10. Regional Opportunities for Warm Season Grain Legumes in the Indo-Gangetic Plain

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Abstract

The major warm season grain legume crops grown in the region of the Indo-Gangetic Plain (IGP) are pigeonpea, mung bean, black gram, cowpea, groundnut, and soybean. There has been a general decline in their area and production in the region over recent decades, coinciding with intensification of cereal-dominated cropping systems such as the rice-wheat rotation. Various abiotic, biotic, and socioeconomic constraints can explain the poor performance of these legumes, relative to that of cereals and cash crops. Further, there is little government price and policy support for grain legumes, compared with the major cereals. These legumes generally remain as subsistence crops, with a consequent reluctance of farmers to invest in key inputs that could raise and stabilize yields to economically competitive levels. Nevertheless, there is evidence that the regional demand for the products (e.g., grain, vegetable oil, and fuelwood) of these legumes remains or is increasing. Further, in view of increasing questions about the long-term sustainability of cereal-based monocropping, there is a rationale for substantially increasing the proportion of legumes in cropping systems of the IGP. There is thus a case for stimulating their production in the region.

There are several niches in the IGP where legume cultivation can be substantially increased, particularly to take advantage of recent improvements in genotype and agronomic practices. There are also several recent location-specific examples, inside and outside of the region, of dramatic improvements in production of grain legumes (e.g., mung bean in Pakistan); it is worthwhile analyzing the reasons for success with a view to emulating the success in specific niches of the IGP. Invariably, the way forward for each of these crops is to move towards commercialization of their production, initiated by appropriate policy incentives. It is concluded that there can be substantial increases in production of these legumes in the IGP without undue competition with rice or wheat. On the contrary, greater use of legumes in rice- and wheat-based cropping systems should ultimately improve total system productivity and sustainability.

Introduction

Several important tropical grain legumes are generally well adapted to the long-day period, from Apr to Oct, in the Indo-Gangetic Plain (IGP). They are usually short-day plants, with flowering and the reproductive growth phase induced by the short daylengths and declining temperatures of the approaching winter. An exception is groundnut (*Arachis hypogaea* L.) where only partitioning of assimilates to pods is favored, in some genotypes, by short-day conditions (Bell et al. 1992). These tropical legumes have their temperature optima for most growth and development processes within the range of 20–40°C, which is the usual temperature limits of the IGP during the long-day period.

The important tropical legumes for the IGP are pigeonpea (*Cajanus cajan* (L.) Millsp.), mung bean (*Vigna radiata* (L.) Wilczek), black gram (*Vigna mungo* (L.) Walp.), cowpea (*Vigna unguiculata* (L.) Walp.), groundnut, and soybean (*Glycine max* (L.) Merr.). In the eastern part of the IGP (Bihar and West Bengal states of India and in Bangladesh), the winters are sufficiently mild to support growth of these crops in this season, although perhaps not at optimum growth rates. But there are some advantages of growing these tropical legumes in the mild winters, which will be elaborated.

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Increasing cultivation of rice and wheat in rotation has reduced opportunities for cultivation of these legumes in the traditional manner. Thus, these pulses were relegated to the marginal areas for cereal cultivation (Ali et al. 1997). However, new opportunities for their cultivation are arising as a result of development of novel genotypes and agronomic practices for these legumes, and problems arising in some of the intensive, non-legume cropping systems. For example, the advent of extra-short-duration and photoperiod-insensitive mung bean varieties makes feasible their cultivation in the narrow cropping window between harvesting of wheat (*Triticum aestivum* L.) and planting of rice (*Oryza sativa* L.) in the rice-wheat cropping systems (RWCS).

The IGP of India grows by far the largest area of warm season grain legumes, as compared to the other IGP countries, but in the Indian IGP, areas are stagnant in the case of pigeonpea and *Vigna* spp and noticeably declining for groundnut and soybean (Table 10.1). In the

Table 10.1. Harvested area ('000 ha) and yield (t ha^{-1}) of warm season grain legumes averaged for the 3-year periods 1985–87 and 1995–97 for South Asian countries, all of Asia, and all of the world.

