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Editorial

Dear readers,

Fertilizer use in Africa is extremely low and insufficient to maintain agricultural productivity at a satisfactory level. According to statistics from the International Fertilizer Association, only 3% and 1.7% of global fertilizer and potash consumption, respectively, is in Africa. Comparing the use of fertilizers across the continent to China and India, which also have no significant food exports, shows that on average, these two countries apply 37 kg and 23 kg of NPK nutrients per capita per year respectively, compared with just 4.5 kg applied to African farmland. Such minimal nutrient application is one of the key factors contributing to Africa's huge food import bill, currently standing at around US$35 billion per year.

Judicious fertilizer application requires, in the first instance, measuring soil and plant nutrient requirements. Results from African soils after many years of depletion show that it is not just nitrogen, phosphorous and potassium which are needed, but also sulfur, zinc, boron and other essential micro-nutrients. As a result, effective dissemination of knowledge to farmers and fertilizer application requires skilled and well-trained people along the fertilizer value chain in order to address this more complex challenge.

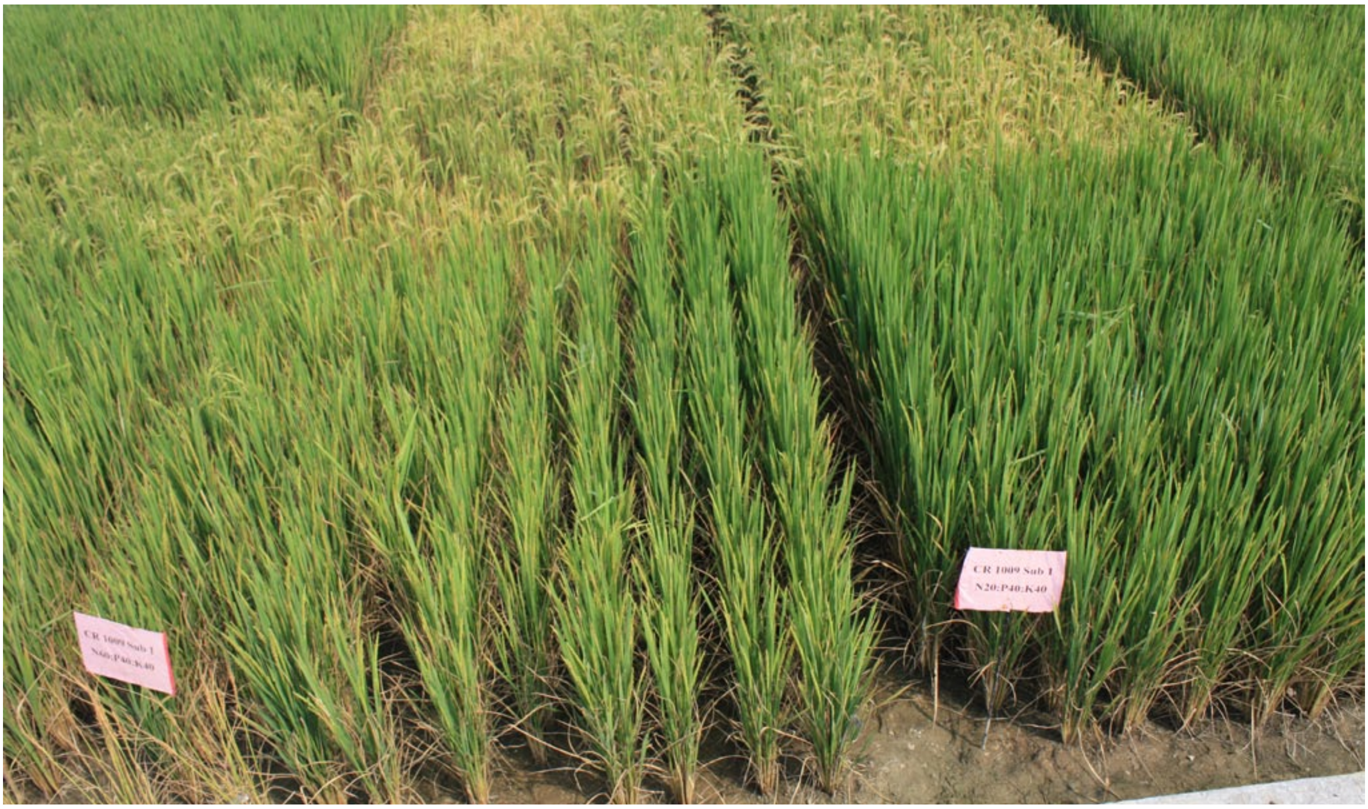
It is high time, therefore, that the fertilizer industry made an impact in terms of increased food production across the continent by providing appropriate tools for measuring site specific fertilizer requirements and forming partnerships to build fertilizer and nutrient management knowledge throughout the value chain.

I wish you an enjoyable read.

Hillel Magen
Director

Photo cover page: Photo by IPI.

