7. Management Factors Affecting Legumes Production in the Indo-Gangetic Plain

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Abstract

Grain legumes are very important in the Indo-Gangetic Plain (1GP) countries for their contribution to human and animal nutrition, as components of indigenous cropping systems, and as restorers of soil fertility. Yields of grain legumes have remained low due to several production constraints. There is a undening gap between the growing demand and production of grain legumes in the IGP. Rice and wheat production has increased significantly over the previous decades but the area and production of grain legumes has gradually declined. Various abiotic, biotic, and socioeconomic constraints can explain the poor performance of these legumes, relative to that of major cereals and cash crops. Previous research on improving grain legumes production in the IGP has been relatively limited and lacking in focus. Efforts to develop, assemble, and evaluate improved production technologies have only been recent. Previous research concentrated mainly on varietal improvement. Factors such as inherently limited yield potential, susceptibility to various pests and diseases, and sensitivity to edaphic and microclimatic changes contribute to large variations in the output of grain legumes from year to year. The problem is therefore highly complex, making it difficult to halt the declining trend of grain legumes (in terms of area and production) unless improved cultural practices ensuring sustainable high yields are developed together with promising cropping patterns. It is concluded that substantial increases in the production of grain legumes in the IGP can be achieved by fine tuning management aspects and thereby increasing total system productivity and sustainability.

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Introduction

Grain legumes are important food crops in the Indo-Gangetic Plain (IGP), both for human consumption and animal feed, and form a significant component of the IGP cropping systems. Legumes are considered to be important components of cropping systems because of their ability to fix atmospheric nitrogen (N), add substantial amounts of organic matter to the soil, and produce reasonable yields with low inputs under harsh climatic and edaphic conditions.

The major rite (*Oryza sativa* L.) cropping systems and crop rotations including legumes followed in different IGP countries are summarized in Table 7.1. The area under legumes in rice-based cropping systems is substantial, although it varies across **IGP** countries (Table 7.2). Choice of grain legume to be grown is dictated by various factors such as crop season, rainfall pattern, temperature, soil texture, irrigation water supply, available growing period, and pests and

Table 7.1 Major cropping systems including legumes in the Indo-Gangetic Plain.

Country	Cropping systems
Bangladesh	*Aus* rice/jute-fallow-legumes[1]; *aman* rice-legumes; legumes-*amcin* rice-legumes (upland)
India	Rice-wheat (west and central); rice-rice (east); rice-chickpea/khesari (lathyrus)/lentil/pea; pigeonpea-wheat
Nepal	Rice-legumes-fallow; rice-legumes-early rice; rice-wheat - mung bean
Pakistan	Rice-wheat; rice-chickpea/khesari (lathyrus)/lentil/pea/ berseem clover; rice-flax (linseed)-coriander/pea; mung bean/groundnut-wheat

1. Legumn include chickpea, lentil, and khesari (lathyrus).
Source: Fans et al, (1992).

Table 7.2. Area ('000 ha) under rice-based legume cropping in the Indo-Gangetic Plain.

Description	Bangladesh	India[1]	Nepal	Pakistan
Total area under legumes[2]	785	18790	253	1576
Area under legumes in RBCS	750	1990	197	262

1. Legumes include chickpea, pigconpea, and groundnut.
2. Area under legumes in rice-based cropping systems (RBCS1 and non-RBCS.
Source: Faris et al. (1992),

