1432

Integrated management systems to control biotic and abiotic stresses in cool season food legumes

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Abstract

Yield losses in cool season food legumes result from several biotic and abiotic stresses. The most important of these stresses on five cool season food legume crops are listed, and recent progress in research to alleviate some of these is reviewed. Although it is possible to control some stresses by the use of such inputs as agricultural chemicals, economic and environmental concerns limit their use in many farmers' fields. The most desirable means of stress alleviation is through integrated management systems, including host-plant resistance and improved agricultural practices. There is an urgent need to accentuate progress towards cultivars that can withstand various stresses and give large and stable yields. Recent advances in biotechnology may offer us the means by which to do so. Teams of scientists must go beyond their narrow specializations and make the best use of currently available materials and methods within practicable integrated stress management systems.

Introduction

Cool season food legumes are grown over a wide range of environments and are subject to an enormous number of biotic and abiotic stresses. Many of these can completely destroy crops or greatly reduce the quantity and quality of their products. There is great variation in the occurrence of these stresses, both between and within the crop species and across time and space. Stresses that are known to severely reduce yields are given in Table 1. Such a large number of stresses for each of the crops pose a real challenge to scientists to develop effective integrated stress management systems. This paper seeks to review the international progress in developing such components and systems and to discuss the problems and solutions that are apparent at this time.

Chickpea (*Cicer arietinum* L.) is a crop of major importance in South and West Asia, North Africa, and Central America. There are very active research groups in several countries of these regions. Also, it has been selected as a target crop by both the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) in India and the International Center for Agricultural Research in the Dry Areas (ICARDA) in Syria. Pea (*Pisum sativum* L.), faba bean (*Vicia faba* L.), and lentil (*Lens culinaris* Medik.) are grown extensively in both developed and developing countries, and have undergone extensive research and selection. Consequently, farmers in many areas now have a choice of well-adapted cultivars that have high yield potential, and extensively tested agronomic practices that enable them to produce these crops profitably in most years.

Table 1. Biotic and abiotic stresses affecting five cool season food legumes

Crop	Biotic stresses	Abiotic stresses
Chickpea	Fusarium wilt, dry root rot, Ascochyta blight, Botrytis gray mold, stunt, *Orobanche*, pod borer, leaf miner, lesion nematode, root knot nematode, reniform nematode, cyst nematode, weeds	Temperature extremes, drought, salinity
Pea	Seedling and root rots, Fusarium wilt, downy and powdery mildews, rust, mosaic, streak, *Orobanche*, pod fly, pea moth, bean fly, lesion nematode, root knot nematode, cyst nematode, weeds	Temperature extremes, drought, waterlogging
Faba bean	Fusarium wilt, root rot, chocolate spot, Ascochyta blight, rust, mosaics, *Orobanche*, aphids, leaf miner, army worm, stubby root nematode, lesion nematode, dagger nematode, root knot nematode, weeds	Temperature extremes, drought
Lentil	Fusarium wilt, Ascochyta blight, rust, stem blight, *Orobanche*, weeds	Temperature extremes, drought
Lathyrus	Downy mildew, weeds	

In contrast, *Lathyrus* or grasspea (*Lathyrus sativus* L.) is a crop, grown almost entirely by subsistence farmers, that has been relatively neglected by researchers. The presence of neurotoxin associated with this food legume is well known, and this factor may have discouraged research on its improvement. However, it is a very useful crop in many areas, for it can produce substantial yields under poor agronomic conditions and appears to have relatively few pests and diseases. Recently, cultivars containing low neurotoxin content have been developed in Bangladesh, Canada, and India (Kaul and Combes, 1986; Lal *et al.*, 1986; Islam and Matiur Rahman, 1991).

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Components of Integrated Stress Management Systems

The productivity of any crop is dependent upon a large number of components of the system in which it is grown. Most stress management initiatives interact with many of these components, and with each other, and so must eventually be considered and tested as integrated inputs within the crop system, rather than as simple add-on factors.

