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Limits Imposed by Management in Rainfed Farming Systems

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WHEN the Asian Productivity Organization (APO) held a meeting in Chiang Mai, Thailand, in November 1980 to discuss the production of food legumes in Asia, it highlighted that over the previous decade food legume production in the region had remained constant or declined despite growing demand (Suzuki and Konno 1982). The symposium attributed the slow growth in production to slow expansion in the area planted to food legumes, and to low yield per unit area. Poor economic returns and unfavourable government policy towards legumes relative to other crops like rice and wheat discouraged expansion in the area cultivated, while low productivity was blamed on inadequate water (mostly rainfed crops), marginal land, and low production inputs, e.g. fertilisers, disease and insect control. A meeting (organised by ACIAR, ICRISAT, and IRRI) was then held at ICRISAT Centre in December 1985 to review the progress on Asian Regional Research on Grain Legumes (ARRGL) and to develop plans for future cooperation. It was revealed that much of the food legumes are still rainfed and grown on marginal lands. In India, rainfed agriculture represents 75% of the arable land or 108 million hectares, and even if current efforts to bring more area under irrigation were successful, at least 45% of the arable area will remain rainfed by the year 2000 (Guatam 1983). The situation is more or less the same in most Asian countries. Clearly, if a significant increase in food legume production is to be realised, production of the crops in rainfed farming systems will have to be improved.

This paper attempts to give an overview of the limits to food legume productivity and adaptation imposed by management in rainfed farming systems in Asia, factors contributing to such limits, and areas of research needed. Special emphasis is given to the limitations operating at the farm level and in the minds of Asian farmers who make management decisions. As management practices are location-specific and there are several crop species and farming systems involved, discussions are generalised, and specific examples are used only to illustrate the principles which should hold in most Asian countries.

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Constraints to Rainfed Food Legume Production in Asia

The major physical and management constraints to rainfed food legume production in Asia have been identified in the APO meeting in 1980 (Suzuki and Konno 1982) and in the ARRGL meeting in 1985. These are listed in Table 1. Erratic and low rainfall is probably the most important physical constraint to rainfed food legume production, and this has several implications for management. Being grown in low fertility soils and on marginal land means the crops are normally faced with nutritional constraints, and fertiliser application and other soil fertility improvements such as *Rhizobium* inoculation are required. Expansion of food legume production into new areas or new cropping systems will place the crops into new and often unfavourable environments, which require not only new crop varieties adapted to such environments but also different management practices. As in other crops, insect pests, diseases, and weeds are the common yield reducers and effective control measures are needed.

With erratic rainfall, drought and excessive moisture are the major environmental constraints affecting both crop growth and crop management. To overcome these constraints, it is helpful to consider when they occur and what are the consequences. These can be seen by examining the periods in the growing season occupied by legumes in the different types of rainfed cropping systems.

TABLE 1. Major physical and management constraints to food legume production in rainfed areas in Asia.

a) APO Meeting, 1980	
Physical:	Erratic and low rainfall,
	Lack of supplementary irrigation,
	Grown on residual moisture,
	Marginal or poor soils,
	Small holding, less than 1 ha.
Management:	Mainly subsistence level,
	No suitable varieties or uncertain seed supply,
	Lack of disease-resistant varieties or HYV,
	Little use of fertilisers, pesticides.
b) ARRGL Meeting, 1985	
Physical:	Erratic and low rainfall,
	Desire to expand into new areas or during off season.
	Ecophysiological adaptation of existing varieties is poor,
	Low soil fertility, need for rhizobia,
	Marginal land.
Management:	Low inputs of fertilisers, insecticides,
	Low yield potential,
	Little attention to cultural operations, e.g. weed control,
	Lack of quality seeds,
	Need for short-duration varieties,
	Poor stand due to low soil moisture.

In areas with short growing seasons, food legumes are normally sown at the onset of rains, when soils are periodically rewetted and the potential evaporation is low, or in the postrainy season when there is very little rainfall and crops are grown on residual moisture (Squire et al. 1986). In areas where rainfall and water-holding capacity of the soils allow a long cropping season, there is a choice of a sequential system of an early rainy season crop and a mid-late or postrainy season crop, or a single long-duration crop like pigeonpea which is sown at the start of the rainy season and is harvested when residual moisture is used up (Willey et al. 1981). In the traditional systems in north India and parts of central India, such long-season pigeonpeas are usually intercropped with one or more different species (Sheldrake 1984). Regardless of the cropping systems, there appears to be three distinct periods in which food legumes are sown, each with different management constraints. These periods are early rainy season, mid-late rainy season, and postrainy season.

