Managing systems for increasing productivity of pulses in dryland agriculture

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Abstract

Successful pulse production in dry areas depends on the ability to obtain economic yields with limited water supply. Management systems should consider: (1) matching crops and cropping sequences with seasonal rainfall; (2) cultural practices designed to maximise water conservation; (3) soil management to prevent compaction and the formation of tillage pans; (4) adequate control of pests; (5) appropriate seedbed preparation and fertilization; and (6) timely planting. These objectives can be accomplished using conservation tillage systems, improved methods of fertilization and exploitation of nitrogen fixation, and appropriate mechanisation.

Introduction

The four food legumes of topical concern are grown over a diverse range of climate, soils, and management systems. They are produced most successfully in cool, but not excessively cold climates; none of them are very tolerant of water stress and temperature extremes. Most of the world supply of each crop is from rainfed production and usually under conditions of limited moisture. In the sub-tropical and warm temperate climates they are grown during the winter reason, either on water conserved from the preceding monsoon rains or on residual moisture after the main crop of cereals (maize, sorghum, or millet). Winter rains are scant and moisture usually limits production irrespective of cropping system.

The food legumes are also grown extensively in the Mediterranean and other regions which have cold and wet winters and warm and dry summers. Here, the crops are also produced on residual moisture but are generally

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sown after soils have warmed in the spring to mature ahead of the drought and extreme summer heat. Yields are often limited by lack of water and also by the short period of 60 to 70 d during which water is available for growth.

In China, the crops are generally autumn-sown in the southern provinces and spring-sown in the nothern provinces. For example, in the south, faba bean is planted after rice or interplanted with cotton or maize in October and harvested about May (Cockbain, 1984). In the north, where faba bean is usually grown in rotation with winter wheat, it is sown in the spring and harvested in July or early August.

The four crops in brief

Faba bean

Faba bean is grown on about 5 million ha (nearly 4 million ha in China alone) with a total production of about 6 million t giving an average yield of 1.2 t ha^{-1} (Table 1). China, Egypt, Italy, Morocco, the USA, and the UK (only 40 thousand ha) each produce appreciably larger yields than the world average. For example, yields in the USA average about 6.6 t ha^{-1} and those in the UK about 3 t ha^{-1} (Duke, 1981). Faba bean benefits from a cool

Table 1. World production and major producing areas of faba bean, chickpea, pea, and lentil.[a]

Crop	Harvested area (Mha)	Production (Mt)	Average yield (t ha^{-1})	Major producing countries	Other significant producing countries
Faba Bean	5	6.0	1.20	China	Egypt Italy Morocco UK
Chickpea	10	6.5	0.65	India	Pakistan Turkey Ethiopia Spain Burma Mexico
Pea	10	10.0	1.00	USSR China	USA Continental Europe; Near East; India UK
Lentil	2	1.1	0.55	India Turkey Syria	Pakistan USA Bangladesh Yugoslavia

[a] From FAO (1984).

season and moderate water supply and is quite susceptible to drought. This crop is not grown in India, but a two-year trial (1983—1985) in northern India (V. P. Singh, pers. comm.) under irrigated conditions indicated a yield potential of nearly 4 t seed ha^{-1}. The crop matured in 160 d, which is a shorter duration than for other winter legumes.

Chickpea

Chickpea is grown on an area of about 10 million ha giving an annual production of 6.5 million t for an average yield of 0.65 t ha^{-1} (Table 1). About 85% of world production is in South Asia where 5.5 million t was produced on 8.6 million ha in 1984 (FAO, 1984). India alone accounts for about 76% of the area and about the same proportion of total production. The average yield in India is about 0.68 t ha^{-1}. Other countries having significant areas of chickpea are Pakistan, Turkey, Ethiopia, Spain, Burma and Mexico.

Chickpea is the most drought tolerant of the four legumes. The growing period varies from 90—110 d in short-duration types to 160—170 d in long-duration types, and is largely determined by seasonal soil moisture availability. For example, in the warm winters of peninsular India, where evapotranspiration is relatively high, only early-duration types can be grown on residual soil moisture (Saxena, 1984). By contrast, late-duration types are grown through the colder winters of northern India, where evapotranspiration is low until March. However, extremes of cold and heat can also determine crop duration in that both low (<5 °C) and high (>30 °C) temperatures can limit pod set and seed development (Saxena and Sheldrake, 1980a; Summerfield *et al.*, 1984).