Plant Resistance

The primary component in any crop is the plant genotype that offers limitless research opportunities to crop improvement scientists. Here there are opportunities, not only for the plant breeders to increase a crop's basic yield potential but also, and perhaps more importantly, to increase the crop's genetic resistance to the many yield-reducing factors that have to be faced in farming situations. As the climatic, edaphic, and biotic threats to cool season legumes vary greatly across the wide geographic range over which they are grown, it is impossible to design a genotype that will be ideal for all environments. Consequently, it must be accepted that the major agro-ecological zones will require differing genotypes of each legume crop.

Each genotype often requires its own, specially designed, agronomic package of practices that will enable it to be profitably exploited within its adaptation range. The type of cultivation, sowing date, and other agronomic practices all interact to influence biotic and abiotic stresses and crop yields.

Ideally, an optimum package of crop genotype and agronomic system should be developed for each location, but this is clearly impossible. Perhaps the best that can be achieved will be the development of widely adapted genotypes, with specific agronomic recommendations for the differing areas over which they will be grown. For example, the optimum sowing date and plant spacing for such a widely adapted cultivar may differ across the range of soil types and climates within its zone of adaptation, and differing crop protection measures may be required to combat the yield-reducing stresses where these are found to be location-specific.

Alternatively, it might be more productive to select a range of genotypes to suit the level of agronomic inputs that can be afforded by the farmers in a specific zone. A high-yielding cultivar that will yield well when provided with purchased inputs can be provided for those farmers who can afford these, while a cultivar with less yield potential but with resistance/moderate resistance to the locally dominant stresses might be more useful to the farmers who cannot utilize such inputs.

Although immunity, or very strong resistance to pests and diseases would be desirable, it is much more likely that lower levels of resistance or tolerance will be more easily found. This seems true in case of faba bean where only moderate degrees of resistance to *Botrytis cinerea* Pers.:Fr. and *B. fabae* Sardina are available, and therefore effective management would involve use of biological and minimal chemical means (Harrison, 1988). Many landrace cultivars are found to have evolved such protection against locally damaging stresses. It is essential to ensure that the improved cultivars developed to replace such landraces are not more susceptible than they are, unless the local farmers have the ability to use alternative means of pest control. For example, no new chickpea cultivar can succeed in peninsular India unless it has better levels of resistance to Fusarium wilt, dry root rot, collar rot, and *Helicoverpa armigera* (Hüb) than the local landraces. For example, the faba bean ILB 1815, an excellent local landrace in Syria and Lebanon, can be crossed with *Botrytis*-resistant BPL 261, to improve its acceptability (Maliha, 1983).

Agronomic Practices

The growth and yield of a crop genotype will be affected by all the components of an agronomic package, i.e., primary cultivation, sowing, spacing, weeding, soil fertility enhancement, and soil moisture control. Changes in any of these components can also have major consequences on the levels of stresses, and their effects on the crop. For example, delaying sowing date and increasing plant population significantly reduced faba bean root rot [*Fusarium solani* (Mart.) Sacc. f. sp. *fabae*] and wilt (*F. oxysporum* Schlechtendahl) incidence (Salih and Ageeb, 1987). In India, delayed sowing of chickpea reduced Ascochyta blight but also reduced yield (Tripathi *et al.*, 1988). Delayed sowing reduced Botrytis gray mold of chickpea in Nepal (Karki *et al.*, 1989).

The crop must not be considered in isolation, for its juxtaposition with neighboring crops can have major effects on the populations of some pests, particularly those that are mobile. When all the farmers in an area sow a crop synchronously, the mobile pests or wind-disseminated pathogens have no opportunity to build up on early sown crops and then invade the later sown, so the available pest populations are diluted across all the fields in the area. The duration and phenology of the crop can also be of great importance in escaping severe pest attacks. For example, a short-duration cultivar may escape severe damage from insect pests that build up their populations in the crop over more than one generation. Short-duration, cold-tolerant chickpeas, if developed, will enable the crop to mature in February, before *H. armigera*, Ascochyta blight, Botrytis gray mold, and hail storms occur in northern India, Pakistan, and Nepal.

It is also obvious that crop rotations have significant effects on some stresses, particularly on the soilborne plant pathogens. Thus, scientists must look well beyond the agronomy of single crops, both in time and space, if they are to develop efficient systems to limit crop losses.