	Pigeonpea		*Vigna* spp[1]		Groundnut[2]		Soybean	
Entity	1985–87	1995–97	1985–87	1995–97	1985–87	1995–97	1985–87	1995–97
Harvested area								
Bangladesh	6.2	6.0	127	120	29.1	35.3	–[3]	–
India - total	3,162	3,517	9,181	9,267	6,983	7,549	1,470	5,354
India - IGP[4]	668	657	843	906	185	167	127	33
Nepal	15.9	25.3	24	38	–	–	15.9	21.1
Pakistan	0.8	–	185	250	61.4	105.0	5.2	4.6
Asia	3,254	3,802	13,211	13,889	11,952	13,139	11,943	15,742
World	3,568	4,135	25,764	26,306	18,946	22,563	52,500	63,671
Yield								
Bangladesh	0.74	0.50	0.64	0.69	1.15	1.14	–	–
India - total	0.77	0.66	0.34	0.38	0.81	1.07	0.64	1.04
India - IGP	1.10	0.99	0.50	0.56	0.96	1.03	0.88	1.11
Nepal	0.75	0.76	0.54	0.50	–	–	0.53	0.55
Pakistan	0.63	–	0.49	0.47	1.04	1.09	0.49	1.25
Asia	0.61	0.66	0.53	0.58	1.19	1.57	1.27	1.43
World	0.76	0.66	0.58	0.55	1.13	1.34	1.87	2.10

Source: FAOSTAT.

1. For South Asian countries represents almost entirely mung bean and black gram but for "Asia" and "World" includes all *Phaseolus* spp and *Vigna* spp.
2. Groundnut in shell.
3. No data recorded.
4. Values for the Indo-Gangetic Plain (IGP) of India are derived from Ali et al. (in this volume) but the most recent 3-year time period is 1993–95 instead of 1995–97.

other IGP countries, areas are either stagnant or in some cases increasing, for pigeonpea in Nepal, for *Vigna* spp in Nepal and Pakistan, for groundnut in Bangladesh and Pakistan, and for soybean in Nepal (Table 10.1). Yields of warm season grain legumes have generally been stagnant over the previous decade, apart from the yield increases in the relatively small areas of soybean grown in the IGP of India and Pakistan (Table 10.1).

Prices of the grain of the warm season legumes have risen, in comparison with other food items, but this is unlikely to be a result of declining consumer preference for pulses (Ali and Abedullah 1998). There is a continuing demand in the region for the traditional products of these tropical legumes. The major demand is for dhal (dry, dehulled split seed) made from the grain of the tropical pulses, particularly for pigeonpea in India and Nepal. There is seemingly an insatiable demand for vegetable oil derived from groundnut or soybean. The legumes under discussion are the main sources of essential vitamins and minerals which are otherwise in marginal supply in the region, as well as of protein. Pigeonpea is increasingly valued as a source of fuelwood, due to an increasing scarcity of firewood in the region. Also of importance, but not widely recognized or quantified, is the existing and potential role of these legumes in contributing to cropping system sustainability in the region through their ameliorative effects on soil health (Ali et al. 1997; Kumar Rao et al. 1998).

Therefore, in view of the continuing, and increasing demand for these legumes (as suggested by price rises of the main products), as well as their potential for contributing to sustainability of the system, there seems a strong rationale for increasing their production within the region. The alternative is to import these products from outside of the region. This chapter highlights opportunities across the region for increasing production of these tropical legumes. Conclusions are drawn from the situation presented in the country chapters of this volume and from the Workshop discussions, and supported by published work as appropriate. Each legume is considered separately, although mung bean and black gram are considered together, because of the quite similar sets of constraints, cropping system options, and potential opportunities for each.

Pigeonpea

Need and Scope

The strongest demand for pigeonpea is in the central IGP, in Uttar Pradesh and Bihar states of India and the Terai of Nepal. There is an increasing demand for pigeonpea grain in the rest of India as well. There is limited demand for pigeonpea grain at the eastern (Bangladesh) and western (Pakistan) ends of the IGP, but there is a potential for export to India for the pigeonpea grown in these regions. Currently, Myanmar and Nepal export pigeonpea to India.

Reports on the substantial and valuable residual effects of pigeonpea, in terms of additions of fixed nitrogen (N) and soil organic matter to the cropping system, have recently been compiled by Kumar Rao et al. (1998). Thus pigeonpea is a desirable crop from the point of view of system sustainability, all across the IGP where soil organic matter is generally decreasing and more rational N cycling (such as through organic matter) is needed. Pigeonpea can therefore substitute green manure crops in having substantial residual benefits with a bonus of grain yield (an immediate return for the farmer). However, there is a need for better quantification of this comparison through conduct of long-term experiments and systems modeling.

