CP 1314

Nitrogen Management in Sorghum/Pigeonpea Intercrop

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Abstract

Considerable gaps remain in our understanding of the extent to which nitrogen (N) fertilizer application in cereal/legume intercropping systems could be synergistic in terms of maximizing biological nitrogen fixation (BNF) by the legume, and optimizing grain yield of the cereal component. There is a high potential to increase the grain yield of sorghum and enhance BNF by pigeonpea through intercropping, without greatly increasing the use of fertilizer N. This review suggests that: (1) Medium-duration pigeonpea can reduce the N fertilization needs of sorghum by 50% in a sorghum/pigeonpea intercrop. (2) Split-delay of modest N rates is a sound strategy to increase N-use efficiency, and to enhance BNF by pigeonpea in the semi-arid tropics. This is because of the heavy rains that can occur at the onset of the rainy season, leading to a substantial downward water flow, coupled with the increased chance of water deficits during the growing season. (3) In areas where soil mineral N is relatively high so as to suppress BNF by legumes, intercropping cereals with legumes is vital to reduce the inhibitory effects of soil N on BNF. This is supported by the experimental evidence that starter doses of 20–25 kg N ha^{-1} *suppressed BNF by sole-cropped, but not intercropped pigeonpea. (4) Intercropped legumes removed less N from the soil than their respective sole crops, suggesting the potential of reducing N mining from the soil through intercropping. (5) For more efficient use of N by intercropping systems, companion crops that exhibit different root system architecture are vital to prevent competition for water and N by roots.*

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Introduction

Semi-arid tropical soils used for agriculture are exceptionally low in organic matter (usually less than 1%) compared with soils in temperate environments (2–4%). Because organic matter is a source of soil-available N, many soils in the SAT are incapable of maintaining N in adequate amounts to sustain productivity of sorghum without adding N fertilizer. In the past, shifting cultivation and bush fallow, and traditional farming systems in many parts of the humid and semi-arid tropics (SAT), seemed stable enough to maintain soil fertility. Currently, because of high population pressure, increasing demand for agricultural production, and increasing use of agricultural land for residential and industrial purposes, this system is being replaced by more frequent and permanent forms of cultivation. Consequently, the equilibrium between soil, vegetation, and climate with regard to nutrient mining (especially of N) by crops, and regeneration of N status is being disrupted, and soil fertility is declining (Sanchez and Salinas 1981).

Nitrogen fertilizer has played, and will continue to play an important role in increasing cereal (sorghum) production in most countries. However, N use in the soil-plant-atmosphere continuum must be managed effectively to ensure productivity, stability, and sustainability of agroecosystems, without degradation of other physical resources. This is most desirable in the SAT, where vast areas of land are rainfed, and rainfall distribution is erratic. The adoption of such cultural systems as rotation of diverse crop species, and/or intercropping of cereals and legumes is beneficial as they reduce the use of chemical fertilizers and maintain soil fertility and other soil properties.

Sorghum and pigeonpea are important staple food crops in many countries in the SAT. Both crops thrive well on relatively marginal lands, and in limited rainfall environments. Apart from its N_2-fixation ability in soils, the deep rooting ability of pigeonpea could enhance the possibility of recycling of nutrients (especially N and P), and water from deeper soil layers, and help improve N resource and water use efficiency (Ofori and Stern 1986, Ito et al. 1994). Ae et al. (1990) reported that pigeonpea has the ability to take up P from an Fe-bound form, through the release of piscidic acid in root exudates. These characteristics make the combination of pigeonpea and sorghum unique in intercropping systems. In this paper, we examine some of the physiological and agronomic bases of improving N-use efficiency and overall productivity in this intercropping system by (1) examining some fertilizer management strategies to enhance the dependency of sorghum on soil N, and pigeonpea on biological nitrogen fixation (BNF), and (2) quantifying the utilization of N from different sources by the component crops. Suggestions are made for future directions of research to improve productivity and N resource use in sorghum/pigeonpea intercropping systems.

Current Knowledge on Sorghum/Pigeonpea Intercropping Research in the Semi-Arid Tropics

Earlier work by Willey et al. (1981, 1986), Rao and Willey (1980), and Natarajan and Willey (1980) on sorghum/pigeonpea intercropping has improved our knowledge of the production efficiency, yield stability over the years, efficient utilization of sunlight, and monetary returns of intercropping compared with their respective sole crops. Willey (1996) provided an excellent review of intercropping by highlighting the principle of complementarity in intercropping. In sorghum/pigeonpea intercrops, where maturity periods of the two component crops are typically 100 and 180–210 days, there is a fuller use of resources over time than can be achieved by sole crops. Appreciably greater capture of light over time has been shown in sorghum/pigeonpea intercropping (Natarajan and Willey 1980, Venkateswarlu et al. 1981). Analysis of the results from 80 experiments on sorghum/pigeonpea intercropping in India have shown that:

- High yield advantage can be expected only when maturity periods of genotypes of the component crops differ widely. Thus, the longer the duration of sorghum, the lower the yield of pigeonpea.
- High production efficiency of intercrops was recorded compared with their respective sole crops. The land equivalent ratio (LER)varied from 1.1 to 1.8, and the area time equivalent ratio (ATER) varied from 1.1 to 1.7.
- Identification of compatible component genotypes is important for complementarity, and to improve the overall productivity of sorghum/pigeonpea intercropping systems.

In drier areas, temporal complementarity might ensure fuller use of rainfall over the season, and where access of N is limited by water availability, there is better use of N that progressively becomes available from mineralization (Willey 1996).

