, largely in the form of apatite, as the available P level of Vertisols as measured by Olsen's method is generally very low. In Vertisols, increasing amounts of Ca-P can be released with a decrease of extractant pH such that the available P level estimated with acid extractants is not categorized as low (Ae *et al.*, 1991 a). Chickpea was found to lower the rhizosphere soil pH by exuding a large amount of citric acid from the root system (Table 3). Therefore, it can be concluded that chickpea solubilizes otherwise insoluble Ca-P in alkaline soil by lowering the rhizosphere pH. This P uptake mechanism indicates that chickpea is a crop adapted to alkaline soils such as Vertisols or Aridsols in the dry areas.

Pigeonpea, on the contrary, showed some response to P application in a Vertisol field, but did not show any response in an Alfisol field (Fig. 2).

In contrast to the Vertisols, soil P in Alfisols is mostly bound to iron (Table 2). Thus, the weak response of pigeonpea to P application in an Alfisol field suggested that pigeonpea was able to efficiently utilize iron-bound P (Fe-P). Pigeonpea, unlike chickpea, does not have a

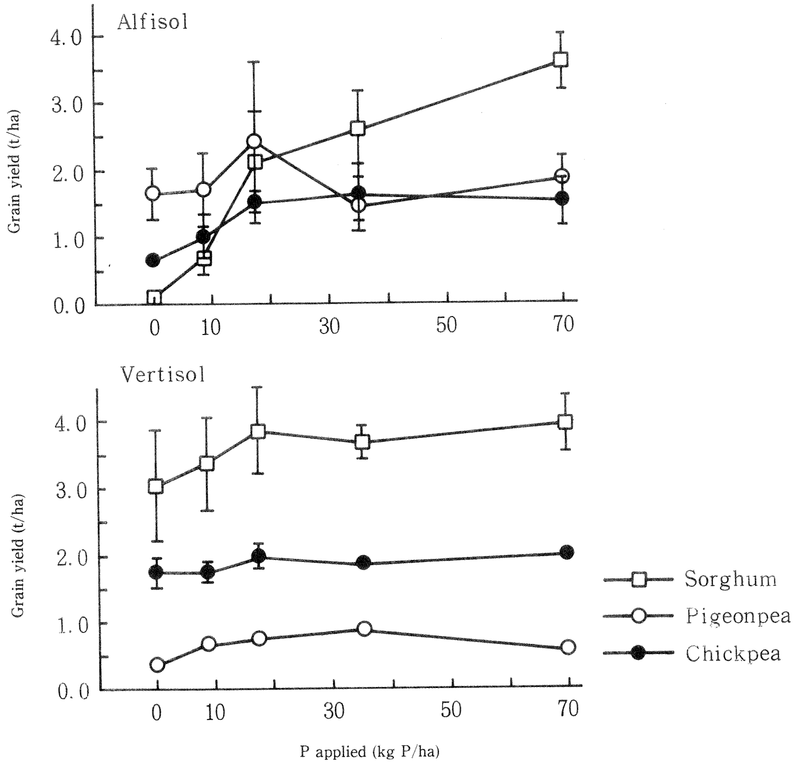


Fig. 2 Phosphorus responses of rainy season sorghum and pigeonpea and post-rainy season chickpea in an Alfisol and a Vertisol field, 1987/88.

Table 3 Major organic acids of root exudates* from sorghum, soybean, chickpea and pigeonpea

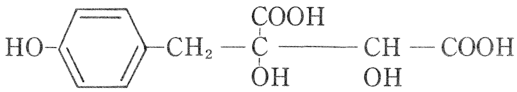
Crop	Organic acid (mg/g dry root*)			
	Malonate	Succinate	Citrate	Malate
Sorghum	trace	trace	0.045	0.008
Soybean	0.324	0.046	0.481	0.078
Chickpea	trace	0.054	1.292	0.025
Pigeonpea	trace	0.025	0.101	0.047

* Roots of two months old plants were washed in water and soaked in 2mM $CaCl_2$ for collection of root exudates.
(from Ae *et al.*, 1991b)

unique ability to lower the rhizosphere soil pH, because the amount of organic acids exuded by pigeonpea is not as large as that of chickpea but comparable to the level of other crops (Table 3).

Contribution of mycorrhizal associations to P uptake of pigeonpea has been demonstrated (Manjunath and Bagyaraj 1984). We compared the contribution of mycorrhizal associations of pigeonpea with that of sorghum in pot experiments using Alfisol with an extremely low available P level. The death of sorghum plants and the survival of pigeonpea plants irrespective of the mycorrhizal association clearly ruled out the involvement of mycorrhizae in the efficient P uptake of pigeonpea from Alfisols (Ae *et al.*, 1991 b).