Soil solarization, using polyethylene covers, has been found to be of immense value (Katan, 1981). In field experiments, carried out in Syria from 1985–89, soil solarization for 40 days increased yields of faba bean by 331%, lentils by 441%, towards crop improvement, rather than as an end result. It is increasingly evident that the success of a new advance on a research farm may not produce similar benefits when transferred to farmers' fields. Part of the problem is that the ecological conditions in research fields are often grossly atypical of those in farmers' fields.

ICRISAT has addressed these problems with several innovations. Most research is carried out in projects that involve multidisciplinary, crop-based teams. A large area of ICRISAT's central research farm is kept free from irrigation and agricultural chemicals, other than small applications of fertilizer. All promising new crop genotypes that are developed and selected in protected, high-fertility pots, plots, and fields are then extensively tested, both in specific disease and abiotic stress nurseries and in large plots in the pesticide-free area, to determine their susceptibility to the stresses that they may encounter in farmers' fields.

Another large area of the research farm is devoted to farming systems research. Here the new crop genotypes, components, and systems are tested in large fields within watersheds. Simultaneously, the new materials and methods are tested on other research stations, usually in cooperation with national research scientists in coordinated networks. Finally, the advances are taken to farmers' fields, where their progress is monitored by both national and ICRISAT research scientists. The whole process, from the preliminary experimentation to confirmation of benefits in farmers' fields takes many years and is very expensive. However, the process ensures that the scientists are encouraged to follow their findings through to farmer utilization, and do not regard the publication of their data as the end product of their research. Many farmers are now benefiting from new crop genotypes, and other innovations that have reached them as a result of this system, and many more major improvements are already in the pipeline.

A good example of integrated management of pea root rots in Canada is the strategy that includes planting resistant cultivars, using fungicides for seed treatment, avoiding phenoxy herbicides, but using dinitroaniline and triazine herbicides, reducing soil compaction, practicing fall chisel plow or fall plow plus spring raised seedbed preparation, using soil indexing to determine both levels of field infestation and cultivar susceptibility, and planting green manure crops between pea crops (Tu, 1987).

The result of another interesting study was published by McEwen and Yeoman (1989). Field experiments compared four spring faba bean cultivars using two pest control programs based on (1) "standard" control of *Ascochyta fabae* Spegazzini, *Ditylenchus dipsaci* (Kühn) Filip., and seedborne viruses and (2) "enhanced" control of *Sitona lineatus*, bean leaf roll virus transmitted by the vector *Acyrthosiphon pisum*, *B. fabae*, and *Uromyces viciae-fabae* in addition to pests and pathogens in the "standard" control. The average increase in yield was 1.1 t ha^{-1} with the "enhanced" treatment.

Most traditional systems of agricultural production have evolved to ensure relative stability in yields, rather than opting for large yields but with greater risk. Chickpea in Syria offers a very good example. When this crop is sown at the beginning of winter, the potential yields are much greater than those produced by the traditional spring sowings. However, the winter-sown crops are frequently destroyed by Ascochyta blight, and the severe frosts that occur in some years can also kill the plants. Consequently, this crop is traditionally sown in the spring. In such circumstances, the obvious approach is to seek genotypes that combined resistance to both blight and low temperatures through the vegetative phase. Chickpea breeders, pathologists, and physiologists from ICARDA and ICRISAT have cooperated in screening the available germplasm with considerable success (Singh *et al.*, 1991). It has been possible to develop breeding lines that resist Ascochyta blight and low temperatures (K. B. Singh, ICARDA, personal communication) and so will add stability to the high-yield potential of the winter-sown crop. Recent efforts of Kamal and Solh (1990) in developing dual-season chickpea, suitable for both winter and spring seasons, are noteworthy.

Drought is a major abiotic stress factor. Irrigation, of course, can eliminate effects of drought, but where it is unavoidable, breeding for drought escape (e.g., short-duration cultivars) and drought resistance should yield useful cultivars. The ICRISAT short-duration kabuli chickpea cultivar ICCV 2, resistant to Fusarium wilt and tolerant to salinity, escapes both terminal drought and heat stress.