Pea

Pea (mainly *Pisum sativum*) is grown on an area of about 10 million ha producing about 10 million t of seed for an average yield of about 1.0 t ha^{-1} (Table 1). Countries in the Near East obtain yields of about 1.1 t ha^{-1}. India has about 10 per cent of the world hectarage but its average productivity of 0.75 t ha^{-1} is well below the world average.

Pea is grown most successfully in a cool, sub-humid climate; it grows poorly in hot and dry or hot and wet weather. The crop has a relatively good yield potential and responds well to phosphate fertilizers in deficient soils. It competes poorly against weeds and is sensitive to excessive soil moisture and to waterlogging. Damping-off of seedlings, powdery mildew infestation and leaf-miner attack cause heavy losses. The crop is also very sensitive to moisture stress, especially during and after the flowering period.

Lentil

Lentil is grown on about 2 million ha which produce slightly over 1 million t of seed for an average yield of about 0.55 t ha^{-1} (Table 1). India and Pakistan, together, account for about 50% of the area and production, with an average yield of about 0.5 t ha^{-1}. Other important lentil-growing countries are Egypt, Turkey, the USA and the USSR. The crop matures in about 70 to 100 d and so is well adapted to areas where moisture is available only for this short period. Like pea, lentil is also sensitive to excesses and shortages of mositure. No improvements in the yields of this crop have been evident in the recent past.

Advantages of legumes in the cropping system

Grain legumes offer several advantages when grown in a rotation system with cereals and possibly with other crops too (Papendick, 1982). Some of these benefits are described briefly below.

Nitrogen fixation

In many cases, the legume if properly inoculated and well nodulated will fix a substantial part of the nitrogen needed for seed production and so will minimize depletion of soil nitrogen (Bezdicek *et al.*, 1982). In some situations, the legume may also contribute to the nitrogen requirement of a succeeding non-legume crop. For example, in northern India, chickpea can contribute the equivalent of 60—70 kg N ha^{-1} to a following maize crop, compared with a wheat or fallow control (Ahlawat *et al.*, 1981). Even in southern India, where total above-ground dry-matter production is less than in the north (3.5 and 5.5—6.5 t ha^{-1}, respectively) chickpea can supply the equivalent of 20 kg N ha^{-1} to a succeeding sorghum crop, when compared to a safflower control (M. Natarajan, pers. comm.). There is also evidence in Egypt that cereals and millets benefit from an equivalent of 15—20 kg N ha^{-1} when following a faba bean crop. The amount of nitrogen fixed by a legume crop can vary considerably and will certainly depend on the management system used.

Soil improvement

Grain legumes, and legumes in general, can help to improve soil physical properties, which improves water infiltration and stabilizes the soil against erosion. Grain legumes should also be considered for their potential use as green manure crops for soil improvement, particularly as a substitute for bare cultivated fallow. Used in this way they can return substantial amounts of nitrogen to the soil, improve the soil structure and water infiltration rate, and in some cases increase the availability of nutrients (e.g. of phosphorus).

And so the legume used as a green manure may improve subsequent crop yields and reduce soil erosion for at least one year or longer after cropping. Research in a 400 mm rainfall area of the Pacific Northwest, USA, has shown that yields of winter wheat following winter pea grown for green manure in a green manure-winter wheat-spring wheat rotation were comparable to those following cultivated fallow and an application of 54 kg N ha^{-1} to the wheat (Haimanot, 1977).

Weed control

Several soil-active herbicides are available for controlling grass weeds in legume crops which are otherwise very difficult or impossible to control in continuous cereal cropping. These include trifluralin (Treflan), ethylfluralin (Sonalan), and propham (Chem Hoe), and they can be soil-incorporated before planting and remain active through the growing season. A new family of post-emergence herbicides that control most grasses in broadleaf crops will also soon be labelled for control of these weeds in the legume crops. Of these, two products, fluazifop-butyl (Fusilade) and sethoxydim (Poast), show extreme selectivity for post-emergence control of both perennial and annual grass weeds which are not easily controlled in most cereal crops (and see pp. 535—548, this Volume).

Disease control

Legumes in rotation with cereal crops can also be extremely effective for breaking disease cycles in both the cereal and the legume crop. This reflects the fact that in most cases the legume crop is not a host for the cereal pathogen, and the cereal crop is not a host for the legume pathogen. For example, in the Pacific Northwest, USA, the take-all fungus *Gaeumannomyces graminis* var. *tritici* is often a serious pathogen of winter wheat following a cereal crop. A single year of pea or lentil is usually adequate to reduce the inoculum of this pathogen to a safe level for a following wheat crop (Cook, 1986). Similarly, pea or lentil in the rotation also aids in the control of Cephalosporium stripe, also a serious root pathogen of winter wheat when grown in a monoculture system.