When the crops are sown at the onset of the rains, quite often seeds are placed in relatively dry soils resulting in low seed germination and poor crop establishment. Subsequent crop growth is also in the period of erratic rainfall when either drought or excessive moisture may occur, affecting crop growth and development. Weeding is difficult in wet soils, and delayed weeding can cause substantial yield reduction. The crops mature in the period with frequent rains creating difficulties in harvesting and drying. High humidity is also favourable to fungus development on pods causing yield loss and poor seed quality.

In mid-late rainy season sowing, land preparation and seeding are done during the wet period. Excessive moisture makes land preparation and seeding operations difficult, and heavy rainfalls may result in poor crop establishment. Soils are wet during early growth, affecting crop growth and development and causing a delay in weeding. Crops will run into dry soil conditions during late growth stages, and quite often suffer from drought stress.

Postrainy season sowing may involve wet or dry soil, depending on the land and soil type and the preceding crop. In any case, it creates a constraint for crop establishment. Drought stress during the latter part of crop growth is normally more pronounced than mid-late season sowing, resulting in low crop yield.

The above discussion sets the scene for the constraints to rainfed food legume production imposed by environmental and biotic factors. On top of those, food legumes are normally grown by small farmers with limited resources, unable to afford high cash inputs or high risks. These farmers also have several enterprises and will allocate their resources according to priorities in their small holdings. In most cases, food legumes are considered secondary crops which are of low priority in the farmers' view. These are the conditions which scientists have to face in developing improved management practices.

As food legumes are generally grown in association with other crops in various cropping systems, improving management should be considered in the context of cropping or farming systems. These can be done by improving the management of the cropping system components and the management of the entire system.

Components of a cropping system include sowing date, crop variety, crop establishment, plant density, fertiliser application, *Rhizobium* inoculation, weed control, control of diseases and pests, and harvest and postharvest handlings. Limits to management of several of these components are discussed in detail in other papers in these proceedings (e.g. Beck and Roughley, Buddenhagen et al., Byth et al., Crasswell et al., Lawn and Williams). In this paper, discussions will concentrate on the components which have not been covered in other papers, touching briefly on some of the others regarding management issues.

Limits Imposed by Management of Components of Cropping Systems

Sowing Date

As mentioned earlier, under rainfed conditions, drought and excessive moisture are probably the most important factors affecting crop yield. One way to minimise these problems is to adjust sowing date to a period in which the problem is less likely to occur. Numerous date-of-sowing trials have been conducted for food legumes, and the sowing dates for the best crop yields have been identified for many areas. However, in many instances, it is not practical for the farmers to sow on such dates for several reasons.

In areas with a long growing season, double cropping systems are preferred because they are more profitable and pose less risk of crop failure than single cropping. Durations of the two component crops normally cover the full length of the growing season, leaving little room for adjusting sowing date. In many cases, food legumes are grown as opportunity crops to take advantage of the period left over from other crops, e.g. growing food legumes before and after rice. In such cases, the sowing date of the legumes is determined by the duration of the main crop.

Even in areas where monocropping is practiced, farmers normally prefer early sowing at the onset of the rains, even though the crops may suffer from drought stress. This is because the weed population is lower than at later sowing, making land preparation and weeding much easier and thus requiring less labour. Other activities may also affect the choice of sowing date. For example, in an area in Khon Kaen province of northeast Thailand, the sowing date of groundnut varies from year to year depending on the time of rice transplanting. In this area, the land is undulating and rainfall is quite erratic. Rice is grown in the depressions while field crops are grown in the upland portion of the undulating terrains. Rice is grown primarily for home consumption and is considered the most important enterprise. If rainfall is low during the early rainy season, groundnut is sown first and rice transplanting is done later when the heavy rains come. On the other hand, if heavy rains come early and water is sufficient for rice transplanting, farmers will transplant rice first and sow groundnut later. In this case, the sowing date of groundnut is adjusted to fit the labour supply of the farm family which is allocated to different enterprises according to their priorities.

It appears that a major change in sowing date of food legumes is unlikely to be accepted by farmers. However, there are possibilities of adjustments within those limits imposed by the individual cropping systems that will improve the legume yield. This very much relates to the timeliness of sowing to get to the right moisture condition for good crop establishment, and will involve some modifications in land preparation and sowing practices which will be discussed later. In some cases, there is a need to change the variety of the preceding crop so that sowing date of the following legumes could be moved forward to avoid drought stress during late growth stage. This is the case with rice-based cropping systems in which early rice varieties are required. These sowing date adjustments also involve mechanisation to reduce the turn-around time and speed up the seeding operation. More research is needed in these areas.

