Role of optimum nutrition in drought management

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Role of Optimum Plant Nutrition in Drought Management in Rainfed Agriculture

Rainfed areas experience frequent drought spells resulting in severe moisture stress in soil-plant system. Besides the amount and distribution of rainfall, soil type and its depth are other important factors, which affect the moisture availability for crop growth. Soils in rainfed areas are generally deficient in one or more nutrients. Optimum plant nutrition helps in earl / establishment of rainfed crops by developing the right crop canopy structure and root system. Balanced nutrition increases the amount of vegetative cover which has a key role in retarding runoff and increase the infiltration. Optimum nitrogen and phosphorus nutrition results in the development of deep root system, increased leaf area and chlorophyll content. Adequate potassium supply on the other hand helps in plant water economy by regulating stomata resistance. Sulphur addition is essential to oil seed and pulse crops on S deficient soils. Zinc deficiency is more common in most of the soils in rainfed regions of India. In view of these multinutrient deficiencies, addition of optimum nutrients act as 'drought insurance' for dry land crops. Supply of nutrients in the form of organic manures helps in retaining more moisture which otherwise will go waste as runoff water, increasing water storage capacity and thereby increases water and nutrient use efficiency in drylands. Combining in-situ soil moisture conservation and balanced nutrient supply boosts the productivity levels in dryland agriculture.

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Of the net cultivated area of 142 m. ha, about 97 m.ha still depends on rainfall. About 90 per cent area under cereals (sorghum, pearlmillet and fingermillet), 90 per cent under pulses (chickpea and pigeonpea), 80 per cent of oil seeds (groundnut, rapeseed, mustard and soybean) and 65 per cent under cotton is rainfed (13). Even crops that formed the backbone of the green revolution, such as rice and wheat, still have 50 per cent and 19 per cent area under rainfed condition, thus, emphasising the importance of rainfed agriculture in India. In dryland agriculture which constitute the unirrigated rainfed areas receiving less than 750 mm annual rainfall in arid and semi-arid regions emphasis is on water conservation, appropriate cropping system, optimum inputs for soil fertility maintenance and control of wind and water erosion are the key strategies whereas in rainfed agriculture, the emphasis is more on harvesting of surplus rainwater maximising both crop yields and input use efficiency.

Rainfall distribution and variability: Rainfed farming in India is practiced under a wide range of climate and soil conditions. Based on the annual rainfall, the country can be divided into three zones: low (<750 mm), medium (750-1150 mm) and high (>1150 mm) rainfall zones. Rainfed area is distributed in all the three zones. The amount of rainfall, more importantly its distribution, is critical for the productivity of rainfed crops. Nearly, 80 per cent of annual rainfall in these areas is received during the south west monsoon. The main types of weather aberrations encountered are 1) late onset of monsoon, 2) early withdrawal, and 3) prolonged breaks (24). There is wide variation in the amount of rainfall in arid and semi-arid regions. For instance, the coefficient of variation varies from 20 per cent at Hyderabad receiving an annual rainfall of 792 mm to 43 per cent at Jodhpur receiving an annual rainfall of 382 mm (24). The coefficient of variation generally increases with the decrease in annual rainfall.

Occurrence of drought and its intensity: The National Commission on Agriculture (1976) has categorised drought in to three types viz. meteorological, hydrological drought and agricultural drought. Meteorological drought is said to occur when rainfall over an area is less than 25% of its normal. Meteorological drought, if prolonged, results in hydrological drought with marked depletion of surface water and consequent drying up of reservoirs, lakes, streams and rivers. Agricultural drought occurs when soil moisture and rainfall are inadequate to support a healthy crop growth. Thus, shortage of rainfall coupled with erratic distribution during the rainy season causes severe water deficit conditions resulting in various intensities of droughts. Technical committee on DPAP (Drought Prone Area Programme) and DDP (Desert Development Programme) identified about 120 m.ha area in the country, covering 185 districts (1173 blocks) in 13 states as drought prone. However, drought like situations generally prevail in one or other part of the country every year.

Soils of rainfed regions: Vertisols and vertic sub-groups (black soils), Alfisols (red and lateritic), Inceptisols and Entisols (alluvial) and Aridisols are predominant soil groups in rainfed areas **(Table 1)**. Higher clay content (30-70 %) and high available water holding capacity but low infiltration in Vertisols results in high erosion and large runoff. Alfisols have moderate clay content (10-20%), low water retention, compact sub-soil and are prone to erosion and crusting. Inceptisols and