Management constraints and considerations for increasing legume productivity

A major disincentive to improving legume productivity through better management in many places is the widespread but erroneous belief that these crops have only a very small yield and profit potential. Farmers often regard grain legumes as crops of secondary importance in comparison with those such as rice, wheat, and maize, and so they provide this trio with the greater share of the agronomic inputs and managerial attention. As a result, the pulses are often grown under marginal soil and moisture conditions without the benefit of fertilizers, adequate pest control, or optimum sowing date. For example, planting may be delayed from an optimum date until after the main cereal crop has been harvested, or the legume crop may receive agronomic attention only if there is some direct benefit (e.g. pest control) to the succeeding cereal crop (Summerfield, 1981). Moreover, equipment and cultural practices used in grain legume production are often the same as those specifically designed for cereal culture even though they may not be appropriate for the needs of the legume crop.

An important consideration in pulse production is not only to increase the yield on farms but also to increase the stability of yield between seasons. A major deterrent to farmers applying inputs to these crops is their unpredictability of yield. Unstable yield can often be attributed to the susceptibility of commonly used cultivars to insect and disease attack, and to weed competition. These biotic factors can interact strongly with various elements of the management system and so appropriate agronomic practices are needed to minimize crop losses from these sources.

For well known reasons of yield physiology, the grain legumes cannot be expected to be more productive than cereals. However, with appropriate management practice on a range of soils the legume crops have greater productive and economic potential than is generally believed. Pate and Minchin (1980) have shown that faba bean can yield 296 kg protein ha^{-1} compared with 193 kg by a cereal crop. Chowdhury (1970), in an all-India estimate, calculated that rainfed grain legumes were more profitable than cereal/millet cropping even with current production technology. Gupta (1955) reported an average yield of 1539 kg ha^{-1} from unirrigated and unfertilized chickpea over an area of 211 ha throughout a period of 23 years. Genotype yields ranged between 1286 and 1710 kg ha^{-1} as compared with an average national yield of 600 to 700 kg ha^{-1}.

In Bangladesh, chickpea seed is often hand-broadcast into recently-harvested rice fields after the monsoon season, with no soil tillage or any other input. This type of basic management contributes to the meagre farm yields in South Asia (0.4 to 0.8 t ha^{-1}) compared with yields as large as 4 t ha^{-1} that can be obtained on research stations. The "yield gap" is indicative of inadequate agronomic management of this crop on farmers' fields and shows the scope for improvement.

The experimental evidence and field experience make it reasonable to expect that yields of present legume cultivars could be doubled over existing world averages with good management — such as water conservation, appropriate land preparation, timely sowing at optimum density, use of appropriate fertilizers, and adequate control of weeds, insects, and diseases. The obvious need in many areas is to develop an infrastructure that will provide education and yield-boosting inputs to farmers so that they can take better advantage of the current yield potential of their pulse crops.

Agronomic limitations

Factors that most commonly limit the yield of pulse crops include water and nutrient deficiency, inadequate stand establishment, and the presence of weeds, diseases, and insects. The relative importance of these factors may differ markedly in different regions. Moreover, these yield-limiting factors are seldom independent and may interact with soil and management variables that can affect productivity (e.g. soil compaction, soil salinity, date of sowing, and plant population).

Water

The four legumes are most often produced on limited amounts of stored water which may be available for a relatively short growing period. Where crops are dependent on residual moisture there is usually a direct and positive relation between available water and yield. For example, Singh and Bhushan (1979) found that chickpea seed yield was linearly related to water use over the range 110 mm to 240 mm (and see pp. 813—829, this Volume).

In addition to the usual shortage of water there is often an underutilization of soil moisture that could be potentially available. For example, in parts of India, large areas of rice fallows are not sown to pulses because the surface of the heavy clay paddy soils dries rapidly and becomes very hard during rice harvest or soon afterwards even though there is adequate moisture in the deeper layers for a following legume crop. There is no suitable implement for timely shallow cultivation of these soils to reduce drying of the seed zone and enable establishment of chickpea, pea, or lentil. An alternate approach practiced in some areas is to sow the legume seed into the standing rice crop before harvest so that the legume seedlings can establish while the soil surface is still moist.

