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FARMING SYSTEMS RESEARCH IN INDIA: A HISTORICAL PERSPECTIVE

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SUMMARY

This review gives a historical perspective of the development of Farming Systems Research (FSR) in India over the past 60 years, as India changed from a traditional, subsistence oriented agriculture to one based on science and technology. The first period relates to the years 1930–50, when the Government of India created the Indian Council of Agricultural Research (ICAR) and initiated research on dryland agriculture.

The second period relates to the development of coordinated agronomic trials and simple fertilizer experiments on farmers' fields during the years 1950–65. This development was a forerunner of networks of coordinated applied agronomic research relevant to farmers' cropping systems and adaptive research with farmers' participation. The development of a soil conservation research network in the same period strengthened research on the natural resource base countrywide. The third period started with the reorganization of ICAR, the establishment of State Agricultural Universities and the introduction of coordinated research programmes on high-yielding varieties (HYVs). At the same time the coordinated dryland agricultural research programmes, and subsequently the Central Research Institute for Dryland Agriculture (CRIDA), were established, leading to the development of a national system of FSR for rainfed agriculture.

The fourth period of FSR started with the establishment in 1972 of ICRISAT, an international agricultural research centre that accepted FSR as its mandate and developed the concept of integrating the management technologies for various components of climate, soil, water and crops with a farmers' perspective. ICRISAT's work was complementary to that of CRIDA and helped to bring about conceptual changes in Indian FSR through research aimed at understanding principles and processes of semi-arid tropical (SAT) farming systems. Following this, mechanisms for strengthening on-farm research were emphasized so as to provide stronger linkages between researchers, extension workers and farmers.

Today, FSR with a farmers' perspective occupies pride of place in India's agricultural research agenda. Yet it is a long way from bridging the gap between the generation of technology and its adoption by farmers, who have shown a preference for its components rather than for the full package of technology.

Investigacíon de sistemas de cultivo en India

RESUMEN

Este reseña brinda una perspectiva histórica del desarrollo de la Investigación de Sistemas de Cultivo (ISC) en India durante los últimos 60 años, al tiempo que la India pasó de una agricultura tradicional con orientación hacia la subsistencia, a una agricultura basada en la ciencia y la tecnología. El primer período se relaciona con los años 1930 a 1950, cuando el

Gobierno de la India creó el Consejo de Investigación Agrícola de la India (CIAI), e inició la investigación agrícola para las tierras secas.

El segundo período se relaciona con el desarrollo de ensayos agroquimicos coordinados y experimentos simples con fertilizantes en campos de agricultores durante los años 1950 a 1965. Este avance fue el antecesor de las redes investigación coordinada de agronomía aplicada con la participación de los agricultores. El desarrollo de una red de investigación sobre la conservación del suelo durante este mismo período fortaleció la investigación sobre la base de los recursos naturales en todo el país. El tercer período se inició con la reorganización del CIAI, el establecimiento de las Universidades Agrícolas del Estado, y la introducción de programas coordinados de investigación sobre variedades de alto rendimiento (VAR). Al mismo tiempo, se establecieron los programas coordinados sobre investigación agrícola en las tierras secas, y subsiguientemente, se creó el Instituto de Investigación Central para la Agricultura en Tierra Seca (IICAT), lo cual llevó al desarrollo de un sistema nacional de ISC para agricultura a base de precipitaciones.

El cuarto período de ISC comenzó con el establecimiento de CIITSA (Instituto Internacional de Investigación de Cultivos para el Trópico Semi-Arido), centro internacional de investigación agrícola que aceptó como comisión la ISC y desarrolló conceptos para integrar las tecnologías de manejo de los diversos componentes del clima, suelo, agua y cosechas, y la perspectiva de los agricultores. El trabajo de CIITSA se complementó con el trabajo de IICAT y contribuyó a lograr cambios conceptuales en la ISC de la India a través de una investigación dirigida a comprender los principios y procesos de los sistemas de cultivo del trópico semi-árido (TSA). Luego de ello, se puso énfasis en los mecanismos para reforzar la investigación agrícola in situ a fin de proporcionar un vínculo más estrecho entre los investigadores, el personal de extensión, y los agricultores.

En la actualidad, la ISC según la perspectiva del agricultor ocupa un lugar primordial dentro de la agenda de investigación agrícola en la India. No obstante, queda mucho camino por recorrer para reducir la brecha existente entre la generación de la tecnología y su adopción por parte de los agricultores, quienes han demostrado una preferencia por los componentes individuales más que por el conjunto total de la tecnología en sí.

INTRODUCTION

This paper attempts to take stock of FSR in India over the past 60 years and provides a springboard for future FSR. It details how the national agricultural development priorities have evolved over time and how they have influenced the part played by FSR in national and international agricultural research institutions located in India.