Based on these results, pigeonpea was considered to be endowed with a unique mechanism whereby P in the Fe-P complex is released in soil. We were able to identify the substance responsible for the release of P in the complex as (*p*-Hydroxybenzyl) tartaric acid, called piscidic acid (Ae *et al.*, 1991 b). It has the following formula:



This acid probably binds Fe^{3+} by chelation and thus releases P. The Fe-piscidic acid complex is suggested to be not absorbed by pigeonpea roots due to the lack of special channels, presumably due to the toxicity of the phenolic bases. Thus it is proposed that pigeonpea can take up P strongly bound to iron in Alfisols without experiencing the toxic

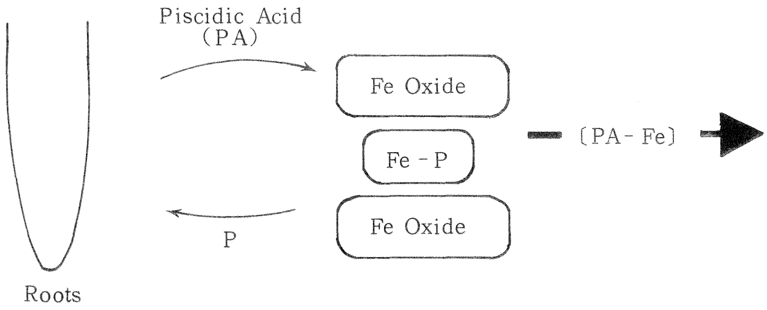


Fig. 3 Postulated mechanism for the absorption of iron-bound phosphorus from soil by pigeonpea.

effects of excess iron (Fig. 3). This mechanism suggests that pigeonpea can grow well not only on Alfisols but also on other tropical soils related to Alfisols having a large fraction of its inorganic P bound to iron.

Effects of pigeonpea and chickpea on P availability of Alfisols and Vertisols

An important aspect of these unique P uptake mechanisms of chickpea and pigeonpea in relation to soil fertility improvement is whether these legumes can increase the available P pool in marginal soils. We tested the residual effect of growth of these two legumes on P uptake of a subsequent maize crop, which generally absorbs only water-soluble P from the soil. Pigeonpea, chickpea, sorghum, and a sorghum-pigeonpea combination were successively grown four times in pots filled with Alfisol and Vertisol with a low P availability. Even though the P uptake of the preceding crops was higher for pigeonpea than for sorghum and chickpea, maize following pigeonpea absorbed a larger amount of P from the Alfisol than that following the other two crops (Table 4). Phosphorus uptake of maize in the Alfisol was highest when it followed a sorghum-pigeonpea combination, which absorbed the largest amount of P. In the combination, as available P was estimated to be completely removed by sorghum, P absorbed by maize may have been derived from Fe-P solubilized by pigeonpea. In the Vertisol, P uptake was highest for maize following chickpea, which also absorbed the largest amount of P. These data suggest that the available P pool in the soil increased with the cultivation of pigeonpea in an Alfisol and of chickpea in a Vertisol.

Root development of pigeonpea and chickpea

The extent of a crop root system in a soil profile depends on the crop species and soil type. Generally, crops develop deeper root systems in Vertisols than in Alfisols, the example

Table 4 **P uptake of sorghum, pigeonpea, chickpea and sorghum-pigeonpea combination grown in pots filled with Alfisol or Vertisol of low P fertility and effects on P uptake of succeeding maize**

Soil	Sorghum	Pigeonpea	Chickpea	Combination
	P uptake of each crop (mg/pot)			
Alfisol	4.07	5.83	2.82	8.37
Vertisol	4.85	2.96	6.71	3.99
	P uptake of maize (mg/pot)			
Alfisol	4.22	5.97	3.43	8.33
Vertisol	5.03	2.83	6.68	4.01

(from Arihara *et al.*, 1991)

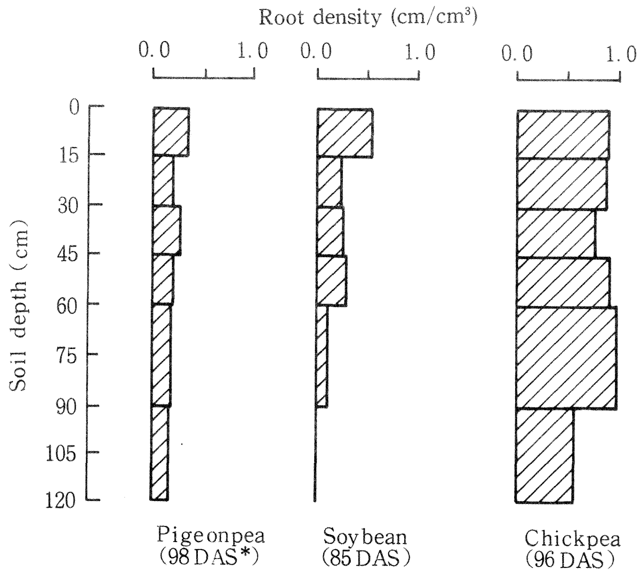


Fig. 4 Root distribution of pigeonpea and soybean (rainy season, 1985), and chickpea (postrainy season, 1984/85) in a Vertisol field.

*** DAS : Days after sowing.**

of soybean being shown in Fig. 5.

Among various crops, chickpea is especially able to develop deep root systems in Vertisols as shown in Fig. 4, and as illustrated by Sheldrake and Saxena (1979). Thus chickpea can grow well in a post-rainy season under receding soil moisture conditions by utilizing the water and minerals of deep soil layers. It is suggested that the ability of deep rooting in calcareous soils is related to acid exudation from the chickpea root system (Ae *et al.*, 1991 a).