Nitrogen Fertilizer Management to Enhance Yield and Use Efficiency in Intercropping Systems

Rate, Time, and Methods of Application

Species capable of fixing nitrogen have played an integral role in cropping systems since the domestication of plants. In intercropping systems, such species are grown interspersed with or between rows of non N$_2$-fixing species to improve N nutrition and yield. To date, several studies, reviews, and published proceedings on BNF in cereal-legume cropping systems have shown that in areas where the soil mineral N content is high (> 30µg N g^{-1} soil, Wani et al., these proceedings), there is increased growth of the cereal. This in turn, because of increased competition, decreases the growth of the legume and limits its ability to fix N. In addition, it is well documented that high doses of fertilizer N suppress nodulation and BNF by legumes. In areas where the soil mineral N is below the critical level to suppress nodulation and BNF, fertilizer N application to the cereal component in cereal-legume intercropping is vital to optimize the yield of the cereal, and to maximize BNF by the legume component.

Since several studies (Tobita et al. 1994, Chalk 1996, Ofosu-Budu et al. 1993, Kumar Rao et al. 1987) have confirmed that there is little or no direct transfer of N from legumes to cereals in intercropping systems, fertilizer N requirement (time and quantity) of crops is the most critical management factor when considering N economy in such systems. Legumes grown in association with cereals could help reduce the fertilizer N inputs, compared with pure stands of cereals in soils typified by low N. But the extent to which legumes can reduce the N fertilization needs of the cereal in cereal-legume intercropping systems is not fully understood.

From the results of a 4-year sorghum/pigeonpea intercropping study on Alfisols at the ICRISAT Asia Center (IAC), Adu-Gyamfi et al. (1996 b) reported that a moderate dose of 25 kg N ha^{-1} was required for maximum yield of sorghum, when grown with a medium-duration pigeonpea, compared with 50-100 kg N ha^{-1} when grown as a sole crop (Fig 1). In the above study, N rates ranging from 0–100 kg N ha^{-1} were conveniently applied by banding between the two sorghum rows (or applied only to the sorghum row) to make it readily available to sorghum, but to keep it away from pigeonpea in a 2:1 (sorghum:pigeonpea) row arrangement commonly used in sorghum/pigeonpea combinations at IAC. The results indicate that pigeonpea can reduce the N fertilization needs of sorghum by 50%. Although this observation is bound to be site specific, the result agrees with that of Narain et al. (1980) who recommended 25–30 kg N ha^{-1} for sorghum/pigeonpea intercropping at a different location in India.

In a similar study where N was applied at 100% at sowing (basal), or 67% at 40 days and 33% at 60 days after sowing (delayed), grain yield was significantly higher when fertilizer N was applied as delayed N than as basal N. In the SAT of India and Africa, nitrate-N accumulates during the long dry fallow period. Before sowing of crops, mineral-N in the top 15 cm soil profile could be as high as 50 kg N ha^{-1} (Adu-Gyamfi et al. 1997). However, heavy rains that occur at the onset of the rainy season could lead to leaching and/or immobilization of the accumulated mineral N. In semi-arid regions of South Asia where the initial monsoon rains in June-July account for a quarter of the total annual rainfall, there is a substantial downward water flow, especially in Alfisols. Since the crop need for N, and the capacity for N uptake at the early vegetative stage are small , delaying fertilizer application helps minimize the amount of fertilizer that is not utilized by crops. Fertilizer applied at the later stages resulted in increased sorghum grain yield, and total N accumulation, perhaps due to a greater synchrony in N demand and supply.

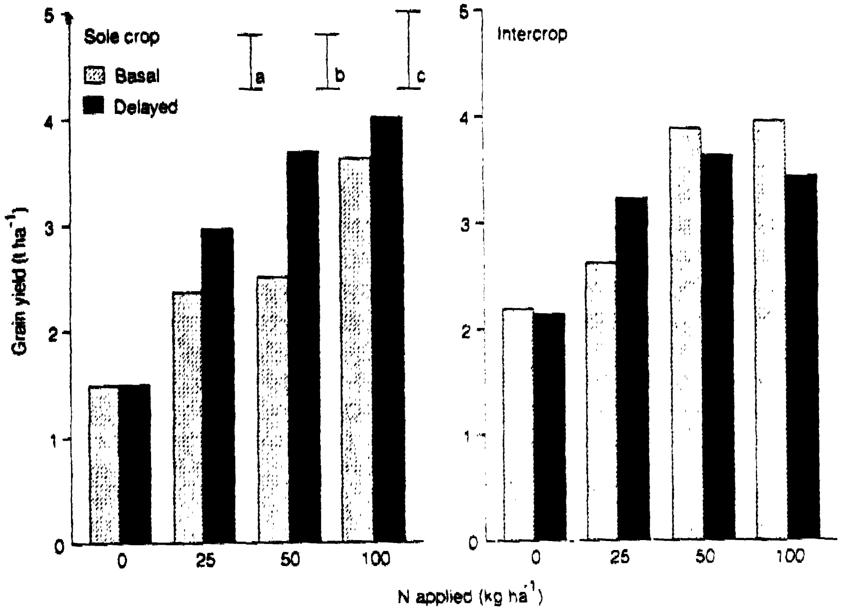

Figure 1. Mean grain yields of sole-cropped and intercropped pigeonpea in response to timing and rates of N application during a 2-year period. Nitrogen rates were 0, 25, 50, and 100 kg ha^{-1} applied (i) 100% at sowing (basal) or (ii) 67% at 40 days, and 33% at 60 days after sowing (delayed). Bars indicate LSD ($P < 0.05$) values when comparing (a) cropping systems × time (b) cropping systems × fertilizer, and (c) cropping systems × time × fertilizer. Source: Adu-Gyamfi et al. (1997).

