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Biological Nitrogen Fixation and Residual Effects of Winter Grain Legumes in Rice and Wheat Cropping Systems of the Indo-Gangetic Plain

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ABSTRACT

Legumes have long been recognized by farmers and scientists alike as builders and restorers of soil fertility. Chickpea, the dominant winter legume in India and Pakistan can potentially fix at least 80% of its nitrogen (N) needs from air (like other legumes) and can acquire up to about 140 kg N ha"[1] from air. Lentil, a major winter legume in Nepal and Bangladesh can potentially acquire about 190 kg N ha"[1] from air. But the quantities of N_2-fixation by these legumes in farmers' fields in these countries are normally much less than half the potential fixation levels, according to experiments using ^{15}N methods. An increase in irrigation facilities, ready and cheap availability of chemical fertilizers, relatively less stable yields of legumes, and government policies favoring cereal production have driven away the legumes from the intensive cropping systems of the Indo-Gangetic Plain. Any significant increase in area under winter legumes in the intensive cereal-cereal cropping system will require a change in this scenario.

Also, it seems that the continuous cereal-cereal cropping system has changed the soil environment (including high mineral N levels suppressive to N_2 fixation by legumes) such that it is less conducive for producing high yields of legumes. This needs to be confirmed. It is possible to develop cultivars of winter legumes suitable for the likely new soil environment (such as increased mineral-N). Chemical fertilizers were regarded as important inputs for yield increases of

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cereals during 1960s to 1980s. Since then yields have plateaued and even declined, but use of chemical fertilizers (and other agrochemicals such as pesticides) is still growing significantly. Soil organic matter, an important pool of nutrients for raising crops, is feared to have declined significantly. Frequent application of organic materials such as farm-yard manure should help maintain soil organic matter and may ameliorate the suppressive effect of soil mineral-N on N_2 fixation by winter legumes. This aspect needs to be studied.

The Indo-Gangetic Plain (IGP) constitutes a major assured irrigated area and rice *(Oryza sativa)-wheat (Triticum aestivum)* is its major cropping system. Crop productivity in this ecoregion is plateauing or declining (CIMMYT 1990,1991,1992). But increasing human population (nearly 2% per annum) demands increased production of these staple grains. This means that major cropping systems of the region need critical evaluation to devise strategies to increase or to sustain their productivity.

The importance of legumes as builders and restorers of soil fertility has long been recognized. Productivity of soils of the region was perhaps maintained over the years as legumes were regularly grown in the past. Apart from their recognized positive effects on soil fertility, grain legumes are important ingredients of diets of the people in the region and legume fodders are important for livestock. However, the need to grow more food for the increasing population, significant increase in irrigation facilities, ready and cheap availability of nitrogenous fertilizers, and market forces have significantly reduced the area under legumes in the IGP (Joshi 1998; Kumar Rao and Rupela 1998). This paper addresses our current understanding on nitrogen (N) fixation by winter legumes and their residual effect with particular reference to rice- and wheat-based cropping systems of the IGP. Research information specific for the IGP region, however, is very scanty. All available information from unpublished reports and from reports with limited circulation have been used. Data from non-IGP areas have only been used to provide an overall perspective on the topic.

Much of the work on N_2 fixation by legumes in the IGP involved development and evaluation of rhizobial inoculants. The inoculation technology has been adopted in farmers' fields and therefore data on N_2 fixation from on-farm experiments only have been used in this paper. Some legumes, particularly chickpea *(Cicer arietinum),* are best suited to dry areas. With the increase in irrigation facilities and use of chemical fertilizers the microclimate, particularly that of soils, in the IGP seems very different than a legume would face in climatically drier areas. Possibilities to harness biological nitrogen fixation (BNF) by legumes in these changed environments is discussed.