Elsewhere in India, cultivation in preparation for planting is not carried out until well after the rains cease and much water has been lost by runoff, evaporation and weed transpiration. At sowing time, in late October or early November, the seedbed has dried and initial crop stands may be very sparse. Remedial measures are to soak the seeds before planting, to increase the seeding rate by 10 to 15 percent, or to adjust the sowing depth so that seeds are placed into moist soil (which may be below 10 cm). All of these methods to improve stand establishment could be alleviated by good moisture conservation practices. Moreover, it is noted that the nodulation capacity of chickpea decreases when seeds are sown deeper than 5 cm (O. P. Rupela, pers. comm.). Thus, soil water status in the seedbed not only affects crop establishment but indirectly may also influence the nitrogen fixation potential of chickpea.

In some areas, excess moisture may limit yields of some pulse crops more than lack of available water. For example, in northern India wet winters may limit yields of chickpea by inducing excessive vegetative growth to the detriment of seed production. High moisture conditions cause lodging and increase crop susceptibility to disease. In the Pacific Northwest, USA, precipitation in April decreased pea yields by 3 kg ha^{-1} mm^{-1} (Pumphrey *et al.*, 1979). These authors suggested that excess rainfall may have aggravated effects of cold soil and/or anaerobic soil conditions on pea seedling growth.

Nutrients

Over much of the world, grain legumes are grown on infertile soils and often show little response to applied nutrients because yields are limited by other management practices. Little, if any, fertilizer is required to obtain the 600 to 800 kg ha^{-1} yields realized by many farmers using poor management techniques. Green (1980) has estimated that legume crops require only 13—14 kg P_2O_5 ha^{-1} for each 1000 kg seed ha^{-1} produced. This amount is already available in most soils.

Phosphorus appears to be the major nutrient which limits grain legume crop yields when they are well managed. Prasad *et al.* (1968) have reported results of several hundred trials on farmers' fields showing profitable responses of chickpea, pea, and lentil to applications of phosphorus under rainfed conditions in India. Chickpea response to phosphate fertilization is often more variable and less than that recorded for the other crops (Saxena, 1980). Chickpea is often grown on calcareous soils deficient in available phosphorus. One reason for the small fertilizer response on such soils may be exudation of acids by chickpea roots, thus dissolving precipitated phosphorus (N. P. Saxena, pers. comm.).

Nitrogen is seldom limiting if the legumes are well nodulated with effective strains of *Rhizobium*. Strains of *Rhizobium* capable of nodulating chickpea are very specific for *Cicer* species (Raju, 1936; Guar and Sen, 1979). Inoculation appears to be less important in those areas where the legume crops are routinely grown, but is essential when they are introduced into new areas and where available soil nitrogen concentrations are low. Sometimes, even with apparently satisfactory nodulation, it is possible to obtain significant yield responses to fertilizer nitrogen. In these cases, a starter application of 15 to 20 kg N ha^{-1} is beneficial, presumably by ensuring rapid seedling establishment before the symbiotic system becomes effective.

There have been few reported responses of these four grain legumes to potassium fertilization. Deficiencies of sulphur (Dube and Misra, 1970), iron in alkaline soils (Saxena, 1980; Saxena and Sheldrake, 1980b), zinc (Saxena 1980; Singh and Gupta, 1985), and molybdenum (Singh *et al.*, 1984) have been reported for chickpea, but systematic characterizations of mineral nutrient deficiencies are not available for this or the other three legumes for any region or soil type.

In brief, the four food legumes appear most responsive to applications of 30 to 60 kg P ha^{-1} where they are well managed, i.e. including the use of recommended cultivars, timely planting, water conservation, and control of pests. Moreover, the response is especially good when the phosphate fertilizer is placed below the seed or banded beside the seed row. In most cases, this is best accomplished during seedbed preparation or simultaneously with planting.

Biotic factors

The cool season food legumes are poor competitors against weeds. The crops are of short stature and their rates of growth, especially early growth, are small. Weeds can outgrow them and deplete both the soil moisture and nutrient supply. Weeds are especially devastating in very dry soils. Singh and Chowdhury (1970) harvested only 50 to 200 kg ha^{-1} of lentil and pea from unweeded plots compared with 2000 to 2800 kg ha^{-1} from hand-weeded plots (Table 2).

Table 2. Seed yield of lentil and pea as affected by weed control treatments at New Delhi, India.[a]

Treatment		Seed yield (kg ha^{-1})	
		Lentil	Pea
Unweeded control		50	189
One hand-weeding		2361	2054
Two hand-weedings		2807	—[b]
Treflan	1 kg ha^{-1}	470	1124
Balan	1 kg ha^{-1}	302	1766
Eptam	3 kg ha^{-1}	126	292
Knoxweed	3 kg ha^{-1}	204	2320
Amiben	3 kg ha^{-1}	244	870
LSD (5%)		918	1449

[a] From Singh and Chowdhury (1970).
[b] Not included.