In areas where intercropping is commonly practised, farmers prefer basal to delayed application because they consider that the crops require N for their early growth. As reported by Adu-Gyamfi et al. (1996a), however, the mineral N content due to the long dry period, in most cases, is adequate for early establishment of the component sorghum because of less competition for soil N with the associated pigeonpea. A basal N application is required to promote early growth of the associated sorghum only on soils with a very low N status.

Delaying N application is advantageous because if crop establishment fails due to insufficient rainfall, no fertilizer cost is incurred. Nevertheless, fertilizer-N recommendations depend on the ability of the farmer to apply N fertilizer easily at any time during the growing season, and circumstances where the N fertilizer needs to be applied while the plants are small, to avoid mechanical damage. The second option is uncommon among subsistence farmers in the SAT. Timing of fertilizer application also depends much on the rainfall pattern. Despite a mean annual rainfall of 600-800 mm, flooding at the time of sowing (June) is not uncommon. Hence basal application is not recommended. However, caution must be exercised when trying to extrapolate findings to wider locations than the research station where the study was conducted.

Fertilizer N Recovery

The challenge to using N fertilizers for sustainable agricultural systems has been to promote its appropriate use to reduce ground and stream water pollution, which is well documented. In the SAT where water deficit is frequent and most farmers use relatively low doses of N fertilizer, the issue is not environmental pollution, but efficient use of the low N doses by crops.

Many review papers have concluded that to improve fertilizer N recovery, it is desirable to split or delay its application. The subject has been widely covered in recent reviews (Strong 1995, Bacon 1995) for sole crops. Nevertheless, few studies have examined the effect of N application on N recovery in intercropping systems. Fertilizer N recovery (FNR) calculated for crop uptake with or without the use of labelled ^{15}N has been extensively reviewed (Jansson and Persson 1982, Jenkinson et al. 1985, Strong 1995). Recovery was usually higher for the difference method than for the ^{15}N enrichment method wherever the two FNR methods were compared. This is due to the "added N interaction" (ANI) described by Jenkinson et al. (1985), which has also been described in detail by Jansson and Persson (1982).

In the field experiment described in the preceding section, Adu-Gyamfi et al. (In press) compared the difference method of determining fertilizer N recovery, and the ^{15}N enrichment method in a sorghum/pigeonpea intercropping. The N recovery by the difference method was higher than by the ^{15}N method (Fig. 2). Delaying N fertilization to sorghum for 40 days significantly ($P < 0.001$) increased ^{15}N recovery in the shoot from 15 to 32 % in sole-cropped sorghum, and from 10 to 32% in the intercrop. This result suggests that the recovery of fertilizer N in sorghum was enhanced when intercropped with pigeonpea, compared with when grown as a sole crop (Fig. 2).

At IAC, Moraghan et al. (1984a and b) reported a fertilizer N recovery of 30-0% in Vertisol, and 50-60% in Alfisol by sole-cropped sorghum (grown on a flat ed) using ^{15}N fertilizer. These values are substantially higher than what was eported (15-32%) by Adu-Gyamfi et al. (1996b). Tobita et al. (1994) and Yoneyama et al. (1990) reported FNR values of 12-20% by sorghum in sole- and ntercrop. The ridge-and furrow system with ridges spaced at 60 cm, used by Tobita et al. (1994) and Adu-Gyamfi et al. (1996b), compared with the flat bed by Moraghan et al. (1984a and b), could partially account for the differences in FNR by sorghum.