Pigeonpea shows a deep rooting character in Alfisols, where root development of soybean and maize is generally restricted to within 30-45cm of the soil surface (Fig. 5) as roots seem unable to penetrate the murrum layer of iron nodules generally found at a depth of 40-60cm. The ability of pigeonpea roots to easily penetrate this layer may be attributed to its unique

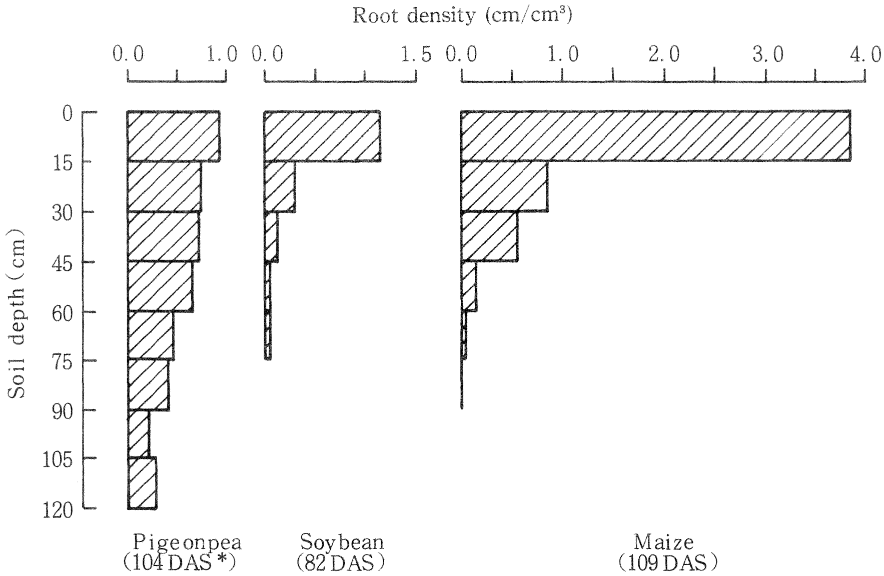


Fig. 5 Root distribution of pigeonpea, soybean, and maize in an Alfisol field, rainy season, 1985.

*** DAS : Days after sowing.**

P uptake mechanism whereby Fe^{+3} is solubilized through the exudation of a chelator, as already mentioned. Thus pigeonpea can more easily develop a root system into the argillic horizon of Alfisols (Fig. 5). There are considerable advantages for the P nutrition and drought tolerance of pigeonpea if the crop is able to reach deeper soil layers containing higher levels of P, as indicated in Fig. 1, and water. When pits were dug to a depth of 2m and the vertical soil profiles across plant rows were observed, it was found that cracks developed through the murrum layers under pigeonpea rows in several Alfisol fields at ICRISAT Center. This finding suggests that crops following pigeonpea may be able to develop deeper root systems via the openings left by pigeonpea roots.

Furthermore, it can be proposed that subsequent crops can benefit from the effect of pigeonpea, or chickpea in Vertisols, by recycling P and other nutrients from deep layers.

Residual effects of pigeonpea and chickpea

Several studies show the beneficial effects of pigeonpea and chickpea on yields of subsequent crops, presumably due to the improvement of the soil nitrogen (N) status resulting from N fixation by these legumes. Kumar Rao *et al.* (1983), Kushwaha and Ali (1988) and Johansen *et al.* (1990) provide examples for pigeonpea and Ahlawat *et al.* (1981), Jessop and Mahoney (1985) and Keatinge *et al.* (1988) examples for chickpea.

However, not all of the improvement of the subsequent crop is attributable to N addition associated with fixation by the legumes, because the previous cultivation of pigeonpea resulted in higher yield of the subsequent crop even at high N application levels (e.g. Kumar Rao *et al.*, 1983 ; Johansen *et al.*, 1990). Thus additional beneficial effects to residual N are suggested. We investigated these additional residual effects for both pigeonpea and chickpea, independently.

Additional residual effects of pigeonpea on sorghum (CSH 5) growth in both a Vertisol and an Alfisol were investigated at ICRISAT Center in 1989. In the rainy season of the previous year (1988), short-duration pigeonpea (ICPL 87) was grown without fertilizer under rainfed and irrigated conditions, or the field was left fallow. The nitrogen fertilizer was applied to sorghum at a rate of 120kg N/ha to mask the effect of fixed nitrogen.

In the Vertisol, sorghum grain yield following pigeonpea was almost the same as (rainfed) or lower than (irrigated) that following fallow (Fig. 6). But in the Alfisol, sorghum yield after pigeonpea exceeded 2t/ha while that after fallow was less than 1t/ha (Fig. 6).

Similar results were obtained in experiments on the response of sorghum (CSH 5) to P application, in which sorghum was rotated with pigeonpea (ICPL 87). In this experiment also, nitrogen fertilizer was applied at 120kg N/ha. In an Alfisol field, the grain yield of sorghum cultivated after pigeonpea increased at all P levels (Fig. 7). Without P, the yield of sorghum was low in the first year but it increased to 2t/ha after cultivation of pigeonpea. In a Vertisol field, however, the effect of pigeonpea cultivation on sorghum grain yield was not consistent (Fig. 7).

The results of these two experiments show that pigeonpea improved the grain yield of subsequent sorghum on Alfisols but not on Vertisols. In the case of Alfisols, the beneficial effects of pigeonpea could be ascribed to its ability to absorb relatively unavailable Fe-P, as described earlier.