Table 1 - Soil order, climate and fertility status of dryland centres

Major Order		Climate / water holding capacity (cm)	pH (1:2)	Organic carbon (%)	P_2O_5 (kg ha^{-1})	Research centres
Alfisols	Arid	5 - 6	6.0-7.0	0.25 -0.30	10-15	Anantpur
	Semi-arid	5-13	5.5 - 6.5	0.50- 0.75	8-12	Hyderabad
Aridsol	Arid	5-9	7.5-8.0	0.15-0.22	12-18	Jodhpur, Hissar
	Semi-arid	10-15	7.5-8.0	0.25-0.30	20-35	Dantiwada
Inceptisol	Arid	5 -6	7.5-8.0	0.20-0.38	15-25	Agra, Hoshiarpur
	Dry sub-humid	20 -25	7.0-7.5	0.10-0.25	15-35	Varanasi, Rakh – Dhiansar
Oxisol .	Moist sub-humid	12-24	5.0-6.0	0.30- 0.45	10- 25	Bhubaneswar, Ranchi
Verti - subgroups	Arid	9-11	7.5-8.0	0.50-0.70	25- 30	Rajkot
	Semi-arid	10 – 22	7.5-8.5	0.40-0.60	8-15	Jhansi, Kovilpatti
Vertisols	Semi-arid	18 – 40	7.8-8.5	0.20-0.35	20-40	Akola, Solapur, Indore, Bijapur, Udaipur
	Dry sub-humid	12 – 15	6.5 – 7.0	0.10 – 0.20	10 – 15	Rewa

Source : (37)

Entisols are deep and variable in texture, possessing high agronomic potential. Aridisols are found in low rainfall regions of north west India, have low clay and low water retention capacity.

Nutrient requirements of dryland crops and fertiliser consumption: Nutrient removal per tonne of grain production of some important dryland crops is presented in **Table 2**. Survey conducted in 151 districts of the Indian semi-arid tropics (SAT) reveals that per hectare consumption of primary nutrients (N+P+K) was even less than 5 kg ha^{-1} in 28 non-irrigated SAT districts (3). The fertiliser consumption varied between 5 to 10, 10 to 20 and 20 to 40 kg ha^{-1} in 22, 27 and 22 districts. It was only two districts where the consumption of fertiliser nutrient exceeded 40 kg ha^{-1}. Another survey conducted by Jha and Sarin (11) showed that average fertiliser use was 18.5 kg in the non-irrigated SAT districts against 57.5 kg ha^{-1} in 78 irrigated SAT districts during 1977-79. Thus, a huge gap between nutrient additions and removals resulted in negative balance of nutrients in rainfed agriculture. Many recent reports indicated the negative balances for many nutrients under various rainfed production systems (21). This problem gets more aggravated if soils are already deficient of particular nutrient.

Table 2 - Average nutrient removal per tonne of yield production for some rainfed crops

Crop	N	P_2O_5	K_2O
Sorghum	22.4	13.3	34.0
Maize	26.3	13.9	35.8
Fingermillet	29.8	11.3	39.0
Pearlmillet	42.3	22.6	90.8
Chickpea	46.3	8.4	49.6
Pigeonpea	63.8	17.7	42.3
Groundnut	58.1	19.6	30.1
Soybean	66.8	17.7	44.4
Castor	30.0	12.0	10.0
Cotton (seed)	44.5	28.3	74.7

Source · (39)

Role of Optimum Plant Nutrition in Drought Management

Initially, fertiliser use under dryland conditions was a point of debate and fertilisers were generally thought of questionable utility under limited water supply conditions. Over the years, experimental results obtained in different rainfed regions showed that fertiliser application is essential for realising higher yield under a given amount of water availability. Rainfall is the most important factor in determining the amount of nutrient required for particular crop. Even more important is the distribution of rainfall, which determines the extent of crop response to particular nutrient. Due to frequent dry spells, crops suffer from water stress which may be a prolonged or intermittent drought. Viets (35) concluded that fertiliser use in dry areas not only corrects nutrient deficiencies but also helps in efficient use of limited moisture. Optimum nutrient supply in rainfed farming helps in adaptation of crop plants to face adverse growth conditions through a good root system and physiological and biochemical adaptations to moisture stress. Subbarao and Chandrasekharao (30) reported that a two to three fold yield increase can be realised in rainfed crops with improved management practices particularly with soil moisture conservation and nutrient management **(Table 3)**.