BIOLOGICAL NITROGEN FIXATION BY WINTER GRAIN LEGUMES

With the increase in irrigation facilities and ready availability of fertilizers in the IGP, area under legumes has greatly reduced in the past 2-3 decades. Farmers are aware of the importance of legumes in cropping systems (Joshi 1998). But they seem to have other alternatives to the good value of legumes (source of fixed N_2 and as a break crop) particularly in the intensively cultivated areas of the IGP. Chemical fertilizers can provide N and other high value crops, such as sunflower *(Helianthus annuus),* can break the continuous rice-wheat cycle. In addition, with continuous rice-wheat the soil environment seems to have become less conducive for N_2 fixation by legumes, particularly for chickpea. High soil mineral N is known to suppress BNF by legumes (Streeter 1988; Rupela and Johansen 1995). Soils in at least some parts of the IGP already have suppressive levels of soil mineral N (Kumar Rao and Rupela 1998).

A survey of the literature revealed that much of the work on BNF by winter grain legumes in the four IGP countries (Bangladesh, India, Nepal, and Pakistan) was on evaluation and development of rhizobial inoculants. A large number of experiments on response to rhizobial application have been published from the region based on the work done at research stations (Khurana and Dudeja 1981; Podder and Habibullah 1982; Rewari 1985; Bhattarai and Shrestha 1989; Namdeo et.al. 1989). Lately, the rhizobial application technology has been transferred to farmers' fields as part of the coordinated research programs [such as that coordinated by the International Atomic Energy Agency (IAEA), Austria] within and between countries. Almost all the experiments conducted at a large number of sites suggested a positive yield response due to rhizobial application. Data compiled from three papers presented at a workshop on BNF at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, India, 20-24 August 1996, suggested 19-63% improvement in chickpea yield and 11-32% improvement in lentil (*Lens culinaris)* yield in farmers' fields (Table 1).

Table 1: Response to rhizobial inoculation of chickpea and lentil cultivars in farmers' fields during 1993/94 to 1995/96.

Legume/ Country	No. of locations	Yield (t ha^{-1}) of noninoculated plots Range	Mean	Mean increase due to rhizobial inoculation over control (%)	Reference
Chickpea					
Bangladesh	211	0.62-1.45	1.01	35.9	Sattar et al. (1997)
India	50	0.64-1.75	1.08	18.5	Khurana et al. (1997)
Pakistan	20	0.20-0.50	0.25	63.2	M. Aslam, NARC, Pakistan (personal communication)
Lentil					
Bangladesh	203	0.54-1.20	0.84	28.8	Sattar et al. (1997)
India	14	0.41-1.06	0.79	11.4	Khurana et al. (1997)
Nepal	13	0.70-1.70	0.95	32.3	Bhattarai et al. (1997)

[1]A11 the experiments on farmers' fields (except those conducted by the Bangladesh Agricultural Research Institute) were non-replicated. Plot size was generally 24 m^2 in Bangladesh, and 0.42 ha in India. In Nepal a plot size of 100 nr was intended but actual plot size varied depending upon the availability of land with a farmer.

Both chickpea and lentil are traditional legumes in the region and such large responses to rhizobial inoculation were unexpected. Rhizobial inoculation also resulted in increased N_2 fixation from air (measured by ^{15}N methods) in the experiments in Bangladesh and Pakistan conducted under the auspices of the IAEA (Table 2). Although the per cent N derived from

Table 2: Grain yield and nitrogen (N) fixed and removed from soil (^{15}N enrichment method) as affected by rhizobial inoculation of chickpea in Bangladesh and lentil in Pakistan.

	Noninoculated control		Rhizobial inoculation	
Character	Range	Mean	Range	Mean
Chickpea (Bangladesh)				
Grain yield (t ha^{-1})	0.59-0.67	0.64	0.78-0.95	0.86
Total N yield (kg ha^{-1})	58-75	68	102-126	111
%Ndfa[1]	54-74	63	70-81	76
Amount of N (kg ha^{-1})				
from fixation	34-49	42	80-87	83
from fertilizer	2.5-4.3	3.5	3.0-5.6	4
from soil	15-26	21	17-33	23
Lentil (Pakistan)				
Grain yield (t ha^{-1})	NA[2]	0.31	0.42-0.48	0.44
Total N yield (kg ha^{-1})	NA	38	52-67	60
%Ndfa	NA	19	26-33	30
Amount of N (kg ha^{-1})				
from fixation	NA	7	15-24	21

[1] Percent nitrogen derived from air.