The residual effect of chickpea (K 850) was found to improve grain production of subsequent pigeonpea (ICPL 87), as compared with sorghum (CSH 5), at all levels of P application in both a Vertisol and an Alfisol (Fig. 8). This effect of chickpea on the improvement of pigeonpea yields in both fields also could not be attributed to residual N as a response of pigeonpea to N fertilizer could not be observed in these soils over several years (symbiotic N fixation was apparently adequate to meet the N requirements of pigeonpea).

In the Vertisol, the solubilization of the relatively insoluble Ca-P complex, which is one of the major inorganic P pools in Vertisol, by citric acid exuded from chickpea may have contributed to the absence of a P response in subsequent pigeonpea.

On the other hand, in the case of Alfisol, the results suggest that the same root exudate of chickpea can to some extent solubilize Fe-P, the major form of inorganic P in Alfisol. Phosphorus so solubilized may be utilized by the subsequent pigeonpea crop, resulting in growth enhancement at a lower rate of P application. The growth of chickpea itself was limited in the Alfisol (see Fig. 2), possibly due to an excessive amount of Fe in the plant tissue (Ae *et al.*, 1991 a), which forms insoluble P-Fe complexes in plant.

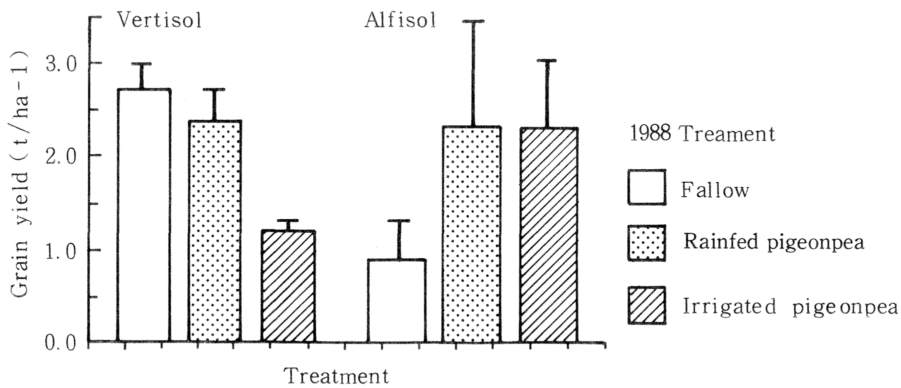


Fig. 6 Effect of pigeonpea cultivation on grain yield of subsequent sorghum grown with 120kg/ha of nitrogen (ICRISAT Center, rainy season, 1989).

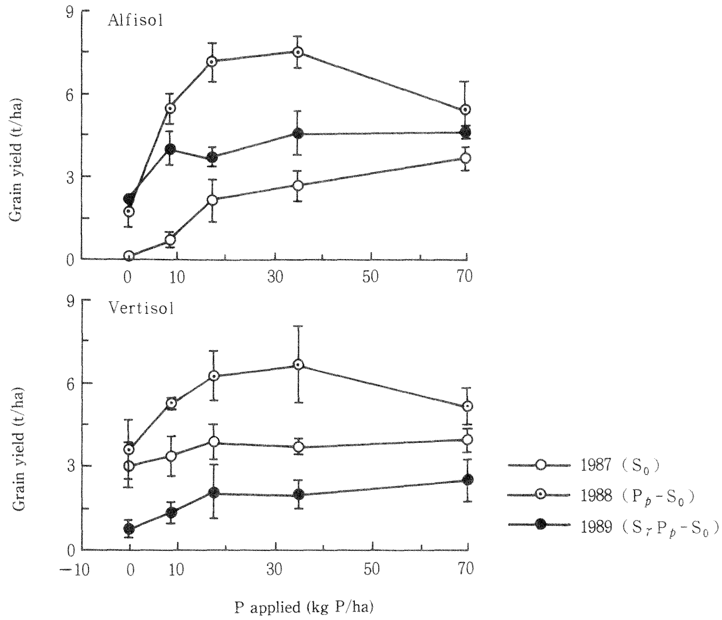


Fig. 7 Effect of previous cultivation of pigeonpea (Pp) on P response of sorghum (So) in on Alfisol and a Vertisol field of low P fertility (ICRISAT Center, rainy seasons, 1987-89).

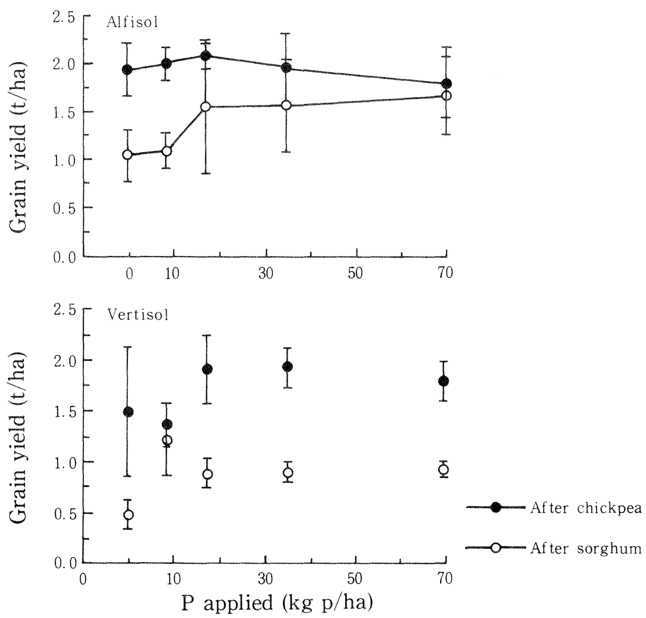


Fig. 8 Effect of cultivation of previous crop on P response of short-duration pigeonpea (cv. ICPL 87) in an Alfisol and a Vertisol field of low P fertility (ICRISAT Center, rainy season, 1989).