Nitrogen: Optimum N nutrition boosts crop growth under a given water availability condition and increases the leaf area index (LAI), chlorophyll content and total drymatter. During early stages of crop growth, low LAI limit light interception **(Table 4)**. As a result evaporation losses are high during this period. Nitrogen supply reduces the period required to attain effective crop cover by increasing the rate of cell growth. Time required to reach a LAI of one was reduced by 8 and 28 days with the application of 100 kg N ha^{-1} to sorghum and pearlmillet, respectively

Table 3 - Average yields of crops under improved versus common practices

Region	Crop	Mean yield (q/ha) Common Practices	Improved Practices
Agra	Pearl millet	7.9	17.2
	Mustard	8.5	15.8
	Barley	11.0	18.9
Anand	Pearl millet	24.5	32.9
	Tobacco	5.2	7.3
Anantapur	Groundnut	9.6	17.1
Dehra Dun	Maize	9.2	29.1
	Wheat	10.1	23.5
Hyderabad	Sorghum	12.3	28.9
	Castor	10.9	18.4
Kovilpatti	Sorghum	1.8	13.1
Ludhiana	Maize	18.5	29.7
	Wheat	15.6	30.7
	Mustard	5.1	14.3
Ranchi	Upland rice	14.0	31.1
	Barley	4.6	15.9
Solapur	Sorghum	5.3	24.8
	Safflower	5.8	15.6
Varanasi	Barley	7.6	13.9

Table 4 - Effect of nitrogen on leaf area index and root density of some dryland crops

	Fertiliser nitrogen (kg ha^{-1})	Leaf area index at 55 days	Root density Soil depth (cm/cm^3)	
			0-15 cm	15-30 cm
Sorghum	0	1.05	0.513	0.131
	50	1.73	1.186	0.444
	100	1.97	1.432	0.445
	150	2.47	1.330	0.382
Pearlmillet	0	0.53	0.274	0.263
	50	[illegible]	0.352	0.798
	100	2.01	0.541	0.705
	150	2.41	0.543	0.725

Source : (18)

(18). With increased leaf area and chlorophyll contents, plants will be able to intercept more radiation, and achieve higher photosynthesis rate. Fertilisation often increases the amount of crop cover which in turn, increases infiltration rate and retard runoff. Thus, fertilisation indirectly increases the efficiency of use of limited moisture available in rainfed regions (35).

Under semi-arid conditions, crops are subjected to dry periods which affect the crop growth due to high moisture stress between rains. If the plant has produced its crop, the magnitude of damage due to high water stress during drought gets reduced. Therefore, the major problem of rainfed agriculture and its management is to determine whether a favorable moisture interlude in the cycle of plant development coincides with the supply of sufficient nutrients for maximum growth. During these cycles, optimum nutrition can increase the net assimilation rate and crop growth, thereby risk of exposing the crop plants during sensitive vegetative and flowering stage is reduced.

Nitrogen plays significant role in increasing the soil water availability to plants by increasing the root length density. Rao *et al.* (18) reported that fertiliser nitrogen increased leaf area index and root density of sorghum and pearlmillet thus helping in early establishment of the crop under moisture stress conditions (**Table 4**). These changes due to N application depend on type of crop, soil type and N status and rainfall distribution.

Major soil groups in rainfed areas are low in organic carbon content and available nitrogen. According to report of Ghosh and Hassan (7), 63 per cent of the total districts surveyed in India are low in available nitrogen and 33 per cent are medium. Nitrogen content in black and alluvial soils increased with rainfall and decreased with increase in temperature. Nitrogen and carbon losses are more pronounced in areas having dry climates. Low level of soil nitrogen was attributed primarily to climate and cropping systems. Characterisation of ten soil profiles in rainfed pulse growing regions of India (**Figure 1**) showed that despite of continuous cultivation of pulses, all the ten soils were N deficient (26). Therefore, addition of N is essential for improved crop production in dryland crops. Singh and Prihar (23) reported that response to N application increased with increase in moisture storage capacity of the profile. Therefore, optimising N application based on profile moisture storage capacity results in maximum response of post rainy season crops. The magnitude of nitrogen response in Vertisols was in the order of maize>sorghum>pearlmillet>wheat (**Table 5**).

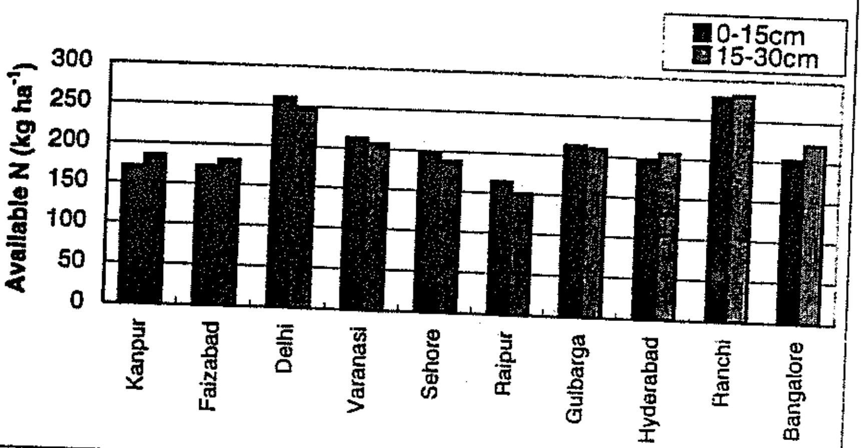

Figure 1 - Available nitrogen content in different soil types in chickpea growing regions