Weeds can be less of a problem with legumes grown under receding moisture conditions than with rainy season crops because of the less vigorous growth of many annual weeds as the soil dries out. Weeds may also be more serious in some environments (e.g. chickpea in northern India) where cool weather retards crop canopy development and the top-soil remains moist. There has been considerable testing of herbicides in the grain legume crops and chemicals are available for control of both grass and broadleaved weeds. For example, application of fluchloralin (Basalin) or pendimethalin (Prowl) seems able to control weeds successfully in chickpea (Balayan and Bhan, 1984). Herbicides have been used successfully for many years for weed control in pea and lentil in the Pacific Northwest, USA (and see pp. 535–548, this Volume).

The legumes are also subject to many disease and insect problems which can markedly decrease crop yields. Common diseases include wilts, blights, rots, and mosaics. Insect pests include various beetles, borers, jassids, aphids, and cutworms. Consequences of diseases and insects can range from complete crop failure, where there is no protection, to good yields where crop protection measures are applied (Green, 1980; Saxena, 1980; and see pp. 519 and 577, this Volume).

Research in the Pacific Northwest, USA, shows that tillage and residue management can markedly influence the severity of root rot in pea caused by the soil-borne pathogens *Pythium ultimum* and *Fusarium solani* f. sp. *pisi* (Wilkins *et al.*, 1985). Surface residues tend to create a cool, moist environment which is conducive to build-up of *P. ultimum*. Similarly, concentrating the residues into a buried layer by ploughing can also lead to large populations of *P. ultimum* in the soil near the residue. Futhermore, a tillage pan created by the plough or other implements may restrict drainage during wet weather, which favours large populations of *F. solani* f. sp. *pisi* in the layers just above the compacted zone. The result of such management is restricted root growth caused by both mechanical impedance and root rot, and ultimately, reduced pea yields. Disease can be minimized by distributing the crop residue uniformly within the tillage layer, by limiting the amount of residue left on the surface, and by rupturing the tillage pans before the rainy season.

Planting date

The cool season pulses have specific environmental adaptation and so planting time is often a critical factor which influences crop yield. Planting too early or too late from the optimum date can markedly decrease crop yields (Table 3). Environmental factors which determine optimum sowing date are the pattern of moisture availability during the growth period,

Table 3. Effect of date of planting on seed yield of chickpea at New Delhi, India.[a]

Date of planting	Seed yield (kg ha^{-1})
17 October	3290
2 November	3648
17 November	2149
LSD (5%)	225

[a] From Chowdhury *et al.* (1971).

temperature, and photoperiod. For example, the optimum planting date for chickpea on Vertisols in peninsular India is during early October, but may vary from year to year according to the extent and duration of the preceding monsoon rains (Saxena and Yadav, 1975). The sowing date should be sufficiently early for the crop to make maximum use of stored soil moisture and late enough to ensure that the seedlings are not exposed to excessive heat and aridity early in the season. In the semi-arid plains of northern India, early sowing may lead to excessive vegetative growth of chickpea and cause lodging or increased disease in the spring. Delayed sowing can limit reproductive growth to periods when hot and dry air and/or dry soil would adversely affect pod fill.

In the Mediterranean environments and in the Pacific Northwest, USA, grain legumes must fit into a restricted growing season defined by cold at the beginning and heat and moisture stress at the end. Thus, for maximum yields, pea and lentil in the Pacific Northwest are planted as early as possible after winter rains to allow the crops to mature ahead of the summer drought (Muehlbauer *et al.*, 1983; Summerfield *et al.*, 1982). Similarily, in West Asia and the Near East, chickpea is sown in early March and also grown on the soil water stored after winter rains. However, with the advent of genotypes tolerant of Ascochyta blight, it has been shown that in rainfed conditions winter-sown (early December) crops have at least double the yield potential of those sown in March (Saxena, 1987).

Plant population

All four crops have the capacity to compensate for variations in planting density by branching and are able to form a closed canopy over a range of plant populations. However, when soil moisture is limited, dense plant populations may decrease seed yields due to the crop depleting water by or during the reproductive phase (Saxena, 1984). With more water, seeding rate is less critical but small rates can reduce yields. Increased plant population may also counteract the effects of delayed sowing by providing more dry-matter per unit area by the onset of reproductive growth (Saxena, 1984). Thus, there are strong interactions between plant population, soil moisture and sowing date which must be considered for the different locations where these legumes are grown.