Effect of pigeonpea and chickpea on the improvement of physical conditions of soils

The lack of structural development or stable aggregation in Alfisols in the SAT causes rapid surface sealing following rainfall events and crusting in subsequent drying cycles (El-Swaify *et al.*, 1987). This leads to a reduced water infiltration rate and enhanced run-off early in the rainy season. Thus the water infiltration rate is a good indicator of the soil physical conditions of Alfisols. As shown in Fig. 9(a), water infiltration in plots planted to sorghum following pigeonpea was greater than in continuous sorghum plots. Water infiltration into plots planted to pigeonpea, on the other hand, was greatest in the plots in which chickpea was

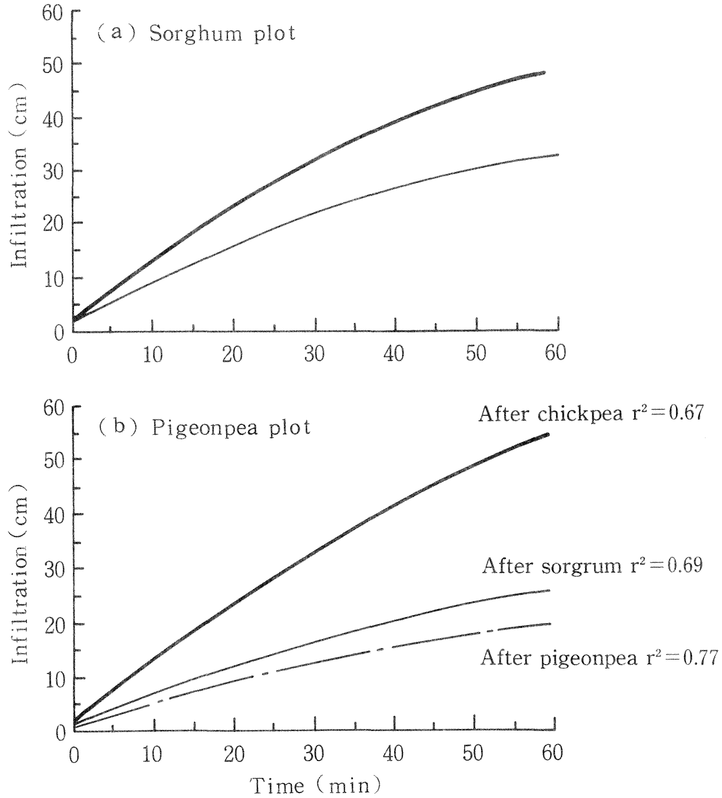


Fig. 9 Effect of cultivation of previous crops on infiltration rate in sorghum(a) and pigeonpea(b) plots in an Alfisol field (ICRISAT Center, rainy season, 1989).

previously grown (Fig. 9(b)). These results clearly indicate that the structural development of the Alfisol was improved by the cultivation of pigeonpea and chickpea. Improved water infiltration rate results in 1) decreased crust formation, a major obstacle to seedling emergence in Alfisols, and 2) improved soil aeration, one of the most important factors affecting the growth of crops on Alfisols (Okada *et al.*, 1991).

These results demonstrate the advantages of crop rotations including pigeonpea or chickpea on the soil physical conditions, as compared with continuous cropping. This could be attributed to the exudation of organic acids from particular crops, such as citric acid from chickpea and piscidic acid from pigeonpea. Contribution of root residues as an input of bulk organic matter into soil, which is often cited as the cause of the enhancement of soil aggregation leading to improved physical characteristics, could be overlooked, because the amount of root production in pigeonpea and chickpea is lower than that of sorghum. Furthermore, as previously mentioned in the case of pigeonpea growing in Alfisols, water channels may be created in the remains of previous roots. However, these possible effects await quantification.

Improved P status, physical conditions, and formation of water channels by the cultivation of pigeonpea in Alfisols are considered to improve the root development of succeeding crops. Root development of sorghum grown in an Alfisol was enchanced by the