Research in a systems mode is important for tackling the problems of dryland farming in India as drylands constitute 70% of the cultivated area in the country and irrigated dryland areas are the main food basket of the country.

FSR, by its very nature, is both farmer- and systems-oriented. Any proposed change in the existing farming system involves a series of careful considerations of agronomic, socioeconomic and infrastructural support services. Of late, issues related to environmental degradation have assumed importance, and sustainable farming systems hold the key to maintaining the quality of the environment.

FARMING SYSTEMS RESEARCH IN INDIA, 1930–1950

Historical perspective

Farming systems in subsistence agriculture are rather complex; they are based on agroecological, socioeconomic and technological factors, and are strongly influenced by farmers' perceptions, experiences and needs. Walker and Ryan (1990) observed that in some of the dryland farming tracts of central India as many as 20 different cropping systems are found in a village. Agricultural research in India at the beginning of the twentieth century was directed at cataloguing farmers' cropping practices. Some simple agronomic trials of the 'rates-and-dates' type were also initiated. The factors studied were replacement of crop or variety, and the effect of time of planting, irrigation, crop rotation, or the use of green manures and farmyard manure on crop yields. All this research was directed at subsistence agriculture through small and technologically feasible interventions, without the use of manufactured inputs.

During the colonial period prior to 1947, agricultural research concentrated on export-oriented commodities such as cotton, jute, sugarcane, tobacco, tea and coffee, rather than on food crops. It was aimed at plant breeding aspects rather than FSR. Plantation crops amenable to large-scale farming received most attention, but even so the approach to the improvement of cultural practices and use of companion crops and crop rotations was narrowly-based rather than FSR. The traditional farming systems used by farmers in India are based on centuries of experience, and the main aims are to achieve stability of production, provide subsistence for the family, and guard against weather aberrations and other environmental stresses. At the time, food surpluses were small and little emphasis was given to planned or centrally-coordinated research. Marginal improvements in crop yields occurred where improved methods were adopted but generally, farmers showed little interest in new techniques.

The Royal Commission on Agriculture

The Government of India, concerned about the rather dismal state of affairs in agriculture in the 1920s, appointed a Royal Commission on Agriculture. This reported that the Department of Agriculture had directed its research efforts entirely towards irrigated crops, which offered the best economic prospects for success (Royal Commission on Agriculture, 1928). The problems of agriculture in rainfed areas had been largely neglected. To emphasize the importance of well-organized agricultural research, the Commission recommended the establishment of an Imperial Council of Agricultural Research (ICAR). After independence this was renamed the Indian Council of Agricultural Research; the acronym remained unchanged.

Early research on dryland farming

ICAR was established in 1929 to conduct crop and agronomic research with special emphasis on food crops. Research on commercial commodities (such as cotton, sugarcane and jute) remained with the Commodity Committees set up by the Government of India in 1920 and this research was assured continuing financial support under the Commodity Cess Act of 1923 (Randhawa, 1979). Dryland farming research began in Bombay State (now called Maharashtra). It involved the study of soil and water conservation practices, land use and cropping systems, including intercropping and mixed farming, in drylands. Investigations were initiated in 1934–35 at five stations in the famine-stricken areas of the states Bombay, Mysore, Madras, Hyderabad and Punjab. The locations were Solapur (now in Maharashtra), Bijapur, Hageri, and Raichur (now in Karnataka), and Rohtak (now in Haryana). This research was funded by ICAR until 1943, when responsibility for funding transferred to the state governments concerned. The meagre support for dryland farming research was discontinued after independence in 1947, but this project represented the first organized attempt at the development of dryland farming systems based on traditional and subsistence agriculture for drought prone areas. It developed a holistic approach, with improved soil and water conservation achieved through deep tillage, contour bunding and mulching. Improvements in soil fertility were achieved by fallowing and green manuring. Improved agronomic and intercropping practices were employed. This project served as a trendsetter for FSR in India.

The dryland farming research lacked the support of an intensive plant breeding programme or an improved biological system for exploiting the environment. It was confined to adaptive trials with tillage practices for moisture conservation and locally selected landraces and included no research on animal production, although this is an integral part of farming systems in the arid regions of India. The package of practices that evolved was locally adapted, with names such as 'Bombay' or 'Madras' dry farming methods. The Bombay dry farming method claimed a yield advantage of 60 to 99% over the farmers' method or over the untreated control (Kanitkar *et al.*, 1960), but increases in production were meagre as the base yields were only 200–400 kg ha^{-1}. The increase in grain yield therefore barely amounted to 100–150 kg ha^{-1}, which was too small to enthuse the dryland farmers. For example, Kanitkar *et al.* (1960) reported that experiments conducted over seven years (1934–41) at Solapur resulted in increases in grain yields of only 36–132 kg ha^{-1} in sorghum grown under improved technology, with similar increases for other cropping systems (Table 1). On deep black soils, a cotton–sorghum rotation was more remunerative than conventional continuous sole cropping. Fallowing and alternative cropping on deep black soils gave good yields even in drought years. However, because of weather-induced risk, the location-specificity of improved technology, the poverty of dryland farmers, and the low market prices of agricultural commodities, the improved dryland farming practices remained largely unadopted and the traditional farming systems that ensured a crop sufficient to meet the minimum survival needs of the farmers remained in use.