Research Findings



The experimental plot at Narendra Deva University of Agriculture and Technology (NDUAT), Kumarganj, Faizabad, UP, India. Photo by E. Sokolowski.

The Beneficial Effects of Applying Potassium Alone or with Phosphorus During Nursery Management in Enhancing the Survival and Yield of the Rice Variety Swarna-Sub1 in a Flood-Prone Ecosystem

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Abstract

The introduction of submergence-tolerant SUB1 rice varieties has enhanced productivity of average lowland rice yields by over 2 t ha^{-1}. Considering the benefit of these varieties the government of Uttar Pradesh has launched a large-scale seed production program to greatly increase the cultivation of the Swarna-Sub1 variety in the flood-prone, rainfed lowlands of eastern UP. However, relatively little is known concerning nutrient management, especially that of potassium (K), phosphorus (P) and nitrogen (N), to provide the best potential for the growth of SUB1 rice varieties. This question is investigated in nursery applications in a study carried out at the Instructional Farm of Narendra Deva University of Agriculture and Technology,

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Kumarganj, Faizabad, India during the 2010 and 2011 *kharif* seasons. Seven nutrient treatments, representing nursery nutrient management were applied 10 days after seed sowing with various combinations of fertilizers, with N supplied as urea, P as single superphosphate and K as muriate of potash. The 25-day old seedlings obtained were transplanted in an outdoor submergence pond. Fifteen days after transplanting, plants were submerged for a period of 13 days. Survival and recovery were recorded five and 15 days after desubmergence, respectively. Growth observations and nutrient analyses were carried out at different stages of crop growth, i.e. just before transplanting, before submergence, just after desubmergence and at the recovery stage. A significantly higher survival rate after desubmergence was recorded in treatment T_5 when K was applied alone (0-0-40 kg N-P_2O_5-K_2O ha^{-1}) and in T_6, when K was applied together with a higher dose of P in the nursery treatment (0-60-40 kg N-P_2O_5-K_2O ha^{-1}). Maximum underwater shoot elongation (25.4%) was recorded in T_1 (40-40-40 kg N-P_2O_5-K_2O ha^{-1}) when K and P were supplied with N, whereas at recovery, greater plant heights were recorded in T_6 (0-60-40 kg N-P_2O_5-K_2O ha^{-1}) and T_5 (0-0-40 kg N-P_2O_5-K_2O ha^{-1}). Reduction in N, P and K concentrations and their uptakes were recorded after desubmergence. The highest grain yield (t ha^{-1}) was recorded in T_5 (0-0-40 kg N-P_2O_5-K_2O ha^{-1}), which was significantly superior to all other treatments except T_6 (0-60-40 kg N-P_2O_5-K_2O ha^{-1}). A high positive correlation was recorded between K concentration and its uptake at the nursery stage and survival and yield. The present study revealed that K alone or in combination with P during rice nursery management significantly improved crop survival and regeneration after desubmergence to ensure faster recovery and a better crop stand.

Introduction

Flooding affects about 20 million ha in Asia each year and estimates indicate that submergence stress in rice causes corresponding annual losses of US$650 million to US$1 billion (Herdt, 1991; Dey and Upadhyaya, 1996). In India, about 16.1 million ha of rainfed lowland rice are grown each year, of which 4.4 million ha are highly submergence-prone (intermediate rainfed lowlands; Haefele and Hijmans, 2007). In addition, submergence might also occur in shallow rainfed lowlands and irrigated lowlands. Recent research has identified the SUB1 gene as the main gene controlling submergence tolerance in rice. The cloning of the gene underlying tolerance (Xu *et al.*, 2006) has enabled the development of precise marker targeted transfer of this gene into widely accepted "mega varieties" (Neeraja *et al.*, 2007; Septiningsih *et al.*, 2009) through a marker-assisted backcrossing approach. The effects of SUB1 on plant survival under submergence are dramatic, and the gene has no yield penalty under non-submerged conditions. Results of research carried out by the International Rice Research Institute (IRRI) showed that SUB1 varieties gave an average of 1-3.8 t ha^{-1} higher yield than non SUB1 types under 12-17 days of complete submergence (Singh *et al.*, 2009). Similar results were also obtained on farmers' fields in several states in India, namely Uttar Pradesh (UP), Bihar, West Bengal and Orissa. In some cases, SUB1 varieties gave a near normal yield under submergence while intolerant varieties were irretrievably damaged (Mackill *et al.*, 2012). In India, Swarna-Sub1 was released by the states of UP and Orissa in 2012 and this variety has enhanced the productivity of rice by 1-2 t ha^{-1} compared to the average lowland yield.