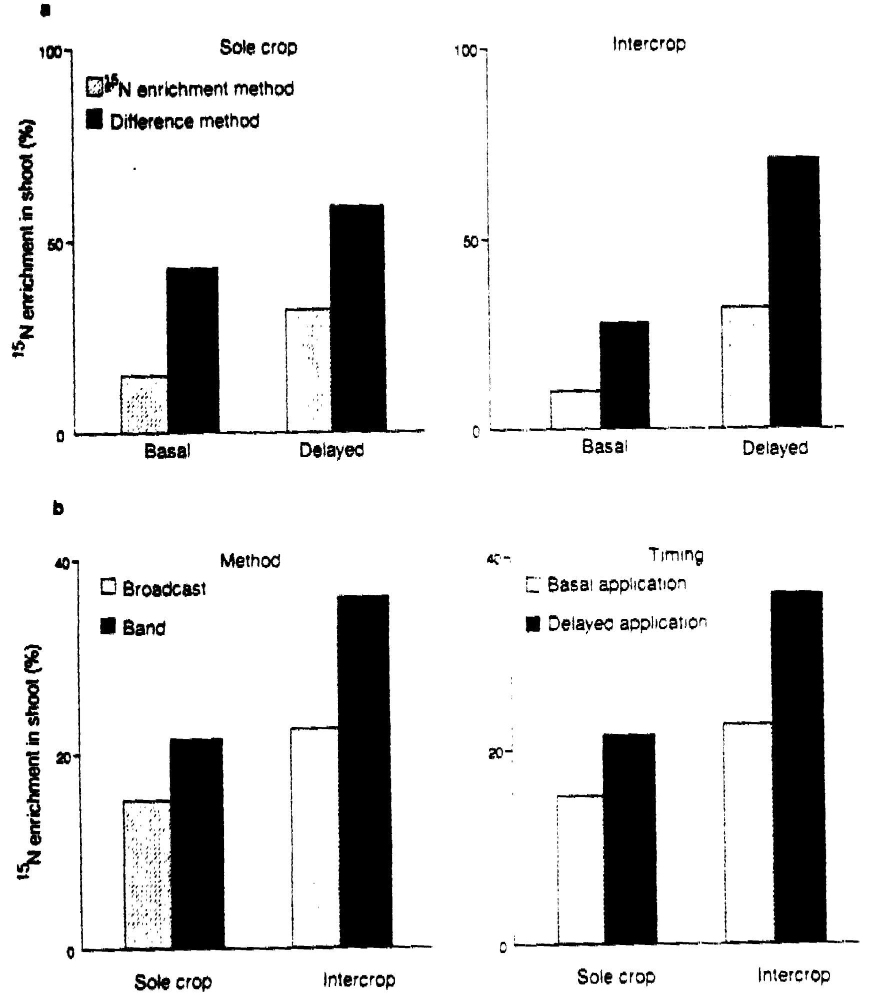

Figure 2. (a) Fertilizer N recovery (FRN) estimated by the conventional difference method, and the direct ^{15}N recovery by the crops, in shoot of sorghum grown as a sole crop and as an intercrop with pigeonpea on an Alfisol at ICRISAT Asia Center, Patancheru, India. Fertilizer N (50 kg ha^{-1}) was applied (i) 100% at sowing (basal) or (ii) 100% at 40 days after sowing (delayed) (b) Method of N application on FRN in shoot of sorghum grown as a sole crop and as an intercrop with pigeonpea. Source: Adu-Gyamfi et al. (1996 b, 1997).

Similarly, when N was applied at 40 days after sowing (DAS), there was a significant ($P < 0.001$) increase in N recovery by the difference method from 43 to 59% in sole crop and from 28% to 71% in intercropped sorghum. Fertilizer N applied as delayed resulted in a higher FNR by sorghum than when N was applied at sowing (basal).

The method of fertilizer application is frequently constrained by the nonavailability of labor. In the SAT where labor is relatively cheaper than in the temperate environments, banding of fertilizer N to sorghum row in a sorghum/pigeonpea intercrop resulted in a higher ^{15}N recovery (36%) in sorghum shoots than by broadcasting (19.1%) (Adu-Gyamfi et al. 1996b). Similar results were reported by Myers (1979) and Tomar and Soper (1981).

BNF in Sorghum/Pigeonpea Intercropping

Bilogical nitrogen fixation plays a vital role in the N economy of sorghum/pigeonpea intercropping system, since both crops are usually cultivated on soils with low nutrient availability, and in water-limiting environments. It is, therefore, imperative that we understand not only the contribution of this process to various agricultural systems, but also the current limitations to BNF under field conditions. Large variations in the BNF estimates for pigeonpea could be attributed to the method used for quantification; maturity duration; and of course, soil, and other environmental factors.

In an Inceptisol in India, Kumar Rao et al. (1996b) reported the proportion of N derived from air (% Ndfa) in pigeonpea genotypes, ranging from 0 to 35%, using the natural abundance method. The %Ndfa was lowest in extra-short duration (4%) and highest in long-duration (35%) genotypes. Compared with the ^{15}N natural abundance method, the N-difference method tended to underestimate the %Ndfa by extra-short duration (ESD) and short duration (SD) pigeonpea on Alfisol and Vertisol fields (Kumar Rao et al. 1996a). Peoples and Herridge (1990) also showed a high variation (10–88%) in %Ndfa by pigeonpea genotypes. It is, therefore, important that measurements of BNF indicate which environmental resources are limiting, the maturity duration of the crop, and the method used to quantify BNF.

Despite the fact that pigeonpea is grown as an intercrop, few studies have quantified the proportion and amount of N fixed when it is grown as a sole crop, compared with when intercropped. In the semi-arid regions, medium- or long-duration genotypes are usually grown as intercrops. In a field experiment on an Alfisol at IAC, Tobita et al. (1994) estimated between 122 and 170 kg ha^{-1} of fixed N by a medium-duration pigeonpea (ICP 1-6) using the ^{15}N natural abundance method. This value compares favorably with the 3-year data of Adu-Gyamfi et al. (1996b) who reported an amount between 120 and 170 kg ha^{-1} for pigeonpea genotype ICP 1-6 on an Alfisol, using the ^{15}N natural abundance method. In the