In arid climates, subsistence farming based on millet and animal grazing continued to be the dominant system, with no significant improvement in yields or in input levels. Millet remained a poor man's crop suited only for marginal lands and rainfed farming. Dryland farmers were thus becoming increasingly dependent on animal husbandry as their prime source of income.

In the semi-arid tropics of India, cereal-based cropping systems, combining commercial crops such as cotton, groundnuts and pulses, were popular but

Table 1. *Yield (kg ha^{-1}) of crops from dryland farming experiments in Solapur, 1934–41*

	Deep black soil		Medium black soil		Shallow black soil	
	Grain	Straw	Grain	Straw	Grain	Straw
Monocrop sorghum						
Improved 'Bombay Dry Farming Method'	242	513	169	408	69	249
Farmers' mean yield, without improved method	110	276	80	291	33	162
Intercropping system						
Pearl millet and pigeonpea, five year mean (1937–42)	217	937 (millet straw)				
Groundnut and pigeonpea, four year mean (1938–42)	410	890 (groundnut haulms)				

Source: Kanitkar *et al.* (1960).

agricultural research organizations did not devote any appreciable resource or technical manpower to developing improved farming systems for these areas. There was an attempt to develop improved moisture conservation techniques and tillage practices, but these did not impress the dryland farmer as there was no improved technology for enhancing biological productivity. Thus the whole effort was geared toward stabilizing subsistence agriculture rather than toward developing new and more productive farming systems adapted to diverse environments.

Irrigation and farming system development

Irrigation is essential for improved agriculture and has consistently received a high priority in development programmes. However, expansion of irrigation stimulated research on commodity improvement rather than on farming systems development. It did not significantly change the farming system, except in canal-irrigated areas of the former state of Punjab, where irrigated food crops, cotton, sugarcane, forage crops and horticultural crops became an integral part of the farming system.

By the early 1940s, India's population had increased substantially, creating an urgent need to increase food production. A 'Grow More Food Campaign' was started in 1943 (Randhawa, 1979). This later gave further impetus to the increased production of food crops, and cotton, sugarcane, jute and tobacco, in the post-independence period, though little attention was given to the overall development of agricultural production systems. FSR and subsistence agriculture predominated in India up to 1950. Farming systems were based on low inputs and extensive rather than intensive agriculture, and even irrigation was used as a protective input to stabilize production rather than to increase productivity. Surface irrigation was provided through a network of canals, and groundwater irrigation remained largely unexploited. There was little indigenous fertilizer production in the country, and fertilizer trials were conducted mainly on research stations, where soil fertility and management conditions were not the same as on farmers' fields. The plant genotypes available were not capable of responding to moderate to high fertilizer inputs as high yielding varieties and crop hybrids had not yet been bred. Lack of industrial infrastructure and poor communication and transport facilities were severely limiting factors. The agricultural research enterprize considered food crops, particularly wheat and rice, to be of prime importance, but only under irrigated conditions. India's agricultural production between 1931 and 1947 remained stagnant, with an annual compound growth rate of only 0.03% (National Commission of Agriculture, 1976).

PLANNED AGRICULTURAL DEVELOPMENT IN THE 1950S AND 1960S

Planned agricultural development in India started in 1950. The First Five Year Plan (1951–56) gave special emphasis to agriculture, irrigation and rural development, encouraging extensification of traditional agriculture rather than the development of improved farming systems. Thus during the period of the plan, major increases in agricultural production came from increases in area rather than in productivity. Even the extensive network of agricultural extension built through the Community Project Programme failed to bring about changes in farming systems, as it lacked the support of appropriate technology and on-farm and on-station research. A project for the intensification of research on cotton, oilseeds and millet, based on the concept of agroecological regions, integrated farming systems and multidisciplinary research effort, also failed to develop new farming systems through lack of adequate financial support, back-up by research institutions and appreciation of the benefits of on-farm research.

The Government of India therefore sought the advice of experts in agriculture from several developed countries. Successive reviews were held in 1955, 1959 and 1963. The 1963 review recommended a complete overhaul of the agricultural research, education, and extension system, both at the central (federal) and at the state level (Randhawa, 1979). It suggested the reorganisation of ICAR, making it an autonomous central organisation for agricultural research and education, with all the central government agricultural research institutes and programmes under its umbrella. It also suggested the creation of State Agricultural Universities (SAUs), based on the pattern of the US Land Grant System and linked with ICAR as the central agency for the coordination of research and education.

