Abstract

Citation: Rupela, O.P., Kumar Rao, J.V.D.K., Wani, S.P., and Johansen, C. (eds.) 1994. Linking biological nitrogen fixation research in Asia: report of a meeting of the Asia Working Group on Biological Nitrogen Fixation in Legumes, 6–8 Dec 1993, ICRISAT Asia Center, India. (In En. Abstracts in En, Fr.) Patancheru 502 324, Andhra Pradesh, India: (International Crops Research Institute for the Semi-Arid Tropics). 140 pp. ISBN 92-9066-297-2. Order Code: CPE 092.

Reports from Bangladesh, Nepal, Thailand, and India on the on-farm use of rhizobial inoculants are presented. Other topics covered include the status of soybean *Bradyrhizobium* research in India, influence of cropping system and other factors on population of cowpea rhizobia, improvement of biological nitrogen fixation (BNF) in groundnut by host-plant selection, expectations of research administrators and breeders from BNF research, intra-varietal variability in nodulation in chickpea and pigeonpea, the role of legumes in cropping systems, and iron chlorosis in groundnut. Details are given of experiments on rhizobial inoculants and on host-plant selection for high BNF. Working Group work plans are outlined.

Résumé

La recherche en Asie sur la fixation biologique de l'azote: rapport d'une réunion du Groupe de travail Asie sur la fixation biologique de l'azote chez les légumineuses, 6–8 déc 1993, Centre ICRISAT pour l'Asie, Inde. Cet ouvrage présente des rapports, en provenance du Bangladesh, du Népal, de la Thaïlande et de l'Inde, sur l'utilisation en milieu réel des inoculants rhizobiaux. D'autres sujets qui sont abordés: statut de la recherche sur *Bradyrhizobium* du soja en Inde, influence du système de culture et d'autres facteurs sur la population des rhizobia du niébé, amélioration de la fixation biologique de l'azote chez l'arachide par la sélection de la plante-hôte, résultats attendus par les administrateurs de recherche et sélectionneurs sur la recherche sur la fixation biologique de l'azote, variabilité intra-variétale de la nodulation chez le pois chiche et le pois d'Angole, rôle des légumineuses dans les systèmes de culture et enfin, chlorose ferrique chez l'arachide. Sont également inclus des détails des expériences sur les inoculants rhizobiaux et sur la sélection des plantes hôtes pour une fixation biologique de l'azote élevée. Des projets de recherche futurs du Groupe de travail sont présentés brièvement.

The opinions in this publication are those of the authors and not necessarily those of ICRISAT. The designations employed and the presentation of material in this publication do not imply the expression of any opinion whatsoever of the part of ICRISAT concerning the legal status of any country, territory, city, or area, or of its authorities, or concerning the delimitation of its frontiers or boundaries. Where trade names are used this does not constitute endorsement of or discrimination against any product by the Institute.

CP-917 (7)

Linking Biological Nitrogen Fixation Research in Asia: report of a meeting of the Asia Working Group on Biological Nitrogen Fixation in Legumes

6–8 Dec 1993
ICRISAT Asia Center, India

Edited by
O P Rupela,
J V D K Kumar Rao,
S P Wani, *and*
C Johansen

1401

ICRISAT

International Crops Research Institute for the Semi-Arid Tropics
Patancheru 502 324, Andhra Pradesh, India

1994

6

Contribution of Legumes in Cropping Systems: A Long-term Perspective

S P Wani[1], T J Rego,[1] and J V D K Kumar Rao[1]

Introduction

It is widely believed that legumes maintain or improve soil fertility because of their N_2-fixing ability. In support of this argument, the substantial amounts of N_2 fixed by legumes are cited. However, in assessing the long-term contribution of legumes in a cropping system, we need to consider not only the amount of N_2 fixed by legumes, but also the overall nitrogen balance of the cropping system.