The response of wheat to fertiliser N in the farmers field was about 10 kg grain kg^{-1} N, while response in case of post rainy sorghum, maize and pearlmillet was 18, 25 and 12 kg grain kg^{-1}, respectively (16). In most of the crops, yield increases due to N application were highly dependant on depth of soil. It was reported that under dryland conditions, most of the crops responded up to 90 kg

Table 5 - Response of rainy and post-rainy season crops to nitrogen under dryland condition

Rainy season		Post-rainy season	
Crop	Range of response (kg grain / kg N)	Crop	Range of response (kg grain / kg N)
Sorghum	3.4 – 43.4	Wheat	4.9 – 52.3
Pearlmillet	2.1 – 24.8	Barley	4.0 – 31.6
Fingermillet	5.0 – 42.4	Oat	8.3 – 20.0
Maize	4.1 – 67.4	Chickpea	1.9 – 23.5
Rice	4.5 – 33.9		

Source : (17)

Table 6 - Grain yield (q ha^{-1}) of pearl millet as influenced by irrigation

N levels (kg ha^{-1})	Irrigation regime					
	I_0	I_1	I_2	I_3	I_4	Mean
0	4.09	13.13	11.40	12.32	13.51	10.90
40	7.73	23.66	19.64	21.73	24.98	19.55
80	8.10	32.50	27.60	29.81	36.50	26.90
120	7.93	31.59	27.08	29.23	35.52	26.27
Mean	6.96	25.22	21.43	23.92	27.63	

I_0: Control
I_1: Irrigation at termination of vegetative stage to meet 50% of ASW from 1 m soil profile.
I_2: Adequate water early vegetative (up to 30 DAS) and flowering to grain development state (50 DAS of physiological maturity; No water between (30-30 DAS).
I_3: Irrigation with held at flowering and grain development stage (50 DAS onwards).
I_4: 100% of replenishment of crop water use.

Table 7 - Interaction effects of nitrogen application and supplementary irrigation of stored water on wheat yields (q/ha) at Dehradun (mean of 4 years)

Time of application	Quantity of water (cm)	Level of nitrogen (kg ha^{-1})			
Control	0	14.8	17.0	100	150
Pre-sowing	5	26.8	33.2	19.8	42.0
Grown root	5	26.4	31.0	35.9	39.3
Presowing + grown root	10	30.7	39.8	44.9	51.9

Source : (36)

N ha^{-1} on deep soils whereas on shallow soils (50 cm) response was obtained only up to 30 kg N ha^{-1}. Besides, the choice of fertiliser source, method and time of application of N according to moisture status of soil boosts the yield levels and water-use efficiency of dryland crops.

Regulation of N applications to suit the soil moisture regime is most important. This fits into the philosophy of split applications of N recommended so that the top dressings can be withheld in the vent of drought or failure of monsoon. The following models developed by Leggett in 1959 relating the yield to the soil moisture, rainfall and soil and fertiliser nitrogen are pertinent to the point under consideration.

Y (from moisture) = 153 kg/ha (SM+R in cm) – 1600; and

Y (from N) = 21 kg/ha (soil NO_3 – N + fertiliser N in kg/ha)

Where Y = yield in kg/ha;

SM = available moisture April (total soil moisture minus wilting point);

R = anticipated rainfall between April 1 and crop maturity.

Similar models under our situations might help in the rational use of nitrogenous fertilisers for dryland crops. Fertiliser recommendations based on the soil moisture regimes, particularly under receding soil moisture conditions, are yet to be worked out for different crops (12). In some areas substantial quantities of runoff occurs and part of the water can be harvested and stored in ponds for irrigating crops during critical stages or for taking a second crop for increasing cropping intensity (**Tables 6 and 7**) (12,36).

Phosphorus: Phosphorus has an important role in improving the water use efficiency due to its favorable effect on root development and higher production per unit water used. Adequate P nutrition promotes more extensive and deeper root growth which in turn enables the crop to draw water from deeper layers which otherwise is not accessible to the unfertilized crop. This helps the crop during drought period. Rao et al. (18) reported that urdbean root length and root mass increased by 70 per cent due

Table 8 - Effect of P on root growth of urdbean at 50 per cent field capacity

Root Parameter	Phosphorus (kg/ha)	
	0	50
Root length (mg/pot)	8.8	13.1
Root mass (g/pot)	0.11	0.16

Source : (18)

to application of 50 kg P ha^{-1} (**Table 8**).