Crop Establishment

As discussed earlier, food legumes are sown either in the early rainy season, mid-late rainy season, or postrainy season depending on the cropping systems in which they were grown. In all three sowing periods, the soils are likely to be either too dry or too wet and crop establishment becomes a major constraint. For example, in India where chickpea is normally grown on residual soil moisture in the postrainy season, crop stand is poor in the majority of farmers' fields, probably due to early moisture deficit (Saxena 1984). In the rice-soybean double cropping system in Indonesia, farmers broadcast the soybean just before harvesting the rice crop, resulting in poor stand (Syarifuddin and Zandstra 1978).

There are possibilities to improve crop establishment of rainfed food legumes. Work at IRRI on the effects of several cultural practices on soybean establishment under rainfed conditions has shown that drainage a day before rice harvest followed by one rotovation gives the best soybean yield (Syarifuddin and Zandstra 1978). When seeds are sown on residual soil moisture or when the onset of the rainy season is unreliable, the ability of seeds to germinate and establish when the top soil is drying out becomes a major determinant of crop establishment (Lawn and Williams, these proceedings). Deep sowing is an obvious way to reduce the effect of early moisture deficit, and this practice has been used successfully in establishing groundnut grown after rice on residual soil moisture by farmers in Surin province in northeast Thailand (Patanothai 1985). However, seedling emergence and subsequent vigour is dependent on seed quality and genotype. Therefore, the use of good quality seeds and appropriate variety is a prime prerequisite.

In areas where the onset of rains is reasonably predictable, timeliness of sowing is crucial for early and good stand establishment. Detailed analyses of the trend and dependability of rainfall would provide useful information to formulate management strategies (Vermani 1980). Such studies at ICRISAT Centre have resulted in the use of dry seeding on the deep Vertisols which become sticky when wet and prevent a sowing after the onset of the rains (Kampen 1982). On the deep black soils of central India, the most efficient way to grow a postrainy season crop is by means of the simultaneous sowing of intercrops, because this eliminates the necessity of a second land preparation at the end of the rainy season (Rao and Willey 1982).

Appropriate farm implements could also improve crop establishment. Choudhary and Pandy (these proceedings) reported the successful development of a multicrop seeder (invert-T) which would extend the range of field conditions where seeding and crop establishment could be achieved with minimum risk of failure. However, this equipment is good only in light to medium soils but poor in heavy clay soils (Carangal et al., these proceedings).

The above examples indicate that there are several ways to improve crop establishment of rainfed food legumes. However, they are specific to different conditions. As poor crop establishment is an important and widespread constraint, additional research is needed. The major determinants for management practices appear to be soil type and moisture regime. Thus, there is a need to derive a classification of environments based on these two parameters so that research results could be compared or extended to similar conditions. An example is also given to illustrate that there are farmers' practices which give good results. These should be scientifically studied to understand why they are successful and under what conditions, so that the transfer of these practices could be done appropriately.

Land Preparation

Good land preparation is another prerequisite for good crop yield, because it provides favourable conditions for seed germination and subsequent crop growth and also reduces weed population. However, good land preparation takes time and labour, and in some situations needs appropriate farm equipment. Most farmers only have animal-drawn equipment, although some may have small tractors. Small equipment makes land preparation slow and poses some difficulties to farmers when land preparation needs to be done in a short time or on heavy soils.

In some areas, land preparation is done by custom plough with large tractors. In such cases, land preparation is often inadequate, as only one ploughing is normally done. The contractors do not have the harrower, and additional operations would cost more. Quite often, land preparation cannot be done at the time needed because the tractor may not be available.

With all these limitations, many farmers still conduct reasonably good land preparation. There are also cases where land preparation done by the farmers is exceptionally good. For example, in growing groundnut after rice on residual soil moisture in Surin province in northeast Thailand, farmers plough and harrow the fields several times until the soils reach a fine tilth. Such good land preparation is required to conserve moisture to support crop growth for the entire cropping period.

The major problems in land preparation are land levelling and drainage. With the available equipment, land levelling is difficult and drainage furrows are seldom incorporated. As a consequence, small depressions occur in the fields causing water stagnation following heavy rains and reducing crop growth in those areas. Improvement of land preparation, thus, lies in the improvement of farm equipment and drainage management. The equipment should be low-cost so that small farmers could afford to use it.