Net N Balance of Legume Crops

In order to assess the contribution of legumes in a given cropping system, a proper estimation of the fixed nitrogen is essential. It must be remembered that it is a common practice for farmers to remove legume plant material from the field for use as fodder. In such cases, only nodulated roots and fallen plant parts are returned to the soil. However, in most studies, the amount of fixed nitrogen in the roots and fallen plant parts is not taken into account while quantifying BNF.

The net nitrogen balances calculated for several cultivars of pigeonpea grown at ICRISAT Asia Center, Patancheru, and of chickpea grown at Gwalior, Madhya Pradesh, India indicated that all the varieties depleted soil nitrogen (Table 1). Nambiar et al (1988) observed that groundnut fixed 190 kg N ha^{-1} $season^{-1}$ at Patancheru. However, the crop showed a negative net N balance as 20–40% of its N requirement came from soil and fertilizer. Such negative N balances are more likely for legumes grown on high-fertility soils. Positive net N balances of up to 136 kg ha^{-1} have been observed by Peoples and Crasswell (1992) in several legume crops following seed harvest. However, when crop residues were removed from the field, the net N balances ranged from −27 to −95 kg ha^{-1} in groundnut, −28 to −104 kg ha^{-1} in soybean, −24 to −65 kg ha^{-1} in green gram, −25 to −69 kg ha^{-1} in cowpea, and 28 kg ha^{-1} in common bean. These results show that legumes also mine soil N as do cereals. However, total plant N yields are far higher for legumes than for cereals. From these results, it is concluded that when plant material is removed from the field, legumes in general slow the decline of, rather than enhance, the N fertility of the soil.

1. Senior Scientists, Soils and Agroclimatology Division, ICRISAT Asia Center, Patancheru 502 324, Andhra Pradesh, India.

ICRISAT Conference Paper number CP 917.

Wani, S.P., Rego, T.J., and Kumar Rao, J.V.D.K. 1994. Contribution of legumes in cropping systems: a long-term perspective. Pages 84–90 *in* Linking Biological Nitrogen Fixation Research in Asia: report of a meeting of the Asia Working Group on Biological Nitrogen Fixation in Legumes, 6–8 Dec, ICRISAT Asia Center, India. (Rupela, O.P., Kumar Rao, J.V.D.K., Wani, S.P., and Johansen, C., eds.). Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

CP 0917

Table 1. Net nitrogen balances calculated for pigeonpea cultivars grown at Patancheru, and chickpea cultivars grown at Gwalior, India.

Cultivar	Total plant N uptake (kg ha^{-1})	Estimated plant N derived from fixation (kg ha^{-1})	Net N balance (kg ha^{-1})[1]
Pigeonpea[2]			
Prabhat	69	4	−49
UPAS 120	92	27	−39
T 21	108	43	−39
BDN 1	118	53	−32
Bhedaghat	101	36	−20
JA 275	78	13	−33
Bhandara	108	43	−22
NP (WR) 15	114	50	−27
Chickpea[3]			
Annigeri	110	31	−77
G 130	104	26	−75
ICC 435	102	29	−72
ICCC 42	88	23	−64
ICCV 6	107	30	−76
K 850	104	40	−63

1. Net N balance calculated as Total plant N uptake – (N derived from BNF + N derived from fertilizer + N added to soil through plant roots and fallen plant parts).
2. N derived from fixation calculated for roots also.
3. N derived from fixation calculated only for above-ground plant parts.

Source: Kumar Rao and Dart (1987). O.P. Rupela, ICRISAT, personal communication 1993.

Residual Effects of Legumes

Notwithstanding the negative N balances, there have been consistent reports on the residual benefits of legumes. In a long-term crop-rotation experiment in progress since 1983 at ICRISAT Asia Center, such benefits to the succeeding sorghum crop have been observed consistently (Fig. 1). Improvement in cereal yields following monocropped legumes ranged from 0.5 to 3.0 t ha^{-1}, which were 30 to

350% higher than the yields in cereal-cereal cropping sequences (Peoples and Crasswell 1992).