The reorganisation of ICAR and the SAUs caused revolutionary changes in agricultural research and education and developed a strong National Agricultural Research System (NARS). It encouraged the use of science and technology for agricultural development, with research guided and coordinated by ICAR. This reorganisation was an inevitable result of the serious crises brought about by food shortages in the country. Mr C. Subramanian, the Union Minister of Agriculture in the Government of India, played a catalytic role in reorganising ICAR, and in outlining the new strategy for agriculture in the mid-1960s (ICAR, 1972). He emphasized the need for a dynamic research programme to produce a deliberate and calculated change in land use patterns, with agricultural change targeted at the farmer, its ultimate client. He also introduced the national demonstration programme and emphasized the linkages of researchers with farmers, giving impetus to research in farming systems with a farmers' perspective.

On-station and on-farm research

One of the early leaders in promoting the need for a coordinated network of experiments was Dr A. B. Stewart of the Macaulay Institute of Soil Research, Aberdeen, UK, who was invited by the Imperial Council of Agricultural Research (ICAR) in 1945 to advise on the planning of research on soil fertility and fertilizer use for increasing crop production. He suggested that ICAR should start a series of coordinated agronomic experiments at carefully selected centres representing different agroclimatic and edaphic regions, combined with simple manure trials on farmers' fields selected at random. Following these recommendations, ICAR initiated a coordinated programme of agronomic experiments in 1956, integrated with an existing US–FAO Technical Cooperation Mission (TCM) project on soil fertility and fertilizer use which had commenced in 1953. The experience gained from this project led to the establishment of a coordinated research project on maize in 1957, with financial assistance from the Rockefeller Foundation. Such coordinated research programmes have become the background of Indian agricultural research, with more than 76 projects now in operation (DARE, 1990).

The main objective of the complex agronomic experiments conducted at research stations was to obtain information on the response of crops to different conditions of soil, climate and cropping. The results obtained were markedly different from those obtained from the simple manure trials on farmers' fields (Mahapatra, 1971). The two sets of experiments were carried out by multidisciplinary teams of agronomists, soil scientists and statisticians, with the technical support of the Indian Agricultural Research Institute and the Indian Agricultural Statistics Research Institute at New Delhi, and were the most extensive continuing agronomic research effort ever conducted in India and the first type of FSR in India. The on-farm trials helped in the formulation of recommendations for a package of practices or component technology for increasing productivity. They showed that nutrient deficiency on farmers' fields is a major limiting factor, both under irrigated and rainfed conditions. Research before 1966 was confined to local improved varieties but later shifted to the development of cropping systems using high yielding varieties (HYVs) and high-input technology, with an emphasis on productivity with limited inputs.

Additional work was done at most of the central crop research institutes of

ICAR, the Indian Agricultural Research Institute, New Delhi and by the All-India Coordinated Research Projects on rice, wheat, sorghum, maize, millets, pulses, oilseeds, cotton, sugarcane, jute, forage crops, tubers, potatoes, horticultural crops and vegetables, as well as at the National Dairy Research Institute, Karnal. Another project involved intensive studies on cropping systems for irrigated agriculture and covered most of the irrigated areas of the country.

IRRIGATED FARMING AND FSR IN THE GREEN REVOLUTION ERA

Resource-based FSR

On the basis of data from the All India Coordinated Agronomic Trials (1979–85), Bhatnagar *et al.* (1989) identified a number of cropping systems which were more productive and profitable than traditional systems in different agroecological regions of India (Table 2). In areas with assured irrigation, use of fertilizers and good agronomic management, two to three crops can be grown successfully and 7–10 t ha^{-1} of grain can be harvested in a year. However, the optimum system varies with the needs and perceptions of the farmer, the availability of credit, labour and other inputs, and market demand. Attempts are now being made to introduce a network arrangement for cropping system research for irrigated areas in the 1990s.

The introduction of stiff-strawed, dwarf-type, fertilizer-responsive HYVs of wheat, rice, maize, sorghum and pearl millet led to the Green Revolution in India in the mid-1960s, as long-duration, photo-sensitive varieties were replaced by photo-insensitive short-duration HYVs, thus making new cropping systems possible, particularly in the irrigated areas. At the same time, the price support policy for wheat and rice ensured better returns for farmers, and the development of SAUs ensured adequate technological support, encouraging a shift from subsistence to intensive market-oriented agriculture, and from monocropping to multiple cropping in irrigated areas. Many of these HYVs also performed well in dryland farming and moisture deficient environments, and their large-scale introduction combined with suitable improved production technology caused one of the biggest changes in Indian agriculture of the century.

