Management of Fertilizer Nutrients Other Than Nitrogen in the Semiarid Tropics of India

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Abstract

Available information on the management of fertilizer nutrients other than nitrogen in the semiarid tropics (SAT) of India (about 96 million ha) is reviewed. Crop responses to fertilizer nutrients are high under dryland conditions. Phosphorus and then zinc are of major importance for the nonirrigated SAT, but significant yield responses to potassium and sulfur, in addition to P and Zn, are also obtained under dryland conditions in the reddish brown lateritic soils of the Bangalore area. Iron chlorosis is increasingly being mentioned as a problem in the SAT. Available information on P, K, S, Zn, and Fe has been reviewed by continuously searching for information applicable to rainfed systems in irrigation-oriented overall research in nutrient management and soil fertility even for major dryland crops. Suggestions for further research have been made for the nutrients reviewed.

Introduction

The SAT cover nearly two-thirds of the 143 million ha net cropped area in India. Two-thirds of the SAT area does not have access to conventional irrigation, and farming systems are mostly rainfed/dryland. The SAT areas are spread over ten states (Andhra Pradesh, Gujarat, Haryana, Karnataka, Madhya Pradesh, Maharashtra, Punjab, Rajasthan, Tamil Nadu, and Uttar Pradesh). The nonirrigated SAT areas occur primarily in central Andhra Pradesh, Gujarat, Karnataka, Madhya Pradesh, Maharashtra, and eastern Rajasthan.

Improving the productivity of the nonirrigated SAT is crucial for the future development of Indian agriculture, the well-being of millions of farmers who live off these lands, and the production of high-value crops such as pulses, oilseeds, and cotton. Three statements concerning the SAT/drylands are often made: (1) the drylands are more hungry than thirsty; (2) lack of water management, not lack of water, is a key constraint in many areas; and (3) by growing suitable varieties and adopting improved soil-water-fertilizer management practices, crop yields can be increased substantially without irrigation.

This paper reviews available research on the management of fertilizer nutrients other than nitrogen in the semiarid tropics of India. The nutrients covered are phosphorus, potassium, sulfur, zinc, and iron because these are considered to be of sufficient practical importance at present and/or in the near future. Results discussed pertain mostly to nonirrigated conditions. Discussion on N is included only where it is a component of nutrient interactions or for the complete description of a system.

Research Scenario and the Development of Fertilizer Use

Soil fertility and fertilizer use have been important components of agricultural research in India. However, specifically for rainfed/dryland systems, apart from field experiments to study fertilizer responses, research has always been and continues to be glaringly weak. This is because research on SAT soils or crops grown on them often includes liberal application of water. Research programs that have studied crop responses to nutrients under nonirrigated conditions have not gone into nutrient dynamics, balances, or soil fertility/crop response correlations. Virtually the entire research effort of otherwise well-developed, coordinated research programs such as on soil test/crop response correlations, long-term fertilizer experiments, and secondary and micronutrients is under irrigated conditions.

The net result of the above scenario is that, except for data on field responses to nutrient applications, detailed information on nutrient management, transformations, balances, and interactions is either lacking, piecemeal, or derived from data pertaining to fully or partially irrigated conditions. It is important to recognize this feature in order to initiate realistic, in-depth research programs aimed at providing answers to questions on nutrient management that are specific to the unirrigated SAT agriculture.

It is a well-known fact that fertilizer use in India, which is at present 9 million tonnes nutrients, continues to be confined largely to irrigated areas or to nonirrigated cash crops. Fifty percent of the total fertilizer is consumed in only 69 of the more than 350 districts. In a general analysis, the mean fertilizer consumption in predominantly nonirrigated SAT districts was 31% of that in the predominantly irrigated SAT districts (Jha and Sarin, 1984). Since irrigated and nonirrigated holdings coexist in a given district or village, small pockets of irrigated lands in predominantly rainfed areas can dominate the fertilizer-use pattern.

Dryland cereals, millets, pulses, and oilseeds probably receive very little fertilizer other than some N on the high-yielding varieties (HYVs) and some P on groundnut. A fertilizer demand study had projected that the share of sorghum and pearl millet in the "effective demand" in 1986/87 could be 3.0% of the total demand for N, 2.2% for P, and 1.7% for K, even though these two crops occupy 15% of the gross cropped area (NCAER, 1978).

There is a lack of systematic surveys and monitoring of fertilizer application rates and management practices actually used by the farmers. The application of P is recommended for most dryland crops while recommendations for K, S, and Zn are gradually emerging for specific soil-crop conditions.

Role of Nutrients in Dryland Crop Production

At the research level, the importance of fertilizer nutrients is well recognized for increasing the yields of dryland crops. With improved technology, including the use of N and P in Vertisols, Alfisols, and Inceptisols, crop production in the SAT can be substantially increased (Kanwar, 1986). Crop responses to fertilizer are high under dryland conditions (CRIDA, 1987). Deficiencies of P and Zn are quite widespread, whereas those of K, S, and Fe occur on a much smaller scale; where they do occur, however, the application of these fertilizer nutrients results in significant yield increases, as discussed later.

Nutrient uptake and removal by crops per unit yield may not be much different under irrigated and nonirrigated conditions. An idea of the amounts of nutrients absorbed by important crops to produce a tonne of economic yield is provided in Table 1, primarily as background information. The nutrient drain caused by common dryland crops is no less than the drain by irrigated crops. Application of fertilizer plus improved management techniques can increase the yield of dryland crops three- to sevenfold (Table 2).

To understand the importance of fertilizer, it must be seen as a component of the package of improved practices and not in isolation. Under well-managed conditions, using proven sorghum hybrids, grain yields of 5-6 tonnes ha^{-1} and dry-matter yields of 11-12 tonnes ha^{-1} can be

Table 1. General Estimates of Total Uptake of Nutrients Per Tonne Economic Yield

Crop	N	P_2O_5	K_2O	Ca	Mg	S	Zn	Fe	Mn	Cu	B	Mo
	(kg)						(g)					
Rice	20	11	30	7.0	3.0	3.0	40	153	675	18	15	2
Maize	26	14	36	5.4	7.8	3.8	130	1,200	320	130	-	-
Wheat	25	9	33	5.3	4.7	4.7	56	624	70	24	48	2
Sorghum	22	13	34	6.4	4.8	2.8	72	720	54	6	54	2
Pearl millet	42	23	91	-	-	-	40	170	20	8	-	-
Chick-pea	46	8	50	-	-	-	38	58	30	14	-	-
Pigeon pea	64	18	42	-	4.0	3.3	24	40	14	14	-	-
Groundnut	58	20	30	28.0	7.3	5.7	28	1,500	118	15	133	4

Source: Compilations by Kanwar and Youngdahl (1985), Kemmler and Hobt (1987), Munson (1982), Tandon and Sekhon (1988).

Table 2. Impact of Fertilizer Application on Grain Yields Under Rainfed Conditions at the ICRISAT Center

Crop	Average SAT Yield (30 Years)		Fertilizer Level A		Fertilizer Level B	
	kg ha^{-1}	Base	kg ha^{-1}	Relative to Base	kg ha^{-1}	Relative to Base
Sorghum	842	100	2,627	312	4,900	582
Pearl millet	509	100	1,636	321	3,842	755
Chick-pea	745	100	1,400	188	3,000	403
Pigeon pea	600	100	1,000	167	2,000	333
Groundnut	794	100	1,712	216	2,572	324

Fertilizer Level A: 43 kg N + 20 kg P_2O_5 ha^{-1} for sorghum and millet, 20 kg N + 20 kg P_2O_5 ha^{-1} for other crops.
Fertilizer Level B: 86 kg N + 40 kg P_2O_5 ha^{-1} for sorghum and millet, 18 kg N + 46 kg P_2O_5 ha^{-1} for chick-pea and pigeon pea, 60 kg P_2O_5 ha^{-1} for groundnut.

Source: Kanwar (1986).

attained without irrigation (Sivakumar and Huda, 1983). Taking sorghum again, multi-location research has shown that the yield gap between the crop planted early and that planted during the traditional (late) period can be as much as 1.1-3.7 tonnes ha^{-1}, with obvious impact on fertilizer efficiency (Spratt and Chowdhury, 1978). Trials with grain legumes show that 25%-35% of achievable yield can be lost if fertilizer is not applied (Chandra and Ali, 1986).

The importance of nutrients in dryland agriculture needs to be seen from several angles, such as the role of P in enabling crops to grow deeper roots and absorb water from the subsoil during periods of drought, the role of K in regulating transpiration losses and bringing about water economy, the role of S in increasing total oil yield per unit area by improving seed yield as well as oil content, to cite a few examples.

Phosphorus

Phosphorus Status of Soils and Crops

Widespread phosphorus deficiency in the Indian SAT is one of the most limiting factors for producing high yields (De, 1988; Kanwar, 1986; Rao and Das, 1982; Tandon, 1987; Venkateswarlu, 1987). In six states that together have a cropped area of 98 million ha, 80% of which is rainfed, soils in 44% of the districts have been categorized as low in available P and those in 55% of the districts as medium in available P (Table 3). An analysis of 24 districts, which accounted for 50% of the total sorghum area, showed that the P-fertility rating was low in 15 districts and medium in 9 districts (Tandon and Kanwar, 1984).

