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Research Findings

Photo 1. Typical vertisol that is used for cereal production (Ethiopia 2012). Photo by IPI.

Potassium Response in Vertisols in Long-Term Fertilizer Experiment in India

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Abstract

Ongoing long-term fertilizer experiments (LTFE) were carried out between 1972 and 2006 at 17 locations throughout India with the aim of monitoring the response of crops to nutrients in different soils and cropping systems in relation to the role of fertilization in sustaining soil health and crop productivity. Results generated over the years in the LTFE indicated that at five locations of vertisols or associated vertisol centres which were considered rich in potassium (K), crops began to show response to K fertilizer application. In order to assess the response of crops to the applied K, the data generated over the years has therefore been closely re-examined. At one of the locations in Jabalpur, a response to K was seen after a few years of experimentation in soybean-wheat and a gradual increase in magnitude of response to applied K has been observed with time. At another site in Akola, both sorghum and wheat showed response to applied K, which also increased with time despite the available K content of the soil being greater than that generally considered as high status. Analysis of soil K revealed that an absence of K in the fertilizer schedule resulted in a decline in K status from 2.1 to 9.7 kg ha^{-1} yr^{-1} and addition of nitrogen (N) and phosphorus (P) accelerated the mining of K. On the other hand, the decline in available K status was arrested by the addition of K (NPK and NPK+ farm yard manure; FYM), which in some cases led to an increase in available K. The relationship between available K status and Bray's percent yield

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Distribution of vertisols (marked in brown on the map). *Source:* Harmonized World Soil Database Viewer V1.21 3/2012 .

indicated ~330 kg K ha^{-1} as a threshold value for vertisols rather than the current recommendation in India of 280 kg ha^{-1}. This finding indicates that there is a need to modify or raise the critical limit for K rating of vertisols, otherwise a lack of K could pose a threat to sustainability.

Introduction

Potassium (K) is an essential plant nutrient playing an important role in various physiological and biochemical activities and is required in high amounts to maintain adequate crop growth (Mengel and Kirkby, 2001). The post Green Revolution era in India saw the use of imbalanced chemical fertilizer applications often high in nitrogen, the introduction of irrigation and the advent of high yielding varieties. The combined effect of these developments has been to accelerate the mining of K in soils resulting in inadequacy of available K in many soils. Currently the majority of Indian soils are in negative balance of K in terms of crop production. Rainfed crops are more prone than irrigated crops because, in contrast to irrigation water, rainwater does not allow any possibility of addition of K to the soil (Singh and Wanjari, 2012). Another important factor relating to the negative K balance is that in India, crop residues are not returned to the soil. Despite the fact that it contains a high proportion of K taken up by the crop, straw has multiple other competitive uses including for cattle feed and fuel. A response to K fertilization is thus to be expected.

An all India Coordinated Research Project on long-term fertilizer experiments (LTFE) has been in progress for many years at 17 locations across the country. It covers predominant cropping systems and soil types studying the response of crops to applied nutrients in terms of crop productivity and also monitoring nutrient status in the soil as well as the nutrient balance in the various soil crop systems. At several locations it is now well established that availability of K has become a yield limiting factor and a decline in yield because of 'hidden hunger of K' in very different soils of India was reported by Wanjari *et al.* (2004). Regular monitoring of the soil is essential to establish soil K status to avoid loss in productivity and in this respect these long-term fertilizer experiments have provided an excellent opportunity to study the impact of continuous fertilizer application on K-status and crop response under different cropping systems. Additionally, experiments have allowed the development of strategies for efficient utilization of K in sustaining productivity.

Of the 17 centres across India at which these LTFE are located, five of the locations are on vertisols or associated vertisols. These soils are considered to be high in available K as well as in reserve K because of the presence of K bearing minerals, including biotite and vermiculite, so application of K fertilizers has not generally been considered necessary. There is now much evidence, however, at least on some of these soils, that the rate of release of K is unable to meet the demands of the crop so that yields are impaired, especially when other nutrients are present in adequate amounts. For example, a negative balance of 56-163 kg K ha^{-1} yr^{-1} in an eight year old rice-wheat system was reported by Singh *et al.* (2002a). Similarly, in a soybean-wheat cropping system, an annual negative K balance of as high as 66-107 kg K ha^{-1} yr^{-1} was recorded by Singh *et al.* (2002b). Crop responses to K fertilization on a vertisol have also been found by Singh and Wanjari (2012), a finding in accord with the report of a long-term study in vertisols cited by Khan *et al.* (2014), indicating a sharp decline in available soil K as measured by ammonium acetate extraction.

This paper further investigates K balance in crop production and the response of different crops to K growing in vertisols using results emanating from the LTFE in India.