Management strategies for increasing legume productivity

There appears to be a range of possibilities for improving the productivity of grain legumes through various management options using current technology. Many of the changes needed can be accomplished on existing farms without major adjustments in farm structure or increases in operating costs. Others may require the development of farm infrastructure to improve the managerial ability and operational skills of the farmers, and to provide agricultural inputs now not readily accessible to many farmers who produce legume crops. Aspects of legume production where more attention to management factors should pay dividends in terms of increased and more stable yields are discussed below.

Optimum sowing practices and plant population

Most legume "cultivars" now grown by farmers, as well as advanced breeder lines, appear to have very specific environmental adaptation. For this reason it is imperative to continue field trials and to expand these as necessary in order to determine optimum sowing date and plant population for specific locations. This is particularly so when new regions are planted to legumes and for new genotypes introduced into any region. Many studies, mainly in India, indicate that there is little scope for reliable extrapolation of results from one region to another. Experiments need to be repeated over several seasons to account for the effect of annual climatic variations and to discover how sowing date and population are influenced by soil moisture status. In the absence of widely adapted genotypes, such experimentation is essential for optimizing yield and improving yield stability. The research on management variables should be conducted in close collaboration with breeding research in order to develop more widely adapted legume genotypes.

Under rainfed conditions, sowing depth is a critical determinant of stand establishment and, with chickpea, of whether the crop will be adequately nodulated. Summerfield *et al.* (1982) report research showing that a soil covering to produce a weight of at least 3 g above individual lentil seeds is indispensible for root penetration and successful crop establishment. They also indicate that deep plantings can be advantageous from the standpoint of improved moisture for germination, but can also result in poor emergence because of soil crusting following heavy rains or compaction by farm machinery. Differences in soil physical properties, particularly water-holding capacity, and potential evapotranspiration will ensure that optimum sowing depth is strongly site-specific. Thus, multi-location trials repeated over seasons with respect to this factor are also recommended. Use of seed drills would also enable planting at a uniform, pre-set, depth.

Water conservation

There are at least two major objectives with water conservation in dryland cropping and sometimes three. These are: (a) maximizing the capture and retention of precipitation; (b) minimizing evaporation and weed transpiration; and, in some situations, (c) retaining adequate moisture in the seeding zone for rapid stand establishment of the crop (Papendick, 1984). When rains occur, it is desirable to achieve rapid and maximum infiltration of water into the soil in order to prevent runoff or delayed ponding on the surface. Deep penetration of the water into the soil also minimizes evaporative loss during extended drying periods.

Where there is potential runoff it may be beneficial to loosen or fracture the soil in anticipation of rains and preferably using undercutter tools such as a sweep plough or sub-soiler, which does not invert the soil and bury the crop residue. Other practices to reduce runoff and increase water intake include terracing, ridging, and stubble retention or surface mulching. Furrow dam tillage also encourages water retention whereby small earthen dams are constructed at 3 to 5 m intervals across lister furrows, effectively tying the ridges together (Stewart and Musick, 1982). Such dams are usually constructed after the crop has been planted and are left intact as micro-catchment basins to retain precipitation and runoff. Although furrow damming equipment is available commercially, it has also been constructed successfully by hand in several developing countries in the semi-arid tropics and used with positive results.

Evaporation losses are best minimized by crop residue mulches during rainy periods but their value for this purpose decreases when rains cease and the soil begins to dry. Shallow tillage before the soil drys too deeply, especially for the finer-textured soils, can markedly reduce evaporation losses and enhance water retention in the seed-zone. In addition, weeds (which are heavy users of water) must be controlled at the early growth stage to prevent serious loss of water from both deep in the soil profile and from the seed-zone during the interim before crops are planted.

Conservation tillage is a concept of farming that is being adopted by more and more farmers around the world as a means to improve water conservation as well as to control erosion and reduce farm energy requirements (Papendick, 1984). The concept basically incorporates the best known features of crop residue management and tillage to reduce runoff and evaporation, and minimizes the number of tillage operations. Emphasis is placed on retention of stubble, rough tilled surfaces, and minimum disturbance of the soils while, at the same time, maintaining adequate weed control. These systems depend on herbicides to replace tillage for weed control and so appropriate chemicals and applicator equipment must be available.