Considering the benefit of the Swarna-Sub1 variety, the UP government has launched a large-scale seed production program for Swarna-Sub1, increasing its cultivation extensively. However, limited progress has been made in the development of accompanying crop and nutrient management options to harness the potential of the newly developed SUB1 introgressed rice varieties. Recent research has shown that leaf N concentration is negatively correlated with plant survival under flooded conditions, and addition of P seems to enhance tolerance of plants grown on P deficient soils (Ella and Ismail, 2006). Furthermore, unpublished results indicate that low as well as high leaf nitrogen (N) concentrations reduce survival, whereas zinc (Zn) application on Zn deficient soils increases survival. Interestingly Wade *et al.* (1999) reported that slow release N fertilizer was the most beneficial fertilizer in submergence-prone rainfed lowlands. Additionally, balanced nutrition (N-P-K-Zn) with farm yard manure (FYM) together with lower seed density in the seed bed, and the transplanting of older seedlings, also significantly enhanced survival following flooding after transplanting (Bhowmick *et al.*, 2014).

Very little work has been conducted on the effect of potassium (K) nutrition on yield improvement under flood prone situations. However, available information on nutrient management after flooding (recovery) shows that a significant increase in yield can be achieved through application of nutrients, particularly N, because of its effects in stimulating recovery growth and early tillering (Ram *et al.*, 2009). Thus, there are clear indications that crop and nutrient management may have a major impact on the performance of these SUB1 varieties. Given the fact that Swarna-Sub1 has already been released in India and Bangladesh, and its release is pending in several other countries, there is an urgent need to obtain more information on the effects of nursery nutrient management. The purpose of this work was therefore to investigate the influence of nutrient management, especially that of K, in relation to the high potential of Swarna-Sub1 to withstand submergence induced by flooding.

Materials and methods

Site description

The investigation was carried out during the 2010 and 2011 *kharif* seasons at the Instructional Farm, Department of Crop Physiology, Narendra Deva University of Agriculture and Technology (NDUAT), Kumarganj, Faizabad, UP, India. This site lies in the

Gangetic alluvium of eastern UP, situated at latitude 26°47' North and longitude 82°12' East and at an altitude of 113 m above sea level. This is in a semi-arid zone receiving a mean annual rainfall of above 1,100 mm, of which about 80% is precipitated during the monsoon season (July to end of September) with the remainder falling mainly as showers in winter. The pooled nursery physico-chemical soil test results of the experimental site in 2010 and 2011 were as follows: sand 35.20%, silt 48.60%, clay 16.20%, field-capacity 39.60%, bulk density 1.3 g cm^{-2}, pH 7.6, EC 0.2 dS m^{-1}, organic carbon 0.3%, available N 57 ppm, available P_2O_5 7 ppm ($NaHCO_3$ pH 8.5) and available K 218 ppm. Nitrogen, phosphorus (P) and K content were estimated and calculated according to the methods given by Subbiah and Asiza (1956), Jackson (1969), and Olsen *et al.* (1954), respectively.

Experimental layout and crop management

Nursery raising

The experiments were conducted using a randomized complete block design with three replications using Swarna-Sub1. Seeds (at 50 g m^{-2}) were sown in the nursery at NDUAT's instructional farm using the wet method in a 2 x 2 m^2 plot size on 7th June of both years of the experiment. Seven nursery nutrient treatment combination doses of N, P_2O_5 and K_2O were applied after 10 days of seed sowing. These treatments are referred to throughout the text as N-P-K (Table 1).

Nitrogen, P and K were applied as urea, single superphosphate and muriate of potash, respectively. Phosphorus and K were applied in one dose as a basal dressing whereas N was applied in two equally split doses, the first at 10 days after seeding and the second 20 days after seeding.

Main field experiment (in side pond)

The 25-day old seedlings were transplanted into a newly constructed submergence pond covered with plastic sheets (size: 20 x 17 x 1.5 m^3) at NDUAT's Crop Physiology research field and were retained there until the end of experiment. FYM (cow dung) was applied at 6 t ha^{-1} one week before transplanting. 80-40-40 kg N-P_2O_5-K_2O ha^{-1} was applied in the side pond. The P and K was applied as a basal dressing whereas N was applied in three split doses: the first in the form of a top-dressing of 40 kg N ha^{-1} five days after desubmergence, and the second and third top-dressings of 20 kg N ha^{-1} were made at 60 and 90 days after transplanting.

The seedlings were transplanted at 20 x 15 cm spacing using single seedlings per hill in plot size 2.5 x 2 m^2 on 2nd July in both years. Fifteen days after transplanting, the plants were completely submerged for 13 days by filling the pond with turbid stream water. Water was not released into the ponds until noon thus allowing the plants enough time to have accumulated carbohydrates from photosynthesis in the morning. A 70-75 cm water depth was maintained by adding water regularly to the ponds. Survival and recovery respectively, were recorded at days 5 and 15 after desubmergence. Recommended conventional agronomic treatments and protective measures were applied throughout the experiment.