Phosphorus deficiency is considered to a limiting factor in many dryland crops. The data on P fertility status showed that 24 districts which account for 50 per cent of the total sorghum production, had mean available P low in 15 districts and medium in 9 districts. Therefore, response to P application is very common. However, extent of crop response depends upon crop, soil and moisture availability. Legume crop generally show less response to P application as compared to cereals as organic acids released in the chickpea and pigeonpea rhizosphere solubilise insoluble soil P. Response of rainy and post-rainy season crops to P under dryland conditions is presented in **Table 7.** Among rainy season crops, maize, sorghum, finger millet and upland rice showed greater response to P application. Among post–rainy crops, wheat followed by chickpea responded greater in comparison to others (**Table 9**). Tandon (38) summarised yield responses of 20 crops to P application under rainfed/dryland conditions in trials

Table 9 - Response of rainy and post-rainy season crops to phosphorus under dryland condition

Rain season		Post-rainy season	
Crop	Range of response (kg grain / kg P)	Crop	Range of response (kg grain/ kg P)
Sorghum	2.4-59.0	Wheat	2.6-41.3
Pearlmillet	1.7-14.3	Barley	1.9-9.2
Fingermillet	6.4-38.9	Chickpea	4.5-38.2
Clusterbean	6.7-10.7	Peas	3.7-10.9
Rice	5.1-31.8	Lentil	3.2-6.3
Maize	68.0-80.0		
Mungbean	1.5-11.6		
Urdbean	1.8-6.7		
Pigeonpea	3.1-8.3		

Source : (17)

Table 10 - Comparison of methods of P application for grain yield improvement of dryland crops

Method of P Application	Fingermillet	Chickpea	Soybean	
			A	B
Broadcast	100	100	100	100
Drilled	132	137	123	169
Mixed with seed	129	118	123	135

Source : (8, 22, 33)
A: 40 kg P_2O_5 ha^{-1}; B: 80 kg P_2O_5 ha^{-1}

Table 11 - Nitrogen and phosphorus interaction in some crops under rainfed condition

Applied Fertiliser	Relative grain yield		
	Sorghum	Fingermillet	Maize
None	100	100	100
N only	113	122	304
P only	135	110	189
N+P	192	174	493
Contribution of Interaction to the Yield under N+P	48%	57%	20%

Source : (4, 34)

n cultivators fields (1969-84). Results howed considerable response to P in all he crops. Ganeshamurthy et al. (6) eported that phosphorus deficiency is sually the main limiting factor for low seed ield of pulse crops in all the soil types and fertilisation has become the base of ıanuring pulses in India.

ield data from several experiments show ıat P can increase water use efficiency by 5-20 per cent in wheat, 22-55 per cent in nger millet, 41-99 per cent in chickpea, 7 per cent in linseed and up to 19 per cent the wheat+chickpea mixed stands. crease in WUE due to P application is ore on light textured than on heavy xtured soils. Tandon (38) stated that rtilised crop is better equipped to face a ought situation mainly by its ability to deeper soil layers for water. Thus, timum nutrient supply can provide ought insurance to certain extent. ethod of P application also important achieving higher P use efficiency ded P and high yields. Drilling of tiliser appears to be a best method of P lication which resulted in higher grain lds than broadcasting **(Table 10)**. nilarly larger yield benefits can be ained from interaction effects of nutrient application in rainfed conditions **(Table 11)**.

Potassium: Potassium activates about 60 enzymes associated in major metabolic processes and involved in water relation and stomata regulation. Potassium enhances resistance of plants in many cases to withstand adverse environmental conditions such as drought, salinity and sodicity. Potassium removal of important rainfed crops extends up to 90 kg per tonne grain production. However, application of K in Indian agriculture is meager compared to removals. In many cases, K additions are mainly done to plantation and commercial crops.

Available K status in rainfed soils varied from low to high. Vertisols and Vertic subgroups showed relatively higher available K. Red and lateritic soils, light textured acidic alluvial soils are low in available K status (28). However, many field crops particularly cereals extract major portion of their K requirements from nonexchangeable K fraction of soil (29). The agroecological regions covering different rainfed regions of India showed wide variations in available and nonexchangeable K status (31)

Potassium improves water use efficiency and helps to maintain crop yield under moisture stress or reduce the extent of crop losses under such conditions (20). A relationship between the K content of the leaves and the osmotic potential and turgor potential was observed in *Phaseolus vulgaris* (2). An increase in K concentration significantly lowered the osmotic potential and increased the turgor potential. Guard cells have been shown to take up K salts in larger quantities to account for turgor changes, as indicated by tracer studies (5). Regulation of stomata is a well-established function of K. An electron probe study by Humble and Raschke (9) clearly showed the relationship between K content in the guard cells of *Vicia faba* and the opening and closing responses. The decrease in the osmotic potential of guard cells from –35 bars in the open stomata to –19 bars in the closed stomata could be correlated with the fall in K content from 424 to 20 x 10^{-14} g eq respectively **(Table 12)**.