Table 3. Generalized P and K Fertility Status of Some SAT Areas

State	Available Phosphorus Number of Districts			Available Potassium Number of Districts		
	Low	Medium	High	Low	Medium	High
Andhra Pradesh	17	4	0	2	13	6
Gujarat	5	13	1	0	0	19
Karnataka	15	4	0	3	9	6
Madhya Pradesh	15	30	0	3	9	30
Maharashtra	15	10	0	0	13	12
Rajasthan	1	22	3	0	5	14

Source: Ghosh and Hasan (1976, 1979).

In a survey of the P status of standing crops, the percentage of samples found deficient in P was as follows: 98% for groundnut, 24%-52% for sorghum, 28% for maize, 94% for finger millet, and 6% for pearl millet (Singh and Venkateswarlu, 1985). In Maharashtra State, a survey of 74 sorghum fields showed that the percentage of P-deficient (<0.2% P) samples was 58% in shallow soils, 42% in medium deep soils, and 27% in deep black soils (Narkhede et al., 1981). Some workers from the same state have reported that P responses are obtained only on shallow black soils (Patil et al., 1981), whereas others have reported significant responses to P on medium black soils (Nagre, 1982).

The relative abundance of common forms of inorganic P is governed largely by the degree and intensity of weathering and can be reasonably predicted by the prevailing pH. In neutral-alkaline soils, Ca-bound forms of P dominate, whereas in very acid soils, Al- and Fe-bound forms are more abundant along with the reductant-soluble and occluded forms. In a Vertisol of pH 7.5-8.2 and containing 60%-69% clay, the Al-, Fe-, and Ca-bound forms accounted for 56% of the total P and individually for 5%, 15%, and 36% of total P (Bapat et al., 1965). In the Alfisols, the order of dominance can be Fe-P > Ca-P > Al-P (Goswami and Sahrawat, 1982). The chemical/surface reactivity of the Al- and Fe-P forms has been shown to be greater than that of Ca-P, and thus the Al- and Fe-P forms are capable of making a contribution to available P that is greater than their relative abundance. Lack of data on P transformations as affected by soil and crop systems under field conditions is a missing link (Goswami and Sahrawat, 1982).

Crop Responses to Phosphorus

There is a considerable volume of data on the responses of crops to P application under a wide range of soil-climatic conditions in India (Tandon, 1987). It is necessary to mention at the outset that (1) field response data are available from both "on-station" and "on-farm" experiments and (2) yield responses by themselves may not provide the complete picture because dryland crops vary threefold in their unit market value, and thus an agroeconomic perspective is necessary while evaluating fertilizer responses. This is illustrated in Table 4.

Table 4. Break-Even Response Ratios for Some Important SAT Crops to the Application of P, K, Zn, and S

Crop	Official Procurement Price (Rs/tonne)	Kilogram Grain Needed to Pay for 1 kg Input: P_2O_5	K_2O	S	$ZnSO_4$
Sorghum	1,320	4.5	1.7	1.5	4.6
Chick-pea	2,800	2.1	0.8	0.7	2.1
Pigeon pea	3,250	1.8	0.7	0.6	1.8
Groundnut pods	3,900	1.5	0.6	0.5	1.5
Mustard	4,150	1.4	0.5	0.5	1.4

Procurement prices announced for 1986/87.
US $1 = Rs 14 approximately.
Prices of input: Rs 6.0 per kg P_2O_5 through SSP/DAP; Rs 2.2 per kg K_2O through MOP; Rs 2 per kg S and Rs 6 per kg zinc sulfate.

Cereals and Millets – Experiments by the All India Coordinated Research Project on Dryland Agriculture (AICRPDA) show that 30-50 kg P_2O_5 ha^{-1} increased sorghum grain yield by 9 kg per kg P_2O_5 (Singh and Venkateswarlu, 1985), and trials by the Coordinated Sorghum Project suggest a mean optimum level of 40 kg P_2O_5 ha^{-1} for sorghum HYVs in the rainy season (Singh et al., 1981). In a review of fertilizer research on sorghum, responses to P at the research stations in the rainy season were found to range between 7.3 kg and 34.3 kg grain per kg P_2O_5 (Tandon and Kanwar, 1984). The magnitude of response was generally in the order red soils > alluvial soils > black clay soils. It was also observed that (1) at similar levels of available P, a black soil could support a higher yield level than a red soil; (2) sorghum varieties exhibited differential response to P application, and their ranking for responsiveness to P was similar to their ranking for yield potential; and (3) P application increased grain yield by producing 16%-46% more grain per ear and also resulted in a 5%-22% improvement in the harvest index.

Estimates of nutrient responses based on a large number of "on-farm" fertilizer experiments without irrigation have been periodically summarized. Table 5 is

Table 5. Average Crop Responses to the Application of P and K in a Large Number of "On-Farm" Experiments in India During 1977-82, Under Unirrigated Conditions

Crop	Season	Kilogram Grain Response Per Kilogram of P_2O_5	K_2O
Sorghum	Kharif	7.0-10.6	5.1-8.8
Sorghum	Rabi	5.3-11.1	3.7-6.9
Pearl millet	Kharif	3.2-8.1	2.1-8.2
Blackgram	Kharif	3.0-6.2	0.8-8.4
Blackgram	Rabi	3.9-6.6	2.9-4.7
Chick-pea	Rabi	3.7-11.4	0.7-5.7
Pigeon pea	Kharif	4.6-10.7	0.3-5.6

Responses are average values of experiments in a state.
Responses for P are to 30 kg P_2O_5 ha^{-1} over 90 kg N for cereals and millets and to 40 kg P_2O_5 ha^{-1} over 20 kg N for legumes.
Responses to K are to 30 kg K_2O ha^{-1} over 60 N and 60 P_2O_5 for cereals and millets and to 20 kg K_2O ha^{-1} over 20 N and 40 P_2O_5 for legumes.

Source: Randhawa et al. (1985).

based on data reported by Randhawa et al. (1985). Unit responses to P range from 3 to 11 kg grain per kg P_2O_5. This wide range includes many dryland crops. Yields of finger millet and maize in the P-deficient reddish brown lateritic soils of Bangalore can be increased by 1-2 tonnes ha^{-1} without irrigation as a result of P application (AICRPDA, 1983b).

Pulses – Chick-pea and pigeon pea together occupy about 11 million ha, that is, nearly half of the total area under pulse crops. Low soil fertility and lack of weed control have been identified as two major constraints to improving the yield of pulses (Chandra and Ali, 1986). Among nutrients, P-deficiency is stated to be the major cause for low yields (Saraf and Ganga Saran, 1986). Grain yields of 2.5-4 tonnes ha^{-1} can be obtained with optimum fertilizer use when combined with other improved practices. Reviewing the results of about 2,200 trials, Tandon (1987) reported an average response of 7.8 kg grain per kg P_2O_5. In addition to response data summarized in Table 5, some responses of chick-pea to P application under rainfed conditions are given in Table 6. Phosphorus application increased yield by 13%-42%. Optimum rates of P application for rainfed chick-pea range from 20 kg to 75 kg P_2O_5 ha^{-1} (AICRPDA, 1983a).

Table 6. Responses of Chick-Pea to Fertilizers Under Dryland Conditions in Rajasthan

Application Rate			Response to Treatment			
			Alwar District		Chittorgarh District	
N	P_2O_5	K_2O	($kg\ ha^{-1}$)	(%)	($kg\ ha^{-1}$)	(%)
---($kg\ ha^{-1}$)---						
0	0	0	(1,338)	-	(927)	-
20	0	0	+470	35	+215	23
20	40	0	+638	48	+598	65
20	40	20	+954	71	+689	74
Number of trials			48 (1975-77)		58 (1978-82)	

Sources: Rawal and Yadava (1986), Rawal and Bansal (1986).

Responses of pigeon pea to P application have been obtained both at research stations (Ahlawat et al., 1985) and on farmers' fields (Table 5). These are, in general, similar in magnitude to those for chick-pea, and optimum application rates recommended are in the range of 40-60 kg P_2O_5 ha^{-1} (AICRPDA, 1983a). In certain situations, such as the Vertisols at the ICRISAT Center, responses of pigeon pea to P application have not been obtained (Kanwar, 1986). Possible reasons stated for this nonresponsiveness include role of mycorrhiza, low P requirement of the crop, and ability of the crop to absorb P from very low concentrations.