Cropping patterns

A national symposium on cropping patterns in India organised by ICAR provided an analysis of the existing situation and future needs for research on cropping systems. It highlighted the changing scenario in different states following the introduction of HYVs and improved technology. In the same symposium Kanwar (1972) proposed the concepts of Relative Yield Index and Relative Spread Index as criteria for identifying efficient and inefficient cropping zones.

The efficient zone of a crop is characterized by a high yield index, and a high spread index; it allows the dominant cropping system to achieve its maximum potential. The inefficient zone is characterized by a low yield index and a low

Table 2. *Mean grain and protein yields (t ha^{-1}), calories (K × 10^6 ha^{-1}) and gross returns (Rs × 10^3 ha^{-1}) obtained from the most promising cropping systems*

	Mean yield	Protein yield	Calories	Gross return
Subtropical zone of Jammu and Kashmir				
Rice–wheat–fallow	8.6	0.73	30	11.0
Rice–wheat–mung bean	7.0	0.61	24	9.5
Northern dry zone, Karnataka				
Sorghum–wheat–sorghum	9.1	0.97	31	11.2
Sorghum–chickpea–sorghum	8.7	1.03	30	11.9
Blackgram–cotton–safflower	NA	0.43	11	14.9
Southern zone of Kerala (humid tropics)				
Rice–rice–mung bean	7.3	0.49	25	8.3
Rice–rice–mung bean	7.4	0.53	25	8.4
Rice–rice–groundnut†	7.7 1.6†	0.96	35	13.0
North Konkan region of Maharashtra				
Rice–sorghum–mung bean	7.2	0.70	26	6.2
Rice–chickpea–sorghum	5.6	0.52	19	8.3
Rice–groundnut†–fallow	3.6 2.2†	0.84	25	8.6
Scarcity zone of Maharashtra				
Sorghum–chickpea–pearl millet fodder‡	7.8 46.0‡	0.97	28	16.8
Southern and humid zone of Rajasthan				
Rice–wheat–mung bean	7.4	0.69	25	8.4
North-western dry zone of Rajasthan				
Pearl millet–wheat–mung bean	6.3	0.80	22	8.8
Groundnut†–wheat–fallow	3.8 3.0†	1.27	30	14.0
South-western Uttar Pradesh				
Maize–wheat–mung bean	7.5	0.90	26	10.9
New alluvium zone of West Bengal				
Rice–wheat–maize	9.5	0.93	33	11.7

† Yield of oil seed crop; ‡ yield of forage.
Source: Bhatnagar *et al.* (1989).

spread index, indicating the need for the development of a more efficient cropping system. The intermediate crop efficiency zones are characterized by a high yield index and low spread index, or a high spread index and low yield index; for the former, research is needed to remove constraints to an increase in area and for the latter, constraints to an increase in yield. On the basis of these criteria for efficiency, Kanwar (1972) identified nine efficient cropping systems, based on

Table 3. *Realized potential yields ($t\ ha^{-1}\ a^{-1}$) of cropping systems in irrigated areas of India, 1940–1980*

1940	Monocropping	1.0
1950	Double cropping	2.5
1960	Double cropping (HYV)	10.0
1970	Double/triple cropping, HYV, improved technology, summer pulses/vegetables etc.	14.0
1980s	Efficient use of monetary and non-monetary inputs	15.2

Source: Mahendrapal *et al.* (1986).

rice, wheat, sorghum, pearl millet, sugarcane, cotton, maize, jute and plantation crops.

There are a large number of cropping systems suited to areas with irrigation or assured rainfall in India, but their full potential has yet to be exploited. However, Mahendrapal *et al.* (1986) showed that under favourable conditions, productivity had increased from 1 t ha^{-1} a^{-1} in 1940 to 15 t ha^{-1} a^{-1} in 1980 (Table 3). Intensive cropping systems that have become popular in the irrigated areas of north and central India following the introduction of HYVs include rice–wheat–mungbean, pigeonpea–wheat–mungbean, and soyabean–wheat–mungbean. Similarly, numerous new systems are replacing the traditional cropping systems based on cotton, jute, sugarcane, groundnut, sorghum and millets. Changing socioeconomic and technological factors are bringing profound changes in cropping systems in irrigated areas.