Experimental details

The five locations of the vertisols or associated vertisol centres from which data was collected were: Akola (sorghum-wheat), Jabalpur (soybean-wheat), Junagarh (groundnut-wheat), Raipur (rice-wheat) and Parbhani (soybean-safflower). Details of cropping system, soil type, and state and locations of LTFE are described in Table 1.

Amount of nutrients applied were based on recommended dose of each nutrients based on soil analysis. The methods used for determination of available nitrogen (N), phosphorus (P) and K were $KMnO_4$ oxidizable N, Olsen P, and ammonium acetate extractable K, respectively.

The 100% doses of N, P and K for each crop grown at different locations are given in Table 2. In one of the treatments, FYM was applied once a year during the rainy season, in addition to the 100% NPK. Each year, the amount of nutrient applied was the same in the particular experimental field for each of the respective treatments. During the rainy season (June to September) crops were sown with the onset of the monsoon but irrigated in the event of an early end to the monsoon or, in the case of a prolonged dry period, between two rain events. However, the second crop (November-April) was grown exclusively under irrigation. On all five selected sites in the study the soils were alkaline and non-saline and developed on basaltic parent material. The initial available N, P and K status of the soils is given in Table 3. The intercultural operations such as weeding, insect and pest control measures were followed as required. Crops were harvested at maturity and grain and straw samples were analyzed for K concentration to determine uptake and balance. Grain yields were reported at 11% moisture content in the grain.

Results and discussion

Soil nutrient status

Nitrogen

Soils on all the five sites selected were low in available N at the time of inception of the experiment (Table 2). Application of 100% NPK resulted in little increase in available status of N, possibly because of increase in soil organic carbon.

Phosphorus

Akola, Junagarh and Jabalpur soils were low in initial P-status (available P) (Table 2). Continuous use of 100% recommended dose of NPK enhanced this value at all the sites, whereas the value declined in the absence of P in the fertilizer schedule.

Potassium

Potassium status data revealed that absence of K supply resulted in a decline in available K in all five soils except at Parbhani. Application of K as per recommended dose maintained its status in Akola and Parbhani soils only, maybe because of a shorter period of the LTFE, while at the other locations decline in available K was recorded.

Table 1. Nutrient rates used under various cropping systems at different LTFE sites.

Location, soil type	Crop	Fertilizer rates at 100% NPK based on soil test			FYM added(1)
		N	P	K	
		kg ha^{-1}			*t ha^{-1}*
Madhya Pradesh; Jabalpur (1972), Typic Chromustert	Soybean	20	35	17	15
	Wheat	120	35	33	-
	Maize fodder(2)	40	30	17	-
Maharashtra; Akola (1986) Typic Haplustert	Sorghum	100	50	40	10
	Wheat	120	26	50	-
Gujarat; Junagarh (1996) Vertic Ustochrept	Groundnut	25	22	0	5
	Wheat	120	26	50	-
Chhattishgarh; Raipur (1996) Typic Haplustert	Rice	100	26	33	5
	Wheat	100	26	33	-
Maharastra; Parbhani (2006) Typic Haplustert	Soybean	30	26	25	10
	Safflower	60	18	0	-

(1)FYM=Farm yard manure; (2)Maize fodder discontinued in 1994

Source: Swarup and Wanjari, 2000; Singh and Wanjari, 2009.

Table 2. Initial and current status (0-15 cm) of available N, P and K (kg ha^{-1}) at different LTFE locations.

Location (year LTFE was initiated)	Available N			Available P			Available K		
	Initial	Control(1)	NPK	Initial	Control	NPK	Initial	Control	NPK
	kg ha^{-1}								
Madhya Pradesh; Jabalpur (1972)	193	192	263	7.6	9.0	29	370	175	266
Maharashtra; Akola (1986)	120	170	273	8.4	12	29	358	228	386
Gujarat; Junagarh (1996)	183	203	204	7.6	7.9	24	290	187	210
Chhattisgarh; Raipur (2006)	236	218	241	16.0	11.0	25	474	448	428
Maharashtra; Parbhani (2006)	216	194	223	16.0	15.7	18	766	745	792
Critical range(2)		N = 280-560			P_2O_5 = 11-25			K_2O = 121-280	

(1)Control means growing crop without fertilizer and manure; (2)Dhyan Singh *et al.*, 1999.

Note: Bulk density of surface soil (0-15 cm) was used to calculate nutrient status in kg ha^{-1} in each soil.

Source: Singh and Wanjari, 2009.

Table 3. Average crop yield (kg ha^{-1}) in vertisols at different locations of the All India Coordinated Research Project; AICRP-LTFE.

