Research Findings

Castor crop in Andhra Pradesh. Photo by Ch. Srinivasarao.

Impact of Potassium on Crop Productivity, Use Efficiency, Uptake and Economics of some Rainfed Crops in Andhra Pradesh, Southern India: On-Station and On-Farm Experiences

Srinivasarao, Ch.[1]

Introduction

India makes up only 2.5 percent of the world's land mass but supports as much as 17 percent of the global population. Since the inception of the Green Revolution about 50 years ago, the population of India has increased three-fold to approximately 1,140 million. Over this period there has been a sustained effort to increase food grain production using irrigation, hybrid seeds and fertilizers. To meet the needs created by further forecasted population increases, it is estimated that by 2020, India will need an annual production of about 294 mt of food grains, compared with the 230 mt produced today. An additional production of 64 mt of food grains has therefore to be achieved from the same or smaller land area, when degradation of cultivated land and the possible detrimental effects of climate change are taken into account. Proper nutrient management, through efficient, judicious and balanced or integrated use of nutrients coupled with other effective measures in soil and agronomic management, is therefore top priority (Subba Rao *et al.*, 2011).

While rainfed agriculture in India represents 58 percent of the total arable land area of 141 M ha, it produces only 40 percent of the food (Venkateswarlu *et al.*, 2012), with the productivity

[1]Central Research Institute for Dryland Agriculture, Santoshnagar, Saidabad (P.O.), Hyderabad-500059, Andhra Pradesh, India

levels of rainfed, dryland crops far below those of irrigated crops. This to some extent may be accounted for by the rainfall-scarce environments of the tropical and sub-tropical regions of the country, which are characterized by arid and semi-arid climates with soils inherently low in organic matter. This is a major component determining soil quality and is strongly related to food security (Srinivasarao *et al.*, 2012). Increasing the productivity of rainfed cropping systems is therefore an urgent and challenging task to meet the food demands of an ever increasing population.

Until relatively recently, the general opinion of Indian scientists and policy makers has been that Indian soils are rich in potassium (K); hence, not much attention has been given to K as a crop nutrient (Tandon and Sekhon, 1987). In soil, K is generally considered in relation to the forms (or pools) of K present: i.e. in solution, exchangeable, non-exchangeable or as mineral K, and the mobilization of K between these pools (Syers, 2003). Under intensive cropping, in solution and exchangeable K (together measured as available K), are readily taken up by roots from the soil solution. This uptake of K induces further release of K from less accessible sources, including the non-exchangeable fraction. Under conditions of low K availability, the quantity of non-exchangeable K in the soil, its rate of release into the soil solution and the extent to which the K release from this fraction is able to match the K demand of the crop, are important factors relating to K nutrition of crop plants (Mengel, 1985; Darunsontaya *et al.*, 2012; Srinivasarao and Surekha, 2012). Many rainfed crops can remove 100 to 200 kg K ha^{-1} during a growing season. This is usually far in excess of that released from slowly exchangeable sources in soils low in available K. Likewise, the current rates of K application in mineral fertilizers in India are much lower than those required for crop supply, as is evident from current NPK consumption data (Fig. 1). K consumption was low for all eight crops shown. Only two crops (groundnut and cotton) were supplied within the range of 10 to 15.2 kg K_2O ha^{-1} and the remaining six crops were supplied with even lower amounts, with only sunflower receiving more than 6 kg K_2O ha^{-1}.

Different soil types occur in agro-ecological regions such as alluvial, medium and deep black soils, and red and lateritic soils. The K status of these soils varies depending on soil type, parent material, texture and management practices. Red and lateritic soils with kaolinite as a dominant clay mineral and of light texture are low in exchangeable as well as non-exchangeable K (Subba Rao *et al.*, 2011). This is the case, for example, in the acidic soils of Bangalore, which contain about 94 percent kaolinite, 4 percent mica, 1 percent quartz and 1 percent feldspars. Most red and lateritic as well as alluvial soils of India are low in exchangeable and non-exchangeable K. The amount of mica, as well as biotite mica, in acidic soils is low, as expressed by X-ray diffraction (XRD) peak intensities in several red and lateritic soils of India. Soil reserves of K (non-exchangeable K) are thus very low in acidic red soils.