Adaptation

Due to the limitation caused by risk of frost, long-duration pigeonpea (LDP), which is sown in Jun–Jul and harvested in the following Apr–May, and rabi (postrainy season) pigeonpea, sown in Sep and harvested in Apr, are adapted only in the eastern half of the IGP (east of about 80° E). Thus short-duration pigeonpea (SDP) and extra-short-duration pigeonpea (ESDP) (see Gupta et al. 1989 for pigeonpea growth duration nomenclature), which is normally sown in May–Jun and harvested in Oct–Nov, is required in the western IGP (west of 80° E). Development of frost-tolerant LDP or rabi pigeonpea would be difficult and ranks as a low priority in genetic improvement of pigeonpea.

On the other hand, cultivation of rainy season SDP or ESDP in the eastern IGP is severely constrained by insect pests [*Maruca testulalis* Geyer (legume pod borer), *Helicoverpa armigera* Hübner (pod borer), and *Melanagromyza* spp (podfly)], waterlogging, and rain damage to maturing pods. However, some of these SDP and ESDP genotypes may be suitable for rabi cultivation in eastern IGP (Ahmed et al. 1996).

Major Abiotic and Biotic Constraints

For SDP and ESDP, insect pests [primarily *H. armigera*, *M. testulalis*, and *Mylabris pustulata* Thunberg (blister beetle)] pose the severest constraints to yield realization and yield stability. Components of integrated pest management (IPM) strategies are available (Lal et al. 1996) but large-scale evaluation of improved packages is yet to be done. Other constraints limiting yields and discouraging further adoption of SDP and ESDP are waterlogging, salinity, drought (in rainfed areas of the western IGP of India), sterility mosaic (SM) [caused by virus (?)], and phytophthora blight (*Phytophthora* f. sp *cajani*). Significant alleviation of these constraints relies mainly on improvement of genetic resistance to these factors, a long-term process; progress in this regard is summarized in Laxman Singh et al. (1996).

Although the main advantage of rabi pigeonpea is escape of *Helicoverpa* damage, as pods mature during the coldest time of the year when insect incidence is lowest, this pest remains the greatest threat to this crop. Other major yield reducers of this crop are waterlogging (if sown before the monsoon rains cease), drought (if late sown), podfly, alternaria blight (*Alternaria* spp), and phytophthora blight.

For LDP the major constraints are podfly, SM, and fusarium wilt (*Fusarium udum*); waterlogging, salinity, and phytophthora blight pose lesser problems. There are good sources of host plant resistance to the major biotic constraints (Reddy et al. 1990; Lal et al. 1996) but they are yet to be assembled in agronomically superior cultivars and their value in alleviating these stresses demonstrated on a large scale in farmers' fields. Poor podding observed sometimes in rabi pigeonpea and LDP in the eastern IGP is suspected to be due to boron (B) deficiency; this is currently under test in Nepal (S P Srivastava, Nepal Agricultural Research Council, Rampur, Nepal, personal communication).

Socioeconomic Constraints

The socioeconomic constraints that limit increased production of pigeonpea in the IGP can be summarized as follows:

- Lack of well-developed markets for pigeonpea, especially in non-traditional pigeonpea areas where long-distance movement would be involved.

- Lack of appreciable consumption outside of India.
- Inadequate processing units, for dhal, in production areas.
- Lack of policy support, in the same way that rice and wheat are supported.
- High risk in production, and its predictability, due to vulnerability to weather and biotic stress, and consequent price fluctuations.
- Limited availability of key inputs, such as quality seed and effective insecticides.
- Limited information on the non-grain value of pigeonpea, e.g., sustainability contributions, household fuel, and building materials.
- Limited knowledge of farmers on the latest production technologies for the crop.
- Increasing labor costs for pigeonpea cultivation, necessitating mechanization, particularly in the western IGP of India.
- The long-duration of the crop, even of so-called SDP varieties in northern India, that makes it difficult to fit in with rice and wheat cultivation.

Priority Needs and Opportunities

The priority needs and opportunities for pigeonpea can be summarized as follows:

- On-farm evaluation and demonstration of existing technologies, in an attempt to narrow the gap between yields realized on farmers' fields and those on research stations.
- Special attention to alleviate seed production and distribution problems. The partially outcrossing behavior of pigeonpea results in rapid loss of varietal purity when different genotypes are grown adjacent to each other. Therefore, particular precautions in seed production are necessary to ensure dissemination of improved varieties, such as insistence on proper isolation distances and development of varieties with cleistogamous behavior (Laxman Singh et al. 1996). Development of pigeonpea hybrids (Saxena et al. 1996) should be pursued not only to improve yield potential but more importantly to commercialize pigeonpea seed production. However, in practice this means development of cytoplasmic male sterile systems, now under way (Saxena et al. 1996). Success here would mean that pigeonpea could lead the way among grain legumes in terms of a commercialized seed industry.
- There is a need for a focused and systematic research effort on the key constraints to pigeonpea, with insect pest management having first priority. The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, India used to assume this role but research reorganization and funding constraints have severely limited such efforts.
- There is a need to develop short-duration cultivars with high yield potential (e.g., 3–5 t ha^{-1}) that could strongly compete with modern improved cereal varieties.
- There is a need for improved quantification, including monetary evaluation, of the "other products" of pigeonpea, particularly residual benefits.
- Improvement of the "policy and marketing environment" for pigeonpea, along with that of other grain legumes.