The utilization of host-plant resistance to combat both biotic and abiotic stresses is obviously a most attractive option, and considerable research activity is directed towards this component, particularly in the international agricultural research centers. Intensive screening of the available germplasm has revealed that resistance can be found to combat most of the major yield-reducing stresses in a crop such as chickpea (Pundir *et al.*, 1988; Singh *et al.*, 1991). However, the simple identification of a resistant source is only the first, and perhaps the easiest step. The combination of such resistances into a commercially acceptable cultivar can be an extremely difficult and lengthy process.

Multiple Stress Resistance

To breed lines with multiple stress resistance is not easy. There are examples of cultivars with combined resistance to three stresses; but combining resistance to more than three stresses is very difficult. One interesting example of a cultivar of cowpea, however, is worth mentioning. The cultivar Iron has combined resistance to one nematode, four fungal, two bacterial, and three viral diseases (Nene, 1988).

A good example of difficulty in breeding for multiple stress resistance is provided by the research at ICRISAT that is directed towards the selection of useful chickpea genotypes that have resistance to *H. armigera*, the major insect pest of this crop in India. Screening the available germplasm soon revealed several genotypes with considerable resistance to this pest, but these selections were highly susceptible to Fusarium wilt. However, several sources of resistance to this disease were already available, so the breeders, pathologists, and entomologists embarked on an intensive program to combine these resistances into chickpeas that also possessed all the other required characteristics. Recent selections show considerable promise, and it is expected that useful cultivars will be available for widespread use within the next few years. The ICRISAT kabuli cultivar ICCC 32 (ICCV 6), combines high yield with resistance/moderate resistance to Fusarium wilt, some root rots, *Helicoverpa*, and soil salinity and was released in Nepal in 1990.

A major achievement in interspecific hybridization in chickpea was the production of F_2 seeds between the cross *C. arietinum* and *C. echinospermum* P. H. Davis (ICARDA, 1990; Legumes Program, ICRISAT, 1991). Some accessions of *C. echinospermum* are resistant/moderately resistant to cold, Ascochyta blight, bruchids, Fusarium wilt, and leaf miner (Singh *et al.*, 1991). The segregating hybrid progenies will be useful in chickpea improvement and provide an opportunity to transfer stress-resistant genes from *C. echinospermum* to the cultivated species.

Building Integrated Stress Management Systems

Variability, in space and time, of the various factors, including stresses, that determine the growth and yields of crops ensure that there can be no universal blueprint for a system that would ensure the maximum yield of any crop in all fields and years. Similarly, the ideal genotype which possesses all the traits demanded both by consumers and producers, including resistance to all potential stresses, will never be developed. But it is equally certain that the genotypes, and farming systems that are currently in use can be greatly mproved.

A wide knowledge of the relative importance of the stresses that occur locally or regionally is essential. It is appropriate to reproduce a table (Table 2) from a recent publication (Van Rheenen, 1991). The information contained in the table clearly identifies the areas of research that should lead to developing integrated stress management systems.

The traditional systems and crop landraces have many unrecognized virtues hat have evolved in response to the stresses that have threatened man and his crops over many centuries. Care must be taken to ensure that any changes made hrough breeding are beneficial, not only in increasing the farmers' profits and yields, but also the crops' stability and sustainability. We have attempted to ndicate relationship between research on components and integrated stress management systems (Figure 1).

Table 2. Desirable characters for chickpea in different zones of the world and their priorities for stress management[a]

	Zones (°latitudes)				
Desirable characters	A 0-20	B 20-25	C 25-30	D 30-45	
Stable, high yield	+	+	+	+	
Good seed quality	+	+	+	+	
Resistance to stresses					
Biotic					
Fusarium wilt	2-1	2-1	2-1	3	
Ascochyta blight	-	-	6[b]	1	
Botrytis gray mold	-	5	3	-	
Root rots	3	3	5	4	
Stunt	4	4	4	5	
Helicoverpa	1-2	1-2	1-2	6	
Leaf miner	-	-	-	2	
Nematodes	?	?	7?	7?	
Abiotic				Spring	Winter
Drought	1	1	1	1	-
Salinity	3	3	2	-	-
Excessive moisture	-	4	5	-	-
High temperature	2	2	4	2	-
Low temperature	-	-	3	-	1

a. 1 = highest priority; 9 = lowest priority; + = required;
- = not required; ? = uncertain.
b. In case of epidemics, the crop damage is severe.