Seed Quality

Seed quality is another important factor affecting plant stand. As seeds of most food legumes lose viability rapidly or are easily attacked by insects during storage, farmers rarely store their own seeds. Seeds are normally purchased from local merchants shortly before planting. The local merchants procure their seed supply from other areas or sometimes from the farmers themselves. The quality is poor, not only in terms of viability but also in varietal purity. Often, improved variety seeds are not available. Since food legumes are minor crops and self-pollinated crops, no large seed company is interested in producing seeds of these crops. Although there are government seed multiplication programs, the amount produced falls short of the demand. In addition, the seed distribution system is generally inadequate, and most farmers still have to depend on poor quality seeds from local merchants.

Obtaining adequate plant stand is of great concern to the farmers. When plant stand is too low, the farmers may have to prepare the land again and resow, thus losing time, labour, and cash inputs. Sometimes it may be too late for resowing, and this would mean a season is lost. It is not uncommon to see abandoned fields because of poor crop stand. Farmers anticipate these problems by using a high seeding rate to make sure that they get enough plant stand. However, if germination is good, the result is excessive plant stand and clumps of several plants per hill.

Strengthening government seed multiplication programs and improving the distribution system are obviously needed, but these can only serve a fraction of food legume growers. There are, however, possibilities of improving seed storage at the farm level by which the farmers could save their own [illegible]

[illegible]

Plant Density and Method of Sowing

Plant density and spatial arrangement can have a major effect on the final yield of most legumes, and the general response of yield to increasing population is well documented. Fig. 1 illustrates the types of response reported for many legumes in dryland agriculture.

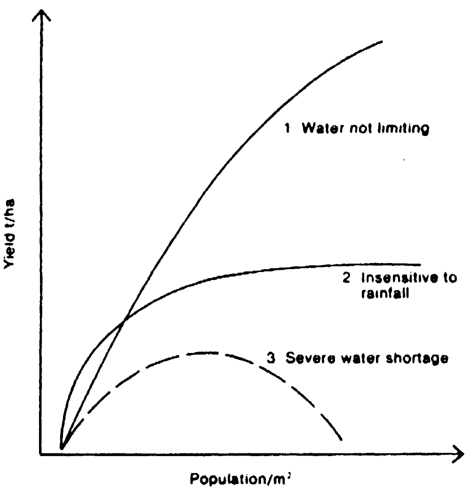

Fig. 1. Three major examples of yield-population responses.

Example 1 illustrates the situation where water deficit is not serious, and the legumes are compact and short, e.g. groundnut and chickpea (Saxena 1980). In such instances, the recommended plant population may be determined by other factors such as cost of seeds or limits of planting practice. The extra early or short season legumes would also fall into this category.

Example 2 represents the legumes like medium- and long-duration pigeonpea where individual plants have the ability to rapidly spread their branches to intercept light between plants and also the ability to remove moisture from deep in the soil profile. For instance, Rao (1986) observed that seed yield of pigeonpea cv. ICP 1 at ICRISAT Centre was virtually constant at 1000 kg/ha over a wide range of plant populations (2-15.6 plants/m²). The [illegible] reported [illegible] sorghum at [illegible]

[illegible] typical [illegible] populations which enable the plant to extract the maximum amount of available moisture and allowing adequate plant growth for the seed to reach physiological maturity. There are very few reports of how these examples of yield-population responses are modified by the erratic rainfall distribution in many of the rainfed farming systems. In the study of Rao (1986), seasonal variation in rainfall from 650 to 910 mm appears to have no major influence on pigeonpea yield; presumably the response also depends on soil water-holding capacity.

Planting arrangement is unlikely to have a major effect on yield in many situations when plant population is optimum for yield (Saxena and Sheldrake 1976). The main exception is in intercropping where the final yield proportion of the component crops may be predetermined to achieve the full yield of one of the crops. Increasing the population of one component crop will tend to make that component relatively more competitive, especially if it is the dominant crop. The maintenance of a high population of a dominant crop may be necessary to achieve a worthwhile yield contribution (Willey and Rao 1981). Such a combination would result in a higher total plant population, and this is most common in an intercrop which involves crops of vastly different maturity, e.g. sorghum and pigeonpea.