Conclusion

By extending existing pigeonpea production technologies to farmers' fields, area expansion and yield increases (>20 %) would be feasible across the region. We propose that it would be possible to meet the large and increasing demand for pigeonpea grain in the central IGP from within the IGP region itself.

Focused and concerted research efforts on the major constraints to pigeonpea production offer promise of higher and more stable yields (1.5–2.0 t ha^{-1}). It is further suggested that large increases in pigeonpea production can occur without jeopardizing the required increases in rice and wheat production and, over the longer term, enhancing it through sustainability contributions.

Mung Bean and Black Gram

Need and Scope

Mung bean and black gram occupy important niches in the agriculture of the IGP, with potential for expansion in existing and new niches. Yield potential of these crops in India is around 3 t ha^{-1} but yields in experimental fields range from 1.0 t ha^{-1} to 1.5 t ha^{-1} and that in farmers' fields remain at 0.3–0.5 t ha^{-1} (Lawn and Ahn 1985; Jeswani and Baldev 1990). These crops are grown mostly as mixed crops or intercrops with rainy season crops, and also as sole crops in both summer and winter in the eastern IGP and in summer in Pakistan. The country chapters of this volume have suggested the scope for expanding the summer cultivation of mainly mung bean where irrigation is available, between wheat and rice crops, and of both crops as post-rice crops in the mild winters of coastal, eastern IGP. Both mung bean and black gram are important as green manure crops, after harvest of one or more flushes. The beneficial residual effects on subsequent rice or wheat crops in the IGP region have been documented by Ali et al. (1997) and Kumar Rao et al. (1998).

Adaptation

Mung bean and black gram are quantitative short-day tropical legumes (Lawn and Ahn 1985). Especially for long-duration types, crop phenology is sensitive to daylength, temperature, rainfall, and humidity. Long days prolong flowering and maturity, stimulate successive flushes and cause uneven pod maturity. There are large genotype × environment interactions in the subtropics, by comparison with the tropics, driven by such environmental influences. This contributes to the site specificity of particular genotypes. However, there are recently evolved short-duration genotypes which are relatively insensitive to daylength (Lawn and Ahn 1985; Singh and Satyanarayana 1997).

Growth of these crop plants is adversely affected by cold temperature, with frost causing plant death. Plants can survive over a wide temperature range above freezing but growth processes are slowed at cooler temperatures (<20° C) (Lawn and Ahn 1985). This constrains expansion of these crops as post-rice crops in the colder subtropics. Mung bean can produce at temperatures up to 40°C, but temperatures beyond this range, that can be experienced in the summers in the western IGP, can limit crop performance when it is grown between wheat and rice crops.

Both legumes are susceptible to weathering damage to maturing pods due to rainfall, but black gram genotypes seem more tolerant of such damage. Both crops have limited tolerance of prolonged waterlogging, although black gram seedlings appear more tolerant (Satyanarayana et al. 1997; Singh and Satyanarayana 1997). Greater waterlogging tolerance would encourage expansion of these crops as relay crops to follow rice in parts of the eastern IGP where winters are warmer.

Major Abiotic and Biotic Constraints

The major abiotic constraints faced by both legumes are drought in the western IGP, due to limited availability of irrigation water, and waterlogging and weathering damage in the east. As indicated in the country chapters, the major biotic constraints to both crops all across the IGP are yellow mosaic (mung bean yellow mosaic virus), cercospora leaf spot, powdery mildew, pod borers, whitefly (*Bemisia tabaci* Genn.) (in transmitting viruses), and bruchids (*Callosobruchus* spp).

Socioeconomic Constraints

As for pigeonpea, yields and area expansion of mung bean and black gram are widely limited by inadequate availability of improved seed and knowledge of optimum cultivation practices, limited policy and marketing support, and inadequate storage and processing facilities. An exception to this situation, however, is the recent expansion of mung bean in Punjab province of Pakistan (Ali et al. 1997). These crops also face the problem of unavailability of labor for harvesting, thus necessitating development of mechanization.