Oilseeds – The P requirement per unit yield is highest for oilseeds as compared with other field crops. Yield responses of oilseeds to P have been summarized by several workers (Ankineedu et al., 1983; DOR, 1984, 1985; Kanwar et al., 1983; Kulkarni et al., 1980b; Singh and Venkateswarlu, 1985; Tandon, 1987). Results of 2,462 fertilizer experiments on the response of groundnut to P in 11 soil types are given in Table 7. The unit response ratios varied from 4 to 15 kg pod per kg P_2O_5. Responses were highly significant in the red, red and yellow, coastal alluvial, red loamy, and laterite soils. At research stations as well as in trials on farmers' fields, 20-60 kg P_2O_5 ha^{-1} has been found remunerative for oilseeds under a variety of conditions (AICRPDA, 1983a; Ankineedu et al., 1983; Kulkarni et al., 1980b). In some situations, either no or little response of groundnut to P has been observed. Restricted soil moisture has been reported to be the prime factor for low/erratic response in such cases (Patel and Kanzaria, 1985). Correlation of available P with pod yield and nutrient uptake indicated that subsoil fertility made an important contribution to nutrient uptake by groundnut (Patil and Patel, 1982).

Table 7. Response of Groundnut to Phosphorus Application in "On-Farm" Experiments Conducted Between 1959 and 1970

Soil Group	Number of Trials	Mean Response ($kg\ kg^{-1}\ P_2O_5$)
Red and yellow (Vertisol)	226	15.4
Coastal alluvial (Entisol)	39	9.8
Red loams (Oxisol)	62	9.6
Alluvial soil (Inceptisol)	1,065	8.3
Red sandy soil (Alfisol)	842	5.6
Medium black soil (Vertisol)	381	5.5
Deep black soils (Vertisol)	313	4.8
Response needed to pay for P		1.5

Source: Kanwar et al. (1983), Kanwar (1986).

From 1,014 farm field trials, Pillai et al. (1984) reported an average increase of 300 kg seed ha^{-1} for rapeseed mustard in response to 40 kg P_2O_5 ha^{-1}. Based on a large number of "on-farm" trials, the economical P_2O_5 rates for various oilseeds were reported to be 30-40 kg ha^{-1} for mustard, 40 kg ha^{-1} for safflower, and 15 kg ha^{-1} for niger (Kulkarni et al., 1980b).

Factors Affecting Crop Responses to Phosphorus

The importance of crop variety in affecting the quantum of yield response to P has been stated. The following factors are also briefly discussed.

Available P Status of Soil – It is a common observation that higher responses are obtained in soils that are low in available P than in high-P soils. This general trend is evident also in the drylands (Tandon and Kanwar, 1984). Much of the soil test/crop response correlation research in India is applicable to irrigated systems. Results with dryland wheat in Punjab show that the response to applied P was determined largely by the soil's available P status and the stored soil moisture (Singh et al., 1979). Grain response was 10 kg per kg P_2O_5 where available P_2O_5 was 31-47 kg ha^{-1} and 18 kg per kg P_2O_5 in soils testing 13-15 kg ha^{-1} available P_2O_5. Based on the ICRISAT experience, critical levels of P are reported to be lower in the Vertisols than in the Alfisols (El-Swaify et al., 1985). Mycorrhiza has been shown to modify the critical level of P for pearl millet (Krishna and Dart, 1984).

Methods of P Application – Drilling or placement of fertilizer P below the soil surface is a proven practice for improving the efficiency of P. It is almost universally recommended for the dryland crops (AICRPDA, 1983a; De, 1988; Kanwar, 1986; Singh and Venkateswarlu, 1985). Subsurface drilling of P brings about 23%-69% increase in yield as compared with a broadcast application (Tandon, 1987). Results with finger millet show that drilling of seed + DAP mixture to provide 40-50 kg P_2O_5 ha^{-1} was a feasible practice (Hegde and Reddy, 1984). In rainfed soybean, mixing of DAP with seed was satisfactory at 40 kg P_2O_5 ha^{-1} but caused loss in yield at higher rates of P application (Singh and Singh, 1986).

Interactions of Phosphorus

Three major interactions involving P are those with genotype, nitrogen, and moisture. In commonly conducted field experiments, it is reasonable to assume that a part of the response attributed to P is in fact due to the positive N x P interaction. The N x P interaction is very important for dryland agriculture. It can account for 50%-60% of the combined response to an NP application, as shown in Table 8 for sorghum and finger millet. Nutrient interactions have also been discussed by Kanwar (1986) in general and by Tandon and Kanwar (1984) for sorghum in particular.

Table 8. The Significance of N x P Interaction in Dryland Agriculture

	Response			Estimated Contribution of		
Crop	N	P	N+P	N	P	NP Interaction
	-----	(kg ha^{-1})	----	---------	(%)	--------
Sorghum	110	490	1,570	7	31	62
Finger millet	390	170	1,300	30	13	57

Source: Singh and Venkateswarlu (1985).

The interaction effect of P with plant population produced a yield advantage of 26% in pigeon pea (Ahlawat and Saraf, 1981). Interaction of P with weed control also added 26% to chick-pea yields (Saraf and Ganga Saran, 1986).

Sources of Phosphorus

In general, fertilizers containing most of their P in water-soluble form are preferred for field crops in the SAT (Kanwar, 1986). In the acidic P-deficient soils of Bihar, powdered rock P has been found useful for pulses and oilseeds if (1) applied 20-25 days before seeding, (2) at double the usual rates at seeding, or (3) in suitable combination with a water-soluble source (Mohsin et al., 1984). About 95% of all fertilizer P distributed in India is in water-soluble form. Single superphosphate, by virtue of its having S and Ca in addition to P, is usually favored for groundnut (Reddy, 1985).

Phosphorus and Water Use Efficiency

Efficient use of available water deserves as high a priority as efficient use of nutrients in dryland agriculture. A number of findings on the role of P in improving water use efficiency (WUE) are given in Table 9. The application of P increased water use efficiency by 15%-20% in dryland wheat, 22%-25% in finger millet, 41%-99% in chick-pea, 17% in linseed, and up to 19% in mixed chick-pea + wheat stands. Increase in water use efficiency due to P application is greater on coarse-textured soils than on fine-textured soils (Singh et al., 1985). This characteristic is quite important because it provides extra production support to soils that have low moisture storage capacity. Such results also underscore the role of P in promoting extensive and deeper root growth, which makes the water stored in deeper soil layers accessible to them. This can be very important during droughty periods when the surface soil dries up. Work with transpiration suppressants has shown that spraying of CCC or Atrazine on spring sorghum increased water use efficiency by 31%-53% and P uptake by 17%-21% (Boobathi Babu and Singh, 1984a, 1984b).

Table 9. Effect of Phosphorus Application on the Water Use Efficiency (WUE) of Dryland Crops

Crop (Soil)	Input (kg P_2O_5 ha^{-1})	Grain Yield (kg ha^{-1})	CWU (cm)	WUE (kg grain cm^{-1})	Reference
Finger millet	0	1,336	29	46	AICRPDA (1983b)
(Red)	50[a]	2,223	31	72	
Chick-pea	0			72	Singh and Tiwari (1985)
(Alluvial)	40			143	
Wheat	0	1,630	22	76	Singh et al. (1983)
(Alluvial)	40	2,140	24	91	
Wheat + chick-pea	0	1,697	26	65	Singh et al. (1985)
(Alluvial)	20	2,057	27	77	

a. Combined NP effect due to the application of 50 kg ha^{-1} of N and P_2O_5.

CWU = Consumptive water use; WUE = Water use efficiency.

Phosphorus Management in Cropping Systems

Research on nutrient management in cropping systems focuses mostly on N and very little on other nutrients. A number of recent reviews underscore this general lack of research on nutrient management in systems involving major crops of the SAT (ISA, 1985).

A sorghum/pigeon pea intercropping system removed 31% more P than did a stand of sole sorghum (Kanwar, 1986). Results obtained by AICRPDA suggest that in cereal-legume intercropping, application of P to the cereal components is satisfactory (Singh and Venkateswarlu, 1985). A 6-year research study of sorghum/pigeon pea intercrop followed by castor shows that the total productivity of the system was highest when 50 kg P_2O_5 ha^{-1} was applied to the main system and castor was raised on residual fertility (Venkateswarlu et al., 1986). Other reports emphasize that, in intercropping systems, P recommendations should be able to meet the needs of all the component crops (Ahlawat et al., 1985; Mohsin et al., 1984; Singh and Upadhyay, 1985). There is a dearth of long-term experiments in this area.

Phosphorus Recommendations for Dryland Crops

Phosphorus application is recommended for most dryland crops (AICRPDA, 1983a). Tandon (1987) analyzed the P recommendations generated by the 23 research centers of AICRPDA and found that, of 113 soil-crop situations, the quantities of P_2O_5 recommended per hectare were 15-30 kg for 35%, 30-45 kg for 56%, and 45-60 kg for 9%. Some general recommendations per hectare for P_2O_5 were in the range of 20-50 kg for sorghum, 20-40 kg for millet, 20-75 kg for chick-pea, 30-60 kg for pigeon pea, 25-50 kg for groundnut, 15-60 kg for mustard, 15-40 kg for wheat, 25-50 kg for finger millet, and 40-60 kg for soybean.