Nitrogen effects. The benefits of legumes to succeeding nonlegume crops are quantified in terms of the fertilizer N equivalent or fertilizer replacement value (FRV). This concept does not distinguish between BNF and the 'N-conserving effect' of legumes. The FRV methodology has been widely used but it probably overestimates the N contribution of legumes as it confounds non-N rotation effects with N contribution. The FRV method gave an estimate (125 kg ha^{-1}) that was almost twice the observed value (65 kg ha^{-1}) when sorghum was used instead of maize as the test crop (Blevins et al. 1990). In order to circumvent the problems encountered with nonisotopic methods, the ^{15}N methodology has been used to measure the residual effects of legumes. Based on estimates obtained through this methodology, Hesterman et al. (1987) argued that the amount of N credited to legumes in a crop rotation in north central USA may have been inflated by as much as 123% due to the use of the FRV method. Using the ^{15}N methodology, it

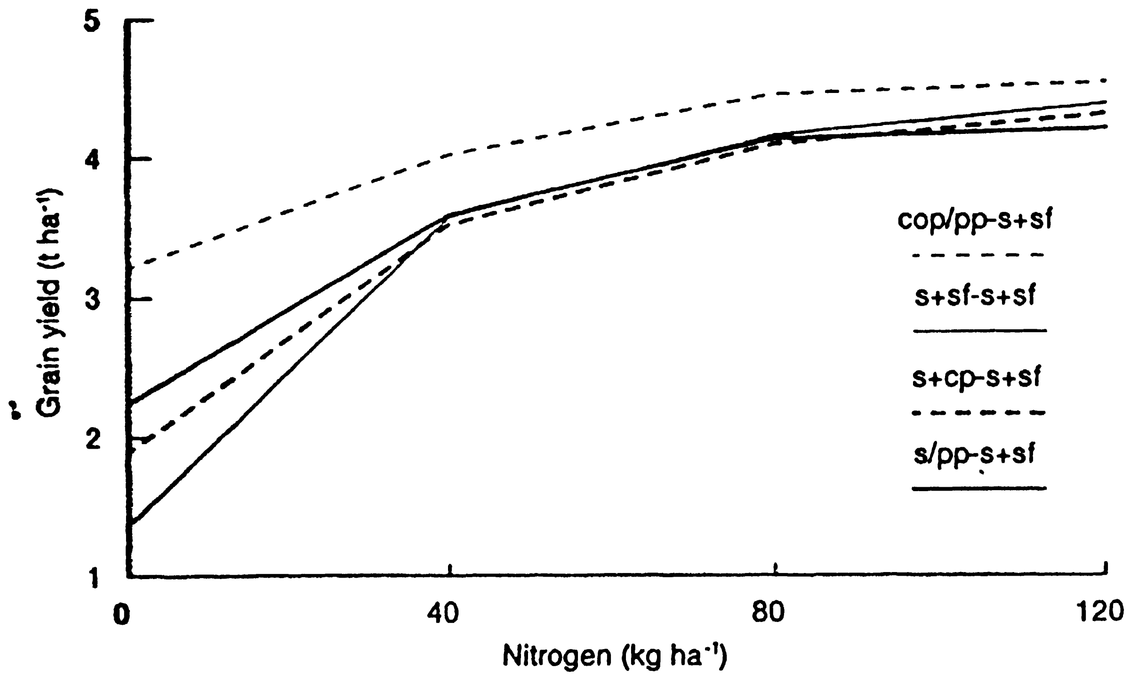

Figure 1. Mean grain yield of sorghum grown succeeding different cropping system in rainy season, 1983–92, ICRISAT Asia Center, Patancheru. (- = 2 year crop rotation, / = intercropped, + = sole crop grown during postrainy season, s = sorghum, pp = pigeonpea, sf = safflower, cp = chickpea, cop = cowpea.)

was reported that only 7–28% of the ^{15}N in legume crops is taken up by the succeeding grain crop (Ladd et al. 1983, S P Wani, unpublished results).