Location, state and place (years)	Crops	Control	N	NP	NPK	150% NPK	NPK+FYM	CD[1] (p=5%)
					-------------*kg ha^{-1}*-------------			
Madhya Pradesh, Jabalpur (41)	Soybean	829	1,036	1,656	1,829	1,849	2,025	150
	Wheat	1,264	1,691	4,104	4,495	4,808	4,932	284
Maharastra Akola (26)	Sorghum	282	1,981	2,701	3,382	4,243	4,291	354
	Wheat	143	932	1,323	2,006	2,495	2,568	241
Gujarat, Junagarh (16)	Groundnut	693	705	742	850	899	952	130
	Wheat	1,785	1,827	2,458	2,603	2,699	3,168	257
Chhattisgarh, Raipur (6)	Rice	2,381	3,722	5,065	5,128	5,610	5,474	356
	Wheat	1,056	1,536	2,272	2,278	2,622	2,497	287
Maharashtra, Parbhani (6)	Soybean	1,382	1,526	2,246	2,368	2,639	2,642	198
	Safflower	1,111	1,248	1,659	1,685	1,844	1,871	183

[1] CD = critical difference

Crop productivity

Yield data (since inception to 2013) clearly demonstrated that application of N and P resulted in increase in productivity irrespective of location (Table 3). Response to K application (NPK treatment), however, was recorded only at Jabalpur and Akola. Slight but non-significant increase in yield was recorded at Junagarh, Raipur and Parbhani. Crops did not show any response to applied K at Junagarh and Raipur even though Junagarh soils were low in K status. At Junagarh, irrigation water contains 6 parts per million (ppm) sodium (Na), which may be responsible for a lack of K response since a number of crops can utilize Na in place of K to a varying extent (Marschner 2012). However, at Raipur, soil K is sufficient to meet the K requirement of crops. But, at the rate at which availability of K is declining, K could become a limiting nutrient in the future (Table 6). The larger yields, with 150% NPK and NPK+FYM, at some of the locations were due to application of organic matter and larger amounts of nutrients.

Data on agronomic efficiency of K at the two responsive sites (Jabalpur and Akola) indicates that application of one kg K resulted in an increase of grain yield which ranged from 10.2-17.0 kg (Table 4). Crop response to the applied K depended on both the availability of K in the soil and productivity level. Continuous growing of crops without K application led to a decline in available K status from 370 to 223 kg K_2O ha^{-1} at Jabalpur, and at Akola available K status dropped from 358 to 255 kg K_2O in the NP treatment. These values are far below even the old threshold level of K so that K response is therefore to be expected and likely to increase in the future.

Potassium response

The response of the crops to K with time has been calculated and presented in Fig. 1A and 1B for Jabalpur and Akola, respectively. Review of the data presented in Fig. 1A indicates a gradual increase in K response with time since inception of the experiment at Jabalpur. In wheat the magnitude of K response was larger than that of soybean. At Akola, both sorghum and wheat showed response to K and a very high response has been seen in recent years (Fig. 1b). This appears to be due to a decline in available K status particularly in the NP treatment. Although slight improvement in yields on application of K at other locations was also recorded, this was not statistically significant. In spite of high estimates of K, the response of crop to applied K could be due to increase in estimates of K availability on drying soil. In fact, in actual moist conditions, K status is probably less than required as reported by Khan *et al.* (2014). Reviewing the results of a large number of studies carried out in many countries revealed that, on drying, ammonium acetate extractable K in soil increases tremendously (~2 to 3 fold) compared to moist soil. This could be a possible reason for crop response to applied K because the available K status is very low in moist soil whereas fertilizer recommendations are made on the basis of K estimates analyzed in dry soil.

Potassium balance in Jabalpur

On the basis of K input (fertilizers added) and output (removal in harvested crop parts) an apparent balance was calculated on the soybean-wheat system at Jabalpur (Table 5) which showed a negative K balance of 72-206 kg K ha^{-1} yr^{-1}. This negative balance, in spite of K application, can be accounted for by the larger K uptake than that applied and this is probably responsible

Table 4. Agronomic efficiency (kg grain/kg K) of applied K in Jabalpur and Akola.

Location (years)	Crop	K application	Yield increase	Agronomic efficiency for K (AE_K)
		kg K ha^{-1}	*kg ha^{-1}*	*kg kg^{-1}*
Jabalpur (41)	Soybean	17	173	10.2
	Wheat	33	391	11.8
Akola (26)	Sorghum	40	681	17.0
	Wheat	50	683	13.7

Fig. 1. (A)Soybean and wheat response to K in vertisols at Jabalpur (MP, India) with time; (B) Sorghum and wheat response to K in vertisols at Akola (Maharashtra, India) with time.

Table 5. Scenario of K balance (after 40 years) in soybean-wheat system at Jabalpur (MP, India).