[2] NA = Data not available

Source: Sattar et al. (1998); Hafeez et al. (1998).

air (%Ndfa) in the inoculated chickpea in Bangladesh (70-81%) was slightly more than that of the uninoculated chickpea (54-74%), the inoculated chickpea acquired substantially more N (83 kg N ha^{-1}) than that by the control (42 kg N ha^{-1}). Similarly, inoculated lentil in Pakistan acquired 14 kg N ha^{-1} more than N acquired by uninoculated lentil (7 kg N ha^{-1}).

Experimental estimates (most of them from non-IGP locations, countries) of N_2 fixation by the winter legumes [chickpea, lentil, pea *(Pisum sativum)* and faba bean *(Vicia faba)]* are given in Table 3. In most experiments at least 50% of the N in the legumes was derived from air. The potential N_2 fixation was maximum in faba bean (330 kg N ha^{-1}) followed by pea (244 kg N ha^{-1}), lentil (192 kg N ha^{-1}), and chickpea (141 kg N ha^{-1}). Quantities of N_2 fixed varied greatly in each of the four legumes (Table 3). Reasons of such a variation have been discussed by Kumar Rao and Rupela (1998). Estimates of N_2 fixation in chickpea (measured by the difference method using nonnodulating chickpea line as a reference) ranged from 0 to 54 kg N ha^{-1} in India (Table 4). For 20 chickpea cultivars assessed in Pakistan using the ^{15}N dilution method, with wheat as a reference, N_2 fixation ranged from 4 kg N ha^{-1} to 61 kg N ha^{-1}. It has been observed in several studies that total

Table 3: Range of experimental estimates of the proportion (%Ndfa) and amount of nitrogen (N) fixed by some winter legumes[1].

Legume	%Ndfa	Amount N_2 fixed (kg N ha^{-1})
Chickpea *(Cicer arietinum)*	8-82	3-141
Lentil (*Lens culinaris)*	39-87	10-192
Pea *(Pisum sativum)*	23-73	17-244
Faba bean *(Viciafaba)*	64-92	53-330

[1]Data mainly from non-Indo-Gangetic Plain countries.
Source: Peoples et al. (1995).

Table 4: Experimental estimates of nitrogen (N) fixed by chickpea in Bangladesh, India, and Pakistan.

	N_2 fixed (kg ha^{-1})[1]		
Location	Range	Mean	Comments
India[2]			
Akola (1994/95)	11-54	29	Experiment involved six cultivars of different nodulation capacities, at least 3 replications, plot size 12 m^2 and non-nodulating chickpea was used as reference (Dudeja et al. 1997).
Akola (1995/96)	21-40	32	The six cultivars as above were grown at two different soil-N levels, at least 3 replications, plot size 12 m^2, and, non-nodulating chickpea was used as reference (Dudeja et al. 1997).
Badnapur (1995/96)	0-18	7	The six cultivars as above were grown at two different soil-N levels, at least 3 replications, plot size 12 m^2, and, non-nodulating chickpea was used as reference (Dudeja et al. 1997).
Sehore (1994/95)	9-33	24	The six cultivars as above were grown at two different soil-N levels, at least 3 replications, plot size 12 m^2, and, non-nodulating chickpea was used as reference (Dudeja et al. 1997).
Bangladesh[3]	61-126 (81 -88)	86 (86)	Eleven cultivars evaluated at Bangladesh Institute of Nuclear Agriculture, Mymensingh, post-rainy season 1993/94 (Sattar et al. 1998).
Pakistan[4]	4-61 (23-68)	22 (44)	Twenty cultivars evaluated (2.7 m^2 plots, 3 replications) at the Nuclear Institute of Agriculture and Biology, Faisalabad, post-rainy season 1993/94 (Hafeez et al. 1998).

[1]Data in parentheses are percent N derived from fixation (%Ndfa).
[2]Fixed N only in grains was assessed
[3]Amount of N_2 fixed is in mg N $plant^{-1}$. Wheat *(Triticum aestivum)* was used as a reference crop in Bangladesh.
[4]Wheat and barley *(Hordeum vulgare)* were used as reference crops in Pakistan.

biomass and grain yield correlate well with %Ndfa and can be used for screening genotypes (Herridge et al. 1994). Thus by selection for high yield in a soil with low levels of mineral N one would most likely be selecting for high N_2 fixation.