Areas for Future Research

1. Strengthening of soil fertility research in dryland research programs and of dryland research in soil fertility-oriented projects operating in the dryland areas.
2. Establishment of long-term fertilizer experiments on adequately characterized sites under rainfed conditions and detailed monitoring of the fertility dynamics and balances.
3. Field verification of critical limits of soils and crops that originated from pot experiments.
4. Nutrient-indexing surveys of standing crops and relating the results to soil fertility status.
5. Extension of soil test/crop response correlation work to rainfed areas.
6. Evaluation of the P fertility status of high-clay soils on the basis of effective root zone and specific surface area of the soil rather than on a per-hectare basis.
7. Expansion of research on interactions of P with N and water.
8. Initiation of field-based research on mycorrhiza, its contribution to the P nutrition of SAT crops, and its role in solubilizing the relatively less available fractions of soil P.
9. Expansion of research on P management in intercropping systems.
10. Strengthening the plant physiology input in soil fertility research.

Potassium

Potassium Status of Soils and Crops

Soil deficiencies of potassium in the unirrigated SAT are important only in certain coarse-textured soils, in some red soils, and at high yield levels obtained without K application for a period of time (AICRPDA, 1983b, 1988; Venkateswarlu, 1987). Some possible areas of K deficiencies are soils of the Anantapur and Karimnagar area in Andhra Pradesh (Venkateswarlu, 1984), red soils of the Bangalore area (AICRPDA, 1983b), and several alluvial soils in Uttar Pradesh (Ghosh and Hasan, 1976). Soil test ratings may not always agree with the K status of standing crops. In Kurnool and West Godavari districts of Andhra Pradesh, rated as medium-high in available K, 29%-60% of the groundnut crop samples were reported to be deficient in K (Subba Rao, 1975).

According to Sekhon (1985), much of the work on K has concentrated on determination of forms of K and that too in soils which cannot be properly correlated because information on soil classification and mineralogy is generally lacking. In soils of the semiarid and arid areas, the K-bearing minerals may be relatively less weathered and therefore potentially capable of releasing more K into the system. However, moisture stress during the crop season may impose a limitation on the extent of actual K release (Sekhon, 1983).

As an average over 19 benchmark soils, of the 1.82% total K_2O in surface soils, 92% was found to be present as mineral K, 6.3% as nonexchangeable K, 1.6% as exchangeable K, and 0.2% as solution K (Tandon and Sekhon, 1988). By now, it is also well recognized by research workers that the nonexchangeable fraction makes a significant contribution to the K taken up by crops and that some measure of this fraction should be included in K-fertility evaluation.

Crop Responses to Potassium

Conclusions about the response of dryland crops to potassium application based upon "on-station" research can be markedly different from those based on "on-farm" experiments. Although responses to K at the research station are indeed not common, responses on farmers' fields are common enough to merit attention (Table 5). It is irrelevant that these are lower than the responses to other major nutrients because the per-unit price of potash is also 30%-40% that of N and P.

Cereals and Millets – Unit responses to K in a large number of on-farm trials were 2-10 for cereals and millets (Table 5). Among major dryland systems, the reddish brown lateritic soils of the Bangalore area are most interesting from the point of view of multiple nutrient deficiencies. The surface soils have a pH of 5.0, available K_2O of 150 kg ha^{-1}, and cation exchange capacity (CEC) of 7.1 me/100 g. Yield responses of dryland maize and finger millet to potassium, along with other nutrients in these soils, are summarized in Table 10. Yield increases per unit K_2O were 7.3-8.7 for finger millet and 15-21 for maize.

Table 10. The Nutrient Response Profile of Acidic Reddish Brown Lateritic Soils (Oxic Haplustalf), Bangalore, Under Dryland Agriculture

Nutrient	Crop	Years Studied	Input (kg ha^{-1})	Yield (kg ha^{-1})	Response (kg kg^{-1} input)
N	Finger millet	4	0	1,820	
			25	2,620	32.0
			50	2,850	20.6
			75	3,060	16.5
N	Maize	2	0	1,950	
			50	4,170	44.4
			75	4,460	33.5
P_2O_5	Finger millet	4	0	1,960	
			30	2,450	16.3
			60	2,840	14.7
P_2O_5	Maize	2	0	2,900	
			30	3,390	16.3
			60	4,170	21.2
P_2O_5	Pigeon pea	2	0	1,550	
			30	1,750	6.7
			60	2,040	8.2
K_2O	Finger millet	3	0	2,860	
			30	3,080	7.3
			60	3,380	8.7
K_2O	Maize	3	0	3,770	
			30	4,220	15.0
			60	5,030	21.0
$ZnSO_4$	Maize	4	0	4,120	
			5	4,490	74
			10	4,630	51
S	Groundnut	3	0	1,310	
			10	1,547	23.7
S	Sunflower	2	0	910	
			10	1,165	25.5

Compiled from data in AICRPDA (1983b). Response to the application of the indicated input is over the general application of other major nutrients at recommended rates.

Kharif sorghum responded significantly to 30 kg K_2O ha^{-1} in 697 trials conducted in Andhra Pradesh, Madhya Pradesh, and Maharashtra States. Responses to potash were inferior in the post-rainy season in all states (Tandon and Sekhon, 1988). Rainfed finger millet responded to 30 kg K_2O ha^{-1} in Karnataka and Orissa with a mean response of 10 kg grain per kg K_2O. Of 247 trials with pearl millet, responses were obtained only in Andhra Pradesh. The yield increase was 7 kg grain per kg K_2O.

Pulses – In fertilizer experiments on farmers' fields, the responses to potash were variable, but application of 20 kg K_2O ha^{-1} was beneficial in a large number of cases for chick-pea, pigeon pea, and blackgram in the presence of 20 kg N and 40 kg P_2O_5 (Kulkarni et al., 1980a). In a set of 16 field trials, highest yields of chick-pea were obtained with an application per hectare of 18 kg N, 46 kg P_2O_5, and 20 kg K_2O (Chandra and Ali, 1986). In soils rated as high in available K, potassium application increased chick-pea grain yield by 9%-23% (Table 6). It is important to view the yield responses of high-value crops in terms of economics in order to have the correct picture. As an example, a physical yield increase of 9 kg grain per kg P_2O_5 for sorghum is as profitable as a yield increase of 1.6 kg grain per kg K_2O for chick-pea, as illustrated in Table 4. In Andhra Pradesh, responses of pigeon pea to potassium application in on-farm trials were 5.5 kg grain per kg K_2O (Tandon and Sekhon, 1988).

Oilseeds – The remunerative doses of potassium for various oilseeds varied from 20 kg to 40 kg K_2O ha^{-1} in a large number of "on-farm" trials with groundnut, mustard, sunflower, safflower, and castor (Kulkarni et al., 1980b). Responses of groundnut to potassium both in Kharif and Rabi were significant in Andhra Pradesh, Karnataka, and Tamil Nadu with an average of 3 kg pods per kg K_2O applied at 40 kg ha^{-1}.

Method of Potassium Application

The most commonly advocated method of applying K_2O is to apply the recommended rate by drilling or placement as a part of the basal dose before planting.

Potassium and Moisture Stress

Potassium may improve water use efficiency and help to maintain crop yields under moisture stress or reduce the extent of crop loss under such conditions (Saxena, 1985). The mechanism of the role of K may be osmotic adjustment, and it is different from that of P, which largely influences root development. Because drought occurrences are quite common in the SAT, intensive research in this area might be very valuable for increasing and stabilizing production.

Potassium Dynamics Under Continuous Cropping

There is a real dearth of long-term fertilizer experiments under nonirrigated conditions. In the Alfisols at ICRISAT Center, an 8-year experiment was conducted using a 2-year rotation of improved cropping system (T. J. Rego, 1987, personal communication). The exchangeable K at the site was 59 ppm initially. It was found that sorghum grain, sorghum stalk, millet stalk, groundnut pods, and pigeon pea grain did respond to applied K but the responses were small. In sorghum grain, these ranged from 10% to 28%. The experiment indicated that, though the site was marginally deficient in available K for all the crops, the severity of K deficiency did not increase with time. Further, the exchangeable K in the soil changed very little after 8 years indicating significant supplies from the nonexchangeable pool. Because the nonexchangeable pool is large, one may not expect a big response to applied K in the near future in spite of harvesting moderately good yields.

In contrast to the ICRISAT site, the exchangeable potassium status of the red soil at Bangalore dropped from 160 kg K_2O ha^{-1} to about 65 as a result of continuous cropping without K application from 1977 to 1987 (AICRPDA, 1988). In response to a range of K levels applied in 1987, grain yield of finger millet increased by 994 kg ha^{-1} as an average of three varieties at an application rate of 75 kg K_2O ha^{-1}. Both the local and the improved varieties of finger millet responded significantly to potassium application. Potash application is recommended for dryland cereals in Bangalore.

Areas for Future Research

1. Establishment of long-term experiments on well-characterized sites under rainfed conditions, with priority on red soil areas.
2. Research on the role of K in drought tolerance of crops, its effect on water economy, and its impact on water use efficiency (with adequate plant physiology input).
3. Assessment of the contribution of leaf fall and other recycled residues in adding K to the SAT soils.
4. Development of methodologies for evaluating the K-fertilizer status of soils by integrating the exchangeable and nonexchangeable fractions.
5. Effect of different rainfall patterns on the distribution of various forms of potassium in soils of varying texture and mineralogical composition.