Observations and statistical analysis

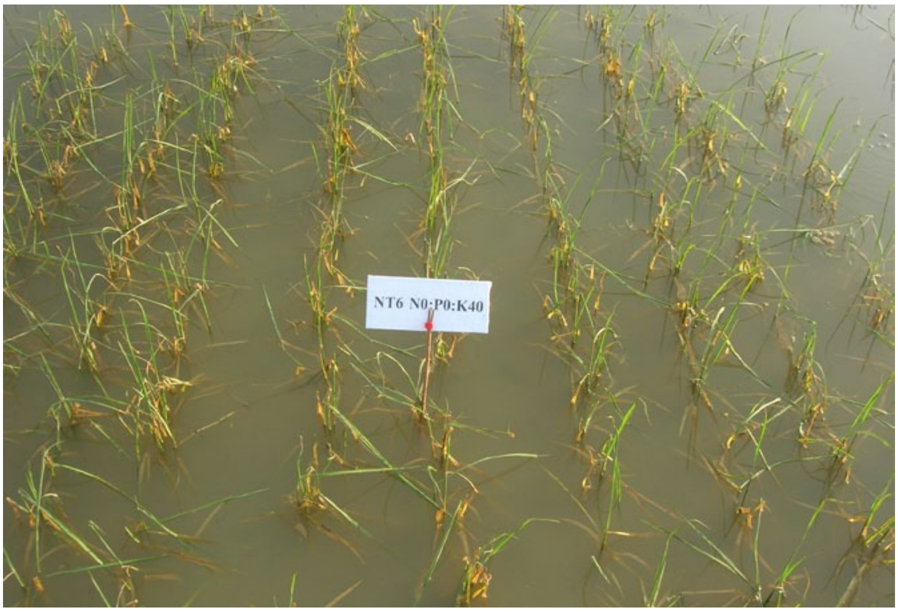
Observations on various growth parameters - plant height (cm), dry shoot biomass (g), plant numbers $plot^{-1}$ and yield (t ha^{-1}) - were recorded. Plant numbers $plot^{-1}$ were counted before, and at recovery, while plant height was recorded before transplanting, before submergence, after desubmergence and at recovery. Dry shoot biomass per plant was determined before transplanting,

Table 1. N-P-K treatments applied at the experiment.

Treatment	N-P-K	N, P_2O_5, K_2O
		------*kg ha^{-1}*------
T_1	N-P-K	40-40-40
T_2	N	40-0-0
T_3	P-K	0-40-40
T_4	P	0-40-0
T_5	K	0-0-40
T_6	P-K	0-60-40
T_7	P	0-60-0

Artificial newly constructed submergence pond covered with plastic sheets for the experimental setup. Photo by E. Sokolowski.

before submergence and after de-submergence, while grain yields were recorded at maturity of all treatments on a per plot basis which was converted into t ha^{-1}. The samples were oven dried at 70˚C to obtain constant weight. All these observations were recorded on 10 initially tagged hills from each plot. Grains were harvested, dried, and weighed. Concentrations of N, P and K in the dried shoot material were determined in plants obtained before transplanting, before submergence and after desubmergence using methods described by Lindner (1944) and Jackson (1973). Nutrient uptakes were calculated as the product of concentration and biomass. Collected data were analyzed statistically following the method of Gomez and Gomez (1984).



Submerged rice seedlings. Photo by E. Sokolowski.

Results and discussion

Survival and growth parameters

A higher percentage of plant survival was recorded with a nursery application of 40 kg K_2O ha^{-1} alone (T_5) or together with 60 kg P_2O_5 ha^{-1} (T_6). Minimum survival was recorded when 40 kg N ha^{-1} (T_2) or 40 kg P_2O_5 ha^{-1} (T_4) were applied (Table 2). The increased mortality in T_2 and T_4 treatments suggests that application of only N or P fertilizers were unable to maintain normal growth and biochemical processes during submergence to support a rapid detoxification of oxygen free radicals which cause damage to plants after desubmergence. We suggest that the beneficial role of K fertilizer alone during nursery application or with a higher dose of P might have resulted for two reasons. The first could be due to the greater capability of these plants to maintain internal gas diffusion or energy levels to sustain normal growth and developmental processes during submergence, and the second might be due to the ability of the this SUB1 gene introgressed variety to enable quick responses of anti-oxidative defense mechanisms after desubmergence. According to Shabala and Pottosin (2014), reactive oxygen species (ROS) production is a major reason for excessive K losses from the shoots of rice plants during submergence. This occurs because unsaturated triglycerides of the membrane lipid bilayer are attacked primarily by ROS leading to destruction of membrane integrity and a leakage of K from the plant. Higher K concentrations in the shoot may thus be an important trait for increasing survival under lowland conditions where flooding is common during the early stage of crop establishment. Moreover, plants supplied with additional K (and P) are better able to avoid K deficiency than those not supplied. Potassium plays a major role in photosynthesis and, when K is deficient, ROS production and their detrimental effect is increased intensely (Cakmak, 2005). In practical terms in the field, avoidance of K deficiency is a major reason for K application.

Table 2. Effect of nursery nutrient management on survival, regeneration and new leaf emergence of Swarna-Sub1 rice variety.