Most of the attention with conservation production systems has been with the cereal crops and more needs to be given to legume cropping. Moreover, in some regions, crop residues are an important source of feed for farm animals and cannot always be spared for stubble mulching. In this case, more emphasis must be given to rough-tilled surfaces.

Estimation of available soil moisture

In many situations, the crop yield produced depends on the amount of water stored in the soil at sowing time. It is possible to predict with reasonable accuracy both crop growth and yield from a given amount of stored water. Methods of doing this are available for chickpea (Singh and Bhushan, 1979;

Huda and Virmani, 1987) and should be possible for the other crops too. By contrast, for crops whose growth is dependent on rainfall received during the growing season, prediction of growth based on expected water availability is usually much less reliable (and see p. 813, this Volume).

It is therefore recommended that calculations of available soil moisture be made for the various regions where legumes are grown. In particular, the relations between rainfall received prior to sowing the crop and available moisture at sowing time need to be established. To accomplish this task by direct measurement alone would be extremely tedious because of variations in soil, cropping, and annual climate. However, a simplified soil water budget model for predicting soil moisture on a regional basis is available (Saxton *et al.*, 1974; Saxton and Bluhm, 1982). Needed inputs are parameters and data which describe climate and soil water-holding characteristics. These are generally readily available or can be obtained quite easily. With this generated information, growers would be able to predict the potential yield for a given season ahead of planting and so could calculate how much, if any, of the crop to sow. Depending on yield prospects they could also make informed decisions about the extent of other inputs such as fertilizers and insecticides that are likely to be close to the economic optimum.

Detection of nutritional limitations

There is much scope for improving the methods of detecting nutrient deficiencies as well as soil chemical toxicities for the legume crops. "Need to inoculate" trials with treatments of no inoculation, inoculation with appropriate strains of *Rhizobium*, and inoculation plus nitrogen fertilizer (Date, 1982) should be conducted. For example, the optimum way to apply inoculum and nitrogen fertilizer for chickpea plants grown on residual soil moisture has not, as yet, been devised. These types of trials need to be conducted at several locations so that the necessity of inoculation for a particular site can be established.

Evaluation of alternative methods for detecting nutrient deficiencies in the grain legumes, including plant symptoms, soil analyses, plant analyses, pot trials, and field trials, should be undertaken. Use of soil and plant analyses is limited because critical concentrations for deficiency have yet to be reliably established for any of these legumes. This type of information is essential for developing fertilizer programmes for increasing productivity and ensuring efficient fertilizer use.

Weed, disease, and insect control

Weeds. On large-scale farms, weeds are controlled most effectively with combinations of tillage and herbicides. Chemicals are generally available for control of both grass and broadleaf weeds in the growing crop and, with present technology, yield losses from weeds can generally be kept to a minimum. In some areas where labour is adequate and rains do not interfer, hand-weeding may still be an option but would be primarily limited to small farms. Farmers everywhere need to be made aware of the importance of good weed control and the effect of weed growth on crop yields. Once effective weed control has been implemented, (whether by mechanical methods or chemicals) then infestations will decrease each year and so will contribute towards stabilizing production on rainfed lands. Additional economical and practical measures of weed control can be achieved through grazing, crop rotations, and fallow. In some case, weed control in the growing crop may also be facilitated by sowing in rows 50 percent wider than normal to enable use of power-drawn cultivators.

Diseases. Management practices to control diseases appear to be limited. Agronomic methods such as crop rotation, burial or removal of infected crop residues, seed treatment, and in some cases shallow sowing or changes in date of sowing can be helpful in specific situations, but are not universal solutions. Also, relations between tillage and residue management practices and disease incidence, such as found for pea in the Pacific Northwest (Wilkins *et al.*, 1985), need to be investigated for the other crops in other environments. The same is true for other management variables such as water and fertilizer usage. Breeding for resistant cultivars appears to offer the best potential solution for disease control, and it is fortunate that progress in this direction is now being made (Nene and Reddy, 1987).

Insects. Insect control, like weed control, is most practical and feasible with chemicals in large-scale farm operations. Insecticides are currently available which provide effective control of most, if not all, of the major crop pests. However, for their use on small farms, an infrastructure must be developed that provides well-organized and well-equipped public or private centers for timely customer service. For successful chemical pest control, it is essential that farmers are educated, advised, and encouraged to sow their pulses in larger concentrated blocks so that fields can be treated effectively with ground spray machines or even from the air. This is already done for cash crops such as cotton and sugar cane but needs to be extended to the grain legumes. Adequate pest control can itself increase yields in many areas by at least 50%.