Priority Needs and Opportunities

Progress has been made in developing short-duration (55–65 days), bold seeded (6–7 g 100^{-1} seeds) mung bean varieties with tolerance/ resistance to powdery mildew and cercospora leaf spot (Reddy and Vishwa Dhar 1997). In India, yellow mosaic resistance in mung bean and black gram is now available for transfer to adapted backgrounds and some resistant, high-yielding lines are also available for more widespread testing (Reddy and Vishwa Dhar 1997). In Pakistan, there has been an accelerated development of yellow mosaic resistant mung bean lines, with 90% adoption achieved by 1997 (Ali et al. 1997). More rapid dissemination of yellow mosaic resistance in other countries is required. Incorporation of weathering tolerance would promote expansion of these crops. There is also scope for strategic research that would lead to an increase in yield potential beyond 3 t ha^{-1} (Satyanarayana et al. 1997; Singh and Satyanarayana 1997).

Systematic exploitation of the wide variation of genetic diversity of the crop in crop improvement efforts is recommended. This could facilitate more adoption of niche- and cropping system-specific varieties for maximizing yield in different agroclimates across the IGP. In this regard, a more focused effort is needed on adaptation of mung bean genotypes, and perhaps also black gram, to the cropping window between wheat and rice in Apr–Jun. Improved tolerance of high temperatures and accompanying high dessication conditions is needed. Labor-saving and mechanization innovations are also required. Emphasis needs to be placed on integrated, rather than component-wise, management of the major pests and diseases, and to improved crop husbandry in general.

Conclusion

It is suggested that there be a concerted effort, applicable across the entire IGP, in fitting mung bean into the summer window of the rice-wheat rotation. Various fragmented studies suggest scope for this system but remaining bottlenecks discourage widespread adoption by farmers (e.g., flaws in plant type, labor/cultivation problems, and timely availability of irrigation water). This system offers the best scope for legume amelioration of the rice-wheat system without having to sacrifice a rice or wheat crop in any year .

There is also scope to learn from the recipes of recent examples of expansion of these crops in the region, so that they can be repeated in other niches. Such examples include recent expansion of mung bean cultivation as a winter crop in southern Bangladesh (M Abu Bakr, Bangladesh Agricultural Research Institute, personal communication, 1999), expansion of mung bean in Punjab province of Pakistan (Ali et al. 1997), and the recent large expansion of black gram following rainy season rice in coastal Andhra Pradesh, India (Satyanarayana et al. 1997). There is scope for evaluating the latter example for its applicability to coastal Orissa and West Bengal in India and to southern Bangladesh.

Cowpea

Need and Scope

In India and Pakistan, cowpea is grown almost exclusively for fodder, as long-duration types during the rainy season. Some dual purpose types are grown in rice fallows during winter in southern Bangladesh. There is only a small localized demand specifically for cowpea grain.

Adaptation

Most of the cowpea area in South Asia is in India, it being a relatively minor crop in Bangladesh, Nepal, and Pakistan. Among grain legumes, and indeed all crops, it is well adapted to marginal soils and drought stress situations. The germplasm available ranges from long-duration, photoperiod-sensitive, indeterminate types to short-duration (60–70 days), photoperiod-insensitive, determinate types (Singh and Sharma 1997).

Major Abiotic and Biotic Constraints

Despite its relative drought tolerance, drought stress often limits the growth of cowpea, as manifested by intermittent stress in the rainy season and terminal stress of the winter-grown crop. There are good prospects of combating drought stress in cowpea by further genetic enhancement of its drought resistance through exploiting escape (i.e., shorter growth duration) and incorporating resistance traits (Subbarao et al. 1995). When grown after rice, cowpea can be constrained by waterlogging, either from residual moisture from rice cultivation or winter rains falling on bunded fields. Excess moisture in the rooting zone and humid canopy conditions promote excessive vegetative growth which in turn encourages crop lodging and disease attack. Further, cowpea is better adapted to acid soils than alkaline ones, thus making it not well suited to the usually alkaline soils of the IGP.

Weeds pose a major constraint to rainy season cowpea. Diseases affecting the crop in the IGP include basal stem rot, choanephora pod rot (*Choanephora* sp), pink rust (*Phakopsora pachyrhizi*), cercospora leaf spot, bacterial blight and canker (*Xanthomonas campestris* pv. *vignicola*), viruses (cowpea aphid mosaic virus), and nematodes (Steele et al. 1985). Major insect pests are aphids (*Aphis* spp), bean fly (*Ophiomyia* sp), blister beetle (*Mylabris* sp), *Maruca testulalis*, and bruchids (Steele et al. 1985).