Source: van Rheenen, 1991.

Future Prospects

Two rapidly expanding scientific fields are likely to play a major role in the improvement of stress management systems: simulation models and the advances in gene transfer across specific and high boundaries.

Modern computers can now handle large simulation models containing several variables. Such simulations will not replace field experimentation but they may provide help in testing interactions, and give indications of the likely effects that may reduce the need for complex experimentation in field trials over many seasons (Rabbinge and Bastiaans, 1989). For example, CHICKBUG, a computer-based decision aid for insect pest management in chickpea and other winter grain legumes, provides information about *Helicoverpa* and derives the required advice which can be used to make a sound management decision (McIntyre and Titmarsh, 1989).

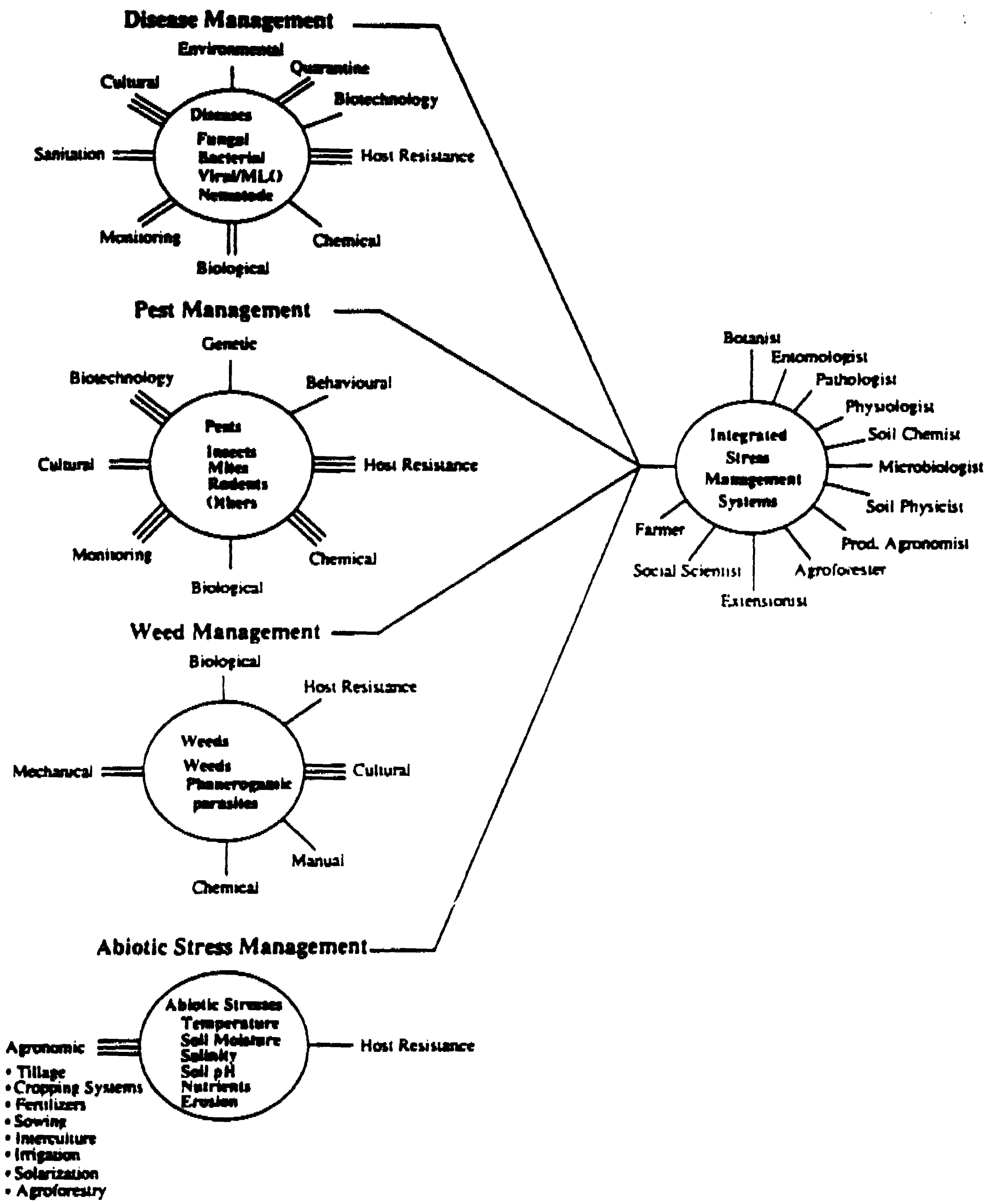

Figure 1. Suggested research emphasis (≡ high, = moderately high, and — normal) and relationship between components and system of integrated stress management in cool season food legumes.

The potential for biotechnology to enable the rapid transfer of specific resistance genes looks particularly exciting. It is already known that some useful resistances are present in the wild relatives of chickpea and lentil that could not be transferred by conventional plant breeding techniques. Research on wide hybridization and embryo rescue in chickpea is in progress at ICRISAT. At ICARDA, studies on wide crosses, use of tissue culture techniques, applications of genetic engineering, and molecular marker techniques for the improvement of chickpea and lentil are in progress (ICARDA, 1990, 1991). In addition, desirable genes from unrelated plants could be usefully transferred to these legumes.

Even without such new technologies there are many advances available now, and in the pipeline, that can give farmers substantial increases in profitability from these legumes. It is essential that research scientists should take these advances to the farmers' fields, rather than leave them buried in research journals and conference reports. Scientists should actively seek partnership with extension workers and farmers to finally transfer useful, integrated stress management technologies.