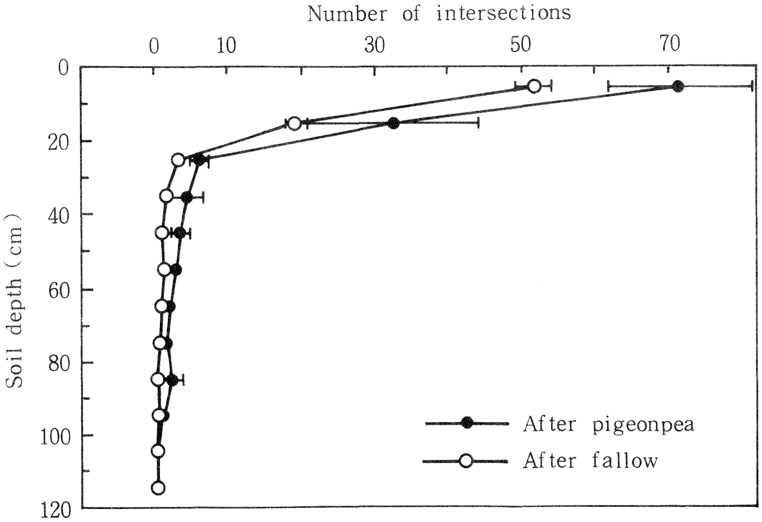


Fig. 10 Effect of pigeonpea cultivation for 3 years on root development of sorghum in an Alfisol field (ICRISAT Center, rainy season, 1989).

previous cultivation of pigeonpea, as illustrated in Fig. 10 where the root development of sorghum was measured in soil pits dug in plots where pigeonpea had been previously cultivated for three yaers or had remained fallow for three years. The differences remain evident to at least 80cm depth. This improved root development with depth may have contributed to the increased grain yield of sorghum following pigeonpea cultivation, as depicted in Fig. 6.

Effect of intercropping of pigeonpea and sorghum

Intercropping of sorghum and pigeonpea is widely practiced in the semi-arid regions of India. The beneficial effects of intercropping in terms of increased total grain yield and stability of yield over seasons have been discussed by Willey (1985) and Ofori and Stern (1987). We examined the basis for improved partial land equivalent ratios ([partial LER] = [grain yield in intercrop]/[grain yield in sole crop] ; Ofori and Stern, 1987) in terms of the rooting characteristics of sorghum intercropped with pigeonpea.

Sorghum (CSH 5) grain yield as a sole crop was compared with that in intercrops with medium-duration pigeonpea (C 11) with either one row of pigeonpea for one row of sorghum (1Pp : 1So), or one row of pigeonpea for three rows of sorghum (1Pp : 3So). Inter-row spacing was 60cm and intra-row spacing was 15cm for both crops (i.e. replacement intercropping design). Rows were 6m long and sown on ridges 60cm apart ; there were 7 ridges for sole sorghum, 9 for 1Pp : 1So and 13 for 1Pp : 3So. Experiments were conducted in the 1988/89 season in a Vertisol field and in two Alfisol fields with high(a) and low(b) fertility. Fertilizer at rates of 18kg N/ha and 20kg P/ha was shallow-banded at the time of sowing. Nitrogen fertilizer was top-dressed 40 and 75 days after sowing at the rate of 50kg N/ha.

At flowering time, the total dry matter of sorghum per row was higher in intercropping

Table 5 Toal dry matter at flowering time and grain yield (per 6m row) and partial LERs of sorghum in different cropping systems (ICRISAT Center, rainy season, 1988)

Field		Flowering time		Harvesting time	
		Total dry matter	Partial LER	Grain yield	Partial LER
		(g/row)		(g/row)	
Vertisol	Sole sorghum	839± 70		349± 40	
	Intercrop (1Pp : 1So)*	860±103	0.51	389± 18	0.56
	Intercrop (1Pp : 3So)	688± 36	0.61	374± 29	0.80
Alfisol(a)	Sole sorghum	1,397±182		1,001±133	
	Intercrop (1Pp : 1So)	1,915±304	0.69	1,778±169	0.89
	Intercrop (1Pp : 3So)	1,425±220	0.77	1,339±108	1.00
Alfisol(b)	Sole sorghum	918± 97		831±108	
	Intercrop (1Pp : 1So)	1,159±240	0.63	1,040±119	0.63
	Intercrop (1Pp : 3So)	1,109±380	0.90	936±162	0.85

* (1Pp : 1So) : 1 row of pigeonpea and 1 row of sorghum.
(1Pp : 3So) : 1 row of pigeonpea and 3 rows of sorghum.
(from Arihara *et al.*, 1991).

than in sole cropping except in the case of 1Pp : 3So in Vertisol (Table 5). The grain yield per row was higher in intercropping in all fields. The mechanism of this beneficial effect of intercropping with pigeonpea on sorghum yield was investigated from both above- and below-ground aspects.

Firstly, the effect of light interception was investigated because Willey (1985) reported that improved light interception was the major benefit of sorghum intercropped with pigeonpea, compared to sole sorghum.

Leaf area index (LAI) and light extinction coefficient (k) of sorghum and pigeonpea in each cropping system at around 83 to 89 days after sowing and at the mid-ripening stage of sorghum, are presented in Table 6. LAI of pigeonpea as a sole crop was much larger than that of sole sorghum in every field. In the 1P : 1S intercropping system, in each field, partial LAI of pigeonpea was larger than that of sorghum for the Vertisol and Alfisol (b) fields and slightly lower for an Alfisol (a) field. Light extinction coefficient (k) in each intercropping system was the same as or larger than that of sole sorghum, indicating that the light interception of the whole canopy of intercropped sorghum was lower than that of sole sorghum. These results indicate that at least during the ripening period, sorghum intercropped with pigeonpea in our experiments did not benefit from larger or better light interception compared to sole sorghum.