Socioeconomic Constraints

In South Asia, cowpea faces all of the previously mentioned constraints associated with subsistence pulses. It also faces the handling and marketing constraints faced by fodder crops. A study of adoption constraints for improved technologies for cowpea in southern Bangladesh revealed all of the problems associated with cultivation of a subsistence crop, such as lack of knowledge about or access to production technology, the low input-low output nexus, and lack of organized marketing (Barman et al. 1990). However, in the target area of this study, cowpea was the second most important crop after rice.

Priority Needs and Opportunities

There is scope for a more detailed geographic information system (GIS) analysis to delineate potential areas in the IGP for the different cowpea types (fodder, grain, dual purpose). This would assist in exploiting the genotype × environment interactions applicable in the IGP region and guide how most effectively to incorporate drought and waterlogging resistance traits. There is a need to better prioritize the pest and disease constraints applicable to the IGP and design host plant resistance breeding efforts and integrated management practices accordingly. There is a need to identify genotypes better adapted to alkaline soil conditions. Short-duration, indeterminate, photoperiod-insensitive types may have a role to play in the wheat-rice summer cropping window, but further genetic improvement work and establishment of optimum cultural practices is needed to achieve this. There is a need for further improvement of genotypes and cultural practices for fodder and dual purpose types for specific agro-environments. Seed aspects, from production, through storage, to distribution of improved seed to farmers, also need attention.

Conclusion

The largest scope for increasing cultivation of cowpea in the IGP is in marginal lands, where it has a comparative advantage over most other rainfed crops. However, there is scope for increasing its cultivation in the wheat-rice summer window and after rice in warmer areas of the eastern IGP. The demand and scope for use of fodder and dual purpose types should increase, with the expansion of dairy enterprises and realization of the need to improve animal nutrition. Development of a regional "cowpea project" would seem viable, at least to assemble and help disseminate the existing but fragmented technology.

Groundnut

Need and Scope

Groundnut contributes to 40% of the oilseeds basket in India but such a contribution is negligible in the other IGP countries. However, in India, production of other oilseeds, such as soybean, rape (*Brassica napus* L.), and sunflower (*Helianthus annuus* L.), is growing at a faster rate than groundnut. Actually, there has been an overall decline in groundnut production across the IGP in recent decades, despite a generally conducive physical environment and ever-increasing demand for the crop's products. On the other hand, there is an expanding groundnut production scenario, especially for oil, in non-IGP parts of India but limited expansion in Nepal, Bangladesh, and Pakistan (Reddy et al. 1992).

Since the mid-1970s, production of irrigated postrainy season groundnut has expanded in India, to now cover 17% of the total 8 million ha sown area (Reddy et al. 1992). The overall average pod yield for India is around 1 t ha^{-1} but for postrainy season (or rabi) groundnut it is 1.7 t ha^{-1}. Orissa is the leading state for postrainy season groundnut and in Bangladesh most production occurs in this season also.

There is an ever-increasing demand for confectionery groundnut but suitable varieties and cultural conditions are rare, despite potentially conducive environmental conditions in the IGP region. The residual effects of groundnut on subsequent crops appear minimal, due to removal of all plant parts except deeper roots from the field at harvest. However, the haulms are prized as fodder.

Adaptation

Rainy season (or kharif) groundnut is mostly rainfed and grows during Jun/Jul–Oct. Many of the problems faced by this crop are associated with excessive vegetative growth and poor partitioning to reproductive growth. The crop has been primarily bred to grow as a sole crop and available cultivars are not well adapted to intercropping.

Postrainy season (or rabi) groundnut is sown in Oct–Nov and harvested during Mar–Apr. It is grown with irrigation or on residual soil moisture in former water courses or after rice. However, there is a paucity of groundnut genotypes of appropriate duration and with low temperature tolerance to exploit the vacant rice fallows and exposed water courses that abound in the eastern IGP during winter.

Summer groundnut, grown during Jan/Feb–May/Jun, relies almost exclusively on irrigation. It follows early maturing winter crops, such as potato (*Solanum tuberosum* L.), rape, and mustard (*Brassica* spp). Suitable genotypes with high water-use efficiency, heat tolerance, and of short-duration are needed.

Major Abiotic and Biotic Constraints

In the western IGP, intermittent drought stress is the major problem faced by rainy season groundnut. Biotic stresses faced by this crop include early leaf spot (*Cercospora arachidicola*), late leaf spot (*Phaeoisariopsis personata*), aflatoxin contamination (*Aspergillus* spp), bud necrosis (bud necrosis virus), sclerotium stem rot (*Sclerotium rolfsii*), white grubs (*Lachnosterna* sp), thrips, jassids, and aphids (*Aphis craccivora* Koch.). Descriptions of these biotic constraints, and how they manifest themselves in northern South Asian conditions can be found in Reddy (1988) and Reddy et al. (1992).