In the long-term experiment being conducted at ICRISAT Asia Center (with 2-year crop-rotation treatments), surface (0–20 cm) soil samples collected after the harvest of the 9th season's crop showed a higher mineral N content in soil under pigeonpea-based cropping systems than nonlegume-based cropping systems. Further, the N mineralization potential (N_o) of soil samples taken from pigeonpea-based cropping systems was almost twice that of the fallow + sorghum (F+S) treatment. Similarly, the 'active N fraction', the quotient of N_o and N_{total} and expressed as a percentage, varied between 9 and 17% with higher values observed for soils under pigeonpea-based cropping systems. However, such results were not observed in chickpea-based cropping systems. Soil samples collected from the same field after 10 years indicated a substantial increase in total soil N in the case of pigeonpea-based systems (Table 2). In nonlegume-based or chickpea-based systems, there was a decline in total soil N.

Sorghum grown in pots filled with surface (0–20 cm) soil samples collected from the ICRISAT experiment after the harvest of the ninth year crop showed the effect of cropping history on plant growth. Sorghum yields were 36–63% higher in pigeonpea-based cropping systems than in the sorghum + safflower (S+SF-S+SF) treatment. In chickpea-based cropping systems, sorghum yields were 18–24% lower than the S+SF-S+SF plot yields. Using the ^{15}N methodology and the S+SF-S+SF treatment as control, it was estimated that 8.4–20% of the total plant N of

Table 2. Total soil N (μg g^{-1} soil) in soil samples taken from different cropping systems, ICRISAT Asia Center, 1983 and 1993.

	Soil depth			
	0–15 cm		15–30 cm	
Cropping system[1]	1983	1993	1983	1993
S/PP-S+SF	559	629	437	480
S+CP-S+SF	540	517	407	443
C/PP-S+SF	543	645	419	501
S+SF-S+SF	537	530	397	438
F+S-F+S	563	491	422	426
F+CP-F+S	567	507	399	446
M+S-M+S	558	559	422	461
F ratio	NS[2]	**[3]	NS	**
SE	±18.4	±13.2	±15.0	±14.4

1. S = sorghum; PP = pigeonpea; SF = safflower; CP = chickpea; C = cowpea; F = fallow; M = mung bean, / = intercrop, + = sequential crop; and - = rotation
2. NS = Not significant.
3. ** = $P \leq 0.01$.

sorghum grown in soil taken from pigeonpea-based cropping systems was derived from N that was either fixed previously and had accumulated, or from soil N that was made available due to the presence of pigeonpea in the rotation. Also, the 'A' values for soil from the pigeonpea-based cropping system were higher by 26 to 76 mg pot^{-1} (5–13 kg N ha^{-1} equivalent) than that of the S+SF-S+SF treatment. The FRV for these treatments using soil from the S+SF-S+SF treatment ranged from 65 to 161 mg pot^{-1} (24–28 kg N ha^{-1} equivalent). These results indicate that increased sorghum yields in pigeonpea-based cropping systems are partly due to increased soil N availability, but that all the benefits cannot be explained in terms of N effects (S P Wani unpublished results).

Non-N effects. The overall benefits of legumes are not fully explained when only their BNF effects are considered. The other likely benefits include increased availability of nutrients other than N (through increased total soil microbial activity and/or increased activity of such specific groups of microorganisms as vesicular arbuscular mycorrhizae or plant growth promoting rhizobacteria), improved soil structure, enhanced level of growth-promoting substances, and reduced pest and disease incidence. The extent of these benefits are dictated by site, season, and crop sequence.