Some studies have reported levels of N_2 fixed by winter legumes in farmers' fields in IGP countries. A large range of %Ndfa (measured by the ^{15}N natural abundance method) has been measured in chickpea (65-87% in Nepal, 21-88% in 1994/95 in Pakistan, 41-95% in 1995/96 in Pakistan), lentil (64-93% in Nepal, 55-91% in Pakistan), and khesari *(Lathyrus sativus)* (85-91% in Nepal), (Table 5) (Aslam et al. 1997; Maskey et al. 1997; Shah et al. 1997). These legumes were rainfed crops from regions that grew wheat. Year to year variation in quantities of N_2 fixed by chickpea in the same region (40-44 fields surveyed in each year) seemed related to rainfall in the preceding rainy season.

Table 5: Estimates of nitrogen (N) fixed (^{15}N natural abundance method[1]) by winter legumes in farmers' fields in Nepal and Pakistan.

Legume	No. of fields	%Ndfa Range	%Ndfa Mean	Amount (kg N ha^{-1})[2] Range	Amount (kg N ha^{-1})[2] Mean	References
Nepal (1995/96)						
Chickpea	9	65-87	79	35-80	56	Maskey et al. (1997)
Lentil	10	64-93	78	19-83	50	Maskey et al. (1997)
Khesari	4	85-91	88	NA	NA	Maskey et al. (1997)
Pakistan						
Lentil (1993/94)	40	55-91	78	16-83	47	Shah et al. (1997)
Chickpea (1994/95)	44	21-88	*75*	<20-78	38	Aslam et al. (1997)
Chickpea (1995/96)	42	41-95	81	21-91	74	Aslam et al. (1997)

[1] Combinations of local weeds in the observation plots of wheat and mustard were used as reference species. $\delta^{15}N$ value of -1.65 for chickpea and -1.50 for lentil was used for the legumes fully dependant on N_2 fixation.

[2] Data on amount of N_2 fixed by chickpea and lentil in Nepal was obtained from S.L. Maskey, NARC, Nepal; NA = data not available.

Rhizobial inoculation of winter legumes can contribute significantly to the N economy (31-53 kg N ha^{-1} in chickpea, and up to 14 kg N ha^{-1} in lentil) of relevant cropping systems (Table 2). By using high-yielding and high N_2-fixing cultivars, and by exploiting an understanding of factors that affect BNF (Kumar Rao and Rupela 1998), the quantity of BNF can be further enhanced.

RESIDUAL EFFECTS OF WINTER LEGUMES

Discussion with farmers in the IGP region revealed that they are well aware of the beneficial effects of legumes (Joshi 1998). Improved yield of crops following legumes has been widely observed by farmers and recorded by researchers. This may be due to N_2 fixation by legumes, breaking cycles of pests and diseases, improvements in soil microbial, chemical, and physical characteristics, and increased activity of soil macrofauna e.g., earthworms (Peoples and Craswell 1992; Kundu and Ladha 1995; Wani et al. 1995). But in most cases rotational benefits of annual crop legumes can be attributed to an improvement in the N economy of soils measured by improved soil reserves of readily mineralizable organic N and microbial biomass carbon and nitrogen (Dalai et al. 1994; Rupela et al. 1995; Wani et al. 1995). An increase in plant available N (nitrate) in soil due to legumes has been measured. Additional soil nitrate after chickpea (14 kg N ha^{-1}) and pea (28-38 kg N ha^{-1}) than after wheat to a depth of 60 or 120 cm has been reported (Jensen and Haahr 1990; Herridge et al. 1995). This extra nitrate, detectable even during growth of the legume, can result from a reduced use of soil nitrate already present in the soil (Evans et al. 1991; Herridge et al. 1995), which is termed as the "nitrate-sparing" effect of legumes. The combination of conserved soil-N, greater mineralization potential of soil-N, and return of the fixed N_2 from fallen leaves and underground plant parts (above-ground plant parts other than grains are also removed by farmers in the region because of their economic value as fodder) has been assessed in some agronomic studies in India. Many of these studies have not been formally published but were available in reports with limited circulation.