The present study examines the impact of increasing levels of K fertilization on productivity, K use efficiency, K content and economics in rainfed groundnut, sorghum, maize and castor grown on the red soils of Andhra Pradesh, both at a research station and on-farm.

Materials and methods

All experiments were carried out in the state of Andhra Pradesh. Field experiments were conducted at Gunegal Research Farm, Central Research Institute for Dryland Agriculture, Hyderabad, Andhra Pradesh, India, using four important rainfed crops. Two oil seed crops (groundnut and castor) and two cereals (sorghum and maize) were supplied at three rates of K (Control, 20, 40, 60 kg K ha^{-1}) during 2010-2011. The soil was a light textured sandy loam (Alfisol), acidic pH, non-saline, low in soil organic carbon (3.2 g kg^{-1}), low in available N (122 kg ha^{-1}), medium in Bray P

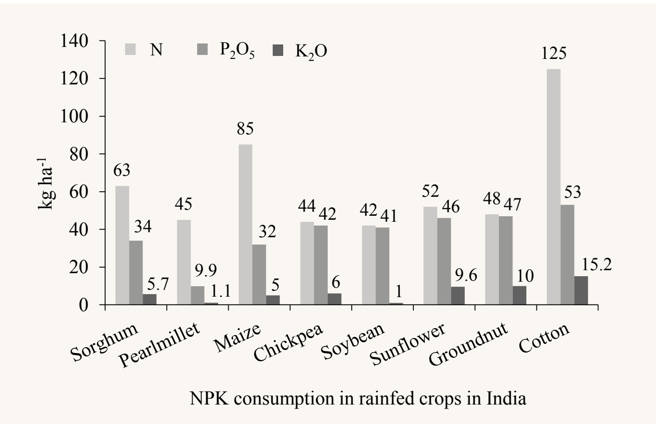

Fig. 1. Typical N, P and K consumption (kg nutrient ha^{-1}) in the main rainfed crops in India. *Source:* FAI, 2011-2012.

Groundnut crop grown in the experiment.
Photo by Ch. Srinivasarao.

(12 mg kg^{-1}) and low in available K (46 mg kg^{-1} ammonium acetate extraction) (Hanway and Heidel, 1952). The soil was also medium in sulphur (14 mg kg^{-1}), low in DTPA extractable zinc (0.45 mg kg^{-1}) and adequate in available iron (Fe), manganese (Mn), copper (Cu) and boron (B) (Jackson, 1973). All other required nutrients were applied as per the soil test data and state recommendations (maize: 100 kg N and 60 kg P_2O_5; sorghum: 80 kg N and 40 kg P_2O_5; groundnut: 20 kg N and 40 kg P_2O_5; and castor: 80 kg N and 40 kg P_2O_5). K was applied in the form of muriate of potash (MOP with 60 percent K) at the three graded levels already described, with three replications per treatment, including the control.

Improved varieties or hybrids were used in the trials viz. groundnut (JL-24), sorghum (SPV 462), maize (Hybrid DHM 177) and castor (DCS-9). Plot size was 5 x 5 meters and the trials were randomized. All appropriate management practices were followed.

Over the same period, 23 on-farm trials were also conducted in nine villages of two rainfed districts of Andhra Pradesh (Khammam and Nalgonda) using three rainfed crops (maize, sorghum and groundnut). In these trials, two treatments only were considered: farmers' practice, and farmers' practice + 30 kg K ha^{-1} as MOP. Farmers' field practice (FFP) of fertilizer application is not based on soil testing. While N is often applied in excess, P application is more or less near to recommended state level. Application of other macro- and micro-nutrients is uncommon. These soils were also predominantly red (Alfisols) with a sandy loam texture, acidic pH, non-saline, low in available N, medium in Bray P, and low to medium in ammonium acetate extractable K (40 to 62 mg K kg^{-1}) (Hanway and Haidel, 1952). DPTA extractable Zn was low (<0.5 mg kg^{-1}) and Fe, Mn and Cu contents were adequate. Soil analysis was replicated three-fold and a mean computed.

Crop yields (grain or pod, plus straw yields) were recorded and plant parts were analyzed for K content. K use efficiency was computed in terms of agronomic efficiency (AE; kg yield increase per kg nutrient applied) and partial factor productivity (PFP; kg harvested product per kg nutrient applied). The economics of K application was computed, based on additional income obtained from K application in relation to the cost of K fertilizer. The K content of different groundnut plant parts (pod, leaf and haulm), and the grain and straw K content of sorghum and maize, was determined (Jackson, 1973). Statistical analysis was carried out as per the methods suggested by Gomez and Gomez (1984).