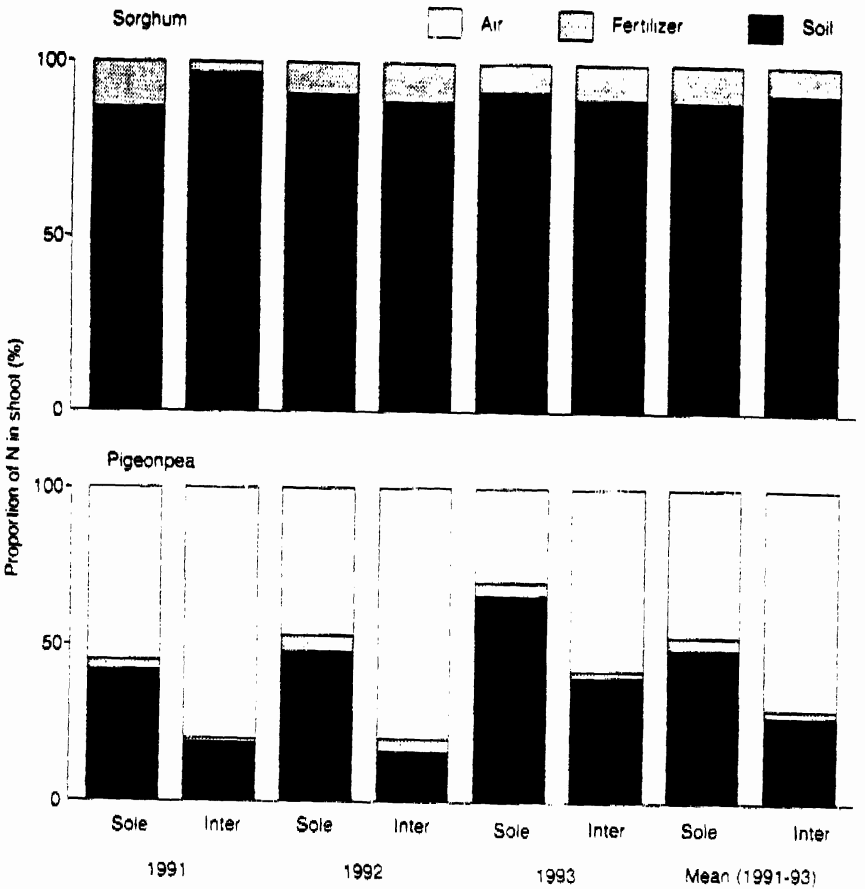

Figure 3. Sources of N for sorghum and pigeonpea grown as a sole- and intercrop on an Alfisol at ICRISAT Asia Center, Patancheru, India. Nitrogen derived from air (Ndfa) was estimated by the ^{15}N natural abundance method, and N derived from fertilizer (Ndff) was estimated by the ^{15}N isotope dilution method. Source: Adu-Gyamfi et al. (1996 b).

3-year study, the mean (1991-93) %Ndfa values in the shoot of pigeonpea (ICP 1-6) ranged from 48 to 70%, and were significantly higher when intercropped with sorghum than when grown as a sole crop (Fig. 3). Similarly, Katayama et al. (1995) reported that pigeonpea intercropped with sorghum derived 56–85% from fixation, which was more than the %Ndfa of sole crop pigeonpea (32–58%). These results indicate that the N_2-fixing ability of pigeonpea is enhanced by intercropping.

The ^{15}N natural abundance and the ^{15}N enrichment methods to estimate BNF by legumes are expensive because they involve the use of mass and emission spectrophotometers, not available in most laboratories in developing countries.

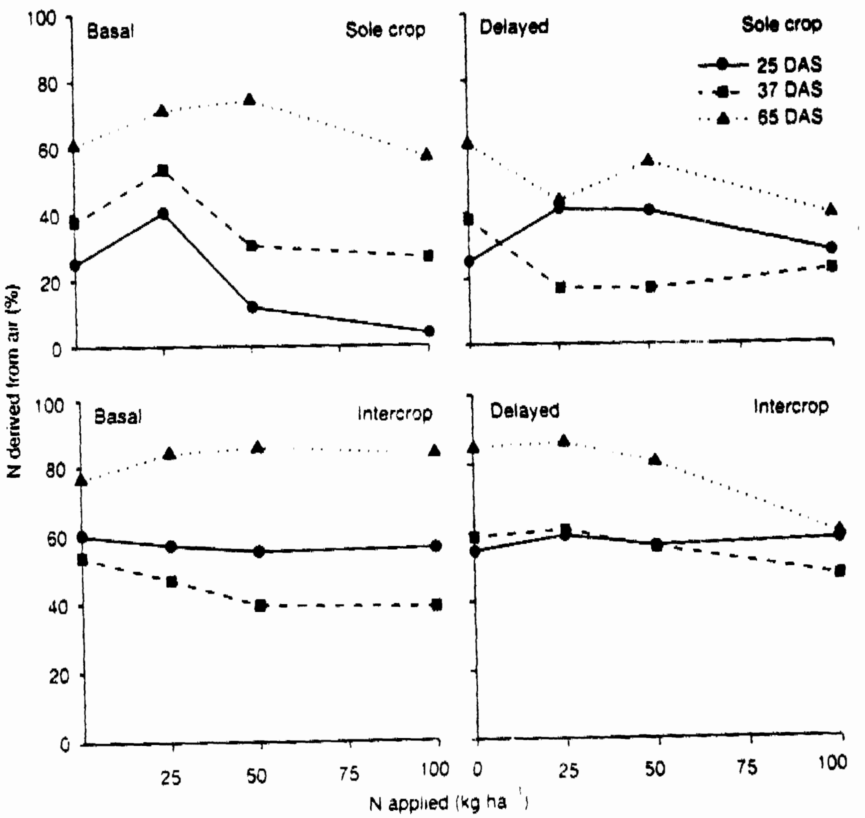

Figure 4. Proportion of N derived from air (%Ndfa) by pigeonpea estimated by the relative ureide abundance method. Nitrogen rates were 0, 25, 50, and 100 kg ha^{-1} applied (i) 100% at sowing (basal) or (ii) 33% at 25, 37, and 65 days after sowing (delayed). Xylem saps were taken on the same day before N fertilization for the delayed plots. Source: Adu-Gyamfi et al. (unpublished).