One of the marked responses of plants to stress conditions is the accumulation of proline. In recent years, the stimulating effect of K on proline accumulation was reported (32). Mukherjee (15) showed the

Table 12 - Potassium, sodium and chlorine present in open and closed guard cells, guard cell volume and changes in stomatal aperture and osmotic pressure in fababeans

Osmotic incipient	Element			Stomatal aperture	Guard Cell volume per	Guard cell pressure from
	K	Na (10^{-14} g eq)	Cl	(μm)	(10^{-12} lt)	(bars)
Open stomata	424	0	22	12	4.8	3.5
Closed stomata	20	0	0	2	2.6	19
Difference	404	0	22	10	2.2	16

Source : (9)

Table 13 - Effect of potassium on proline accumulation under long-term (43 h) mild stress in leaf discs of low and high K plants of two hybrids of maize

Hybrid	K level	Proline µg/g initial fresh weight			
		Control		5 mM KCl	
		without stress	with stress	without stress	with stress
Compo	Low	13.[illegible]	33.0	6.5	212.2
	High	42.[illegible]	328.8	38.6	662.3
Mex	Low	11.6	114.9	13.7	168.6
	High	16.8	119.3	20.3	389.0

Source : (15)

Table 14 - Mechanism of crop adaptation to water stress under optimum K supply in rainfed agriculture

Morphological
- Enhancement of root growth

Physiological
- Higher turgor presssure, with lowering osmotic potential
- More sensitive stomatal movement during water stress
- Reduction in transpiration rate, even under non-limiting water supply, without reduction in drymatter production
- Possible interaction with phyto-hormones in physiological adaptation to water stress
- Increase in regrowth potential with water availability after stress

Biophysical
- Increase in root permeability to water

Biochemical
- Increase in accumulation of proline and faster recovery of enzyme activity such as nitrate reductage upon relief from water stress

effect of K on proline content in stressed leaf discs of maize hybrids **(Table 13)**. Different mechanisms by which crop plants adapt to drought conditions in presence of optimum K nutrition are summarised in **Table 14**. Many field experiments showed the improvement of grain yields due to K supply in water stress condition. Field experiments conducted on winter wheat under rainfed condition on medium K level acidic soil showed that seed treatment with 1% KH_2PO_4 before sowing proved significantly superior in grain yields over dry seeds and distilled water treatment. Grain yields increased by 33.6 per cent with 60 kg K_2O ha^{-1} over control.

Sulphur, calcium and magnesium: Deficiency of sulphur is an emerging problem particularly in oil seed and pulse crops, whose requirement is large. Studies in pulse growing regions of India revealed that the S deficiency extends even up to 60 per cent of soils tested; light textured alluvial soils, calcareous soils and shallow black soils show maximum S deficiency. Optimum S nutrition is associated with root growth nodulation (27). Therefore, application of sulphur improves the nitrogen availability to crop, thereby overall growth and early establishment of the crop plants under moisture stress conditions. Calcium and magnesium are base elements and generally deficient in acidic soils. Application of calcium in the form of lime in acidic soils and gypsum in sodic soils helps in the optimum plant growth. In sodic soils, due to the excess Na^+ content, deflocculating of soil particles takes place thereby disturbing the soil structure. Due to this, water movement in to the soil is restricted resulting in the higher runoff losses. Addition of gypsum to these soils improves infiltration rates and water storage capacity of the profile.

Table 15 - Micronutrient status of 57 benchmark soils (mg kg^{-1})

Nutrient	Range	Mean	SD
Zn	0.12 – 2.80	0.54	0.07
Cu	0.15 – 5.33	1.71	0.61
Mn	4.0 - 102.0	26.0	3.7
Fe	3.4 – 68.1	20.3	2.2

Source : (14)

Micronutrients: Among micronutrients, available Zn deficiency is becoming a major problem. Katyal and Sharma (14) studied the micronutrient deficiencies in 57 profiles and reported that out of these 43 profiles were Zn deficient **(Table 15)**. Available Fe deficiency is encountered in dryland soils as Fe availability is related to reduced/oxidised condition of the soil. Among ten profiles representing major pulse growing regions of India, almost all the profiles were Zn deficient **(Figure 2)** and few locations were Fe deficient. Field scale Zn and Fe deficiencies have been reported in many pulse crops in