Treatments	Total K added	Total K uptake	Apparent K balance	Apparent K balance
	---------------*kg K ha^{-1}*------------------		--------------*K kg ha^{-1} yr^{-1}*-------------	
Control	0	2,889	-2,889	-72
100% N	0	3,924	-3,924	-98
100% NP	0	8,668	-8,668	-217
100% NPK	2,374	9,760	-7,386	-189
150% NPK	3,374	11,633	-8,259	-206
100% NPK + FYM	6,294$^{(1)}$	13,676	-6,552	-184

$^{(1)}$Includes K added through FYM (K=0.65%).

for the crop response to applied K. In agreement with these findings a negative K balance of 66-107 kg ha^{-1} yr^{-1} in soybean system grown for eight years on vertisols of Bhopal was reported by Singh *et al*. (2002b).

Rate of decline in available K

Soil samples (0-15 cm) collected after completion of each cropping cycle were analyzed for available K. Table 6 illustrates the average annual rate of change (negative or positive) of available K in the soil. Irrespective of treatments, change in available K status in the control treatment was negative at all the sites. Moreover, in all locations, except Parbhani, the data further revealed that application of N and NP in the absence of K resulted in a decline in K at a higher rate compared to the control and the treatment receiving K. In Jabalpur and Raipur, K removal was so large that, even at the highest levels of added K, a depletion in K occurred. Yet, in Akola and Junagarh, the application of K minimized the negative K balance, and at high K application even caused an increase in available K in soil.

Critical limit of K in vertisols

To determine the critical limits of available K status for Jabalpur and Akola vertisols, K response trials were conducted on farmers' fields varying in available K status. The grain yield, termed Bray's yield, was noted at the point where an increase in soil K did not result in an increase in yield. Relative yields were calculated against this value for all field trials. The relative Bray's yields were then plotted against soil K status (Fig. 2). These experiments indicated a value of ~330 kg K_2O ha^{-1} (154 ppm K) as a critical limit which is greater than the 280 kg K_2O (132 ppm K) that is currently being used for K recommendation in India. This study clearly demonstrates that there is an urgent need to revise the threshold value of K for vertisols.

Conclusions

From the present study on vertisols at five LFTE sites, it can be concluded that there is evidence on some of these soils of a continuous decline in available K status in the absence of K in fertilizer application. After a few years without K supply crops began to show response to applied K. From experiments on these soils the threshold value for recommending K application was shown to be ~330 kg K_2O ha^{-1} rather than the

Table 6. Change in soil available K at different LTFE locations (kg ha^{-1} yr^{-1}).

Location (years)	Control	N	NP	NPK	150% NPK	NPK+ FYM
	----------------------------*kg* ha^{-1} yr^{-1}----------------------------					
Jabalpur (41)	-2.3	-2.1	-3.6	-2.7	-1.9	-1.4
Akola (26)	-1.7	-5.0	-4.2	+0.9	+2.6	+3.4
Junagarh (16)	-5.8	-6.8	-6.2	-4.5	-2.4	+1.0
Raipur (6)	-3.3	-6.8	-9.7	-5.0	-1.3	-3.1
Parbhani (6)	-3.5	NC(1)	NC	+4.3	+7.3	+9.1

(1)NC = no change.

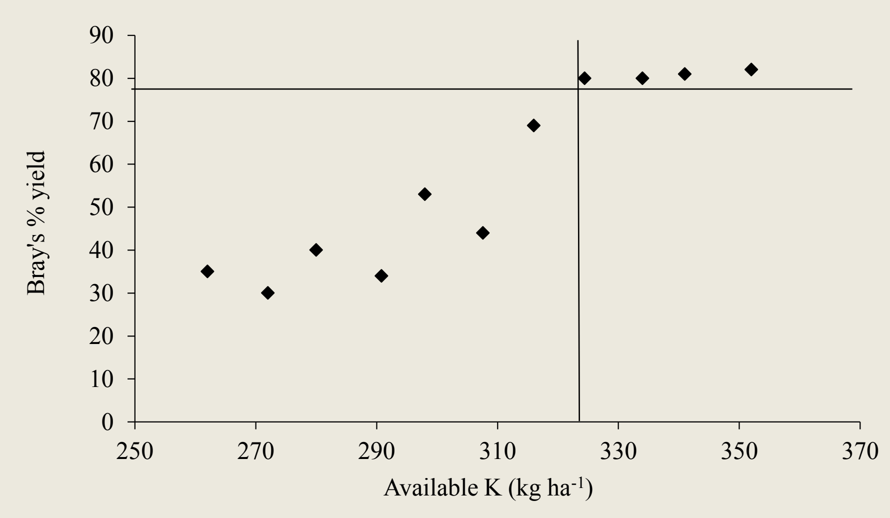

Fig. 2. Potassium response in Jabalpur and Akola vertisols (MP and Maharashtra, India).

lower 280 kg K_2O ha^{-1} which is currently being used in India. There is thus a need to conduct further response studies in the field to assess the threshold level of K for vertisols.

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The paper "Potassium Response in Vertisols in Long-Term Fertilizer Experiment in India" also appears on the IPI website at:

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