The %Ndfa of different winter legumes ranged from 8% to 95% (Tables 3,4, and 5). This means that even under the most conducive N_2 fixation conditions a legume derives part of its N from the soil mineral N pool. Where most or all the above-ground plant parts of a legume are removed from the field, as is mostly the case in the IGP, it is most likely that there will be a net loss of N from soil (negative N balance) unless replenished by fertilizer N. In a field study at Gwalior in northern India a negative net N balance that ranged from - 64 kg ha^{-1} to - 77 kg ha^{-1} was measured in six chickpea cultivars (Wani et al. 1995). These cultivars fixed only 26-10 kg N ha^{-1}. The net N balance measured for pea in farmers' fields in Australia, where crop residues were returned to soil, ranged from -2 to +21 kg ha^{-1} (Peoples et al. 1995).

In spite of a negative N balance, yield of subsequent crops after legumes is invariably greater than that after cereals for the reasons indicated above and discussed by Kumar Rao and Rupela (1998). Terms such as "N residual effect (De et al. 1983)" and "fertilizer N replacement value" or "N equivalent" (Hesterman et al. 1987) are used to describe the role of legumes in crop rotations. These refer to the amount of inorganic N required following a non-legume crop to produce another non-legume crop with an equivalent yield to that obtained following a legume. This comparison provides a quantitative estimate of the benefit of the legume, in terms of fertilizer N, on the following non-legume crop (Table 6). The concept of fertilizer N equivalent does not distinguish between BNF and the "N-sparing" effect which results from substitution by the legume of biologically fixed N_2 for soil N. Fertilizer N equivalent methodology has been widely used but it overestimates the

Table 6: Residual effect of preceding legume on cereal yield in terms of fertilizer nitrogen (N) equivalent.

Preceding legume	Following cereal	Fertilizer N equivalent (kg ha^{-1})
Chickpea	Maize	60-70
Chickpea	Pearl millet	40
Lentil	Maize	18-30
Lentil	Pearl millet	40
Pea	Maize	20-32
Pea	Pearl millet	40
Khesari	Maize	36-48

Source: Derived from Ahlawat et al. (1981), Chandra and Ali (1986), De and Gautam (1987), Nambiar et al. (1988) and Roy Sharma and Singh (1969).

BNF contribution of a legume in a crop rotation. Also, it gives variable estimates depending on the test crop (Peoples et al. 1995). Field studies at the Indian Agricultural Research Institute (IARI), New Delhi, India have clearly revealed that different grain legumes increased grain yield of succeeding maize, on an average, by 19% when compared with fallow and 29% when compared with wheat. Chickpea was more efficient in increasing the grain yield of maize *(Zea mays)* as compared to pea, lentil, or khesari. The N uptake by maize was maximum after chickpea (94 kg ha^{-1}) and minimum after wheat (63 kg ha^{-1}) (Fig. 1).

Field studies by Patel et al. (1981) involving post-rainy season grain legumes in a cropping sequence at IARI, revealed that inclusion of post-rainy season grain legumes (chickpea, lentil, khesari, and pea) improved the soil fertility status by increasing the organic matter, and available N and phosphorus (P). The succeeding crop benefited from the preceding legumes. Total annual production was almost double and the production potential in terms of maize grain equivalent was 3-4 times more from a legume-maize sequence than from a wheat-maize sequence. From an economic point of view, maize grain equivalent and net returns obtained were highest with preceding chickpea followed by lentil, wheat, pea, or khesari, and were least after fallow. Post-rainy season grain legumes benefited following maize to the extent of 50-60 kg N ha^{-1} for a targeted yield of 4 t ha^{-1} of maize grain.