diseases. In areas with good rainfall, including gradual onset and termination, there is potential to grow mung bean (*Vigna radiata* (L.) Wilczek), black grain *(Vigna mungo* (L.) Hepper), and cowpea *(Vigna unguiculata* (L.) Walp.) before rice; and chickpea (*Cicer arietinum* L.), lentil *(Lens culinaris* Medic), khesari (*Lathyrus sativus* L.; grass pea; lathyrus), pea (*Pisum sativum* L.), soybean *(Glycine max* (L.) Merr.), and cowpea after rice. In areas with gradual termination of rainfall (4-5 wet months and 2-4 dry months), the grain legumes grown after rice are chickpea, lentil, and khesari (lathyrus) in Bangladesh, India, and Nepal, and a third crop of mung bean, horse gram (*Macrotyloma uniflorum* (Lam.) Verdc.), or cowpea in rice-rice sequence in Bangladesh and India. On soil with a high clay or loam content, chickpea, lentil, khesari (lathyrus), pea, and soybean are more dominating, while light-textured soils are predominantly planted to groundnut *(Arachis hypogaea* L.) and horse gram. Temperature also plays an important role in determining the crops to be grown after rice. In areas where the temperature is significantly lower during winter, the most common crops are chickpea, lentil, khesari (lathyrus), and pea. In areas where the temperature is slightly warmer during winter, the most common crops are groundnut, mung bean, black gram, rice bean (*Vigna umbellata* (Thunb.) Ohwi & Ohashi), soybean, and cowpea.

Compared with cereals the genetic yield potential of legumes is generally low (Asthana and Ali 1997). However, as can be seen from the country chapters, grain legume yields realized in farmers' fields are usually less than 1 t ha^{-1}. This is well below the moderate yield potentials of these crops (2-4 t ha^{-1}), indicating a large yield gap. This suggests scope for improved management to narrow this gap.

When grown before or after rice, grain legumes encounter some formidable difficulties compared to other cropping systems because the optimum soil physical conditions for rice and legumes differ substantially. Cropping sequences that include rice and legumes therefore, require special management. The important management constraints and possible remedies for sustained and increased production and productivity of grain legumes in the IGP are discussed below.

Tillage and Mechanization

Legumes are cultivated on a wide range of texturally variable soils, from loamy sand in the west of the IGP to heavy clay in the east. After rice harvest, the use of low energy tillage methods confine cultivation to a shallow depth, giving rise to a compacted layer (the plow pan) which may impede the root growth of crops, particularly in clay soils. The soil usually remains saturated after rice harvest and tillage often takes place with the soil moisture content above the plastic limit, which tends to produce an excessively cloddy surface. Furthermore, the intensive rice cropping decreases soil organic matter resulting in reduced organic bonding of soil particles. Consequently the large pores formed during tillage will tend to collapse during subsequent rainfall and the soil reverts to less favorable structural conditions. While cultivation of wet puddled clay soils produce an excessively cloddy surface soil, tillage of dry soil creates a higher proportion of smaller aggregates. Both conditions are not suitable for good legume crop-stand establishment. Poor germination of grain legumes in a cloddy seedbed is due to less seed-soil contact and reduced water transmission to seeds while the fine aggregates after wetting and drying tend to form a compact seedbed with high soil strength, which impedes emergence.

In upland cropping systems, amelioration of compact layers will be beneficial to both legume crops and rice. But in the lowland system the presence of these compaction layers is a dilemma. It is a necessity for the lowland rice crop, but is a production constraint to the following upland grain legume crop.

Optimum land preparation to facilitate seed germination, seedling emergence, and subsequent growth of legumes needs urgent attention. By adopting simple management techniques substantial increases in the yields of legumes can be achieved. The most common practice for cultivation of mung bean, black gram, cowpea, khesari (lathyrus), and lentil in rice fallows is zero tillage. Although zero tillage significantly reduces the risk of crop failures caused by early season drought, substantially reduces expenses on land preparation, and facilitates timely sowing of several legumes, yield levels are generally low. There is a need to encourage minimum tillage, especially in medium- to heavy-textured soils, in both lowland and upland rice fields of the IGP to provide optimum growth conditions and to realize potential yields of grain legume crops. In the heavy-textured soils good seedbed preparation, especially after rice, is of immense significance. Deep tillage can be used to break the strong compaction layers, preferably along parallel strips at 30-50 cm spacing. Legume crops can be sown on the strip to encourage deeper root development and access to the subsoil water. For example, mung bean can be grown successfully after lowland rice by using a single tine to disrupt the compact zone and by sowing the seeds along the tilled strip without fertilizer or irrigation {Maghari and Woodhead 1984). Draining the field a day before rice harvest followed by one tillage with a rotavator can produce very good soybean yields (Syarifuddin and Zandstra 1987).