Treatment	N, P_2O_5, K_2O application	Plant no. plot^{-1}			Survival[1]	New leaf emergence (DAD)
		BS	AS	AR		
	kg ha^{-1}	----------------*No.*	----------------		*%*	
T_1	40-40-40	134.3	108.7	129.6	80.9	3rd
T_2	40-0-0	135.0	96.3	129.0	71.3	3rd
T_3	0-40-40	132.0	115.0	121.0	87.1	3rd
T_4	0-40-0	122.6	92.0	119.0	75.0	3rd
T_5	0-0-40	128.6	116.7	125.3	90.8	3rd
T_6	0-60-40	127.6	114.7	126.0	89.9	3rd
T_7	0-60-0	125.0	106.3	125.0	85.0	3rd
LSD at 5%		2.98	6.35	6.99	2.83	-

Note: BS: Before submergence; AS: After desubmergence (after 13 days of complete submergence); AR: At recovery (15 days after desubmergence); DAD: Days after desubmergence.

[1]Survival was recorded five days after desubmergence.

15 days after transplanting, plants were completely submerged for 13 days in an outdoor pond under natural conditions.

Nitrogen appears to play a major role in determining plant population, particularly when applied after desubmergence

Table 3. Effect of nursery nutrient management on plant height and elongation rates (%) of Swarna-Sub1.

Treatment	N, P_2O_5, K_2O application	Plant height			
		BT	BS	AS	AR
	kg ha^{-1}	------------	------------*cm*------------	------------	------------
T_1	40-40-40	17.67	25.73	32.27 (25.4)$^{(1)}$	46.33 (43.6)$^{(2)}$
T_2	40-0-0	15.93	27.22	32.83 (20.6)	45.77 (39.4)
T_3	0-40-40	14.67	26.97	33.00 (22.4)	43.80 (32.7)
T_4	0-40-0	13.90	28.70	33.83 (17.9)	42.47 (25.5)
T_5	0-0-40	14.07	27.73	33.97 (22.5)	48.83 (43.7)
T_6	0-60-40	16.77	25.80	31.40 (21.7)	47.03 (49.8)
T_7	0-60-0	14.13	28.73	32.80 (14.2)	46.23 (40.9)
LSD at 5%		0.86	0.87	1.14	1.23

$^{(1)}$Figures in parenthesis are percent increase at AS over corresponding values of BS.

$^{(2)}$Figures in parenthesis are percent increase at AR over corresponding values of AS.

Note: BT: Before transplanting; BS: Before submergence; AS: After desubmergence (after 13 days of complete submergence); AR: At recovery (15 days after desubmergence).

15 days after transplanting, plants were completely submerged for 13 days in an outdoor pond under natural conditions.

(Table 2). The maximum plant population of all treatments at recovery - 15 days after desubmergence - was recorded in T_1 (40-40-40 kg N-P-K ha^{-1}) which had also received a supplementary application of 40 kg N ha^{-1} at day five of desubmergence. A somewhat lower population at recovery and survival was obtained for T_2 (40-0-0 kg N-P-K ha^{-1}) (without P and K), which also received the supplementary N application. The minimum plant population of all treatments at recovery was obtained in T_4 (0-40-0 kg N-P-K ha^{-1}), which was deprived of N (and K). This beneficial effect of N is in agreement with the findings of Bhowmick *et al.* (2014) who reported that an additional N dose after seven days of desubmergence improved survival and post submergence recovery and increased grain yields for the same waterlogging resistant rice variety as used in our experiment (Swarna-Sub1). In our experiment, new leaf emergence was observed on the third day after desubmergence in all treatments (Table 2).

The various nutrient combinations applied during nursery management induced significant differences in plant height of the seedlings measured before uprooting for transplanting (Table 3). Heights ranged from 13.9 to 17.7 cm with maximum height recorded in T_1 (17.7 cm) (40-40-40 kg N-P-K ha^{-1}), followed by T_6 (16.8 cm) (0-60-40 kg N-P-K ha^{-1}) with a minimum height being observed in T_4 (13.9 cm) (0-40-0 kg N-P-K ha^{-1}). According to Yoshida (1981), "Plant height is an important plant trait that is controlled by the genetic makeup of the plant as well as the growing conditions, seedling vigour and nutrient status." The greater plant height in T_1 seems likely be associated with the more balanced nursery nutrient supply. Phosphate supplied alone at the lower rate (T_4) resulted in the lowest plant height but when associated with K (and no N) (T_6) it produced a significantly greater plant height (16.8 cm) (Table 3). Before submergence, 15 days after transplanting, maximum plant height was recorded in T_7 (0-60-0 kg N-P_2O_5-K_2O ha^{-1}), which was significantly superior to all treatments except T_4; a minimum height was recorded in T_1. Immediately after desubmergence shoot heights were again measured and shoot percentage elongation during the period of submergence was recorded in all treatments. These ranged from the lowest at 14.2% (T_7) to the highest at 25.4% (T_1). Unlike deep water and other aquatic plants, the importance of slow growth in rainfed lowland rice during submergence has been suggested to be beneficial in that it prevents damage due to lodging once water recedes following a flash flood (Singh, 2001; Jackson and Ram, 2003; Srivastava, 2007). Elongation rates ranged from a maximum of 0.54 cm day^{-1} (T_1) closely followed by 0.52 cm day^{-1} (T_5) to a minimum of 0.34 cm day^{-1} (T_7) (Fig. 1). At recovery, maximum plant height was recorded in T_5 (48.83 cm) followed by T_6