A national demonstration programme was taken up by ICAR in 1965 to intensify the adoption of improved technologies based on HYVs. This programme concentrated on adaptive research with farmers' participation, with irrigated trials involving several cropping systems using HYVs and improved technology. These simple on-farm trials compared the traditional cropping system with one or two improved cropping systems using a package of practices. They were farmer managed but supervised by researchers and were each conducted on a minimum of 0.4 ha. Initially simple varietal trials were grown, but in later years multiple cropping systems were progressively introduced. During 1985 and 1986 (ICAR, 1989), more than 1000 national demonstrations involving promising technologies were laid out on farmers' fields jointly by ICAR and SAUs. Most of these trials included multiple cropping systems and many involved farming systems that combined cropping systems, horticultural crops, dairy farming and related activities. In some (Prasad, 1989), the yields exceeded 11 t ha^{-1} a^{-1} and the returns to the farmers exceeded the traditional farming systems many fold (Table 4).

FARMING SYSTEMS RESEARCH FOR DEGRADED LANDS

A chain of soil conservation demonstration and training centres was set up during the 1950s to develop soil and water conservation systems to increase productivity

Table 4. *National average yields 1971–84 (t ha^{-1}), compared with the average and highest observed yields from National Demonstrations Plots*

	National average yield	National demonstration average	Highest average yields from national demonstrations
Paddy	1.8	5.1	11.5
Wheat	1.5	3.7	7.6
Maize	1.1	3.3	7.5
Sorghum	0.6	3.7	7.1
Pearl millet	0.5	2.6	4.8

Source: Prasad (1989).

and reduce erosion from the degraded lands of rainfed areas. These centres evolved methods for the mechanical measurement of erosion control, and developed effective land use systems based on the best engineering, agronomic, and soil and water management practices. They also trained staff in soil conservation, although their research was limited in scope and concept. In 1967 these centres were transferred to ICAR and one of the leading centres, at Dehra Dun, was converted into a Central Soil and Water Conservation Research and Training Institute with seven regional stations. The research achievements of these centres over the 15 years from 1956 to 1971 have been reviewed by Tejwani *et al.* (1975), who showed that although the research undertaken was on multidisciplinary lines it remained mostly component-oriented, equating soil conservation with contour bunding. Research on alternative land use systems and integrated farming systems based on the watershed concept became more prominent after 1971, but has yet to make a significant contribution to real farm situations.

The watershed management approach has been effective in improving the productivity of land by reducing erosion through the introduction of appropriate land use systems, but it has proved difficult to obtain the cooperation of small farmers who own small parcels of land in the watershed. However, when the social aspects have been effectively managed, as in Sukhomajri and Nada villages in Haryana, the equitable distribution of the benefits of watershed management has ensured the acceptance of the system even by small farmers (Mittal and Gurmel Singh, 1990; Indian Farming, 1989).

FARMING SYSTEMS RESEARCH IN THE SUB-HUMID AND HUMID TROPICS OF NORTHEAST INDIA

Shifting cultivation, locally known 'Jhumming' is widely practised in the hills of northeast India and in tribal areas of Andhra Pradesh, Madhya Pradesh and Orissa. The traditional system followed a 20–30 year rotation cycle, but population pressures and the increasing demand for food have shortened the rotation cycle to between three and six years (ICAR, 1983). Research on farming systems with improved technology to replace shifting cultivation by permanent agriculture was initiated by ICAR in 1975 with the establishment of an Agricultural Research Complex for the North Eastern Hill Region at Shillong. In this region, upland rice is the main crop and is grown in mixture with maize, finger millet (*Eleusine coracana*), setaria, beans, tapioca, yam, banana, sweet potato, ginger, cotton, tobacco, chillies, sesame and vegetables. After two or three years of cultivation the land is left fallow to allow the regeneration of forest vegetation and improvement of soil fertility, but the productivity of the land is declining and food shortages are increasing.

A comparison of shifting cultivation with alternative improved farming systems conducted by ICAR from 1975 to 1980 indicated that bench terraces and contour bunds for conservation, combined with a permanent agricultural system, provide a more stable and remunerative system than shifting cultivation, provided the conservation measures are properly maintained and improved crop management practices and fertilizer are used. Research also showed that the best land use pattern for hill slopes is agroforestry for the upper third of the slope, a horticultural-pastoral system for the middle slope, and agriculture or crop-based systems for the lower part of the slope. The best land treatment is contour bunding for the upper slope, half-moon shaped terracing for the middle slope, and bench terracing for the lower slope.