Plant population and planting arrangement are affected by method of sowing. In Asian countries, food legumes are either planted in hills or by broadcasting, depending on specific situations. Practically no seeding machines are used because appropriate low-cost seeders are not available. Hill planting is normally done by hand, using family labour including children, but sometimes with hired labourers. Irregular row and plant spacings are normally obtained. Equal row spacing has long been advocated, but it takes more time and labour and farmers apparently do not adopt it.

In many cases, broadcasting is used because it is fast and requires less labour. In some cases planting needs to be done quickly, forcing the farmer to go for a quick method. In other cases labour may be a constraint, or the expected output may be too low and too variable for the more intensive management to be worthwhile in the farmers' view. Weeding is also done by hand. Thus, there is no benefit of row planting over broadcasting in terms of weeding efficiency. With broadcasting, plant population is difficult to control.

It appears that while researchers are more interested in optimum plant population, farmers are more concerned with time and labour. In developing improved management practices, it is necessary to take all of these into account.

Examples given previously indicate that optimum plant population varies in the different moisture regimes and plant types. Fertility levels also affect optimum plant population. Generally, in a given condition, there is a range of optimum plant populations for which crop yield is not much affected. There is a need to establish these ranges for the individual food legumes in different conditions. Although a lot of research has been done on plant population of food legumes, for a given crop, generally only one population (spacing) is still recommended for all conditions. More research is needed. In fact, there is a need to establish the yield-population responses for the different conditions, as it may be necessary to go beyond the optimum range for practical reasons. To do this, some kinds of environmental classification are also needed.

Once the optimum population ranges are established, it is a matter of determining how these could be best achieved within the available resources and time constraints of the farmers in a given area. On-farm trials of potential practices are also required to test their suitability to the farmers' conditions. Clearly, low-cost items such as a seeder or even a row marker would play an important role in improving the management. Additional research in these areas is also needed.

Fertiliser Input and Chemical Control of Pests and Diseases

Application of fertiliser, insecticide, and fungicide involves cash inputs. Among the three, insecticide is probably the one used by most farmers. Some farmers may apply fertiliser to their legume crops, but fungicide is rarely used.

Having limited resources, cash input is of great concern to the farmers, particularly when there is a risk involved. Under rainfed conditions, in which crop responses to fertilisers are quite variable due to environmental factors, farmers are generally reluctant to use fertiliser. Other management limits are the unavailability of the recommended fertiliser formulae in the local market and the lack of knowledge of the differences among different fertilisers. The consequence is a misuse of fertilisers and the potential responses are not realised.

Insecticide is normally used because insect damage is clearly visible, and damage from certain insects, for example pod borers, can cause a substantial yield loss. On the other hand, yield losses from most diseases are not apparent, therefore fungicide is considered unnecessary. Sometimes, farmers do not know the difference between insecticide and fungicide, or cannot differentiate between insect and disease damage. In such cases, insecticide is often sprayed on diseased crops. Also insecticide is sometimes applied too late when insect damage has already occurred. This is because the farmers wish to avoid cash outlays and thus generally prefer cure to prevention. Other activities may also prevent them from applying the insecticide on time.

Future research in these areas is discussed in other papers in this workshop. The point to make here is that the risk involved should be taken into account in developing improved practices. Unless the benefit is clear, it is unlikely that the farmers will adopt the recommended practices.

Weeds

Effective control of weeds can be achieved by mechanical means, crop rotation, and chemical control, but hand weeding is by far the most common in rainfed farming. However, increasing labour cost and greater availability of chemicals will favour the use of herbicides. Crop yield is most sensitive to early competition from weeds, but beyond a certain period crop growth is sufficient to suppress weed competition. In soybean, yield losses from weed competition continue until 60 days after planting (Sajjapongse and Wu 1985). A similar response to weed competition has been reported for pigeonpea by Shetty (1981).

Farmers normally weed once or twice, depending on the weed population and the availability of labour. Mechanical weeding is, at present, beyond the reach of most farmers, since there is no low-cost machine available. Herbicide is also costly, and most farmers cannot afford to use herbicide, although some do. High plant population is another means normally used to reduce weed population.

It is often claimed that traditional intercropping systems give better control of weeds. Where total intercrop population is higher than in sole crop (which is often the case), then greater weed suppression can be achieved (Rao and Shetty 1976). However, where the total population is similar to that of the sole crop, weed suppression is likely to be intermediate between the two sole crops, depending on their respective proportions. Slow-growing crops like pigeonpea are less competitive than other legumes, and suppression of weeds may be even poorer in intercropping situations.