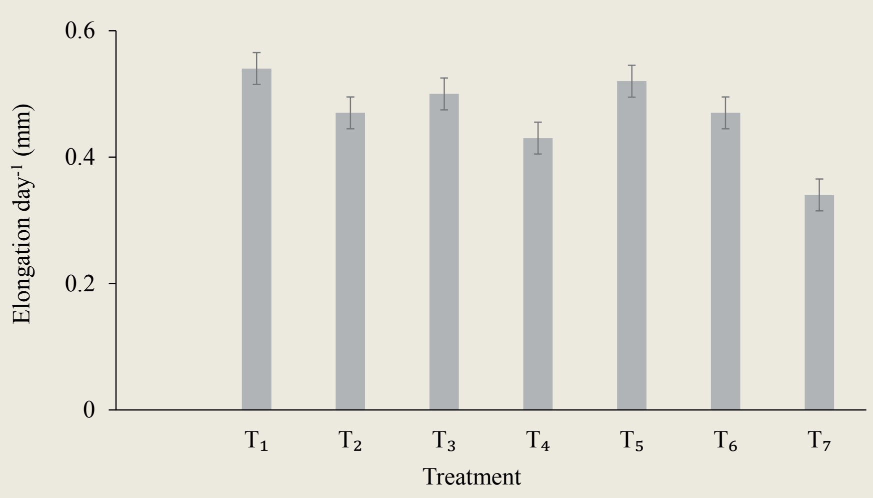


Fig. 1. Effect of different nursery nutrient treatments on underwater shoot elongation day^{-1} (mm) of Swarna-Sub1 during 13 days of complete submergence. Bars represent the corresponding SD values.

Note: T_1: 40-40-40 kg N-P-K ha^{-1}, T_2: 40-0-0 kg N-P-K ha^{-1}, T_3: 0-40-40 kg N-P-K ha^{-1}, T_4: 0-40-0 kg N-P-K ha^{-1}, T_5: 0-0-40 kg N-P-K ha^{-1}, T_6: 0-60-40 kg N-P-K ha^{-1}, T_7: 0-60-0 kg N-P-K ha^{-1}.

15 days after transplanting, plants were completely submerged for 13 days in an outdoor pond under natural conditions.

Table 4. Effect of nursery nutrient management on the dry weight of Swarna-Sub1.

Treatment	N, P_2O_5, K_2O application	Plant dry wt.		
		BT	BS	AS
	kg ha⁻¹	*mg plant⁻¹*		
T_1	40-40-40	0.53	0.60	0.64 (6.67)[1]
T_2	40-0-0	0.51	0.59	0.61 (3.39)
T_3	0-40-40	0.53	0.61	0.63 (3.28)
T_4	0-40-0	0.52	0.59	0.61 (3.39)
T_5	0-0-40	0.53	0.58	0.69 (18.97)
T_6	0-60-40	0.57	0.58	0.69 (18.97)
T_7	0-60-0	0.55	0.56	0.66 (17.86)
LSD at 5%		0.001	0.005	0.003

[1]Figures in parenthesis are percent increase at AS over corresponding values of BS.

Note: BT: Before transplanting; BS: Before submergence; AS: After desubmergence (after 13 days of complete submergence).

15 days after transplanting, plants were completely submerged for 13 days in an outdoor pond under natural conditions.

(47.03 cm) and was lowest in T_4 (42.47 cm). During the 15 day period, from immediately after desubmergence to recovery, maximum increase in height was recorded in T_6 (49.8%) followed by T_5 (43.7%) with a minimum (25.5%) in T_4 (Table 3).

Seedling dry weights (Table 4) varied significantly from 0.51-0.57 mg, at transplanting, the maximum being recorded in T_6 (0.57 mg) and minimum in T_2 (0.51 mg). Singh *et al.* (2005) reported that various features of seedling growth were significantly dependent on nursery nutrient management, which is in agreement with our findings. Before submergence, maximum seedling dry weight was recorded in T_3 (0.61 mg) followed by T_1 (0.60 mg) and minimum in T_7 (0.57 mg) (Table 4). After desubmergence, higher seedling dry weights were recorded for all treatments, with a maximum increase of 18.97% recorded in T_5 (K) and T_6 (P-K) compared with a minimum (3.39%) in T_2 (N) and T_4 (P) (Table 4). Winkel *et al.* (2013) and Winkel *et al.* (2014) reported that rice leaves have gas films that aid O_2 and CO_2 exchange and that underwater photosynthesis can take place supported by high irradiance at depth during submergence, resulting in biomass production after desubmergence. However, much depends on the floodwater characteristics. During submergence a balance may occur between normal metabolic activities consuming reserve food material (RFM) and underwater photosynthesis, compensating for this loss by newly synthesized assimilates. In this respect, genotypes are likely to show differences in photosynthetic activity as confirmed in a recent study by Winkel *et al.* (2014) who compared four contrasting rice genotypes growing submerged for 13 days. Swarna-Sub1 (carrying the SUB1 gene) was shown to decline in photosynthetic activity during submergence and gas film retention was not linked to SUB1.