Appropriate tillage in light-textured soils is also of prime importance to ensure optimum moisture availability in the seeding zone. Light tillage with a rotavator will resolve the most commonly encountered problem of poor germination, plant stand, growth, and yield of groundnut after rice (Prasadini et al. 1993). Higher uptake of N and phosphorus (P) by lentil was noticed with one plowing compared to zero tillage in sandy loam soils of Uttar Pradesh, India (Tomar and Singh 1991).

Time of sowing

Legumes are generally sown when the opportunity exists in the rice- and wheat *(Iriticum aestivum* L.)-based cropping systems, which is not necessarily their optimal time for sowing. Sowing time is a non-monetary input which can have a profound effect on productivity and success of legumes and of the high-intensity crop production systems. It causes a considerable change in the plant environment with respect to temperature, photoperiod, and availability of soil moisture. Better management of turn-around time between rice harvest and the sowing of the following legume crop can be used to avoid the problem of surface soil drying.

Although date of sowing of legumes depends on factors such as duration of rice/wheat crop, cropping sequence, and the lag time from harvest of the rice/wheat crop until the field is prepared for legume cultivation, there are possibilities for adjustments within the available window to improve the timeliness of sowing. Some modifications in land preparation and sowing practices could be involved to coincide sowing with the appropriate soil moisture condition for good crop establishment. In some cases there is a need to change the variety or sowing date of the preceding crop so that sowing date of the following legumes could be advanced to avoid drought stress during the later growth stages. Generally, short-duration rice or wheat varieties are required if sowing time of legumes is to be optimized. The sowing date adjustments may also require mechanization to reduce the turn-around time and speed up the sowing operation.

In areas with double cropping systems, duration of the two component crops normally covers most of the growing season, leaving little opportunity for adjusting the sowing dates for growing grain legumes. In such areas, the sowing date and duration of legumes should be determined by the maturity of the main crop. This requires development of site specific genotypes and agronomy. However, the recently evolved short-duration genotypes of mung bean and black gram (Singh and Satyanarayana 1997), cowpea (Steele et al. 1985), and soybean (Hume et al. 1985) with relative insensitivity to daylength and tolerance/resistance to diseases (Reddy and Vishwa Dhar 1997) can fit into the narrow summer window of the rice-wheat rotation and offer scope for inclusion of legumes without sacrificing a rice or a wheat crop in any year.

Adequate Crop Stand

Low crop stand is one of the major constraints for low productivity of legumes especially under rice- and wheat-based cropping systems of the IGP. Grain yields of legumes can be improved substantially with an increase in plant density. Under late-sown conditions, the plant growth is often restricted and therefore, a higher population is desired for compensating the yield loss plant^{-1}. However, dense stands attract foliar diseases if appropriate plant protection measures are not adopted.

Appropriate sowing method is important to establish an optimum plant population of legumes. To improve germination and plant stand several sowing techniques can be practiced. One such technique is to dibble the seed at the base of rice stubble. Seeding in rows along with tillage rather than broadcasting increases yields. Drying topsoil is a major determinant to crop establishment when seeds are sown in residual soil moisture situations. Deep sowing is an obvious way to reduce the effect of dry topsoil.

In rainy season legumes such as pigeonpea (*Cajanus Cajan* (L) Millsp.), groundnut, and soybean, crop stand is often vitiated due to water stagnation or poor drainage. Raised seedbed and ridge-furrow beds have been quite effective in ensuring optimum plant stand and increased crop productivity. Sowing on raised beds than on flat beds or ridges in a ridge-furrow bed system will be beneficial. Seedling emergence can also be increased and hastened by soaking legume seeds in water before seeding (seed priming), use of bold seeds, and seed pelleting.

Crop and Cultivar Selection

A possible agronomic solution to alleviate the problem of crop establishment in rice- and wheat-based cropping systems of the IGP is to select legume crops that are capable of penetrating hard soil horizons. Seeds of some legume crops have better ability to overcome mechanical resistance over others. Groundnut has higher root elongation rates than pigeonpea and pea when soil mechanical resistance was increased from 0 to 3 MPa (So and Woodhead 1987). Seedling emergence and subsequent vigor is also dependent on seed quality and genotype. Growth chamber studies clearly showed that large seeds had more vigorous growth than smaller seeds (Patanothai and Ong 1987). Therefore, selection of crop, appropriate variety, and use of good quality seed are prime prerequisites.