The relative abundance of ureides (the proportion of ureides, α-amino acids, and NO_3-N concentration in xylem sap) has been used to estimate %Ndfa by soybean and other ureide-producing legumes. Field application of this method to estimate %Ndfa by intercropped pigeonpea does not exist in literature, although Peoples et al. (1989) estimated %Ndfa of pot-cultured young pigeonpea plants.

In a study where N was applied at (i) 100% at sowing (basal) or 67% at 40 DAS, and 33% at 60 DAS (delayed), fixed N accounted for about 80% of the N in intercropped pigeonpea compared with about 60% in sole-cropped pigeonpea at flowering (Fig. 4). There was a marked decrease in %Ndfa in the sole crop, but not in the intercropped pigeonpea as fertilizer rates increased. Although the proportion of N derived from air was higher in N0 than in N100 treatment at 25 DAS, no difference was observed at 65 DAS. The xylem sap exudate could hardly be collected from pigeonpea by the stem exudation method after 80 DAS, because of the woody nature of the stem. Consequently, the total amount of Ndfa at final harvest could not be estimated. Alternative procedures such as the vacuum extraction method (Peoples et al. 1989) are worth investigating.

Rate and Method of N Application on BNF by Intercropped Pigeonpea

A survey of farmers' fields in parts of India and Bangladesh by Wani et al. (these proceedings) recorded a significant number of fields with > 20 and up to 52.3 mg N kg^{-1} soil in the top 15 cm soil profile. In such fields, starter N doses (20–25 kg N ha^{-1} generally recommended for legumes) would not be required for intercropped pigeonpea. In a field experiment on an Alfisol, Tobita et al (1994) observed that N application of 25 kg N ha^{-1} significantly reduced the amount of fixed N from 150 kg N ha^{-1} to 123 kg N ha^{-1} in the sole crop, but not in the intercrop (Fig. 5). The result suggests that in farmers' fields where the initial mineral N content is high at the beginning of the cropping season, intercropping of legumes with cereals will prevent the suppression of BNF by pigeonpea. Starter-N application should be given only when the mineral-N content in the soil profile is < 5 mg kg^{-1} soil.

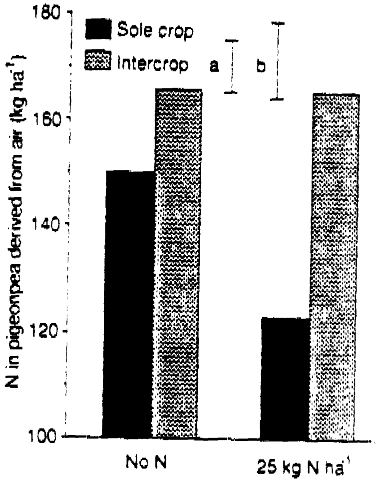

Figure 5. N fertilizer rates and amount of shoot N derived from air in pigeonpea. Bars indicate standard error values when comparing (a) N treatments and (b) cropping systems. Source: Tobita et al. (1994).

Data from Adu-Gyamfi et al. (1996b) showed very high %Ndfa values for split-banding (87%) compared with broadcasting (67%) in intercropped pigeonpea. For sole-cropped pigeonpea, the authors reported % Ndfa values of 26% for broadcast, and 40% for split-band application.

BNF in Pigeonpea-Based Cropping Systems

In the SAT of India, pigeonpea is intercropped with pearl millet, maize, groundnut, and cowpea. Using the ^{15}N natural abundance, ^{15}N enrichment, and the acetylene reduction methods, Katayama et al. (1995, 1996b) reported that the proportion of Ndfa of pigeonpea was higher in pigeonpea/pearl millet and pigeonpea/groundnut intercropping than the other combinations (Fig. 6).

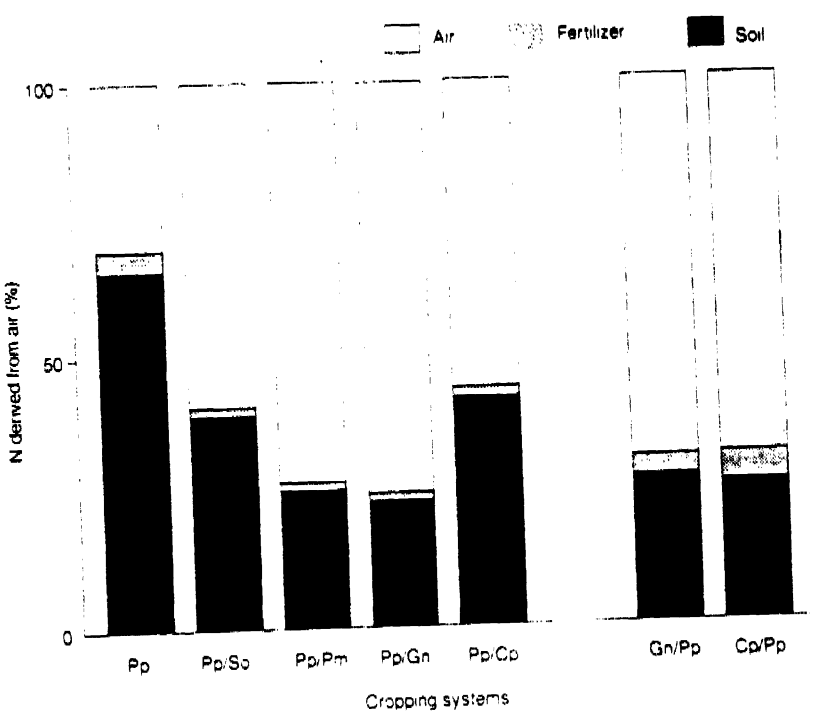

Figure 6. Proportion of N in total above-ground biomass of pigeonpea from soil, fertilizer, and air. Nitrogen derived from air (Ndfa) was estimated by the ^{15}N abundance method, and N derived from fertilizer (Ndff) was estimated by the ^{15}N isotope dilution method. (Pp = Pigeonpea, Pp/So = Pigeonpea/Sorghum, Pp/Pm = Pigeonpea/Pearl millet, Pp/Cp = Pigeonpea/Cowpea, Pp/Gn = Pigeonpea/Groundnut) Source: Katayama et al. (1995).