Planting equipment

Proper placement of seed in soil is essential for satisfactory germination and seedling emergence, especially where moisture is limiting. For this reason managing for large yields requires the use of mechanical planters with good control of planting depth, packing, seeding rate, and row spacing. Drills designed for cereal grain planting are generally satisfactory for sowing legumes provided some adjustments are made. In dry conditions, the furrow drill is most satisfactory because seed can be placed in moist soil below the dry surface layers. Residue clearance can be achieved by using two or more ranks to stagger the seed openers; seed row spacing can be narrowed by increasing the number of ranks. Press wheels provide good seed-soil contact and also firm the soil to prevent excessive covering of the seed. Furrow drills can be obtained or constructed in all sizes to match available power and can be either tractor- or animal-drawn.

Indispensible for conservation tillage systems are no-till drills designed to seed into hard, untilled soil, and through surface crop residues. Some of these drills are equipped with coulters to cut through residues and open a slot immediately ahead of a disc or hoe-opener. No-till planting provides minimal disturbance of the soil and requires the use of herbicides for weed control.

Most conventional drills can be equipped to place fertilizer in the same slot as the seed. Some modern no-till drills can deep-band fertilizer to the side of and below the seed row. Adjustments in row geometry and configuration are also possible with some machines.

Novel cropping systems

With the rapid development of new cultivars and management practices in those crops with which grain legumes may be grown as part of a rotation, it is important to be continually aware of alternatives to the traditional methods of cultivating food legumes. For legumes to retain their place in traditional cropping systems, or to be incorporated into new cropping systems, it is necessary to develop a range of management options. For example, there is increasing interest in using chickpea in rice-based cropping systems (Carangal, 1987). Further studies are also needed on the benefits or otherwise of intercropping these legumes with cereals.

Conclusions

There is considerable potential through management variables awaiting exploitation for increasing the production and productivity of faba bean, chickpea, pea, and lentil. Farmers, particularly those in the developing countries, need to be made aware of this unrealized potential to encourage them to improve their management systems. There is a concurrent need to develop and distribute seed stocks of improved cultivars similar to those programmes for wheat, rice, maize, and sorghum. Until farmers gain more confidence in the productivity and profitability of grain legume crops it is unlikely that they will be sufficiently vociferous in their demands for these improvements.

Greater efforts should be made in the following areas as components of a programme strategy to improve pulse productivity and production:

1. Literature in the form of pamphlets in appropriate languages should be

made available, to inform farmers of the potential productivity and profitability of the grain legume crops. Even the "invisible" gain of fixed nitrogen for other crops in rotation with the grain legumes can be significant, but is often not recognized.

2. Evaluations of variations in sowing date and plant population are needed as a means to increase the yield of current crops. For example, advancing the traditional planting date of faba bean in Egypt and, in certain cases, of chickpea in India increased yields by 10—15%.

3. Concerted efforts should be made by responsible agencies to increase and distribute the seeds of improved genotypes to farmers. Recommended cultivars of the pulse crops yield at least 10—15% more than the heterogeneous, land-race material now being used in many parts of the world.

4. Effective weed control is critical for achieving the full yield potential of grain legumes. The application of herbicides and improved mechanical control technology should be investigated and exploited where practical and feasible (and see pp. 535—548, this Volume).

5. Insect pests account for heavy crop losses each year in many regions but can be controlled quite effectively if farmers concentrate their legume crops into larger blocks of contiguous fields to make custom-spraying worthwhile and practical. Also there appears to be considerable opportunity for improving both insect and disease control through host plant resistance.

6. Moisture conservation practices need to be developed and refined for different growing areas in order to increase the amount of water available for the crop and in the seed zone for improving stand establishment.

7. Soil/plant analyses procedures need to be developed for the different crops and regions for designing optimum fertilizer programmes.

8. Greater use of mechanical planting equipment is needed in many areas in order to place seeds (and fertilizer) into favourable soil and moisture conditions and so improve stand establishment and early crop growth.

9. Equipment for breaking hard and semi-dry soil surfaces for the sowing of chickpea, lentil, or pea after rice harvest needs to be designed and developed. Similarly, simple implements for sowing grain legumes in inter-crop systems are needed.

10. Investigations are needed on how the grain legumes can fit into rotations with other crops to maximize water use efficiency, overall yield, and profitability of the total cropping system.

11. There is a need to identify those cultural and agronomic practices that enhance nitrogen fixation by well nodulated food legumes.

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