Results and discussion

On-station studies on K nutrition in rainfed crops

Grain and straw yields

The impact of graded levels of K on grain yields of four different rainfed crops, viz., groundnut, sorghum, maize and castor, is presented in Table 1. In all four crops, K application significantly ($P<0.05$) increased grain yields. Among the four crops, maize showed higher grain yields, followed by sorghum, castor and groundnut at the various K application levels. The groundnut yields increased from 0.54 mt ha^{-1} (control) to 0.75 mt ha^{-1} (60 kg K ha^{-1}), a 38 percent increase over the control. Sorghum grain yields also rose from 2.8 mt ha^{-1} (control) to 3.74 mt ha^{-1} at 60 kg K ha^{-1} (33 percent increase). Maize too responded substantially to K application, by increases of 18, 25 and 33 percent respectively over the control, at 20, 40 and 60 kg K ha^{-1}. Even under rainfed conditions, maize yields obtained with optimum K application were above 5 tons per ha, indicating the potential of balanced fertilization in raising rainfed crop productivity (Srinivasarao *et al.*, 2010a, b). In castor, another important oil seed crop, grain yields increased from 0.74 mt ha^{-1} (without K) to 0.94 mt ha^{-1} with 60 kg K ha^{-1}, showing 27 percent gain over the control.

Similarly, straw yields of groundnut, sorghum, maize and castor were significantly increased ($P<0.05$) by 11, 19, 32 and 36 percent at 60 kg K ha^{-1}. The substantial crop response to K application in rainfed crops in these regions can be attributed to lack of K in these light textured red soils (Alfisols) (Naidu *et al.*, 1996). These soils, inherently low in K, have been under continuous cultivation, supplemented by N and P mainly in the forms of urea and diammonium phosphate (DAP), without any recycling of crop residues or potash fertilizer as a source of available K. Crop K requirements over many years have therefore been derived mainly from soil K reserves, so-called "mining" of soil

Table 1. Impact of graded levels of K in productivity of rainfed crops on Alfisols in Gunegal Research Farm.

Potash application	Groundnut	Sorghum	Maize	Castor
kg ha^{-1}	----------*mt ha^{-1}*----------			
	Pod/grain yield			
Control	0.54	2.80	3.90	0.74
20	0.60	3.30	4.60	0.86
40	0.67	3.60	4.90	0.92
60	0.75	3.74	5.12	0.94
LSD (P=0.05)	0.05	0.11	0.13	0.05
	Straw yield			
Control	0.29	7.40	6.00	1.60
20	0.36	8.00	7.20	2.01
40	0.38	8.60	7.60	2.15
60	0.39	8.81	7.94	2.19
LSD (P=0.05)	0.06	0.45	0.31	0.21

K, exacerbated by continuous additions of N and P. That crops readily respond to K addition, as evident from our findings, clearly demonstrates the need for K by these soils.

Table 2. AE_K and PFP_K in rainfed crops on Alfisols in Gunegal Research Farm.

K rate	Groundnut	Sorghum	Maize	Castor
kg ha⁻¹	----------------*Agronomic efficiency of K (AE_K; kg kg^{-1})*----------------			
20	12	25	35	6
40	3.4	20	25	4.5
60	3.4	15.6	20	3.3
LSD (P=0.05)	1.1	1.3	1.2	0.4
kg ha⁻¹	------------*Partial factor productivity of K (PFP_K; kg kg^{-1})*------------			
20	30	165	230	43
40	17	90	122	23
60	13	62	85	16
LSD (P=0.05)	1.3	2.1	2.6	2.3

Agronomic Efficiency (AE) and Partial Factor Productivity (PFP) of K application

Nutrient use efficiency is a crucial factor in rainfed agriculture, as low and erratic rainfall often lowers use efficiency of added nutrients. AE of K (AE_K) was seen to be highest for maize, followed by sorghum and groundnut, and was lowest in castor (Table 2). High values of AE_K as obtained in the maize (AE_K of 35 to 20) and sorghum (AE_K of 25 to 15.6) crops should encourage farmers and end their reluctance to apply K, knowing that the additional yield will compensate for the risk that typically exists under rainfed conditions. Such high AE_K also leads to economic profit (see later). PFP_K also varied widely due to soil K deficiency and response to K application (Table 2).