Interactions between the Root Systems of Companion Crops

Intercropping sorghum and pigeonpea of different growth habits has been recognized as a potentially profitable system for crop production. The deep root system of pigeonpea improves uptake of mineral nutrients from soils (Chauhan 1993). The advantages of intercropping in soil resource utilization has been reported by several workers who used shoot growth as an indicator, but did not investigate in detail the below-ground interactions between the root systems of the companion crops.

The balance sheet of N in sorghum/pigeonpea intercropping has been well studied, particularly for the above-ground plant parts (Tobita et al. 1994; Katayama et al. 1996a). However, the N economy of below-ground parts of these crops is not fully understood. N dynamics in the underground parts are very important in long-term cultivation in helping to estimate how much crop residue N is utilized by succeeding crops. The rooting properties of each individual crop should be characterized under intercropping systems, in order to identify better crop combinations which show lower root competition and a higher utilization efficiency of water and N. This area of research has been extensively reviewed (Ito et al. 1996, Katayama et al. 1996a).

Ito et al. (1996) used respiration as an indicator of root activities, and correlated it with N uptake using data from field experiments. Pigeonpea showed a higher respiration rate than did sorghum, and intercrops had a higher rate than sole crops. Using a simple model, it was demonstrated that at the same rate of N accumulation, sorghum could achieve a much higher growth rate than did pigeonpea, and the respiratory cost of N accumulation by pigeonpea was higher than that of sorghum, indicating that pigeonpea required more respiratory activity to accumulate the same amount of N. Further investigations as to whether the higher respiratory burden for growth and maintenance in pigeonpea roots could be related to the function of nodules or to morphological differentiation of the tap root is required.

Future Research Needs

More research and extension need to be done to convincingly demonstrate the economic and environmental benefits accrued by incorporating BNF into regular farm management practices, identify the best species for particular crops, quantify the amount of N fixed by these species, and accurately predict the availability of fixed N as a substitute/replacement of fertilizer N within intercrops. Some topics for research are suggested below:

- Soil water and nutrient interaction studies in cropping systems. Although it is postulated that mineral N suppresses nodulation, few studies have examined the effect of P and mineral N interaction on nodulation and N_2 fixation.
- Quantification of BNF and residual N in soil in farmers' fields.
- Prediction of BNF by legumes over long periods of cropping by means of simulation models using climatic data, soil mineral N content, and plant N accumulation.
- Interactions between root systems of companion crops in intercropping to identify better crop combinations that exhibit high utilization efficiency of water and N.

References

Adu-Gyamfi, J. J., Ito, O., Yoneyama, T., Gayatri Devi., and Katayama, K. 1997. Timing of N fertilization on N_2-fixation, N recovery and soil profile nitrate dynamics in sorghum/pigeonpea intercrops on Alfisols of the semi-arid tropics. Nutrient Cycling in Agroecosystems 48:197-208.

Adu-Gyamfi, J. J., Katayama, K., Gayatri Devi., Rao, T. P., and **Ito, O.** 1996a. Estimation of soil nitrogen status in intercropping through soil solution. Pages 453-468 *in* Dynamics of root and nitrogen in cropping systems of the semi-arid tropics (Ito, O., Johansen, C., Adu-Gyamfi, J. J., Katayama, K., Kumar Rao, J. V. D. K., and Rego, T. J., eds.). JIRCAS International Agriculture series no. 3. Tsukuba, Japan: Japan International Research Center for Agricultural Sciences (JIRCAS).

Adu-Gyamfi, J. J., Katayama, K., Gayatri Devi., Rao, T. P., and **Ito, O.** 1996b. Improvement of soil and fertilizer nitrogen use efficiency in intercropping. Pages 493-506 *in* Dynamics of root and nitrogen in cropping systems of the semi-arid tropics (Ito, O., Johansen, C., Adu-Gyamfi, J. J., Katayama, K., Kumar Rao, J. V. D. K., and Rego, T. J., eds.). JIRCAS International Agriculture series no. 3. Tsukuba, Japan: Japan International Research Center for Agricultural Sciences (JIRCAS).

Ae, N., Arihara, J., Okada, K., Yoshihara, T., and **Johansen, C.** 1990. Phosphorus uptake by pigeonpea and its role in cropping systems of the Indian subcontinent. Science 284:477-480.

Bacon, P. E. 1995. Nitrogen fertilization in the environment. 270 Madison Avenue, New York, USA: Marcel Dekker, Inc. 603 pp.

Chalk, P. M. 1996. Nitrogen transfer from legumes to cereals in intercropping. Pages 351-374 *in* Dynamics of root and nitrogen in cropping systems of the semi-arid tropics (Ito, O., Johansen, C., Adu-Gyamfi, J. J., Katayama, K., Kumar Rao, J. V. D. K., and Rego, T. J., eds.). JIRCAS International Agriculture series no. 3. Tsukuba, Japan: Japan International Research Center for Agricultural Sciences (JIRCAS).