Sulfur

Sulfur Status of Soils and Crops

Research on sulfur is much less than that on other important nutrients (N, P, K, Zn). Sulfur has recently been included in the mandate of the coordinated research program of the Indian Council of Agricultural Research (ICAR), which was earlier confined to micronutrients. It is now being recognized that sulfur deficiencies are widely scattered and not confined to the coarse-textured alluvial soils as traditionally thought. Although these may occur to a varying degree in 90 districts, the available database is grossly inadequate to delineate S-deficient areas (Takkar, 1988; Tandon, 1986). The following assessments are particularly relevant for the SAT:

1. On an average, 17% of the soils in Gujarat State are considered to be deficient in sulfur (Patel, 1988).
2. Sulfur deficiencies are considered to be limiting crop production in many parts of Karnataka (Badiger and Shivraj, 1988).
3. In Madhya Pradesh, results of 1900 soil analyses from 12 districts indicated that 28%-88% of the samples in different districts were deficient in sulfur (Shinde, 1984).
4. In Maharashtra, very meager information is available on the sulfur status of soils under different climatic conditions (Karle et al., 1985).

Although 10 ppm available S is commonly employed as the critical limit for delineating S-deficient/responsive sites, these levels can vary from 8 ppm to 30 ppm depending upon the soil, crop, and the analytical method used (Goswami, 1988; Takkar, 1988). Field-based critical limits and field verification of pot-based critical limits are fit subjects for future research. In the Kurnool and West Godavari districts of Andhra Pradesh, 70%-90% of the groundnut plants were reported to be deficient in S in a survey conducted during the 1970s (Subba Rao, 1975).

There is lack of information on sulfur transformations, particularly under dryland conditions. In general, these may resemble nitrogen transformations. Mineralization of organic S may lead to a flush of sulfate S in soils after a prolonged drought or during normal dry periods (Kanwar and Mudahar, 1986). Depending upon soil texture and intensity of rainfall, part of this mineralized S can leach.

Crop Responses to Sulfur

Although responses to sulfur application have been reported for over 30 crops under field conditions, most of these are obtained under irrigation (Tandon, 1986). Without irrigation, some information is available for oilseeds. As a broad indication for the tropics and subtropics, amounts of S absorbed per tonne of yield production have been given as 3-4 kg for cereals, 5-8 kg for millets, 8 kg for pulses, and 12 kg for oilseeds (Kanwar and Mudahar, 1986).

Significant responses of groundnut to the application of S either through gypsum or elemental S have been reported from Andhra Pradesh (Raman and Subba Rao, 1979). For rainfed groundnut in coarse-textured well-drained, neutral to slightly alkaline soils, application of 40 kg S ha^{-1} through gypsum has been found useful (Pasricha and Rana, 1985). In a medium black soil analyzing 8.7 ppm available S and 0.38 ppm available B, groundnut responded up to 120 kg S ha^{-1}. Sulfur application increased pod yield by 927 kg ha^{-1}, which was further increased by 387 kg ha^{-1} as a result of the application of 15 kg borax ha^{-1} (Karle and Babula, 1985). In this single-season trial, the S + B application increased groundnut yield by 1.5 times and oil yield by 1.8 times. In the red soils of Bangalore, application of 10 kg S ha^{-1} increased pod yield of groundnut by 237 kg ha^{-1} or 18% (Table 10).

Some responses of rainfed mustard to S have been summarized by Ankineedu et al. (1983) and by Aulakh and Pasricha (1988). Sulfur increased seed yields by 17%-28% at moderate yield levels (Table 11). Results with rainfed mustard that received preplanting irrigation show that a combined P + S application increased grain yield by 564 kg ha^{-1}, of which 49% could be attributed to P, 41% to S, and 10% to the P x S interaction (Rauth and Ali, 1985).

Table 11. Response of Mustard to Sulfur Application Under Nonirrigated Conditions

State	Input	Grain Yield Without S	Increase With S
	(kg S ha^{-1})	(kg ha^{-1})	(%)
Orissa	20	960	17
Punjab	30	400	124
Rajasthan	20	1,090	28
Rajasthan	50	1,420	25
Uttar Pradesh	30	1,600	18

Sources: Ankineedu et al. (1983), Aulakh and Pasricha (1988).

Five years of field experiments with taramira (*Eruca sativa*) on a soil testing 7 ppm available S in Haryana showed that S application increased seed yield by 400 kg ha^{-1}, primarily by increasing the number of silique per main shoot from 16 to 22. It also increased water use efficiency by 60% (B. P. Singh, 1983). In assessing the practical value of S responses, it was computed that each unit of S applied to S-deficient soils could augment by three units the supply of edible oils, a commodity in which India is facing a severe deficit (Tandon, 1986).

Recent agronomic studies have demonstrated that S application can improve the yield and quality of pulses (Saraf, 1988). Much of the evidence for this at present is based on irrigated experiments.

Sources of Sulfur

There is very little research on the comparative evaluation of sulfur sources for the unirrigated SAT. The most commonly recommended sources for groundnut are either gypsum or single superphosphate. For nonlegumes, ammonium sulfate can provide N as well as S while ammonium phosphate sulfate (APS) can provide N, P, and S.

Sulfur Recommendations

The most common recommendation is for the application of gypsum or of N and P through S-containing sources. On S-deficient soils, the application of 20-40 kg S ha^{-1} from most of the S-containing fertilizers is highly economical and essential for boosting crop production, particularly of oilseeds and pulses (Takkar, 1987). In the red soils of Bangalore, 10 kg S ha^{-1} is now recommended for rainfed groundnut. For rapeseed and mustard, 20 kg S ha^{-1} is recommended in S-deficient soils (DOR, 1984).

Areas for Future Research

1. Delineation of S-deficient/responsive areas by a two-pronged approach of soil analysis and plant analysis.
2. Determination of the S requirement of SAT crops in relation to productivity under Indian conditions.
3. Monitoring of the S input through rainfall and residues.
4. Study of sulfur responses in dryland cropping systems, particularly ones that include pulses and oilseeds.
5. Standardization of plant composition parameters to generate data applicable to Indian SAT conditions.
6. Study of sulfur transformations in SAT soils in relation to changes in moisture status.
7. Field verification of critical levels of S in soils and plants based on pot experiments.
8. Initiation of fertilizer experiments on cultivators' fields with an S treatment, as has been done for NPK for a quarter of a century. A small beginning in this direction has been made by the FAO sulfur network.

Zinc

Zinc Status of Soils and Crops

Among the micronutrients, research on zinc has received maximum attention, for which the major input has been provided by ICAR's coordinated scheme on secondary and micronutrients. Zinc deficiencies have been found to be widespread. These are considered to be more frequent in arid and semiarid soils than in the humid or subhumid zones (Katyal and Vlek, 1985).

A summary of about 93,000 soil analyses shows that 47% of the soil samples contained less than 0.6 ppm DTPA-extractable Zn and were therefore categorized as deficient in Zn (Table 12). The proportion of Zn-deficient samples in major states of the SAT varies from 26% in Gujarat to 77% in Haryana. In general, the extent of Zn deficiency increased with increase in soil pH and decreased with a decrease in organic matter and clay content (Takkar and Nayyar, 1986).

Table 12. Distribution of Soil Samples Deficient in Micronutrients in Major SAT Areas

State	Zinc		Copper		Manganese		Iron		Boron		Molybdenum	
	TSA	PSD	TSA	PSD	TSA	PSD	TSA	PSD	TSA	PSD	TSA	PSD
Andhra Pradesh	4,405	51	3,197	0	3,197	1	3,197	1				
Gujarat	21,994	26	21,994	4	21,994	1	21,994	8	1,715	1	1,715	11
Haryana	14,472	77	13,739	4	12,435	7	12,778	33				
Karnataka	2,318	24	2,318	4	2,318	1	2,318	1				
Madhya Pradesh	7,643	63	6,786	1	6,801	4	7,070	5	1,249	3	927	18
Punjab	13,341	53	12,531	4	12,421	1	12,564	15				
Tamil Nadu	7,540	36	7,545	10	7,254	11	7,064	19				
Uttar Pradesh	6,093	69	5,098	1	4,774	1	5,710	8				

TSA = Total soil samples analyzed; PSD = Percent samples deficient.

Data Source: ICAR Micronutrient Project Results compiled by Katyal (1985).

Critical limits for DTPA-extractable Zn may range from 0.35 for chick-pea to 1.2 for sorghum (Table 13). The impressive number of soil analyses carried out, however, does not provide an all-India picture. For example, it cannot be concluded that because 47% of the samples analyzed were deficient in Zn 47% of India's cropland is zinc-deficient. This is primarily because micronutrient research continues to be concentrated in nine states, and within these, 54% of all soil analyses originate from three states that account for 12% of the agricultural area, that is, Gujarat, Haryana, and Punjab (Tandon, 1988). In Maharashtra, a major SAT state, it has recently been concluded that studies on Zn are restricted to a few areas and most of the conclusions drawn are based on pot experiments (Malewar, 1987).