FARMING SYSTEMS RESEARCH IN THE HUMID TROPICS

Plantation crops such as coconut, arecanut, cashewnut, tuber crops, banana and pepper are the main crops of the humid tropics in India, especially in Kerala, parts of Tamilnadu, Karnataka, and Andhra Pradesh. The Central Plantation Crops Research Institute and the Coordinated Project on Plantation and Tuber Crops have been leaders in research on mixed cropping and farming systems based on the dominant commodity of interest to small farmers. According to the ICAR Quinquennial Review Team's report for the years 1982–87 (personal communication), intercropping with tuber crops, pineapple and banana is the most promising system in coconut-based farming, while in the mixed cropping system, a combination of coconut with cocoa, pepper and pineapple is the most efficient mixture. A net return of Rs 23 000 ha^{-1} (13 rupees = 1 US dollar in 1987) was obtained from an irrigated intercropped plantation, compared with Rs 11 400 from a sole crop of irrigated coconut, and Rs 6 900 from a sole crop of rainfed coconut. Growing grasses and forage legumes between the coconut palms and raising milk cows is another promising farming system. Besides the normal crop of coconut, five cows can be raised successfully on one hectare of land, giving Rs 14 500 ha^{-1} a^{-1} net profit. The sustainability of the various systems is still being evaluated, but the farmers need better genotypes and improved components of the technology to increase productivity, sustainability and profitability.

FARMING SYSTEMS RESEARCH IN ARID REGIONS

The main limitations to crop production in arid regions are low precipitation and high evaporative demand. The soils are sandy, and wind erosion and the frequent drought are serious problems. To study these problems and to develop a sustainable agriculture, the Government of India established a desert afforestation station at Jodhpur in 1952, which was later converted into the Central Arid Zone Research Institute (CAZRI), Jodhpur, in 1959 with support from UNESCO and the Australian government. It is responsible for developing agroforestry, silvipasture, agro-horticulture and crop–animal based farming systems for the arid zones of India, with an emphasis on socio-economic constraints and the development of farming systems that ensure the efficient management of resources.

Before the Green Revolution, the research at CAZRI concentrated on improving subsistence systems of farming, the stabilization of sand dunes, shelter belt establishment, the selection of shrubs, trees and grasses suitable for different ecological zones, and improving the productivity of crops and animals suited to these environments. Progress was limited by the lack of biologically-superior plant material. However, after the introduction of HYVs, especially hybrid pearl millet in 1964, the institute started introducing more productive genotypes of crops and packages of practices to improve the traditional arid zone farming systems. Emphasis also shifted to the use of water harvesting and recycling to stabilize and increase productivity. Crossbred sheep and scientific range management systems were effectively used for developing improved crop and animal-based farming systems. In the 1980s, silvipastoral, agroforestry and agro-horticultural systems of farming started to receive greater research attention.

FARMING SYSTEMS RESEARCH IN THE SEMI-ARID TROPICS

The reorganised ICAR formulated plans for dryland agricultural research in India following the Green Revolution of the mid-1960s and developed an All India Coordinated Research Project for Dryland Agriculture (AICRPDA) in 1967, comprising a network of 24 research centres. The project was approved by the Government of India, which initially allotted a budget of Rs 5 million to introduce dryland farming research at the soil conservation research and training centre directly under the ICAR management. However, to strengthen and extend the support for research into dryland agriculture to all 24 research centres, and to give it a national priority, the budget was enhanced to Rs 18.7 million from 1970, and headquarters for the coordinating centre of AICRPDA were established at Hyderabad. The centres included in the network of this important research project catered for the needs for technology development for different agroecological regions. The work in the semi-arid tropics (SAT) was relevant to nearly 80% of the geographical area of the country, so this formed the major thrust of the project. The SATs are defined as areas where the mean monthly temperature exceeds 18°C and where precipitation exceeds potential evaporation for two to seven months a year (Troll, 1965). Areas with two to four-and-a-half wet months are called dry semi-arid and those with four-and-a-half to seven wet months as wet dry semi-arid. The SAT environment is characterized by strongly erosive and variable rainfall, by soils that are generally of poor fertility, by numerous biological constraints and by complex risk-reducing farming systems which combine crops and livestock.

The Government of India also allotted a further Rs 200 million for pilot projects to verify, validate and adapt dryland technology on farmers' fields. The research scientists were encouraged to use the pilot project areas as 'on-farm research laboratories'. Financial and technical assistance from Canada enabled AICRPDA to operate an interdisciplinary research team at every centre, consisting of an agronomist, a plant scientist, a soil scientist and an engineer, with supporting scientific staff and with other specialists at the central Coordinating Centre at Hyderabad. In 1985, the project headquarters were upgraded to form the Central Research Institute for Dryland Agriculture (CRIDA). Most of the ICAR-funded FSR relevant to dry farming is carried out at ICAR central agricultural research institutes at Hyderabad, Jodhpur, Dehra Dun, Shillong, the Andaman and Nicobar Islands, and at the SAUs.

A major contribution to FSR in the SAT is also made by ICRISAT, the international centre set up in 1972, which combines its efforts with the NARS in producing dryland farming technology for use in the semi-arid tropics. FSR at ICRISAT had strong implications for research organisation and management but was highly relevant to the SATs of India. Because the national programme is more suited to the development of location-specific applied and adaptive research, FSR at ICRISAT gave priority to strategic and basic research, with the aim of understanding principles and processes, and developing conceptual models through path-breaking research for improving farming systems. It was directed at the identification of constraints, diagnostic surveys, the development of components and packages of component technology for enhancing productivity, sustainability, and the economic viability of a soil- and climate-specific farming system using base data analysis, on-station and on-farm research, but excluding diagnostic surveys and benchmark village level studies.