Farmers are well aware how weeds can affect crop yield, but unavailability of labour at weeding time is normally a constraint, and cash is required in using herbicide. It appears that combination of the two would be a good compromise. Future research should emphasise the use of herbicide in combination with manual weeding to reduce the herbicide cost and also reduce labour requirement for manual weeding. Again, low-cost tillage implements would be of great benefit.

Postharvest Management

Postharvest management is another aspect affecting the yield and quality of food legumes. In double cropping systems, the first crop may mature during the rainy period when damage from fungal attack could be serious and drying is difficult. In some cases, the marketing system has an influence on the postharvest management of the farmers. An example is the case of groundnut in Kalasin province in northeast Thailand. Farmers in this area, and probably in other areas, normally sell their groundnuts soon after harvesting because of cash need. Local merchants come to the village to buy groundnuts, but not every day. If the crop is harvested several days before the merchant comes, drying will be done for several days. But, if the crop is harvested a few days before the merchant comes, it is insufficiently dried. Groundnut is sold by volume, thus, moisture content has no effect on the measurement. No grading system is used, and the farmers get the same price whether their groundnuts are sufficiently dried or not. Therefore, there is no incentive for the farmers to carry out proper drying.

The principles of postharvest handling are well established, but practical applications are rather difficult. Unless there are incentives for good quality seeds, it will be difficult to change the farmers' practices. Improvement thus lies in the changes in marketing system and price structure so that there is an incentive for good quality seeds, and quality grading can be employed.

Labour requirements for harvesting, depodding (in groundnut), and threshing are also high. Obviously, low-cost machinery for doing some of these would be of great benefit. Varieties with synchronous maturity and resistance to weathering and fungal damage on seeds would also reduce the labour requirement for harvesting and improve seed quality.

Limits Imposed by Management of Cropping Systems

The cropping systems involving food legumes in rainfed areas in Asia are numerous, depending on the environmental conditions, marketing opportunities, and farmers' preference and perceptions of the immediate return for their efforts. In terms of productivity and stability, each has its own advantage in certain environments. For example, intercropping has high advantage under low soil fertility conditions (Reddy and Willey 1982) and under moisture stress conditions (Natarajan and Willey 1986). In the long-term stability evaluation of several productive cropping systems conducted at ICRISAT Centre, intercropping of pigeonpea with cereals or low canopy legumes was found to be the most profitable and stable cropping system on deep and medium-deep Vertisols. An extra early pigeonpea or soybean in the rainy season was also found to be remunerative for these soils. The legume/pigeonpea intercrop was the most profitable option with or without fertilisers in both deep Vertisols and medium Alfisols, and the groundnut/pigeonpea intercrop was the best. In the wetter regions of Madhya Pradesh, India, rainy season soybean gave an excellent first crop to be followed by a postrainy season wheat. These options have very high yield potential on deep black Vertisols, compared to the traditional system of growing only a single crop in the postrainy season (Reddy and Willey 1982).

The productivity of existing cropping systems could also be further improved. For example, a decade of research at ICRISAT on both basic and agronomic aspects of intercropping has shown that better agronomic management (e.g. high population and fertiliser input) and the use of improved varieties of both component crops can result in substantial yield increases (Willey and Rao 1981; Reddy and Willey 1982). Improvement of the components of cropping systems discussed previously should also lead to an increase in cropping system productivity.

There is also great potential for incorporating food legumes into new cropping systems and for introduction of food legumes into new areas. In several Asian countries, a number of food legumes have been evaluated in rice-based cropping systems to utilise the residual soil moisture, and several of these cropping systems are now under production (Carangal et al., these proceedings). The promise of several new cropping systems involving food legumes is also reported in some of the contributed papers in these proceedings (Chatterjee and Battacharyya; Pillai et al.; Yadavendra et al.; Sangakkara; Laosuwan et al.). Jain and Farris (these proceedings) provided evidence to show the potential of medium-duration pigeonpea in several new areas. The potential of pigeonpea for smallholder livestock production systems may also lead to new cropping systems (Wallis et al. 1986).

Opportunities also exist for mechanised farming of food legumes. The potential of large-scale mechanised production of early pigeonpea in rainfed systems has been demonstrated in Queensland, Australia (Wallis et al. 1981). Extension of mechanised production of pigeonpea or other legumes elsewhere will depend on the cost of production and the market acceptance of the legumes. Certainly, this type of production is not applicable to small farmers. There is, however, a great scope for small-scale low-cost mechanisation as mentioned several times in the foregoing discussions.