Soil Amelioration

Effective management of surface soil organic matter can improve the structural stability of the soils in rice- and wheat-based cropping systems of the IGP. This can be achieved through mulching, green manuring, stubble incorporation, and relay cropping of short-duration legumes. Opportunity exists for fitting mung bean or black gram into the narrow window of the rice-wheat rotation. Recent large-scale expansion of black gram following rainy season rice in coastal Andhra Pradesh, India (Satyanarayana et al. 1997) opens new opportunities for similar expansion of black gram in coastal Orissa and West Bengal in India and in southern Bangladesh.

The establishment and early root development of legume crops in puddled soils can be improved by using gypsum or slaked lime as sources of calcium. As puddling results in soil dispersion, the application of gypsum is expected to improve the physical conditions of the soil following rice.

Waterlogging can be a serious constraint to the success of legume crops. Where the probability of excessive water during the early part of crop growth is high, several methods can be considered. Firstly, use of calcium ameliorants to improve structure and drainage may be useful, particularly in soils dominated by exchangeable sodium and/or magnesium. Secondly, the use of legumes (e.g., soybean, mung bean, and black gram) that can better adapt to waterlogging conditions and are better suited to high moisture conditions early in the season, compared to other legumes such as chickpea, pea, and lentil.

Nutrient Management

Adequate and balanced supply of plant nutrients is essential for achieving and sustaining higher productivity of legumes. Nutrient management in legumes under rice-wheat cropping systems is rather complex and has received low priority in the past. Most of the studies on fertilizer use in legumes are individual crop based and thus the results have only limited application.

Although legumes derive a large proportion of their N requirement through biological nitrogen fixation (BNF), a starter dose of 10-15 kg N ha"^{1} is often recommended, although microbiologists argue that this reduces nodulation and N, fixation. However, in fields where the rhizobial population is low, late-sown legumes respond to applications of up to 40 kg N ha"^{1}. The application of N may not only be directly beneficial to the legume but may also benefit the succeeding cereal crops, perhaps due to improvement in soil physical conditions because of the legume.

Phosphorus (P) is the most critical plant nutrient for legumes. The soils of the IGP are generally low to medium in available P content and therefore application of 17-26 kg P ha^{-1} will prodvice favorable effects on grain legumes. The All India Coordinated Agronomy Research Project conducted 709 trials with chickpea, 583 with pea, 173 with mung bean, and 179 with black gram in farmers' fields to determine the response of legumes to applied P; the mean response (kg grain) to each kg of P at 29 kg P ha^{-1} was 31 in chickpea, 6 in pea, 1.6 in mung bean, and 3 in black gram (Prasad 1979).

In recent years sulfur (S) deficiency has been observed in the rice-wheat belt of northern India due to increased cropping intensity and use of S-free fertilizers (urea and diammonium phosphate). The S deficiency is more pronounced in legumes than cereals due to comparatively higher S requirement in the former for producing grain. In multilocational studies under the All India Coordinated Pulses Improvement Project during 1991-94, pigeonpea responded up to 40 kg S ha^{-1} whereas chickpea, lentil, black gram, and mung bean showed significant response up to 20 kg S ha^{-1} (*Table* 7.3) (Ali and Singh 1995).

Table 7.3 Productivity (t ha^{-1}) of grain legumes as influenced by sulfur application in the Indo-Gangetic Plain of India during 1991-94.

Legume	No. of locations	Sulfur rate (kg ha^{-1}) 0	20	40
Chickpea	5	1.42	1.86	1.90
Lentil	3	1.02	1.47	1.46
Pigeon pea	6	1.19	1.35	1.52
Black gram	3	0.83	1.00	0.95
Mung bean	3	0.99	1.18	1.16

Source: Ali and Singh (1995).