K content and K uptake

Application of graded levels of K significantly increased the K content of various parts of the groundnut (Fig. 2A), as well as the grains of sorghum and maize (Fig. 2B). In groundnut, leaf and shells' K content was higher compared to that of the pod (Fig. 2A).

K offtakes, as computed from pod/grain and straw yields and the K content in respective plant parts - assuming removal of all plant parts from the field - indicated the substantial increases resulting from K application to the three rainfed crops (Fig. 3). Total K offtake was highest in maize, followed by sorghum, with a very much lower offtake by groundnut, in accordance with the much lower yield and K content. The high K uptake levels in sorghum (up to 120 kg K ha^{-1}) and maize (160 kg K ha^{-1}) underline the importance of K management in K deficient Alfisols (Srinivasarao *et al.*, 2010 a, b). Even without K additions (i.e. control plots), total K uptake was about 65 kg K ha^{-1} in sorghum and maize, providing evidence of large-scale mining of K. These results clearly indicate the need for K application because of the cultivation of K exhaustive crops like maize and sorghum, which has led to depletion of soil K. This is of major importance in the red soil regions of India where K depletion has become an important constraint to crop production.

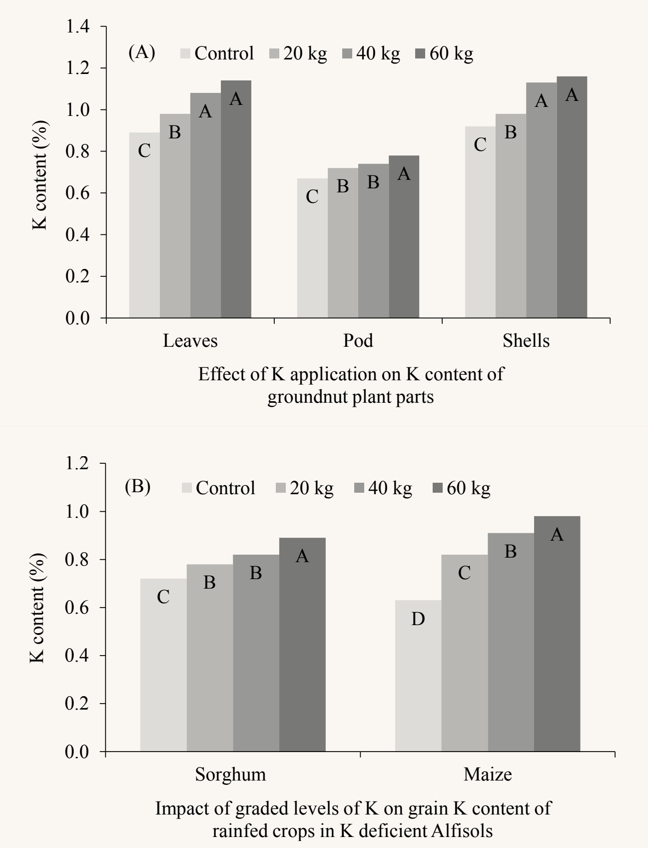

Fig. 2. Variations in K content in groundnut plant parts (A) and in sorghum and maize grain (B) at graded levels of added K.

Economics of K application

Application of graded levels of K on rainfed crops showed substantial economic benefits. Higher economic benefits were obtained in maize, followed by sorghum, castor and groundnut. In the case of groundnut, the additional income obtained was Rs 1,620, 3,510 and 5,670 at 20, 40 and 60 kg K ha^{-1} respectively. Additional returns in sorghum were Rs 4,900, 7,840 and 8,820 with 20, 40 and 60 kg K ha^{-1}. Benefits were much higher in maize at all the levels of K application, showing an additional income of Rs 12,480 at 60 kg K ha^{-1}. Castor also showed significantly higher additional income with K fertilization. Per rupee invested on K fertilization, the return yielded was: Rs 10 for groundnut, between Rs 16 to 27 for sorghum, Rs 23 to 40 for maize and Rs 14 to 26 for castor.