Improvement of existing cropping systems and introduction of food legumes into new cropping systems or new areas requires changes in both management practices and crop variety. Apart from those mentioned earlier, the recent development in Queensland in pigeonpea production is an excellent illustration of the important role of phenological research and the need for new management systems to accompany the introduction of new genotypes (Wallis et al. 1981). From the initial work on a photosensitive genotype, it was found that the most important factors affecting production are choice of sowing date (mainly an interaction with photoperiod) and plant density which has to be increased to compensate for reduced vegetative growth, as sowing is delayed. The introduction of photoinsensitive varieties has helped to simplify these management practices, and yields exceeding 5000 kg/ha have been recorded. The same principle is applied in India where pigeonpea could be grown during the cool, postrainy season when photoperiod is short and the reduced growth of the plants enables them to be grown at high density and to be managed like annual crops (Sheldrake 1984). This evidence suggests that major and stable increases in food legume production will depend on the development of management strategies incorporating many of the genetic improvements.

It should be emphasised that, in management of cropping systems, not only the management of the legumes but also the management of other component [illegible] account, [illegible] they interact with each other. Interactions could be positive or negative. The role of legumes in providing nitrogen to the system benefiting other crops is a clear example of a positive interaction. In turn, the legumes could also benefit from the residual effects of fertilisers applied to other crops. To change the management of the legume may require a change in management of other crops, and this could have a negative effect on other crops. Competition for time, labour, and other resources always occurs. It is important that these interactions be understood and, where possible, quantified, so that positive interactions could be capitalised and negative interactions be avoided. This is another area in which a lot more research is needed, and an interdisciplinary team approach is required.

A prerequisite to that is, perhaps, a change in perspective of the researchers. As a farming system consists of several components, each interacting with the other, a change in one component will affect the others. Socioeconomic factors are also involved. It is particularly important that researchers should have a farming systems perspective.

Another area which should be considered in cropping systems management is the long-term productivity of the land. The enlargement of cleared areas, the shortening of fallow period, the cultivation of steep slopes, etc. have led to a large scale degradation of soils and sites in many parts of the tropics. The implementation of more intensive systems to increase the productivity of agricultural lands must therefore include soil conservation and soil improvement. Crop residue management is important in maintaining soil productivity. Both land management and crop management play an important role in determining the extent of soil erosion by water. For instance, in large areas of the deep Vertisols of the rainfed semi-arid tropics of India where the rainy season fallow is practiced, vegetative cover is absent leading to frequent occurrence of substantial amounts of runoff (25% of rainfall) and soil erosion (2.5-5.0 t/ha). Only 25-30% of the rainfall is actually utilised for evapotranspiration of the postrainy season crop (Kampen 1982). Improvement in the productivity of the deep Vertisols through facilitating rainy season cropping using improved land management and soil tillage (dry land preparation, dry seeding, minimum tillage with intercropping) could result in a 3-5-fold increase in land productivity.

The dominant role of woody perennials for soil improvement and conservation is not confined to shifting cultivation but has a great potential throughout the humid and semi-arid tropics. A considerable amount of agroforestry research at IITA based on the alley cropping concept has [illegible] studies in other parts of the tropics where potential benefits include improvement in organic content of the soils, nutrient enrichment, and reduction in soil erosion and runoff (Kang et al. 1985). The key to the success of agroforestry systems depends on the progress in identifying woody perennial species and crop management practices which do not have an adverse effect on the associated crops of resource-poor farmers.

Summary and Conclusions

The foregoing discussion has attempted to provide an overview of the constraints to food legume production in rainfed farming systems in Asia and the difficulties facing the farmers in managing the crops. Under rainfed conditions where moisture cannot be controlled, drought and excessive moisture are the key constraints which have several consequences in terms of management. Being secondary crops grown on marginal land and coupled with limited resources of the farmers, the crops are placed in unfavourable situations in terms of both natural environments and management inputs. This means much more research is required to develop appropriate management practices than for irrigated conditions where the environments are more favourable.

Examples have also been cited which indicate that possibilities exist in improving the management practices which will lead to higher crop yield. There is also a great scope in incorporation of food legumes into new cropping systems and expansion of the crops into new areas, and this is probably where an increase in food legume production has the greatest potential. In most cases, the improvements have come about by the changes in both management practices and crop variety. This suggests that further improvement will lie in the development of appropriate management strategies that incorporate many of the genetic improvements. It also highlights a need to reorient the direction of breeding programs towards the development of varieties suitable for the various cropping systems.