Responses of legumes to micronutrients such as zinc (Zn), molybdenum (Mo), iron (Fe), manganese (Mn), and boron (B) have also been observed. In chickpea, application of 25 kg zinc sulfate ($ZnSO_4$) ha^{-1} improved nodulation, root growth, and yield (Singh and Gupta 1986) and increased uptake of Zn, Fe, and P (Dravid and Goswami 1987). Lentils are highly susceptible to Zn deficiency and an improvement in yield with soil application of 12.5-15 kg $ZnSO_4$ ha^{-1} has been observed. Foliar sprays of $ZnSO_4$ with lime have also been effective in correcting Zn deficiency in chickpea and lentil.

Molybdenum (Mo), being a constituent of nitrate reductase and nitrogenase enzymes, considerably influences BNF in legumes. In calcareous soils of northern Bihar, India and in Terai areas of Nepal, B deficiency is widespread and application of 0.5-1.0 kg B ha^{-1} proved effective in improving chickpea yields. Poor podding that is sometimes observed in autumn-sown (rabi; postrainy season) and long-duration pigeonpea in the eastern IGP is also suspected to be due to B deficiency. Multilocational trials on micronutrients showed that foliar application of 0.5 kg ferrous sulfate ha^{-1} improved productivity of chickpea by 450 kg ha^{-1} over the control (Takkar and Nayyar 1986). Since genotypic variation in susceptibility to micronutrient deficiency has been observed in chickpea, lentil, and pigeonpea, efforts should be made to choose tolerant and efficient cultivars, which do comparitively better when grown on micronutrient-deficient soils.

As legumes can fix atmospheric N in their nodules through *Rhizobium,* this needs to be fully exploited. The quantum of N fixed by legumes is influenced by several physical, environmental, and biological factors. Lack of native rhizobial population also appears to be one of the major constraints for poor nodulation. Use of efficient rhizobial inoculants can enhance productivity of grain legumes by 10-15%. Legume species not only differ in nodulation capacity but cultivars within a species also differ significantly, suggesting that host factors are also important determinants of nodulation. Thus it is possible to select cultivars that can nodulate better and fix higher N (Kumar Rao et al. 1998).

The increases in fertilizer prices impose serious limitations to the farmer in using optimum inputs for sustaining high productivity of rice-wheat systems. This calls for alternate, cheaper sources of nutrients. The role of organic manures in maintaining soil productivity has been well documented but their use needs to be more widespread. The ready availability of chemical fertilizer has caused a reduction in the use of organic matter. Increased use of organic manures is urgently needed because of greater incidence of multiple nutrient deficiencies, deterioration of soil physical properties, and declining trends in productivity.

A multilocational long-term experiment conducted in India indicated that 25-50% of the N requirements of wet season rice can be substituted through compost/farmyard manure, crop residues, or green manure. The time gap between the harvest of wheat and transplanting of rice permits 6-8 weeks for growing a legume (mung bean, black gram, cowpea, *Sesbania* sp) lor seed, fodder, or green biomass for incorporation in the soil. Studies have further indicated that incorporation of legume biomass can save 30-60 kg N ha ' (Tiwari et al. 1980; Meelu and Rekhi 1981). Mung bean straw buried after picking pods before transplanting rice could save as much as 60 kg N ha ' (Rekhi and Meelu 1983). In all experiments reported in the rice-wheat areas, inclusion of legumes for seed or fodder has helped to increase the total productivity and profitability of the system. Mixed cropping of maize (*Zea mays* L.) Icowpea for fodder purpose during summer after the harvest of wheat also increases the profitability of the sequence.

In view of the potential role of legumes in contributing to cropping system sustainability in the region through their ameliorative effects on soil health (in terms of additions of fixed N and soil organic matter) without having to sacrifice a rice or wheat crop in any year, strong efforts are needed all across the IGP to introduce legumes where soil organic matter is generally declining and more rational N cycling is needed. However, there is a need for better quantification of legume contributions through systematic long-term experiments and systems modeling.