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CP052

Management of Vertisols for Maximising Crop Production—ICRISAT Experience

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1260

Abstract

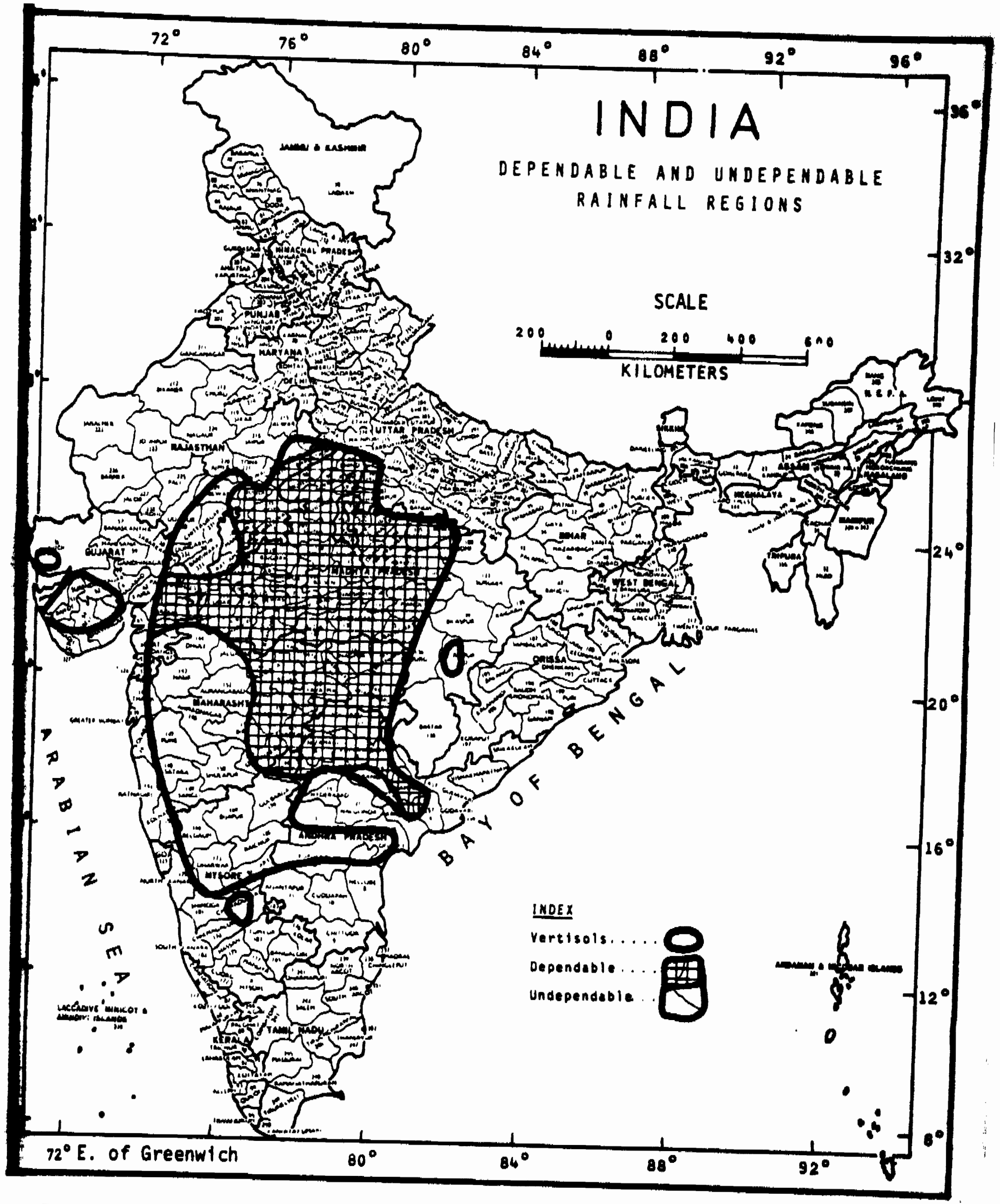
Vertisols are an important group of soils in the semi-arid tropics (SAT) of India and elsewhere. They have high water-storage capacity and high production potential, which remains under-utilised because of the difficulty of managing these soils and the use of traditional technology. Drought and poor drainage are twin problems which discourage most farmers from cropping these soils in the rainy season and make them resort to post-rainy cropping.

A technology based on the watershed concept, broadbed-and-furrow system and land management, use of improved implements, high-yielding varieties, double-cropping and intercropping systems, balanced use of fertiliser and good crop management practices has been evolved and tested for 8 years at ICRISAT Center, near Hyderabad. The technology offers the possibility of increasing yield to 3 to 5 tonnes/ha and of giving profits up to 250% on the investment. The improved technology reduces soil and water loss and increases production. It is likely to improve the employment potential and well-being of the people of the SAT.

The technology needs trials in different agroclimatic environments in India and also critical evaluation and modification elsewhere.