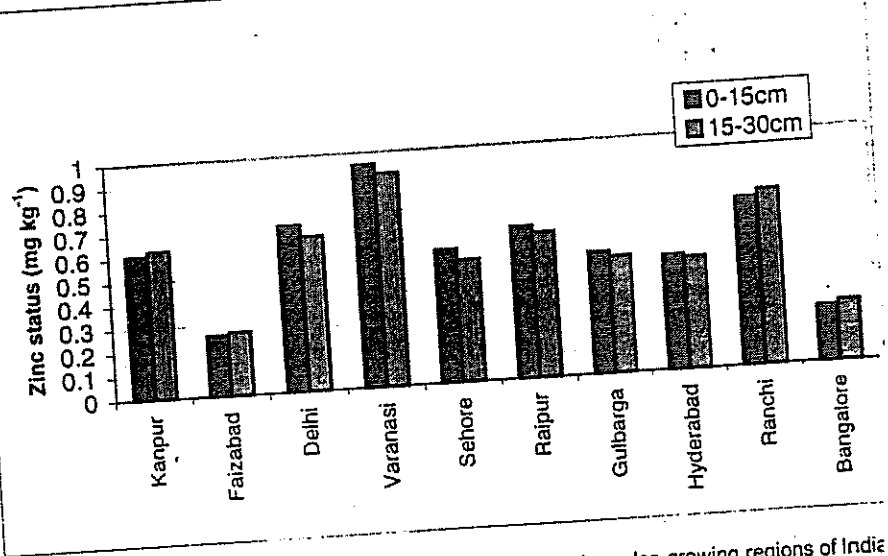

Figure 2 - Available zinc status in different soil types of major pulse growing regions of India

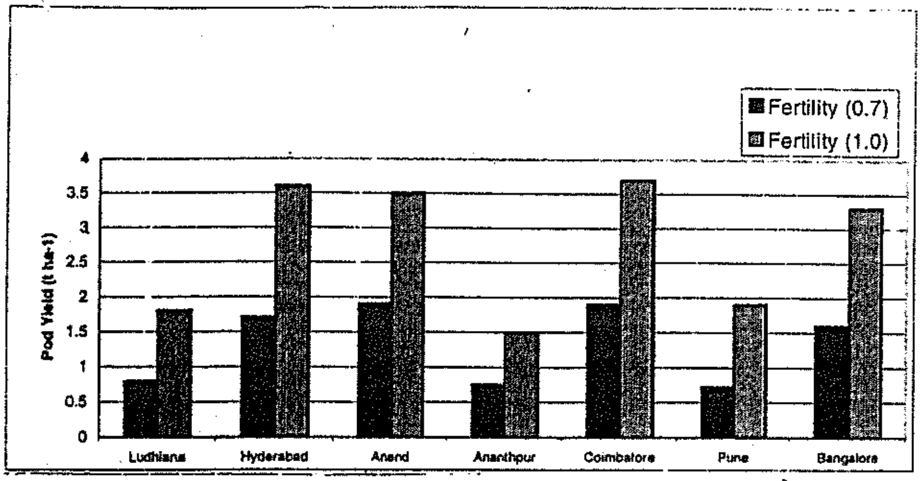

Figure 3 - Yield estimates of groundnut at two levels of soil fertility factor under rainfed situations at selected locations of India (1:Optimum fertility; 0.7 : Suboptimal fertility)

alluvial belt of northern India (26). As such, studies on interaction effects of micronutrient application and moisture stress are rare and no information available on this aspect.

Integrated Nutrient Management-Much Relevant in Rainfed Agriculture

As rainfed agriculture mainly exists on marginal and sub-marginal lands with multi-nutrient deficiencies, soil fertility management showed greater impact on productivity of various rainfed crops. Analysis of quantified yield levels of groundnut cultivar, Robut 33-1 under rainfed conditions showed that response of the crops across the centers was significant (**Figure 3**) and trend in the yield levels due to improved soil fertility was almost similar to that of irrigated conditions, but at reduced magnitude. However, under rainfed conditions the soil fertility improvement through integrated nutrient management (INM) has much more relevant than simple optimum nutrient supply. Source of nutrients also has considerable effect on conserving limited moisture available in dryland conditions. Besides supplying all the nutrients in a holistic manner, organic manures such as compost, crop residues and FYM improve the soil organic matter content thus improving soil aggregation. Improved aggregation raises levels of water infiltration and water storage capacity of profile is increased. Crop residues left over in the field reduce the runoff and improve water movement into the soil. Crop residues also act as soil cover and reduce evaporation losses. Therefore, addition of nutrients in terms of INM not only improves the nutrient availability in soil but also increases soil and water conservation. Microorganisims like VA Mycorrhiza are also reported confirm drought tolerance to crops by promoting increased surface area of absorption. Various options of INM practices for various crops for different dryland regions of India have been compiled (**Table 16**).