Secondly, the possibility of the beneficial effect through the influence of water availability and of nitrogen fixation by pigeonpea could be excluded in this experiment as rainfall was adequate in the growing season of sorghum and nitrogen fertilizer was applied to both sorghum and pigeonpea.

Thirdly, as referred earlier, pigeonpea can absorb Fe-P from soil which is usually unavailable to other crops. It is considered that there would be less competition for soil P

Table 6 Leaf area index (LAI) of sorghum and pigeonpea and light extinction coefficient (k) in different cropping systems at middle of ripening stage of sorghum (ICRISAT Center, rainy season, 1988).

Cropping system	Crop		Vertisol	Alfisol (a)	Alfisol (b)
			Mean	Mean	Mean
Sole pigeonpea	Pigeonpea	LAI	4.41±0.40	3.85±0.49	4.16±0.22
		k	0.82±0.13	0.81±0.07	0.81±0.04
Intercrop (1P : 1S)	Pigeonpea	LAI	1.85±0.20	1.66±0.14	1.75±0.16
	Sorghum	LAI	1.53±0.10	1.84±0.11	1.25±0.08
	Total	LAI	3.37±0.14	3.50±0.22	3.01±0.16
		k	0.58±0.05	0.63±0.04	0.75±0.05
Intercrop (1P : 3S)	Pigeonpea	LAI	0.79±0.05	0.66±0.04	0.87±0.06
	Sorghum	LAI	1.84±0.11	2.28±0.18	1.63±0.20
	Total	LAI	2.63±0.13	2.94±0.18	2.50±0.21
		k	0.58±0.04	0.71±0.07	0.66±0.08
Sole sorghum	Sorghum	LAI	2.05±0.13	2.38±0.17	1.95±0.12
		k	0.59±0.05	0.60±0.06	0.57±0.06

in a pigeonpea-sorghum intercropping system as sorghum absorbs mainly Ca-P and pigeonpea absorbs Fe-P from the soil. This could be one of the reasons for the better performance of intercropping systems than sole crops in this experiment.

Fourthly, the possibility of better physical conditions of soils in intercropping than in sole sorghum was investigated because poor soil aeration is one of the major factors reducing plant growth not only in Vertisols but also in Alfisols (Okada *et al.*, 1991), and because we have observed that sorghum intercropped with pigeonpea appears to experience less damage from waterlogging than sole sorghum. Soil aeration was measured according to the method of Okada *et al.* (1991) over an 18 day period after flowering of sorghum in the above-mentioned intercropping and sole cropping treatments (Fig. 11). In the Vertisol and Alfisol (b) fields, the soil oxygen concentration was directly proportional to the ratio of pigeonpea in the system. Thus intercropped sorghum benefited from better soil aeration conditions which may have resulted in the higher yield per plant as compared to sole cropped sorghum. However, in the Alfisol (a) field where the effect on the increase of partial LER in terms of sorghum grain yield was the most pronounced, the soil aeration in intercropped plots was not consistently higher than that in sole sorghum. These results suggest that the beneficial effect of sorghum on partial LER can not be completely ascribed to the improvement of soil aeration. Further studies are required to elucidate the beneficial effect of intercropping on grain production of sorghum.

Conclusions

These studies rereabd the lollowing:

(1) The deeper rooting ability of chickpea in Vertisols and pigeonpea in Alfisols, as compared to other crops, and the possible advantage for increased productivity (e.g. through improved water extraction from deeper soil profiles)

(2) The unique mechanisms of chickpea and pigeonpea which enable them to take up sparingly soluble phosphorus from Vertisol (chickpea) or from Alfisol (pigeonpea);