In terms of management, the major constraints appear to be in the area of crop establishment and plant population which involve several management practices previously discussed. This is the area in which it is felt a lot more research is needed. To facilitate the management operations, different types of farm equipment are required. Thus, more efforts should be given to the development of low-cost farm implements which are within the reach of small farmers.

Under the high risk situations of rainfed conditions and limited resources of the farmers, it is unlikely that the farmers will adopt high input technologies. Adopting management strategies which require cash inputs, e.g. fertilisation, will rely on the capitalisation of positive interactions of the legumes with other crops in the cropping systems. This is a complex situation in which a lot more research is needed, and an interdisciplinary team approach is required. It is also important that researchers have a farming systems perspective.

There are, however, possibilities for farmers to use higher inputs in some legumes which are grown as cash crops, e.g. soybean and groundnut. The adoption will depend on the economic return of the inputs, which is a function of yield response, cost of input, and crop price. The possibilities are more under irrigated conditions where less risk is involved.

As management practices are location-specific, and different locations differ not only in the natural environments but also in the socioeconomic conditions, difficulties arise on how research should be conducted to serve these various needs. The complex situations of rainfed farming point out that much more research is required both in basic understanding and in adaptive research. A prerequisite to these is a need to derive some kinds of environmental classifications to guide the direction and determine the priority of research, and to facilitate the transfer of research findings. Environmental classification needs not be one, in fact, there is a need for different types of classification to serve the different purposes, and these are not necessarily mutually exclusive. For example, a classification based on soil type and moisture regime at seeding period may be sufficient for crop establishment, but classifications for other managements may require different sets of parameters. There are also hierarchies of classifications depending on how broad the objectives are.

The need for basic research appears to lie in the more basic understanding of crop responses to environments and genotype x environment interactions complex. Phenological research mentioned previously is a good example of how this basic understanding could help the development of management practices. Crop modelling also appears to be a useful approach in understanding the interactions of various factors and in determining the critical constraints in a given situation.

The second level of research would be to transfer those basic understandings into management practices. At this level, research may concentrate on the individual components of cropping systems, and here comes the need for different classifications of environments to serve the different purposes. For a component, there is also a need to develop management alternatives for an environmental class so that farmers in a given area can have a choice.

The third level would be on-farm testing of those management alternatives to evaluate their appropriateness and scope of applicability, and to identify the suitable alternatives for the individual locations. It will not be possible nor desirable to conduct the tests in all locations, thus, some kinds of location classification or 'zoning' are also required.

These different levels of research fit different research groups. While basic research is more appropriate to international research institutes, universities, or well established national research centres, third level research is more fitted to regional research stations or regional research and development programs in the different countries. The second level could be taken up by both international organisations and national research programs, the extent of which depends on the mandate and scope of work of the individual research institutes.

The basic understanding of the food legume production systems in the different locations in

Asian countries also appears to be inadequate. There are several food legume species, each involved in different types of cropping systems. Certainly, management practices will be different. For a crop in a given area, there are usually only a few key constraints which, if overcome, will result in a substantial improvement. There is thus a need for more understanding of the production systems of the individual legumes in the different countries.

Two types of analysis appear to be useful in this regard — the individual crop analysis and the area analysis. In a country, it should not be very difficult to gather information on where the individual legumes are grown, what cropping systems are involved and their extent, what are the farmers' goals in growing the crops and what are the key environmental characteristics in the different production areas. Much more understanding could be obtained by analyses of available secondary data and interviewing local researchers and extension workers in the areas. Identifying key constraints and farmers' practices in the different areas will take more time and effort, but would be worthwhile. Some could readily be obtained from local personnel in the areas.

The type of area analysis like the agroecosystem analysis (KKU-Ford Cropping Systems Project 1982a, 1982b) or the rapid site description used in many farming systems research sites will not only provide a good background of the physical environments and production problems but also give an insight into the socioeconomic conditions in the area. This type of analysis could be employed at the macro, meso, or micro level, and at different depths, depending on the objective. These two types of analysis would provide useful information for deriving the different types of environmental classifications and for determining research priorities. It will also be useful in determining what management alternatives should be tested in a given area.

Lastly, there are several farmers' management practices which have given good results. These practices have survived through a long period of testing and are appropriate for such circumstances. They can readily be transferred to similar conditions. Scientific examination of these practices to understand why they are successful and in what conditions will not only help the transfer of these technologies but also should provide useful information for future research. A lot could be learned from the farmers.

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