Chauhan, Y. S. 1993. Pigeonpea. Pages 78-91 *in* Rooting patterns of tropical crops (Salam, M. A., and Wahid, P. A., eds.). New Delhi, India: Tata McGraw-Hill Publishing Co.

Ito, O., Katayama, K., Adu-Gyamfi, J. J., Gayatri Devi., and **Rao, T. P.** 1996. Root activities and functions in intercropping. Pages 159-172 *in* Dynamics of root and nitrogen in cropping system of the semi-arid tropics (Ito, O., Johansen, C., Adu-Gyamfi, J. J., Katayama, K., Kumar Rao, J. V. D. K., and Rego, T. J., eds.). JIRCAS International Agriculture series no. 3. Tsukuba, Japan: Japan International Research Center for Agricultural Sciences (JIRCAS).

Tobita, S., Ito, O., Matsunaga, R., Rao, T. P., Rego, T. J., Johansen, C., and **Yoneyama, T.** 1994. Field evaluation of nitrogen fixation and use of nitrogen fertilizer by sorghum/pigeonpea intercropping on an Alfisol in the Indian semi-arid tropics. Biology and Fertility of Soils 17:241-248.

Tomar, J. S., and **Soper, R. J.** 1981. Fate of tagged urea N in the field with different methods of N and organic matter placement. Agronomy Journal 73:991-995

van Kessel, C., and **Roskoski, J. P.** 1988. Row spacing effects on N_2-fixation, N-yield and soil N uptake of intercropped cowpea and maize. Plant and Soil 111:17-23.

Venkateswarlu, J., Sanghi, N. K., Rao, U. M. B., and **Rao, C. H.** 1981. Maximum production in sorghum/pigeonpea intercropping system in the semi-arid tropics. Pages 30-34 *in* Proceedings of the International Workshop on Pigeonpeas, 15-19 Dec 1980, ICRISAT Asia Center, India (Nene, Y. L., and Kumble, V., eds.). Vol. 1. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

Willey, R. W. 1996. Intercropping in cropping systems: an overview. Pages 93-102 *in* Dynamics of root and nitrogen in cropping system of the semi-arid tropics (Ito, O., Johansen, C., Adu-Gyamfi, J. J., Katayama, K., Kumar Rao, J. V. D. K., and Rego, T. J., eds.). JIRCAS International Agriculture series no. 3. Tsukuba, Japan: Japan International Research Center for Agricultural Sciences (JIRCAS).

Willey, R. W., Natarajan, M., Reddy, M. S., and **Rao, M. R.** 1986. Cropping systems with groundnut: resource use and productivity. Pages 193-203 *in* Agrometeorology of groundnut. Proceedings of an International Symposium, 21-26 Aug 1985, ICRISAT Sahelian Center, Niamey, Niger. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for Semi-Arid Tropics.

Willey, R. W., Rao, M. R., and **Natarajan, M.** 1981. Traditional cropping systems with pigeonpea and their improvement. Pages 11-25 *in* Proceedings of the International Workshop on Pigeonpeas, 15-19 Dec 1980. ICRISAT Asia Center, India (Nene, Y. L., and Kumble, V., eds.). Vol. 1. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

Yoneyama, T., Nambiar, P. T. C., Lee, K. K., Srinivasa Rao, B., and **Williams, J. H.** 1990. Nitrogen accumulation in three legumes and two cereals with emphasis on estimation of ^{15}N-abundance technique. Biology and Fertility of Soils 9:25-30.

Soil Mineral Nitrogen Concentration and its Influence on Biological Nitrogen Fixation of Grain Legumes

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Abstract

Surveys in farmers' fields in Bangladesh, India, and Vietnam showed that there was mineral N up to 70.7 µg g^{-1} soil (and several fields had about 30 µg N g^{-1} soil) in the surface 15-cm soil profile at or before sowing of a legume crop. Such high concentrations at sowing have been reported to suppress nodulation and N_2 fixation by some legumes. A high level of soil mineral N (31.2 µg mineral N g^{-1} soil) at sowing reduced nodulation of chickpea in a field experiment by at least 14%, and proportion of fixed N by 63%, compared with that in the control plots (7.3 µg mineral N g^{-1} soil). In a pot trial with Alfisol, application of five levels of fertilizer N up to 200 kg N ha^{-1} equivalent much before sowing was used to simulate range of soil mineral N concentration at sowing. It was observed that mean nodule number and nodule mass per plant in three of the five legume species studied were substantially reduced in the presence of a soil mineral N concentration of 31 µg g^{-1} soil (the other two species showed reduction at 43 and 66 µg N g^{-1} soil), compared with a control (no fertilizer) having 23 µg N g^{-1} soil at sowing. In the case of pigeonpea, suppression of N_2 fixation was recorded at 43 µg N g^{-1} soil, and in cowpea, at 66 µg N g^{-1} soil. A direct relationship between nitrogenase activity and different soil N pools at sowing and at flowering was observed in all the five legumes (R^2 = 0.56-0.80) except in mung bean. Based on the available data, it seems that the general recommendation of applying a starter N dose of 20-30 kg ha^{-1} to legumes in the tropics cannot be applicable in all situations, and native soil mineral N should be considered to effectively harness N_2 fixation by legumes.

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