Different legumes have the capacity to leave behind different amounts of N for use by the succeeding crops. It has been estimated that 0.668 million t of N can be incorporated in the soil through the inclusion of legumes in cropping systems (Saraf et al. 1990). Inclusion of legumes in cropping systems has been found to contribute around 50 to 60 kg N ha^{-1}. The amount of N contributed by the legume for the succeeding cereal was 60 kg ha^{-1} in chickpea, and 50 kg ha^{-1} in khesari. Pulse crops can be made more effective by rhizobial inoculation (Tables 1 and 2). Thus in situations where consumption of fertilizers is very low, the residual fertility build-up through legumes is possible (Hegde and Dwivedi 1993). In another study, post-rainy

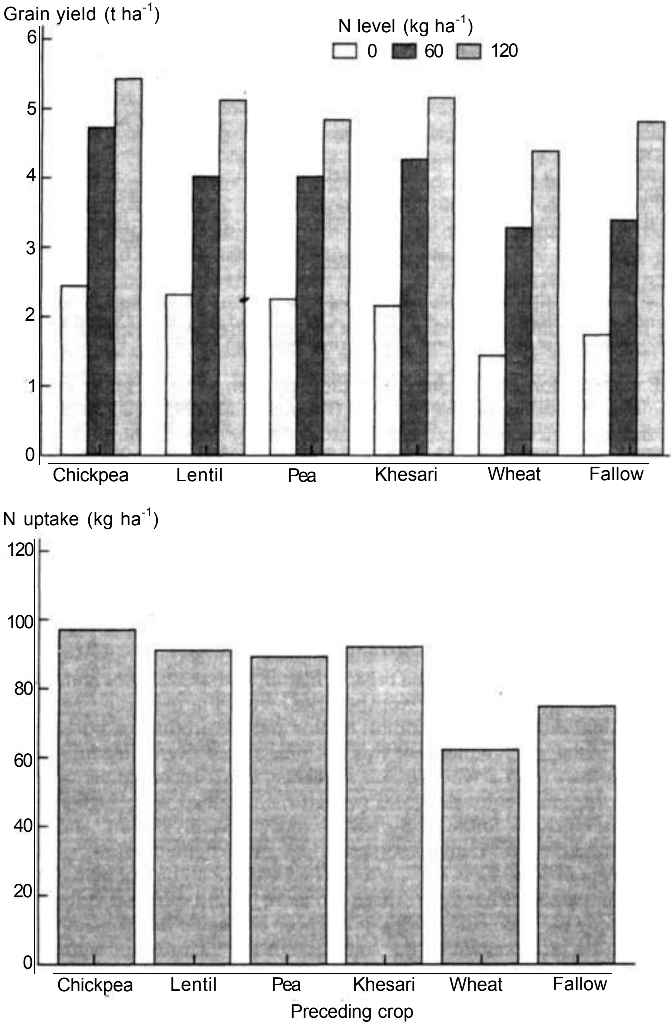

Figure 1: Grain yield and nitrogen (N) uptake of maize as affected by preceding crop and fertilizer N levels at the Indian Agricultural Research Institute, New Delhi, India *(Source:* Saraf and De, unpublished).

season legumes substituted 25% of the fertilizer N needs of rice and pearl millet *(Pennisetum glaucum)* (Hegde 1992). Studies carried out at several locations for many years in the All India Coordinated Agronomy Research Project (AICARP) have indicated that introduction of legumes to replace one of the crops in a rice-wheat cropping system had substantial residual effects on the succeeding crop of rice or wheat, and increased net returns (Table 7).

Table 7: Productivity and profit from rice-wheat and rice-legume or legume-wheat cropping systems at different locations in India

Location/ Cropping system	Average productivity ($kg\ ha^{-1}$)[1] *Kharif*	*Rabi*	Net returns ($Rs\ ha^{-1}$)[2]
Pantnagar			
Rice-wheat	3945	4207	11218
Rice-lentil	4299	1506	14445
Varanasi			
Rice-wheat	3648	3419	8727
Rice-chickpea	3838	1407	11770
Kanpur			
Rice-wheat	3614	3560	9095
Rice-chickpea	3797	1803	13815
Black gram-Wheat	1330	3855	11861
Ludhiana			
Rice-wheat	6111	4372	17271
Rice-pea	6481	2064	22955

[1] *Kharif* = rainy season; *Rabi* = post-rainy season.

[2] 1 US$ = Rs. 39.70 in April 1998.

Source: Hedge (1992).