Conclusions

Farming under dryland conditions is very complex. During rainy seasons the cropping duration is determined by the amount and distribution of rainfall. Parts of the season may be too wet or too dry and subjected to alternative wet and dry condition. Drought with varying intensity may occur randomly at any stages of crop growth. In post-rainy season, water stress is encountered due to the rapid depletion of moisture if monsoon withdrawal occur early. Due to low water storage capacity, light textured and shallow soils show severe water stress during vegetative stage. Under these situations, optimum nutrient supply enables in early establishment of the plant, encourages deeper root system and helps in better adoption of crop. During plant growth cycle, favorable spells of water availability should be supported by optimum nutrient availability in soil. As large areas under rainfed regions are deficient in multinutrients, optimum nutrient supply becomes important for successful dryland farming. Optimising the nutrient supply based on profile moisture availability is crucial in this regard. Besides, nitrogen and phosphorus, potassium plays an important role in water relations of plants and regulates the water loss through stomatal control. Most of the acidic soils and light textured alluvial soils are K deficient. Application of optimum sulphur is essential for oil seed and pulse crops. Zinc application is also needed at least once in few years for realising better yields of dryland crops.

Future line of work

Based on existing information, it is observed that the information on following aspects needs to be generated for making meaningful nutrient supply system under rainfed conditions:

1. Nutritional constraints in various rainfed regions of India
2. Interaction of soil moisture and nutrient availability
3. Profile moisture based nutrient recommendations
4. Impact of various INM practices on soil organic maintenance and soil moisture conservation.

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Table 16 - Integrated Nutrient Management options for various crops in rainfed regions of India

S.No	Regions/locations, rainfall, soil type and crops	INM Options
1	Hyderabad Rainfall: 770 mm Soil type: Alfisol Crop: Sorghum	Conjunctive use of inorganic N through urea and loppings of farm based organics such as subabul (*Leucaena leucocephala*) and Glyricidia (*Glyricidia maculata*) to sorghum crop has been proved as potential options. Leucaena and Glyricidia loppings on dry weight basis contain 3-4% nitrogen. The recommended dose of N for sorghum crop in Alfisols of rainfed areas is 40 kg N/ha. Out of this 40 kg N, 20 kg N can be applied through urea. Remaining 20 kg N can be supplemented through the fresh loppings of leucaena or glyricidia. Considering 3.0% N (Considering lower value) on dry weight basis and moisture content of fresh loppings at 70%, 666 kg of fresh loppings (leaves + twigs) are required to supplement 20 kg N through either of these two materials. This procedure is very easy to adopt. *Glyricidia maculata* is small nitrogen fixing shrub and can be grown through cuttings on bunds or in some spare part of the land. Leucaena is a nitrogen-fixing tree, which can be grown as hedge and alley systems also. 3-4 years plants may be able to generate about 15-20 tonnes of fresh biomass per year per hectare. The fresh loppings can be added to the crop by opening 10-15 cm furrows with the help of bullock drawn plough to the crop at the age of 25-35 days after sowing. Following these options, average yield level of about 1.7 t/ha of sorghum grain can be achieved. This way 50% of N requirement of sorghum can be substituted through organic sources of nutrients. Since these farm based materials have C:N ratios of less than 20, there is no risk of adverse effect of immobilization of native soil N during the process of decomposition. The technology is farmer friendly, economical and can be successfully adopted by using the farmers own family labour. The likely constraint in the adoption of the technology is the raising of these plants by the farmers in open grazing lands, as leucaena is browsable by the animals. If community decision is taken, social fencing is possible. Apart from supplying nutrients, the practice will help in improving soil health by improving soil organic matter.
2	Hyderabad Rainfall: 770 mm Soil type: Alfisol Crop: Sorghum	Other potential options of INM technologies for sorghum crop in this region are i) application of 2 t glyricidia loppings + 20 kg N through urea, ii) Application of 4t FYM + 2t glyricidia loppings, or iii) application of 4t FYM + 20 kg N through urea.
3	Hyderabad Rainfall: 770 mm Soil type: Alfisol Crop: Mungbean	Application of 2t FYM + 10 kg N through urea under conventional tillage Application of 2t FYM + 1t Glyricidia loppings under reduced tillage
4	Faizabad Rainfall: 980 mm Soil type: Inceptisol Crop: Sorghum	Application of 15 kg N through compost + 20 kg N through inorganic fertiliser
5	Ranchi Rainfall: 1200 mm Soil type: Oxisol Crop: Rice, Upland rice	Application of 40-30-20 NPK kg/ha in rice Application of 30-20-0 NPK kg/ha in upland rice.
6	Varanasi Rainfall: 1080 mm Soil type: Entisol, upland rice Crop: Rice	Application of 40-30-20 kg NPK/ha in rice
7	Arjia Rainfall: 660 mm Soil type: Vertisol, Crop: Horse gram, Groundnut Maize + pigeon pea intercropping	Application of 45 kg P_2O_5 Rhizobium + PSB inoculation in groundnut. Combination of 50% of inorganic and remaining of inorganic source to FYM + compost (60-30-0 NPK kg/ha)
8	Rakh Dhiansar Rainfall: 1180 mm Soil type: Entisol Crop: Maize	Application of 60-40-20 kg NPK/ha + 20 kg/ha zinc sulphate

(Continued.....)