On-farm experiments with K fertilization and economic benefits to farmers

The application of 30 kg K ha^{-1} to three important rainfed crops grown in 23 farmers' fields of two districts (Khammam and Nalgonda) in Andhra Pradesh increased yields of groundnut, sorghum and maize as compared to FFP treatments (Farmers Fertilizer Practice) i.e. without K (Fig. 4; page 8).

Pod/grain yield responses due to K application varied widely, however, among crops as well as farmers' fields. The additional yields with K varied from 0.07 to 0.21 mt ha^{-1} for groundnut, from 0.15 to 0.35 mt ha^{-1} for sorghum and from 0.34 to 0.76 mt ha^{-1} for maize (Table 3). Interestingly, all farmers (23) were successful in increasing the yields of their crops after K application, even though the level of improvement varied. Differences in crop response to applied K in farmers' fields were due mainly to variations in available K in the soil, which varied between 40 to 62 mg kg^{-1}. Average yield response to 30 kg K ha^{-1} was 0.14, 0.25 and 0.53 mt ha^{-1} for groundnut, sorghum and maize respectively, with corresponding average additional net income of Rs 2,970, Rs 1,590 and Rs 4,702 (Table 3). From the available K soil data, the recommended dose of K for rainfed crops varied between 20-40 kg K ha^{-1} according to the State Agricultural University and the State Government Agriculture Ministry. However, actual field application of K fertilizer to these crops is almost nil and few other commercial crops receive K fertilization at farmers' level.

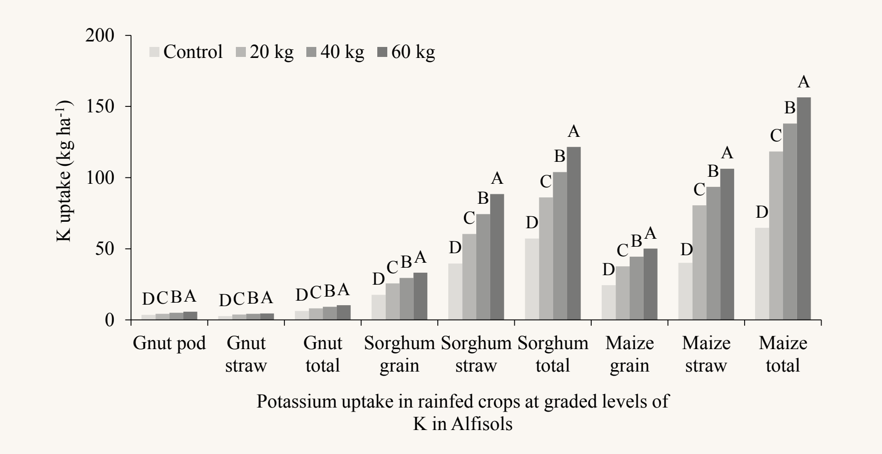

Fig. 3. Offtakes of K in grain, straw and total K in groundnut, sorghum and maize (castor was not analyzed).

Table 3. Response to K and economics of K fertilization in on-farm trials.

Crop	No. farmers	Average yield FFP	Average yield with K application	AE_K	Average response over FFP	Average additional net income
		mt ha^{-1}	*mt ha^{-1}*	*kg kg^{-1}*	*mt ha^{-1}*	*Rs ha^{-1}*
Groundnut	6	0.34	0.46	3-7	0.14	2,970
Sorghum	8	1.01	1.24	5-12	0.25	1,590
Maize	9	4.05	4.58	13-25	0.53	4,702

Conclusions

In most rainfed crops the importance of K fertilization is not given the attention it deserves, despite significant economic benefits that can be obtained. This is because of farmers' lack of knowledge as well as their reluctance to increase inputs, given the uncertainty of crop cultivation in rainfed conditions.

The results of the experiments reported here indicate that rainfed crops - maize, sorghum, groundnut and castor - responded substantially to K application on the K deficient red soils of Andhra Pradesh, Southern India, both in on-station and on-farm conditions. Maize showed the highest yield response (AE_K 13-35) and economic return to K application, followed by sorghum (AE_K 5-25), castor (AE_K 3-6) and groundnut (AE_K 3-12). On-farm trials indicated that additional returns to K application were higher than benefits obtained on-station. These relatively high AE values to K application indicate that in these conditions, K is highly deficient, leading to limited yields, and its application provides a high probability of obtaining additional economic return.