Table 13. Critical Levels of Available Zinc Used in India

DTPA-Extractable Zn (ppm)	Crop	Soil	State
0.35	Chick-pea	Red and black	Madhya Pradesh
0.40	Groundnut	Alluvial	Andhra Pradesh
0.50	Raya[a]	Alluvial	Haryana
0.50	Pigeon pea	Alluvial	Haryana
0.50-0.60	Groundnut	Red	Andhra Pradesh
0.52	Finger millet	Alluvial	Madhya Pradesh
0.60	Chick-pea	Alluvial	Bihar
1.0-1.2	Sorghum	Red and black	Tamil Nadu

a. Raya is *Brassica juncea*.

Source: ICAR Micronutrient Project data from Takkar and Nayyar (1986).

The two main climatic factors affecting micronutrient transformations are temperature and moisture. Little work on their effect on the SAT crops has been reported. Dry soil conditions can reduce the uptake of micronutrients (Kanwar and Youngdahl, 1985). The reactions of Zn added to soil proceed rapidly, and a substantial proportion may be converted into relatively unavailable forms. The absorption/desorption reactions of Zn are pronounced in fine-textured alkaline soils and least in coarse-textured acid soils (Katyal and Deb, 1982).

Crop Responses to Zinc

On a gross basis, there is a considerable volume of field data on crop responses to Zn (Katyal, 1985; Takkar and Nayyar, 1986; Randhawa and Nayyar, 1982). However, for the major crops of the SAT, there is very little information without irrigation. In Madhya Pradesh, for example, 80% of the 204 experiments on the response to Zn were on rice and wheat (Rai and Rathore, 1987). In Andhra Pradesh, application of 5 kg Zn ha^{-1} (25 kg zinc sulfate) increased the grain yield of rainfed sorghum by 80-410 kg ha^{-1} (Subba Rao, 1975). In the red soils of Bangalore having an initial 0.33 ppm available Zn, application of 10 kg zinc sulfate ha^{-1} increased the yield of dryland maize by 510 kg ha^{-1}, returning Rs 12.8 for every rupee invested in Zn (Table 10). According to Joshi et al. (1987), there is immense scope to increase groundnut yields through correction of micronutrient deficiencies.

Differential Response of Genotypes to Zinc

It is well known that varieties of the same crop may respond differentially to a given level of soil or applied Zn. Several crop varieties have been listed for their relative tolerance or susceptibility to Zn deficiency by Kanwar and Youngdahl (1985) and by Kaur (1987). The review by Kaur (1987) lists chick-pea genotypes P 6628 and N 59 and groundnut genotypes M-13 and TG-3 as relatively tolerant to zinc deficiency. Very little work has been conducted under field conditions, and the hazards of screening under protected environments are depicted in Table 14, taking wheat as an example. Sorghum hybrid CSH-1 has been reported to be more susceptible to zinc deficiency than Swarna (Subba Rao, 1975). A field experiment with six finger millet varieties in Bihar has shown that yield responses to 5 ppm Zn varied from 2% to 59% among varieties. Zinc uptake per tonne of grain production varied from 101 g to 151 g Zn, but the ranking of genotypes for this parameter remained the same with or without the application of Zn (Sakal et al., 1985).

Table 14. Susceptibility of Wheat Varieties to Zinc Deficiency According to Screening System Used

System	Susceptibility to Zn Deficiency: Variety Kalyan Sona	Variety WG 357
Sand culture	High	Low
Pot culture (soil)	Medium	Medium
Field	Low	High

Sources: Randhawa and Takkar (1976), Kaur (1987).

Sources of Zinc

The most commonly tested, advocated, and available source of Zn in India is zinc sulfate heptahydrate containing about 21% Zn. Mahendra Singh (1983) has dealt with the desirability of incorporating Zn into suitable phosphatic carriers in view of the widespread deficiencies of P and Zn in Indian soils.

Zinc Recommendations

General recommendations are to apply zinc sulfate as a basal soil application at the rate of 25 kg ha^{-1} in coarse-textured soils and 50 kg ha^{-1} in fine-textured soils once in 1-3 years in Zn-deficient soils. Recommendations specific to dryland conditions are still to emerge (AICRPDA, 1983a) except for the application of 10 kg zinc sulfate ha^{-1} for rainfed maize at Bangalore. For groundnut, the Directorate of Oilseed Research recommends 25 kg zinc sulfate ha^{-1} once in 3 years (DOR, 1985).

Areas for Future Research

1. Characterization of the available zinc status of SAT soils in relation to soil properties and climatic parameters.
2. Research on transformation of Zn and other micronutrients under typical dryland conditions.
3. Investigations on important interactions involving Zn such as with N, P, S, and moisture.
4. Field verification of critical limits for soils and crops.
5. Field-based research on the differential response of crop varieties to micronutrient stresses. To make such research productive, coordination with seed production agencies will be necessary.
6. Field data on the uptake and removal of micronutrients in relation to yield under dryland conditions.
7. Studies on the role of root systems of different crops in responding to micronutrient stresses.
8. Correlation of on-farm data with soil test data. Although a large number of on-farm experiments are conducted, the yields obtained are not correlated with soil test data. Such correlations can provide field-tested critical levels.
9. Effect of climatic features that are characteristic of the SAT (wet spells, droughty periods) on changes in micronutrient availability in the soils.
10. Information on the residual effects of Zn in order to determine the optimum rates and periodicity of application.

Iron

Iron Status of Soils

Iron is the most abundant micronutrient in soils and also the one taken up by most crops in largest amounts (Table 1). Yet iron deficiencies are next only to those of Zn. In general, iron deficiencies may be one-fourth as extensive as those of Zn, but an examination of district-level data shows that, in many areas, these may be as important as Zn (Table 12).

In the highly alkaline soil, under drought conditions and long dry spells, iron deficiency is a possibility in Andhra Pradesh (Subba Rao, 1975). Recent reports show that groundnut variety TMV-2, which is extensively grown in the state, is particularly sensitive to iron deficiency under dryland conditions even in red soils (Venkat Raju et al., 1987). It was reported that the iron content of leaves did not reveal any deficiency, but the yield was increased as a result of spraying iron compounds.

The commonly used critical levels of available iron in soils vary from 3.2 to 7.2 ppm of DTPA-extractable Fe (Table 15). In the Vertisols of Karnataka, DTPA-extractable iron was significantly and negatively correlated with calcium carbonate content (Murthy and Viswanath, 1987). These workers suggested that Fe-deficiency in these soils could be due to the precipitation of iron on the carbonate surfaces. The problem of iron chlorosis has manifested itself on several crops in large areas of Maharashtra (Daftardar, 1987). Although research on Fe is well behind that on Zn, the nutrient is worth watching in the coming years.

Table 15. Critical Limits of Available Iron Used in India

DTPA-Extractable Fe (ppm)	Crop	Soil	State
3.2	Wheat	Alluvial	Haryana
4.0	Maize	Black	Gujarat
4.4	Sorghum	Alluvial	Haryana
6.0	Sorghum	Black	Madhya Pradesh
7.2	Chick-pea	Alluvial	Bihar

Source: ICAR Micronutrient Project data from Takkar and Nayyar (1986).

Although research on iron application to unirrigated SAT crops is yet to be fully undertaken, iron should not be allowed to be unduly overshadowed by zinc. Kaur (1987) has listed some genotypes of chick-pea (T-1, BD-9-3, Chaffa, G-20) and groundnut (TG-1, TG-7, TG-17, Kadiri) reported to be relatively tolerant of iron chlorosis. Research on combating iron deficiencies needs to be pursued. This will require the joint efforts of plant physiologists, breeders, and agronomists/soil scientists.

References

Ahlawat, I.P.S., and C. S. Saraf. 1981. "Response of Pigeonpea to Plant Density and P Fertiliser Under Dryland Conditions," *J. Agric. Sci.*, 97:119-124.

Ahlawat, I.P.S., et al. 1985. "Research Needs and Directions in Pigeonpea Based Cropping Systems," IN *Proc. Natn. Symp. Cropping Systems*, pp. 183-209, Indian Society of Agronomy.

AICRPDA. 1983a. "Improved Agronomic Practices for Dryland Crops in India," All India Coordinated Research Project on Dryland Agriculture.

AICRPDA. 1983b. "Highlights of Dryland Research in Red Soils of Karnataka (1971-1983)," All India Coordinated Research Project on Dryland Agriculture and University of Agricultural Sciences.

AICRPDA. 1988. *Annual Report, 1987-1988*, All India Coordinated Research Project on Dryland Agriculture, Bangalore Center.

Ankineedu, G., et al. 1983. "Advances in Fertiliser Management for Rainfed Oilseeds," *Fert. News*, 28(9):76-90 and 105.