The threat of drought stress is high for both rabi and summer groundnut; terminal stress in receding soil moisture situations and intermittent drought stress during summer. Subbarao et al. (1995) have proposed drought management options for groundnut. In winter, low temperatures (<20°C) can limit growth of groundnut and in summer temperatures above 40°C can be deleterious (Sankara Reddi 1988). In the eastern IGP, groundnut faces B and calcium (Ca) deficiencies and acid soil limitations when not grown on alluvial soils of recent origin. In alkaline soils with excess moisture, iron (Fe) deficiency can be a problem (Reddy et al. 1992). Foliar diseases for rabi and summer groundnut are much less serious than for rainy season groundnut, due to more conducive canopy microclimate conditions during the rainy season. However, rabi and summer groundnut crops are affected by the same suite of soilborne diseases, viruses, and insects as mentioned for rainy season groundnut.

Socioeconomic Constraints

A major constraint to increased groundnut production in the IGP is the relatively high labor and input costs, as most cultivators are resource-poor with little access to credit. There are market infrastructure problems and a paucity of local oil extraction facilities to create an assured market. Production and dissemination of quality seed of improved genotypes to farmers is lacking.

Priority Needs and Opportunities

Development efforts are needed to bridge the large yield gap between farmer's fields and on-station potential especially for rainy season groundnut. A necessary first step is a concerted "quality seed" production and distribution effort. Approaches such as the "oilseeds mission" in India (Reddy et al. 1992) are suggested for Bangladesh, Nepal, and Pakistan.

Better understanding is needed of potential niches, along with their advantages and constraints, the applicable genotype × environment interactions and appropriate plant traits to best exploit those niches.

Research efforts need to better focus on the priority constraints, as delineated in the country chapters, and develop niche-adapted varieties accordingly. There is a particular need for development of adapted confectionery types, and organized markets for them. There is scope for exploration of improved production management practices, such as plastic mulching (Gowda et al. 1996).

Major emphasis should be given to exploration of mechanization and labor-saving options. There appears to be good potential for developing "groundnut development projects" in the region.

Conclusion

The environment of the IGP is generally conducive for oilseed and confectionery groundnut, with numerous specific niches. However, further diagnostic studies of some of the potential limitations, such as photoperiod and temperature responses, B and Ca deficiency, and acid soil effects, are required. The situation is ripe for "development" thrusts using existing knowledge, but with focused research inputs on some bottlenecks, to facilitate commercialization of the crop for which there is a large and growing demand. When considering the potential niches, it is apparent that there is scope for substantially increased groundnut production in the region without competition for rice or wheat area.

Soybean

Need and Scope

There has been a massive increase in area and production of soybean in India over the past two decades from 0.6 million ha in 1980/81 to 5.2 million ha in 1996/97 and from 0.4 million t in 1980/81 to 5.2 million t in 1996/97 (FAO 1998). This expansion has largely occurred as a rainy season crop, in Madhya Pradesh, and only to a much lesser extent in Maharashtra, Rajasthan, and Uttar Pradesh. Soybean in India provides a good example of commercialization of a crop, leading to its rapid expansion in production. Technological innovations in soybean cultivation combined with organized marketing and government policy support led to expansion in its area and production. This followed the establishment of 154 oil extraction mills by 1995 (Ali 1996). Some 85% of the crop is used for oil production, which includes the export of high protein meal (Bhatnagar 1994).

By the year 2000, it is predicted that 6.5 million ha of soybean will be planted in India, yielding an average of 1 t ha^{-1} (Bhatnagar 1994). This provides an outstanding example of how production of a legume can expand, provided all of the critical factors are in place. The situation for soybean in India contrasts with that in the other IGP countries; viz., 20,000 ha yielding 0.6 t ha^{-1} in Nepal in 1993/94; 2,000 ha yielding 0.6 t ha^{-1} in Pakistan in 1991/92 (from 5,000 ha in the mid-1980s); and 1,000 ha in Bangladesh in 1993 (Source: FAOSTAT).