Reduced Legume Yields in Rotation

Generally, cropping-system trials in the tropics are conducted for short periods. Very few long-term trials are monitored. In the long-term trial at ICRISAT Asia Center, pigeonpea yields were observed to have declined (T J Rego unpublished results). To identify the causes for the fall in yields, experiments were conducted in the greenhouse. We confirmed lower yields when pigeonpea was grown in pots filled with soil from field plots of pigeonpea-based systems than when it was grown on soil from F+S-F+S plots. We noticed that the decreased pigeonpea yields were due neither to the increased incidence of fusarium wilt, nor to the increased number of parasitic nematodes (S P Wani unpublished results). They may be due to an allelopathic effect. This needs further research.

Improving the Contribution of Legumes in Cropping Systems

Although legumes have the ability to fix atmospheric nitrogen, it cannot be assumed that the inclusion of any legume in a cropping system will ensure significant contributions to the N cycle. As is evident from published reports, most legumes deplete soil N when plant material is removed from the field. To derive maximum benefits from legumes, we must take a holistic approach and understand the entire BNF and N-cycling system.

Host-plant improvement. Variability exists in legumes for the amount of N_2 fixed and for the proportion of plant N derived from BNF. We need to identify legumes and genotypes that yield more, and derive a large part of their N requirement from fixation. For example, compared to chickpea, pigeonpea returned a large amount of fixed N to soil through nodulated roots and fallen leaves. Similarly, there is a need to identify genotypes that can fix well under adverse soil conditions such as high soil N, soil acidity and alkalinity, Al and Mn toxicity, waterlogging, high and low soil temperature, etc. The natural occurrence of nonnodulating plants within chickpea genotypes indicates a need to ensure that their proportion in that genotype does not increase. Most plant breeding and testing work is done on research stations where soil mineral N is invariably higher than in farmers' fields. Nonnodulating and low-nodulating plants are therefore not discriminated against when selecting and testing improved genotypes. This has been demonstrated in chickpea and pigeonpea (see Rupela pages 75–83 this Report) and may also be true for other legumes. To avoid this, appropriate procedures must be adopted in breeding and testing programs.

Improved crop management. Appropriate crop and soil management practices should be followed to ensure maximum BNF contribution by legumes. For example, reduced BNF due to high mineral N in soil can be managed either by immobilization of the soil N through addition of organic material with a high C/N ratio or through reduced tillage. In intercropping situations in which application of fertilizer N is essential for obtaining high cereal yields, an appropriate form of fertilizer, e.g., slow-releasing formulations or organic N, should be used. Also, suitable methods of fertilizer application, e.g., placement of fertilizer in cereal crop rows rather than broadcasting and mixing in soil, must be followed. Appropriate amendments with nutrients other than N which might limit legume growth—and in turn BNF — should be applied.

Rhizobial inoculation. Under field conditions, response to rhizobial inoculation in traditional legume-growing areas has not been consistent. Situations which need inoculation should be identified and efforts must be focussed on such areas. Research for selection of efficient strains and identification of specific host-bacteria combinations must continue. The important constraints limiting the exploitation of inoculation technology are: 1. poor quality of the inoculants; 2. lack of knowledge about inoculation technology among extension personnel and farmers; 3. ineffective inoculant delivery systems; and 4. lack of appropriate policy support by governments that would favor use of inoculants by farmers.

Conclusion

In addition to the ability of a legume to fix atmospheric nitrogen, its contribution in a cropping system is due to its N sparing effect, the break-crop effect, and enhanced soil microbial activity. A dependable methodology to quantify the benefits derived from these different factors may be difficult to evolve, and will require long-term studies. However, a legume-based rotation is generally more sustainable than a rotation without a legume. Informed decisions to enhance the BNF of a legume crop, and thus its contribution in the cropping system, are essential. This can be achieved by using legume cultivars with high N_2-fixing ability, by ensuring a high population of efficient homologous rhizobia in the soil, and by employing appropriate agronomic practices for high BNF and high yield.