In Bangladesh, Patwary et al. (1989) observed that the total grain and straw yield of rice increased by about 12% following chickpea and 8.5% following lentil in relation to rice following wheat (Table 8). The total N uptake in rice grain following grain legumes (36.8 $kg\ ha^{-1}$ following chickpea and 36.4 $kg\ ha^{-1}$ following lentil) was substantially higher than the N uptake following a wheat crop (28.8 $kg\ ha^{-1}$). The total N yield of rice following legumes was also higher than that following cereal (Table 8).

Table 8: Yield and total nitrogen (N) uptake in rice as affected by preceding wheat or legumes in Bangladesh.

Preceding crop	Total yield ($t\ ha^{-1}$) Grain	Straw	N uptake ($kg\ ha^{-1}$) Grain	Straw	Total
Chickpea	5.27	3.47	36.8	12.6	49.4
Lentil	5.10	336	36.4	13.4	49.8
Wheat	4.72	3.08	28.8	11.2	40.0

Source: Patwary et al. (1989).

In an experiment conducted at IARI, the beneficial effects of preceding legumes were more pronounced in maize receiving no fertilizer. The legume carry-over effect was attributed to higher N and P status of the soil after legumes that reflected favorably on the productivity of succeeding maize and its attributes. Mean "N-equivalent" value of the four legumes (chickpea, pea, lentil, and khesari) was 131 kg N over wheat and *67* kg N over fallow (Table 9).

Table 9: Nitrogen (N) economy of preceding winter legumes on maize at the Indian Agricultural Research Institute, New Delhi, India.

Description	Khesari	Chickpea	Pea	Lentil	Fallow	Wheat
A: Maize grain yields (kg ha^{-1}) produced from the plot of preceding legumes over wheat and fallow under no N.						
Over wheat	1773	1375	1150	1299	789	-
Over fallow	984	566	366	510	-	789
B: Fertilizer N requirement (kg ha^{-1}) to match legume effect.						
Over wheat	164	126	110	123	70	
Over fallow	116	69	32	52	-	70

Source: Patel et al. (1981).

EFFECT OF LEGUMES ON SOIL PROPERTIES

The nature of crop, cropping system, tillage, and other management practices followed for raising crop(s) exert differential influences on soil properties. Legumes are beneficial in cropping systems/rotations for N economy and as cover crops for checking soil erosion, thus contributing to the cropping system, soil fertility and productivity. The build-up of organic matter leading to improvement of soil structure by legumes, especially with the application of phosphate to the legumes, has been reported by some researchers (Morey 1976; Padma Raju 1967).

Properties such as soil pH, electrical conductivity, and texture are not influenced much by legumes (Padma Raju 1967). Legumes in a cropping system, however, improved the physical properties of soil. Improvement in soil structure due to inclusion of chickpea and other legumes has been measured by Shende and Sen (1958), Biswas et al. (1970), and Morey (1976). Legumes can lower the bulk density of soil (Prabhakara 1970; Morey 1976). Padma Raju (1967) reported better soil aggregation due to inclusion of legumes in cropping systems. Morey (1976) studied soil aggregation in a long-term rotational experiment and reported higher percentage of soil aggregates exceeding 0.25 mm in a cropping system involving legumes.

EFFECT OF WINTER LEGUMES ON SOIL FERTILITY

Organic carbon content increased in legume-based cropping systems as compared to wheat-maize or fallow-maize cropping sequences. Among the legumes, khesari as a preceding crop proved superior to lentil, pea, and chickpea, which in turn significantly increased the organic carbon in soil over fallow and wheat treatments (Table 10). The increase in organic carbon content in soil through legumes has also been reported by Rixon (1966). The build-up of soil organic matter through growing legumes has also been reported by Russell (1977).

Table 10: Fertility status of soil under winter legumes and rainy season maize sequence.

Preceding crop	After harvest of winter crop and before sowing of following maize[1]			After harvest of maize and before sowing of winter legumes		
	OC (%)	N (kg ha^{-1})	P (kg ha^{-1})	OC (%)	N (kg ha^{-1})	P (kg ha^{-1})
Khesari	0.553	166.8	13.8	0.467	142.3	13.4
Lentil	0.454	153.5	13.0	0.421	128.8	12.1
Pea	0.431	143.4	12.5	0.399	119.6	11.6
Chickpea	0.502	161.3	13.6	0.453	140.5	12.0
Fallow	0.389	115.4	11.4	0.365	109.7	10.7
Wheat	0.365	106.4	11.2	0.347	102.0	10.9
LSD at 5%	0.041	11.2	0.8	0.084	8.9	0.8

[1] OC = organic carbon; N = nitrogen; and P = phosphorus.