Aulakh, M. S., and N. S. Pasricha. 1988. "Sulphur Fertilisation of Oilseeds for Yield and Quality," IN *Sulphur in Indian Agriculture*, Proc. TSI-FAI Symp., S II/3/1-14.

Badiger, M. K., and B. Shivraj. 1988. "Present Status and Future Strategies of Sulphur Research Needs in Karnataka," IN *Sulphur in Indian Agriculture*, Proc. TSI-FAI Symp., PD II/4/1-8.

Bapat, M. V., et al. 1965. "Forms of Phosphorus in Vidharba Soils," *J. Indian Soc. Soil Sci.*, 13:31-36.

Boobathi Babu, D., and S. P. Singh. 1984a. "Studies on Transpiration Suppressants on Spring Sorghum in North-Western India in Relation to Soil Moisture Regimes. I. Effect on Yield and Water-Use Efficiency," *Exp. Agric.*, 20:151-159.

Boobathi Babu, D., and S. P. Singh. 1984b. "Studies on Transpiration Suppressants on Spring Sorghum in North-Western India in Relation to Soil Moisture Regimes. II. Effect on Growth and Nutrient Uptake," *Exp. Agric.*, 20:161-170.

Chandra, S., and M. Ali. 1986. *Recent Achievements in Pulses Production*, Tech. Bull. 1, Directorate of Pulse Research.

CRIDA. 1987. *Research Highlights*, Central Research Institute for Dryland Agriculture, Hyderabad, India.

Daftardar, S. Y. 1987. "Recent Studies on Problems of Iron Chlorosis of Upland Rice and Sugarcane in Maharashtra," IN *Natn. Symp. Micronutrient Stresses in Crop Plants: Physiological and Genetical Approaches to Control Them*, Rahuri, pp. 158-177.

De, R. 1988. *Efficient Fertiliser Use in Summer Rainfed Area*, Fertiliser and Plant Nutrition Bull. 11, Food and Agriculture Organization of the United Nations.

DOR. 1984. *Rapeseed, Mustard, Sunflower, Linseed*, Extn. Bull. 1, Directorate of Oilseed Research.

DOR. 1985. *Groundnut, Sesamum, Niger, Sunflower, Castor*, Extn. Bull. 2, Directorate of Oilseed Research.

El-Swaify, S. A., et al. 1985. "Soil Management for Optimised Productivity Under Rainfed Conditions in Semi-Arid Tropics," *Adv. Soil Sci.*, 1:1-64.

Ghosh, A. B., and R. Hasan. 1976. *Available Potassium Status of Indian Soils*, Bull. 10, Indian Society of Soil Science.

Ghosh, A. B., and R. Hasan. 1979. *Phosphorus Fertility Status of Soils of India*, Bull. 12, Indian Society of Soil Science.

Goswami, N. N. 1988. "Sulphur in Indian Agriculture," IN *Sulphur in Indian Agriculture*, Proc. TSI-FAI Symp., KS/2/1-26.

Goswami, N. N., and K. L. Sahrawat. 1982. "Nutrient Transformations – Macronutrients," IN *Review of Soil Research in India, Part I*, pp. 123-145, Indian Society of Soil Science.

Hegde, B. R., and M. J. Reddy. 1984. "Ragi Can Be Sown Mixed With DAP," *Indian Farming*, 33(10):9-11.

ISA. 1985. *Proc. Natn. Symp. Cropping Systems*, Indian Society of Agronomy.

Jha, D., and R. Sarin. 1984. *Fertiliser Use in Semi-Arid Tropical India*, Res. Bull. 9, International Crops Research Institute for the Semi-Arid Tropics.

Joshi, Y. C., et al. 1987. "Use of Micronutrients in Groundnut," *Technologies for Better Crops*, No. 31, Indian Council of Agricultural Research.

Kanwar, J. S. 1986. "Crop Production Techniques and Fertilizer Management in Rainfed Areas-ICRISAT Experience," IN *Crop Production Techniques and Fertilizer Management in Rainfed Areas in Southern Asia*, pp. 65-108, Proc. IMPHOS Second Regional Seminar, New Delhi, Institut Mondial du Phosphate.

Kanwar, J. S., and M. S. Mudahar. 1986. *Fertilizer Sulfur and Food Production*, Martinus Nijhoff/Dr W. Junk Publishers, Dordrecht, The Netherlands.

Kanwar, J. S., and L. J. Youngdahl. 1985. "Micronutrient Needs of Tropical Food Crops," *Fert. Res.*, 7:43-67.

Kanwar, J. S., et al. 1983. *Groundnut Nutrition and Fertiliser Responses in India*, Indian Council of Agricultural Research.

Karle, B. G., and A. V. Babula. 1985. "Effect of Boron and Sulphur on Yield Attributes and Quality of Groundnut," IN *Proc. National Seminar Sulphur in Agriculture*, Coimbatore, pp. 158-168.

Karle, B. G., et al. 1985. "Sulphur Nutrition in Maharashtra Agriculture," IN *Proc. National Seminar Sulphur in Agriculture*, Coimbatore, pp. 55-68.

Katyal, J. C. 1985. "Research Achievements of the All India Coordinated Scheme on Micronutrients in Soils and Plants," *Fert. News*, 30(4):67-81.

Katyal, J. C., and D. L. Deb. 1982. "Nutrient Transformations in Soils-Micronutrients," IN *Review of Soil Research in India, Part I*, pp. 146-159, Indian Society of Soil Science.

Katyal, J. C., and P.L.G. Vlek. 1985. "Micronutrient Problems in Tropical Asia," *Fert. Res.*, 7:69-94.

Kaur, N. P. 1987. "The Concept of Fitting Plants to Soil: Identification of Crop Cultivars Efficient in Micronutrient Stress Tolerance," IN *Natn. Symp. Micronutrient Stresses in Crop Plants: Physiological and Genetical Approaches to Control Them*, Rahuri, pp. 214-236.

Kemmler, G., and H. Hobt. 1987. *Potash-A Product of Nature*, Kali und Salz, FR Germany.

Krishna, K. R., and P. J. Dart. 1984. "Effect of Mycorrhizal Inoculation and Soluble P on Growth and P Uptake of Pearl Millet," *Plant Soil*, 81:247-256.

Kulkarni, K. R., et al. 1980a. "Scope for Increasing Production of Pulses Through Use of Fertilisers Under Rainfed Conditions," *Fert. News*, 25(8):3-6.

Kulkarni, K. R., et al. 1980b. "Scope for Increasing the Production of Oilseeds Under Rainfed Conditions Through Use of Fertilisers and Their Economics," *Fert. News*, 25(10):21-26.

Malewar, G. U. 1987. "Zinc Research in Soils and Plants in Maharashtra-A Critical Review," IN *Proc. Natn. Seminar Micronutrients in Crop Production*, Bangalore, pp. 23-34.

Mohsin, M. A., et al. 1984. *Dryland Agriculture Technology and Package of Practices for Oilseeds and Pulses for Plateau Region of Bihar*, Tech. Bull. 2, Birsa Agricultural University.

Munson, R. D. 1982. *Potassium, Calcium and Magnesium in the Tropics and Sub-Tropics*, Tech. Bull. T-23, International Fertilizer Development Center (IFDC), Muscle Shoals, AL, U.S.A.

Murthy, A.P.S., and D. P. Viswanath. 1987. "Micronutrient Status and Factors Affecting Their Availability in Vertisols of Karnataka," IN *Natn. Symp. Micronutrient Stresses in Crop Plants: Physiological and Genetical Factors to Control Them*, Rahuri, p. 74.

Narkhede, P. L., et al. 1981. "Nutritional Status of Sorghum on Farmers' Fields in the Semi-Arid Tropics," *Sorghum Newsletter*, 24:56.

Nagre, K. T. 1982. "Response of Rainfed Sorghum to Split Application of P and K," *J. Maharashtra Agricultural Universities*, 7:233-234.

NCAER. 1978. Reports of the Fertiliser Demand Survey, (several volumes), National Council of Applied Economic Research.

Pasricha, N. S., and D. S. Rana. 1985. "Fertiliser Use in Arid Lands for Increasing the Production of Oilseeds," IN *Proc. FAI (NRC) Seminar on Available Technology and Strategy for Promoting Fertiliser Use in Dryland Farming*, pp. 135-146.

Patel, M. S. 1988. "Sulphur Research and Development in Gujarat–Gaps and Priorities," IN *Sulphur in Indian Agriculture*, Proc. TSI-FAI Symp., PD II/1/1-4.

Patel, M. S., and M. V. Kanzaria. 1985. "Factors Affecting Response of Ground Nut to P Fertilisers in Medium Black Calcareous Soils of Saurashtra," *Fert. News*, 30(3):31-36.

Patil, N. D., et al. 1981. *Improved Crop Production Technology for Drought Prone Areas of Maharashtra*, Tech. Bull., Dryland Research Center, Solapur.

Patil, R. G., and M. S. Patel. 1982. "Influence of Available Nutrients in Surface and Sub-Surface Soils on Yield and Nutrient Uptake by Groundnut," *J. Indian Soc. Soil Sci.*, 31:160-161.