References

Blevins, R.L., Herbek, J.H., and Frye, W.W. 1990. Legume cover crops as a nitrogen source for no-till corn and grain sorghum. Agronomy Journal 82:769–772.

Hesterman, O.B., Russelle, M.P., Sheaffer, C.C., and Heichel, G.H. 1987. Nitrogen utilization from fertilizer and legume residues in legume-corn rotations. Agronomy Journal 79: 726–731.

Ladd, J.N., Amato, M., Jackson, R.B., and Butler, J.H.A. 1983. Utilization by wheat crops of nitrogen from legume residues decomposing in soils in the field. Soil Biology and Biochemistry 15(3):231–238.

Kumar Rao, J.V.D.K., and Dart, P.J. 1987. Nodulation, nitrogen fixation and nitrogen uptake in pigeonpea (*Cajanus cajan* (L.) Millsp.) of different maturity groups. Plant and Soil 99: 255–266.

Nambiar, P.T.C., Rupela, O.P., and Kumar Rao, J.V.D.K. 1988. Nodulation and nitrogen fixation in groundnut (*Arachis hypogaea* L.), chickpea (*Cicer arietinum*), and pigeonpea (*Cajanus cajan* L. Millsp.). Pages 53–70 *in* Biological nitrogen fixation: recent developments (Subba Rao, N.S., ed.). New Delhi, India: Oxford and IBH Publishers.

Peoples, M.B., and Crasswell, E.T. 1992. Biological nitrogen fixation: investments, expectations and actual contributions to agriculture. Plant and Soil 141:13–39.

Declining Yields in Cereal Cropping Systems: Can the Introduction of Legumes Help Arrest the Decline?

A Ramakrishna[1], C L L Gowda[2], and Shanti Bhattarai[3]

Introduction

One of the prerequisites for sustainable agriculture is the maintenance and/or improvement of soil fertility. However, the intensive and exploitative farming systems that are being used to meet the growing food needs of an increasing population have resulted in declining crop yields and shrinking of the agricultural resource base, in both irrigated lowlands and rainfed uplands (Harrington 1991). This paper discusses some of the issues related to the decline in agricultural productivity due to inappropriate land-use systems, and the potential role of legumes in reversing this trend.

Influence of Cereal Cropping on Soil Productivity

Monocropping. In southern Queensland, Australia, continuous cropping and cereal cultivation on soils that previously supported native vegetation resulted in reduced organic matter content, lower nutrient-supplying capacity, and increased bulk density (Dalal et al. 1991). The lower the clay content, the greater was the rate of loss of organic matter under cultivation, and the larger the replenishments required to maintain organic matter at a steady level (Table 1). This situation may be similar for any cropping system involving cereals and legumes. However, there are few studies on this aspect.

Dalal et al. (1991) also reported that under cereal cultivation over several decades, soil organic N declined at a mean rate of 31-51 kg N ha^{-1} per year in a number of Australian soils (Fig. 1). In consequence, degradation of the soil structure and decreased soil aggregation were observed, along with declines in cereal yield and protein content.

1. Scientist (Agronomy) and 2. Coordinator, Cereals and Legumes Asia Network (CLAN), ICRISAT Asia Center, Patancheru 502 324, Andhra Pradesh, India. 3. Soil Scientist, Division of Soil Science, Nepal Agricultural Research Council (NARC), Khumaltar, Lalitpur, Nepal.

ICRISAT Conference Paper number CP 918.

Ramakrishna, A., Gowda, C.L., and Bhattarai, Shanti. 1994. Declining yields in cereal cropping systems: can the introduction of legumes help arrest the decline? Pages 91–99 *in* Linking Biological Nitrogen Fixation Research in Asia: report of a meeting of the Asia Working Group on Biological Nitrogen Fixation in Legumes, 6–8 Dec, ICRISAT Asia Center, India. (Rupela, O.P., Kumar Rao, J.V.D.K., Wani, S.P., and Johansen, C., eds.). Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.