Moreover, as optimal K nutrition is of particular benefit to crops in providing drought tolerance during intermittent dry spells in the rainfed environment, application of K may introduce additional benefits to farmers, beyond remedying the deficient soil K status.

The inclusion of K in nutrient management programs in rainfed crops is hence essential to realize the potential of these crops in K-deficient, red, lateritic, acidic, and light textured soils in rainfed regions of India.

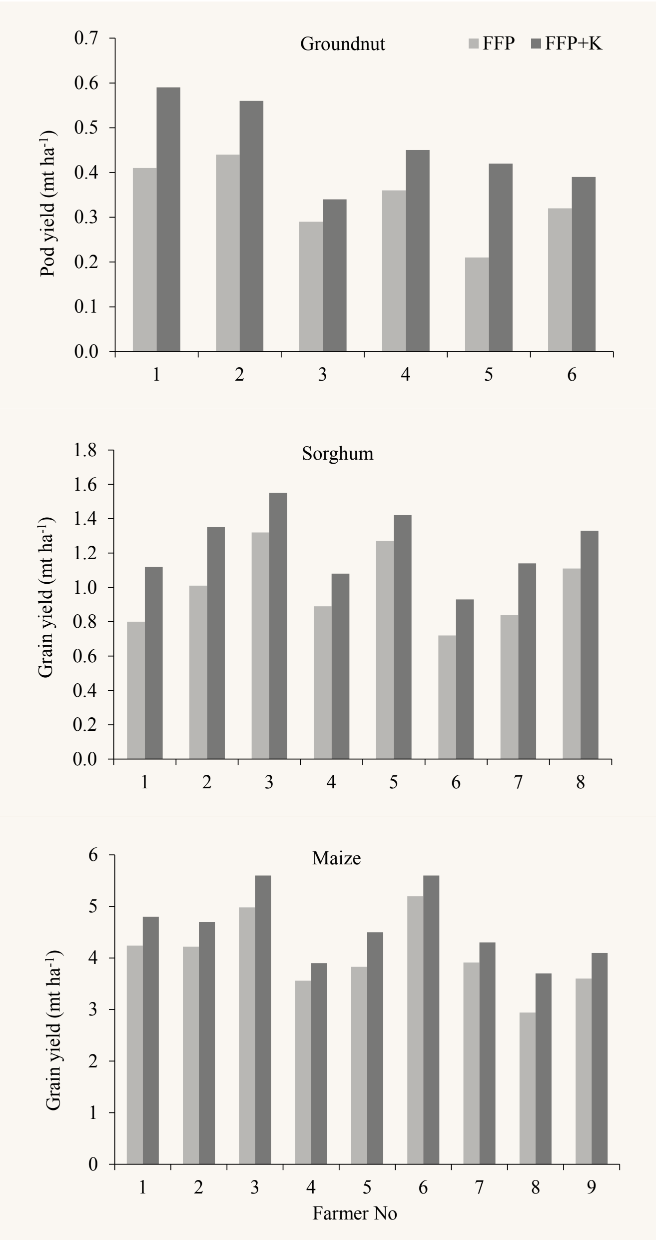

Fig. 4. Additional crop yields due to 30 kg K ha^{-1} application in groundnut, sorghum and maize in farmers' fields.

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Regional activities/India

Dr. Cherukumalli Srinivasarao (left) receiving the IPI-FAI Award 2012 at the Annual Meeting of the Fertilizer Association of India (FAI), December 2012. Photo supplied by Ch. Srinivasarao.

IPI-FAI Award 2012

Dr. Cherukumalli Srinivasarao, Principal Scientist (Soil Science) has done pioneering research and extension work on potassium fertility constraints in various production systems covering food, fruit, and vegetable crops in different agro ecological regions of India. His contributions in soil K fertility assessment based on available as well as nonexchangeable K fraction of soil, development of K fertility maps of India and identification of priority districts in India where K application is essential and regular are highly useful for the farming community. He developed SSNM and INM strategies for meeting K needs of various crop production systems in India based on participatory soil sampling and Soil Health Cards. He extensively worked on soil health management in 85 villages in eight tribal dominant rainfed districts of Andhra Pradesh, delineated K deficiency in soils, documented K deficiency in several dryland crops, developed K recommendations based on individual farmers' field soil tests and crops grown, demonstrated positive impacts of K on farm productivity, quality of the produce, profitability and livelihoods of rainfed farmers.