Pillai, K.G.K., et al. 1984. "Increasing the Production of Rapeseed Mustard," *Indian Farming*, 34(9):3-5.

Rai, M. M., and G. S. Rathore. 1987. "Micronutrient Deficiencies in Madhya Pradesh and Responses in Different Crops," IN *Natn. Symp. Micronutrient Stresses in Crop Plants: Physiological and Genetical Approaches to Control Them*, Rahuri, pp. 1-3.

Raman, K. V., and I. V. Subba Rao. 1979. "Soil Plant Nutrient Relationships," IN *Proc. Symp. Fifty Years of Research in the Service of Andhra Pradesh Farmers*, pp. 29-67, Andhra Pradesh Agricultural University.

Randhawa, N. S., and V. K. Nayyar. 1982. "Crop Responses to Applied Micronutrients," IN *Review of Soil Research in India, Part I*, pp. 392-411, Indian Society of Soil Science.

Randhawa, N. S., and P. N. Takkar. 1976. "Screening of Crop Varieties With Respect to Micronutrient Stresses in India," IN *Plant Adaptation to Mineral Stresses*, pp. 393-400, Cornell University Agricultural Experiment Station.

Randhawa, N. S., et al. 1985. "Current Status of Yardsticks of Crop Response to Fertilisers," IN *Proc. FAI Group Discussion on Means to Increase Crop Response to Fertiliser Use*, pp. 25-46.

Rao, A.C.S., and S. K. Das. 1982. "Soil Fertility Management and Fertiliser Use in Dryland Crops," IN *A Decade of Dryland Agricultural Research in India (1971-80)*, pp. 120-139, All India Coordinated Research Project for Dryland Agriculture.

Rauth, M. S., and M. Ali. 1985. "Studies on P and S Nutrition in Mustard Under Rainfed Conditions," IN *Proc. Natn. Seminar Sulphur in Agriculture*, Coimbatore, pp. 143-148.

Rawal, D. R., and P. P. Bansal. 1986. "Fertiliser Requirement of Gram Under Dryland Conditions in Cultivators' Fields in Alwar District," *Legume Research*, 9(2):106-107.

Rawal, D. R., and G. L. Yadava. 1986. "Fertiliser Requirement of Gram Under Dryland Conditions in Cultivators' Fields in Chittorgarh District," *Legume Research*, 9(2):103-105.

Reddy, P. S. 1985. "Opportunities and Constraints for Increasing Groundnut Production in India, " IN *Proc.*

Symp. Opportunities and Constraints for Increasing Oilseed Production in India, pp. 89-105, Hindustan Lever Ltd.

Sakal, R., et al. 1985. "Screening of Finger Millet Varieties for Their Relative Responses to Zinc in Calcareous Soils," *J. Indian Soc. Soil Sci.*, 33:440-442.

Saraf, C. S. 1988. "Sulphur Fertilisation of Pulses for Yield and Quality," IN *Sulphur in Indian Agriculture*, Proc. TSI-FAI Symp., S II/2/1-7.

Saraf, C. S., and Ganga Saran. 1986. "Crop Production Techniques and Input Management in Rainfed Pulses and Oilseeds," IN *Crop Production Techniques and Fertilizer Management in Rainfed Areas in Southern Asia*, pp. 405-439, Proc. IMPHOS Second Regional Seminar, New Delhi, Institut Mondial du Phosphate.

Saxena, N. P. 1985. "The Role of Potassium in Drought Tolerance," IN *Potash Review*, Subject 16, Suite 102.

Sekhon, G. S. 1983. "Potassium Dynamics in the Soils of Semi-Arid and Arid Areas," IN *Proc. 17th Colloquium*, pp. 153-162, International Potash Institute.

Sekhon, G. S. 1985. "Potassium in Indian Agriculture," *J. Indian Soc. Soil Sci.*, 33:754-767.

Shinde, D. A. 1984. "Agronomy of Sulphur in Madhya Pradesh," College of Agriculture, Indore (unpublished).

Singh, B. P. 1983. "Response of Taramira to Sulphur Application," *Indian J. Agric. Sci.*, 53:676-680.

Singh, Mahatim, and S. R. Singh. 1986. "Improving Productivity in Rainfed Areas Through Balanced Fertilization," IN *Crop Production Techniques and Fertilizer Management in Rainfed Areas in Southern Asia*, pp. 443-456, Proc. IMPHOS Second Regional Seminar, New Delhi, Institut Mondial du Phosphate.

Singh, Mahatim, and R. C. Tiwari. 1985. "Response of Oilseeds and Pulses to Fertiliser in Dryland Areas," IN *Proc. FAI (NRC) Seminar*, pp. 147-159.

Singh, Mahendra. 1983. "Innovations in Zinc Fertilisers–Retrospect and Prospect," *Fert. News*, 28(2):17-26.

Singh, Nathu, et al. 1985. "Yield and Water Use Efficiency of Rainfed Wheat + Chickpea as Affected by N and P Application in Clay Loam, Sandy Loam and Loamy Sand Soil," *Indian J. Agric. Sci.*, 55:13-17.

Singh, Ranjodh, et al. 1979. *Response of Dryland Crops to P Application in Sub-Humid Districts of Punjab*, Bull. No. 12, pp. 454-459, Indian Society of Soil Science.

Singh, Ranjodh, et al. 1983. "Dryland Cropping in Sub-Montaneous Punjab, 1971-81," Punjab Agricultural University.

Singh, R. P., and J. Venkateswarlu. 1985. "Role of All India Coordinated Research Project for Dryland Agriculture in Research and Development," *Fert. News*, 30(4):43-55.

Singh, S. P., et al. 1981. "Agronomic Research on Grain Sorghum," IN *Quarter Century of Agronomic Research in India (1955-1980)*, pp. 130-159, Indian Society of Agronomy.

Singh, S. P., and U. C. Upadhyay. 1985. "Sorghum-Based Cropping Systems in India–Present Knowledge and Research Needs," IN *Proc. Natn. Symp. Cropping Systems*, pp. 102-137, Indian Society of Agronomy.

Sivakumar, M.V.K, and A.K.S. Huda. 1983. "Potential Agricultural Productivity in Summer and Winter Rainfall Areas," IN *Proc. 17th Colloquium*, pp. 23-47, International Potash Institute.

Spratt, E. D., and S. L. Chowdhury. 1978. "Improved Cropping Systems for Rainfed Agriculture in India," *Field Crops Research*, 1:103-126.

Subba Rao, I. V. 1975. *Nutritional Disorders of Crops in Andhra Pradesh*, Tech. Bull. 1, Andhra Pradesh Agricultural University.

Takkar, P. N. 1987. "Economics of Sulphur Fertiliser Use in India," IN *Proc. FADINAP-FAO-TSI-ACIAR Symp.*

on Fertiliser Sulphur Requirements and Sources in Developing Countries of Asia and the Pacific, Bangkok, pp. 123-137.

Takkar, P. N. 1988. "Sulphur Status of Indian Soils," IN *Sulphur in Indian Agriculture*, Proc. TSI-FAI Symp., SI/2/1-31.

Takkar, P. N., and V. K. Nayyar. 1986. "Integrated Approach to Combat Micronutrient Deficiency," IN *Proc. FAI Seminar on Growth and Modernisation of Fertiliser Industry*, PS III/2/1-16.

Tandon, H.L.S. 1986. *Sulphur Research and Agricultural Production in India*, 2nd Ed., Fertiliser Development and Consultation Organisation.

Tandon, H.L.S. 1987. *Phosphorus Research and Agricultural Production in India*, Fertiliser Development and Consultation Organisation.

Tandon, H.L.S. 1988. "Available Information on Micronutrients in India-Some Observations," FAI Meeting on Status of Micronutrients in Indian Agriculture (unpublished).

Tandon, H.L.S., and J. S. Kanwar. 1984. *A Review of Fertiliser Use Research on Sorghum in India*, Res. Bull. 8, International Crops Research Institute for the Semi-Arid Tropics.

Tandon, H.L.S., and G. S. Sekhon. 1988. *Potassium Research and Agricultural Production in India*, Fertiliser Development and Consultation Organisation.

Venkat Raju, et al. 1987. "Iron Chlorosis of Groundnut on Alfisol," IN *Natn. Symp. Micronutrient Stresses in Crop Plants: Physiological and Genetical Approaches to Control Them*, Rahuri, p. 109.

Venkateswarlu, J. 1984. *Nutrient Management in Semi-Arid Red Soils*, Proj. Bull. No. 8, Part B, All India Coordinated Research Project for Dryland Agriculture.

Venkateswarlu, J. 1987. "Efficient Resource Management Systems for Drylands of India," *Adv. Soil Sci.*, 7:165-221.

Venkateswarlu, J., S. K. Das, and U. M. Bhaskara Rao. 1986. "Phosphorus Management for Castor-Sorghum + Redgram Intercropping Rotation in Semi-Arid Alfisol," *J. Indian Soc. Soil Sci.*, 34:799-802.