Source: Ahlawat et al. (1977).

Available N in soil increased when estimated immediately after the harvest of winter legumes and even after the harvest of a succeeding crop of maize in the rainy season (Table 10) (Ahlawat et al. 1977). The plots of preceding legumes possessed higher soil N levels than the fallow and wheat plots. Application of fertilizer N to maize at 60 and 120 kg N ha^{-1} also improved the nitrogen status of soil by 14 and 17 kg N ha^{-1}, respectively, over that with no N fertilization.

Available P in soil for utilization by a succeeding maize crop was higher in plots grown with winter legumes compared with wheat and fallow (Table 10). It was also higher in a legume-maize sequence even after the harvest of the maize crop. The increased availability of P in winter legume plots may be attributed to an effect of organic acids produced by the legume roots. This could also be due to mineralization of organo-phosphatic compounds and solubilization of insoluble soil organic phosphate thereby releasing more P in an available form (Nair et al. 1973).

RESEARCH NEEDS AND STRATEGIES TO HARNESS THE VALUE OF LEGUMES

A total of at least 300 kg nutrients (N, P_2O_5, K_2O) ha^{-1} is recommended for rice-wheat or rice-rice cropping annually. Based on the data of 1995 derived from statistics of the Food and Agriculture Organization of the United

Nations (FAO), Italy, this amount was about twice the average total fertilizer consumption ha^{-1} $annum^{-1}$ in Bangladesh and Pakistan, about threefold of that in India and about eight-fold of that in Nepal. This indicates that rice and wheat receive a major share of the chemical fertilizers in the IGP countries. In some regions of the IGP (such as in Punjab, India) farmers use more than the recommended levels of fertilizers. In a survey conducted in September 1996 it was observed that 56% farmers (of the 231 surveyed farmers cultivating 2383 ha) used more than the recommended level of nitrogen (120 kg ha^{-1} each for rice and wheat) for rice and 5% farmers used more than recommended level for wheat (Sidhu et al. 1998). The reported soil-mineral N levels [mean of 5 to 23 farmers' fields reported in four publications: 61 to 96 mg kg^{-1} soil; see details in Kumar Rao and Rupela (1998)] in Punjab, India are already high enough to significantly suppress BNF (20 to 140 ppm N may suppress N_2 fixation trait(s) approximately by 50% in several legumes; see summary table in Rupela and Johansen (1995) based on published literature). The apparent high use of fertilizer N and consequent high soil mineral N may be one of the reasons for the low level of N_2 fixation (4 to 126 kg ha^{-1}) in farmers' fields in the IGP countries (Tables 4 and 5) compared to the reported high potential levels (141 to 330 kg ha^{-1}) of N_2 fixation (Table 3). Essentially, the soil environment in the rice-rice or rice-wheat cropping system is much different (in terms of N, P, soil moisture, soil compaction, and soil organic matter) than in annual rainfed cropping systems where legumes are largely grown traditionally.

Legumes may be affected by soil-borne diseases in the rice-wheat or rice-rice cropping systems that may be unimportant otherwise. Roots and nodules of chickpea have been found severely affected by black root rot (caused by *Fusarium solani)* in rice-wheat system fields in Bangladesh, Nepal, and Punjab, India (unpublished observations of O P Rupela, ICRISAT, India, during nodulation surveys in these countries). Any program aiming to increase the area under legumes in general and chickpea in particular should consider such adverse factors that may already be affecting yield and stability of these legumes. Studies confirming suitability (or otherwise) of the soil environment for winter legumes, in areas continuously growing rice-wheat or rice-rice will be required. It should be possible to select legume lines able to fix high N at high soil-N levels (Rupela and Johansen 1995). Specific breeding programs targeting particular constraints faced by legumes in rice-wheat cropping systems of the IGP are needed.

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