Nutrient analysis, uptake and yield

Before transplanting and before submergence maximum N concentration was recorded in T_2 (40-0-0 kg N-P-K ha⁻¹), whereas after desubmergence, it was recorded in T_1 (40-40-40 kg N-P-K ha⁻¹), probably as a consequence of N application in both these treatments (Table 5). Maximum P concentrations (before transplanting and before submergence) were recorded in T_6 (0-60-40 kg N-P-K ha⁻¹), whereas after desubmergence these were recorded in T_7 (0-60-0 kg N-P-K ha⁻¹), which had the same P status as T_6 (0-60-40 kg N-P-K ha⁻¹). Maximum K concentration before transplanting was recorded in T_3 (0-40-40 kg N-P-K ha⁻¹) whereas before submergence and after desubmergence maximum K concentrations were recorded in T_5 (0-0-40 kg N-P-K ha⁻¹) and T_6 (0-60-40 kg N-P-K ha⁻¹), respectively.

Table 5. Effect of nursery nutrient management on N, P and K shoot concentrations of Swarna-Sub1 exposed to early stage submergence (5 days).

Treatment	N, P_2O_5, K_2O application	BT			BS			AS		
		N	P	K	N	P	K	N	P	K
	kg ha⁻¹	%								
T_1	40-40-40	4.02	0.77	1.66	3.83	0.94	2.29	3.83	0.08	1.68
T_2	40-0-0	4.20	0.66	1.63	3.93	0.44	2.08	3.84	0.09	1.14
T_3	0-40-40	3.02	0.75	1.86	3.81	0.98	2.26	3.42	0.14	1.62
T_4	0-40-0	3.21	0.78	1.64	3.24	0.96	2.12	3.14	0.13	1.22
T_5	0-0-40	3.30	0.74	1.84	3.42	0.45	2.38	3.23	0.10	1.47
T_6	0-60-40	3.43	1.05	1.83	3.71	1.25	2.36	3.49	0.16	1.70
T_7	0-60-0	3.35	1.04	1.66	3.53	1.02	2.28	3.41	0.17	1.46
LSD at 5%		0.11	0.03	0.05	0.07	0.01	0.06	0.08	0.01	0.12

Note: BT: Before transplanting; BS: Before submergence; AS: After desubmergence (after 13 days of complete submergence).

15 days after transplanting, plants were completely submerged for 13 days in an outdoor pond under natural conditions.

Ella and Ismail (2006) reported that a high N concentration of rice leaves was not beneficial when rice was subjected to flash flooding at an early stage and also that application of N alone was prejudicial to survival. Reserves of shoot carbohydrates were very quickly exhausted and severe post-oxidative damage occurred. However, N accompanied by P and K substantially improved survival of the SUB1 introgressed cultivar Swarna-Sub1. In this regard, Singh (2011) has reported