Water Management

Drought of different intensity is experienced in rainfed areas of the IGP at various growth stages of legumes. Response to limited irrigation has been observed in most of the grain legumes. Among various crops, common bean (*Phaseolus vulgaris* L.; French bean) was found to be more responsive to irrigation followed by pea. The success of mung bean as a catch crop (during summer months) in the rice-wheat system is solely dependent upon adequate supply of irrigation. Late-sown chickpea in sequence with rice also needs irrigation compared to the normal sown crop, probably due to restricted root growth with late sowing.

Pod initiation has been found to bo the most critical stage in most of the legumes. However, the initial soil profile moisture and soil types largely determine the requirement of subsequent irrigation. Similarly, excess moisture or waterlogging reduces oxygen concentration in the rhizosphere and thus affects BNF activity and nutrient availability with consequent yield reduction. Therefore, it is imperative to provide good drainage, especially in low-lying areas.

Weed Management

In early stages of growth, legumes are poor competitors to weeds and consequently suffer heavy yield losses. Yield losses due to weeds in the IGP were 44% in pigeonpea, 50% in black gram, and 42% in chickpea. The nature and magnitude of crop-weed competition is influenced by several factors such as crop species, cropping system, sowing time, plant population, moisture availability, and fertility conditions. Weed competition has adverse effect on crop yield and BNF.

Short-statured and early-maturing legumes such as black gram, mung bean, cowpea, and soybean can be intercropped in wide spaced crops such as pigeonpea to reduce the weed menace. Among various legumes, cowpea is more efficient in smothering weeds, followed by mung bean and soybean. Fast-growing legumes both as sole crops and intercrops suppress weeds and improve physical and biological conditions of the soil and provide high economic returns. In addition various chemical, cultural, and mechanical options are also available for effective and economic weed management in legumes. For more information on weed management see Pande et al. (in this volume).

Strategies for Increasing Legume Production in the IGP

Even though legumes enhance fertility restoration, break pest and disease cycles, and improve rhizosphere conditions in rice- and wheat-based cropping systems of the IGP their primary purpose of cultivation is for grain. Good growing conditions are required for both optimal N fixation and grain yield. Most of the agronomic and genotypic improvements for legumes in the past have heen done for optimal conditions. However, introduction of legumes in rice- and wheat-based cropping systems would be an opportunity cropping, largely under conditions of unfavorable soil moisture, texture, nutrients, and weather. Therefore, there is a need to develop genotypes and management practices to overcome production constraints and to reduce the opportunity costs involved in this cropping. Some steps in this direction are suggested below:

- Delineation of agroecological zones with length of growing season combined with soil types to identify crops and cultivars that can be grown in a given region.
- Identify crops with good seedling vigor for good crop establishment and plant stand.
- Development of legume crop genotypes with early-maturity; drought, cold, and salinity tolerance; resistance to insect pests and diseases for a given production system or ecoregion.
- Identify varieties suitable for late sowing and relay sowing and tolerant to excess moisture for areas having waterlogging/flooding problems.
- Incorporation of seed dormancy, as found in lentil and khesari (lathyrus), in other legumes.
- Efficient *Rhizobium* strains and crops genotypes to enhance symbiotic N, fixation.
- Introduction of early maturing, but high yielding, rice and/or wheat varieties to increase turn-around time for land preparation to ensure proper crop establishment.
- Assess fertilizer requirements and application methods for crop sequences and mixed cropping systems rather than for single crops.
- Production and distribution of quality seed of adapted high-yielding varieties.
- Develop and market low-cost farm implements to facilitate timely sowing and harvesting of legumes.

Conclusion

Introduction of grain legumes in rice- and wheat-based cropping systems of the IGP is an opportunity cropping, largely under conditions of unfavorable soil moisture, soil texture, nutrient supply, and weather. Grain legumes in rice- and wheat-based cropping sequences, therefore, require special management. Most of the agronomic and crop improvement research for grain legumes in the past has been done for optimal conditions. There is an urgent need to initiate appropriate location-specific and/or ecoregion-based production technologies to overcome the production constraints and reduce opportunity costs of grain legumes in the IGP. Recent location-specific examples of dramatic improvements in production of grain legumes strongly suggest that this is feasible. Considerable scope exists for substantial production increases of grain legumes in the IGP provided appropriate agronomic management is given to ensure increased system productivity and sustainability.

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