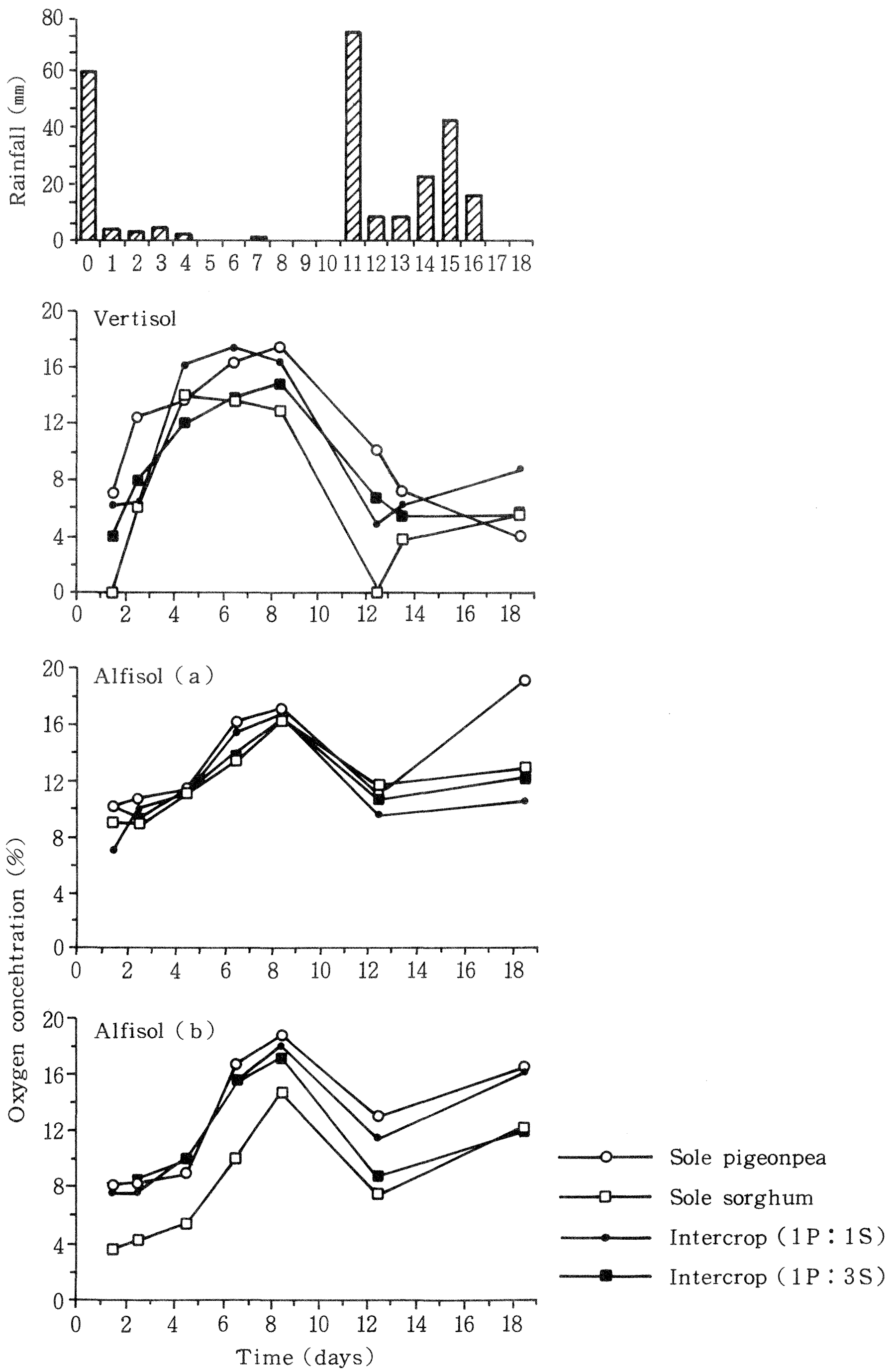


Fig. 11 Soil oxygen concentration at 15cm depth following flowering of sorghum in Vertisol, Alfisol(a) and Alfisol(b) fields with different cropping systems (ICRISAT Center, rainy reason, 1988). Rainfall during the period is also depicted.

(3) The ability of both crops to increase the available soil P pool, through the mechanisms mentioned in (2) which can be utilized by the subsequent crop in the crop rotation or possibly by the companion crop in intercropping systems;
(4) The benefits of incorporating these legumes in crop rotations and intercropping systems. The results also suggest:
(5) The possibility of recycling nutrients especially phosphorus from deeper soil layers by means of (1) and (2);
(6) The possibility of improving the soil physical conditions which may contribute to increased overall productivity in both crop rotations and intercropping systems including either legume as a component.

These results support the rationality of traditional farming systems in the Indian SAT where chickpea and pigeonpea have been recognized as essential components in the cropping systems, despite their low and unstable yield. It is interesting to note how well the traditional farming systems are utilizing the natural resources of the SAT for crop production under low input conditions. It is suggested that further quantification of the apparent beneficial effects of pigeonpea and chickpea is required to demonstrate the importance of legumes in the sustainability of cropping systems in the SAT.

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Discussion

Swindale, L, (ICRISAT): I congratulate Dr. Arihara and his colleagues for going beyond the observation that pigeonpea and chickpea do not respond to phosphorus application. They have cleverly investigated the reasons and greatly improved our knowledge of the unique behaviour of these important legume crops in the semiarid tropics.

Meelu, O. P. (India) : You discussed the effect of compost and rice straw mulch application on the yield of corn. In the case of green manure such as crotolaria, how did you grow it for the incorporation into the maize crop under rainfed conditions? Also regarding the build-up of organic in the different treatments, the amount of organic matter was higher in the case of compost or rice straw application than in the other treatments (green manure). What was the amount of green manure added and how was the green manure brought into the system?

Answer : In the case of green manure such as crotolaria, we used it at a young stage. The effect of that treatment is good in terms of yield and comparable to that of crop residue mulch. We intercropped it with corn, cut it and added it as mulch. The amount depends on the quantity of plant residues obtained (in the case of corn, 5 tons of dry matter, in the case of mimosa or cowpea, the amount was lower).

Iwama, H. (Japan) : Why was the effect of mulch on soil moisture evident in the growing season and not in the dry season?

Answer : The amount of moisture kept in the soil was small due to the low moisture retention capachity of the kaolinitic soil. Soil moisture kept during the rainy season had evaporated during the dry season or was consumed by the succeeding crop, mungbean.

Imai, H. (Japan) : I agree with your conclusions on the importance of mulching in the rainy season cultivation. However based on my experiments, I believe that the application of compost or other organic materials is not very effective in improving the soil physical and chemical properties or in increasing crop yield. Is it really necessary and effective to apply compost continuously to achieve high yields in the tropics?

Answer : I agree with you. I believe that even high applications of compost will not improve the soil physical properties. We may have to wait 6-8 years before getting a yield response.