The Vertisols, commonly known as black soils, and associated soils with vertic characteristics, cover 73 million ha of the geographical area in India; about 28 million ha of these are true Vertisols. About 80% of the Vertisols in India lie in the states of Maharashtra, Madhya Pradesh, Gujarat and Andhra Pradesh, 13% in Karnataka and Tamil Nadu, and the rest in other adjoining states (Murthy et al. this symposium). Unique features of this region are that it lies in a seasonally dry climatic belt. The rainy season is short (with only 2-4$^1/_2$ wet months) and rainfed farming is generally practised. It is no exaggeration to state that the future of agriculture in these six states lies in the efficient management of Vertisols.

Virmani et al. (1981) have divided the Vertisol region of India into two climatic regions: (1) areas with relatively dependable rainfall with a mean annual rainfall ranging from about 750 to 1250 mm or more; (2) areas with relatively undependable and low rainfall, mean annual rainfall generally less than 750 mm (Figure 1). The dependable rainfall areas are characterised by a marked reliability of rainfall occurrence at short intervals, while areas with undependable



The Vertisol areas of India where rainfall is dependable and undependable.

Vertisols and rice soils of the tropics: Symposia papers 2 of the Twe[illegible]th Int. Congress of Soil Science, 8-16 Feb 1982, New Delhi, India

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