Adaptation

Although soybean has done particularly well in Madhya Pradesh, outside of the IGP, the IGP environment is conducive to soybean, with a yield potential of 3.5–4.5 t ha^{-1} (Bhatnagar 1994). It can only be grown as a rainy season crop in the western and central IGP but it can be grown in the autumn and winter in the eastern IGP after jute (*Corchorus capsularis* L.) or rice. Compared with other grain legumes in the region, soybean is less constrained by pests and diseases but more susceptible to drought stress and less adapted to local rhizobia. Soybean can fix up to 100–200 kg N ha^{-1} if properly nodulated

(Gibson et al. 1982), but this would probably be dependent on rhizobial inoculation in the IGP. Among other grain legumes, soybean is particularly tolerant of waterlogging conditions, which contributes to its success in the waterlogging-prone Vertisols of Madhya Pradesh. Soybean is susceptible to pod shattering and has poor seed storage characteristics.

Major Abiotic and Biotic Constraints

The major abiotic constraints to soybean in the IGP are drought, salinity/alkalinity, and specific nutrient deficiencies [sulfur (S), zinc (Zn), and B]. Biotic stresses are mostly local in nature. Stresses include rust (*Phakopsora pachyrhizi*), cercospora blight and leaf spot (purple seed stain) (*Cercospora kikuchii*), frogeye leaf spot (*Cercospora sojina*), anthracnose (*Colletotrichum truncatum*), pod and stem blight (*Phomopsis phaseoli*), bacterial pustule (*Xanthomonas campestris* pv. *glycines*), yellow mosaic, hairy caterpillar, and stem fly (Hume et al. 1985).

Socioeconomic Constraints

The recent history of soybean in Madhya Pradesh provides a good example of expansion through commercialization, whereby the various socioeconomic constraints to adoption were obviously overcome. This example can be emulated at several locations in the IGP provided appropriate policy, development initiatives, and the required inputs are put in place. The alternative is for soybean in the IGP to continue languishing under the "subsistence, local consumption syndrome".

Priority Needs and Opportunities

An examination is needed of how the "Madhya Pradesh model" for soybean expansion can be applied in the IGP, particularly in Bangladesh, Nepal, and Pakistan. Using current knowledge, there is scope for soybean development projects aiming at its commercialization. A first step may be the development of small-scale agroprocessing facilities and measures to improve seed storage. Use of rhizobial inoculants seems mandatory for soybean cultivation (unless large doses of N fertilizer are applied, thereby negating potential sustainability contributions of soybean cultivation), and increased inoculation practice by farmers may have spillover effects for other legumes that could benefit by inoculation of rhizobia. Mechanization possibilities suitable for small holder farmers also need to be explored.

Soybean would be a candidate, along with extra-short-duration pigeonpea, to replace rice in non-flooding areas with irrigation limitations (i.e., not enough irrigation water to support rice throughout the season). It is suggested that there be genotype × environment and "crop potential" analyses done for soybean in the IGP, using crop modeling and GIS. Increased efforts in research on production constraints are needed in Bangladesh, Nepal, and Pakistan, where the crop is currently considered as a "poor cousin" among grain legumes and oilseeds.

Substantial expansion of soybean cultivation in the IGP can make a significant contribution to closing the protein and vegetable oil deficits in the IGP. Compared to most crops, and certainly other legumes, there is a huge research resource base, and ongoing activity (due primarily to the importance of the crop in USA), on which to draw to tackle constraints afflicting soybean in the IGP. Stimulation of soybean production in the IGP through commercialization of the crop could have knock-on effects for other grain legumes with potential in the region, particularly groundnut, pigeonpea, and mung bean.

Overall Conclusions

There is considerable scope for substantially increased production of tropical grain legumes, including those that can be grown during winter in the eastern IGP, without undue competition for rice and wheat area, but with a promise of increased sustainability of rice- and wheat-based systems. This is particularly true for the short-duration legumes such as mung bean. For most of the legumes considered, technology-driven "commercialization" seems the way forward, to create small-scale agroprocessing and thus income and employment opportunities in the IGP. This particularly applies to soybean and groundnut, with their multiple uses.

For each legume, there is good scope for formulation of development projects at the regional or country level. Convincing cases could be made for returns on project investment, especially if the sustainability effects of legume cultivation is also included. There is a possibility of emulating several success stories of legume expansion in the region; these include, soybean in Madhya Pradesh and black gram in rice fallows of Andhra Pradesh, in India, mung bean in Pakistan and Bangladesh, and the promise of the hybrid pigeonpea seed industry.

It is proposed that there be further in-depth crop-wise analysis, using genotype × environment, GIS, and crop modeling techniques now available, to help formulate and update research and development priorities. It would be further desirable to calculate "sustainability value" of each legume × system, so as to calculate the real value of the legume in a long-term systems perspective.

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