Conceptual changes in FSR at AICRPDA/CRIDA

Reviews of the achievements of ten years (AICRPDA, 1982) and fifteen years of dryland agricultural research in India (CRIDA, 1986) provide an insight into the development of farming systems research in the national programme. The change from simple experiments to systems research has been an evolutionary process, with a series of phases of research development (Singh, 1983).

At first, AICRPDA attempted to change the traditional farming system by replacing the long-duration photosensitive varieties of crops with the higher-yielding short-duration and non-photosensitive varieties (HYVs). It also mounted a programme for screening and modifying landraces and locally improved varieties for their adaptability to a range of environments typical of the rainfed areas in India.

In the first phase, which coincided with the world oil crisis, which made fertilizers and pesticides, the two important inputs in agriculture, expensive and unattractive to risk-prone agriculture, research was aimed at developing technologies involving low monetary inputs. Extensive investigations showed that plant nutrient deficiency was as serious a yield-limiting factor as moisture stress; that matching of genotypes and nutrients with moisture availability in the soil would make the farming system more efficient; and that the short duration HYV and hybrids, though developed for more favourable environments, showed equally good potential in the moisture stressed environments of SAT. Thus development of dryland technology all over India was aimed at improving the productivity of existing crops and cropping systems, and adapting the new genotypes to those cropping systems.

In the second phase (1975–80), much effort was directed at studying long term climatic data (Singh, 1987) in order to minimize risk during crop growth. During the same period ICRISAT worked on concepts for intercropping and on environmentally adapted cropping systems. ICRISAT also started research on strategies for changing the physical, chemical and biological environments and their management, resulting in the concepts of watershed Vertisol management technology.

The third phase (1980–85) considered integrated farming system development. This period was marked by an appreciation of the importance of soil and rain water management technology and of integrated nutrient management techniques and their integration with cropping systems. Growing awareness of agroclimatological and socioeconomic factors, agroforestry, tillage and land-use system research influenced research on dryland agriculture during this period.

In the final phase (1985–90) the concept of watershed management was appreciated, with acceptance of responsibility for research on watersheds in different agroclimatic regions. In this, CRIDA/ICRISAT collaboration has stimulated greater research effort on farming systems and sub-systems and on the components of integrated dryland technology. The development of farming systems research in India has thus been an evolutionary process in which the national and international agricultural research organisations have played complementary roles.

LOOKING AHEAD

During the last quarter of a century Indian agriculture has gradually moved from a tradition-based, subsistence-oriented enterprise to a science-based and market-oriented enterprise. The most important single development has been the ability of Indian farmers to continually enhance agricultural production and productivity, thereby ensuring greater food availability and security for an ever-increasing population. The commodity-based strategy of farming systems is making greater progress than resource-based farming systems, but the concept of the farming system is having an impact on both research and development.

The successes of the Green Revolution are built on the scientific use and upgrading of germplasm. Agronomic technology and inputs were tailored to meet the demands of the HYVs, the key element of the Green Revolution. This mode of intensive agriculture is costly and is more suited to favourable environments, such as areas with irrigation or good rainfall. The less well-endowed ecosystems now need greater attention. In future the attributes of different agro-environments will be defined in crop breeders' terms and new genotypes will be tailored to match these environments. Special efforts will have to be made to use biotechnology to expand the gene pools for our major crops and cropping systems, including agroforestry, silvipastoral and agro-horticultural systems. Interdisciplinary research, including crop scientists, resource management scientists and social scientists, and using an FSR perspective, will have to develop a strategic plan for future farming systems development for the important agroecological zones of India. Modelling research should be at the forefront of this effort. This will need to seek ways to measure and evaluate the rapid and often profound changes brought about by changes in farming systems, and to alert the policy makers to these consequences.

Greater research effort is needed on new farming system development, to provide better options for farmers and raise their sights toward greater productivity. Sustainability and profitability are important considerations for a good farming system. Although India has one of the largest agricultural research systems in the world, and has used the concept of coordinated multidisciplinary research for over three decades, the major emphasis has still been on commodity-oriented rather than resource-oriented research and much less emphasis has been given to the integration of both.

The partnership between the international agricultural research centres and the development of regional zonal centres and SAUs, which provide an infrastructure for a networking arrangement of interdisciplinary research in different agroecological regions, offer a better future for FSR in India. To produce synergistic effects, the combined strengths of international agricultural research in basic and strategic research and of national programmes in applied and adaptive research are necessary.

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