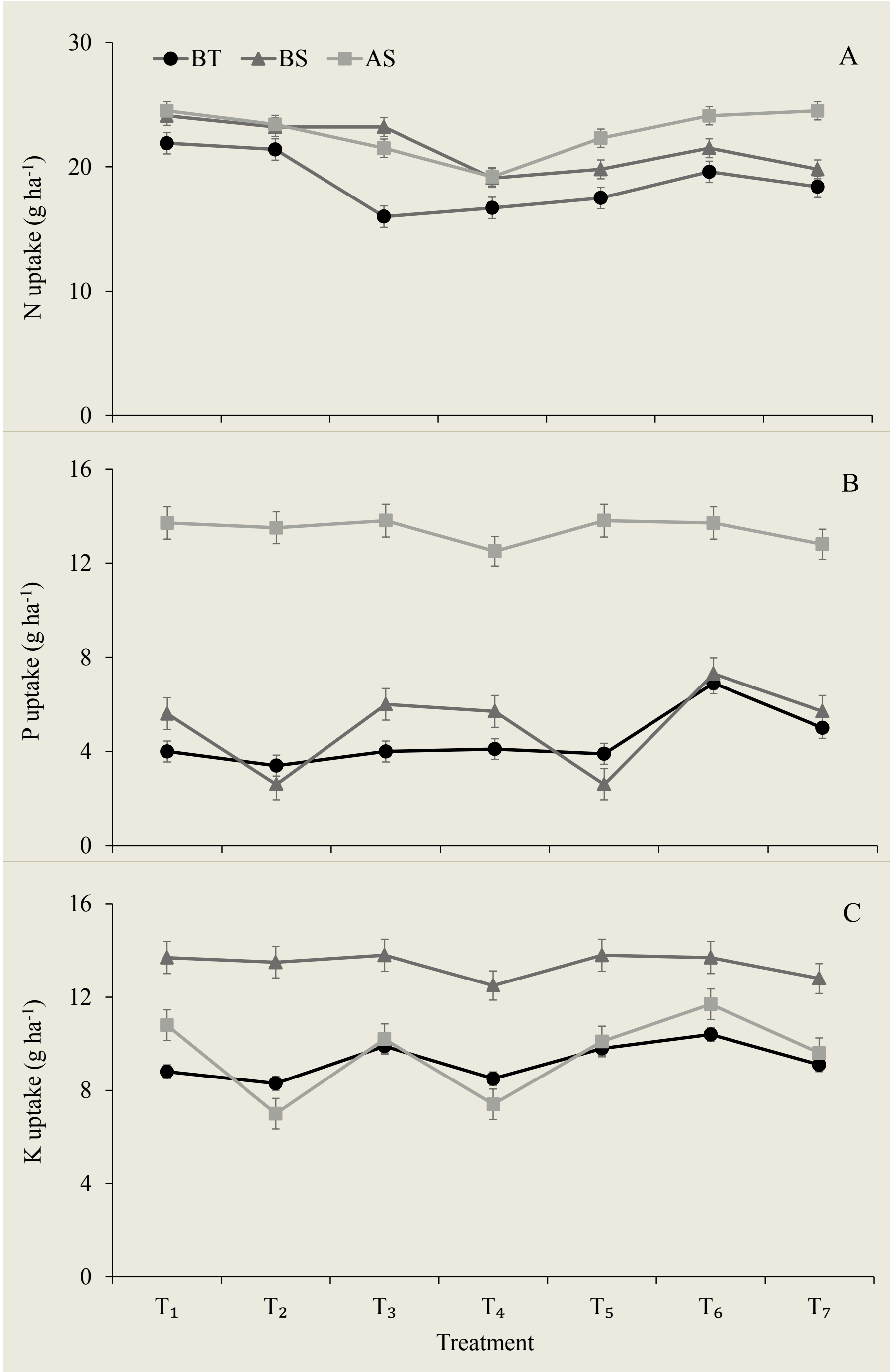


Fig. 2. Effect of different nursery nutrient treatments on nutrient uptake; A) N uptake (g ha^{-1}), B) P uptake (g ha^{-1}), C) K uptake (g ha^{-1}). Bars represent the corresponding SD values.

Note: BT: Before transplanting; BS: Before submergence; AS: After desubmergence (after 13 days of complete submergence).

T_1: 40-40-40 kg N-P-K ha^{-1}, T_2: 40-0-0 kg N-P-K ha^{-1}, T_3: 0-40-40 kg N-P-K ha^{-1}, T_4: 0-40-0 kg N-P-K ha^{-1}, T_5: 0-0-40 kg N-P-K ha^{-1}, T_6: 0-60-40 kg N-P-K ha^{-1}, T_7: 0-60-0 kg N-P-K ha^{-1}.

15 days after transplanting, plants were completely submerged for 13 days in an outdoor pond under natural conditions.

that higher regeneration of plants after desubmergence in treatments (applied with doses of N, P and K during nursery management) was associated with the first dose of N applied in the field (five days after desubmergence) rather than the N applied in the nursery, with P and K.

Nitrogen, P, and K uptakes (g ha^{-1}) before transplanting, before submergence and after desubmergence are shown in Fig. 2 (A-C). The pattern of N uptake was similar in all stages, showing higher uptake in treatments supplied with higher N (T_1 and T_2). After desubmergence, a sharp decrease in N uptake was noticed in T_4 (0-40-0 kg N-P-K ha^{-1}), probably due to an interaction between P and N uptake during submergence (Fig. 2A). A higher uptake of P before transplanting was recorded in T_6 and T_7 treatments due to higher P doses (40 and 60 kg ha^{-1}), however T_7 recorded lower P uptake than T_6. Lower P uptake was recorded in T_2 and T_5 (solely applied N and K fertilizers respectively) than the rest of the treatments before submergence. After desubmergence, higher P uptake was recorded in all treatments presumably due to increased availability of P in the submerged soil (Singh, 2011) (Fig. 2B). Higher uptake of K before transplanting was recorded in treatments supplied with K doses. Interestingly, the higher dose of P along with K (T_6; 0-60-40 kg N-P-K ha^{-1}) produced a significantly higher K uptake than a lower dose of P (T_3; 0-40-40 kg N-P-K ha^{-1}). Higher K uptake before submergence was recorded in all treatments compared to their respective values before transplanting. After desubmergence a drastic reductive K uptake pattern was recorded in all treatments (Fig. 2C) with higher reduction in treatments with N and P alone (T_2, T_4 and T_7).

Maximum grain yield (t ha^{-1}) was recorded in T_5 (0-0-40 kg N-P-K ha^{-1}), which was significantly superior to all other treatments except T_6 (0-60-40 kg N-P-K ha^{-1}). Higher P

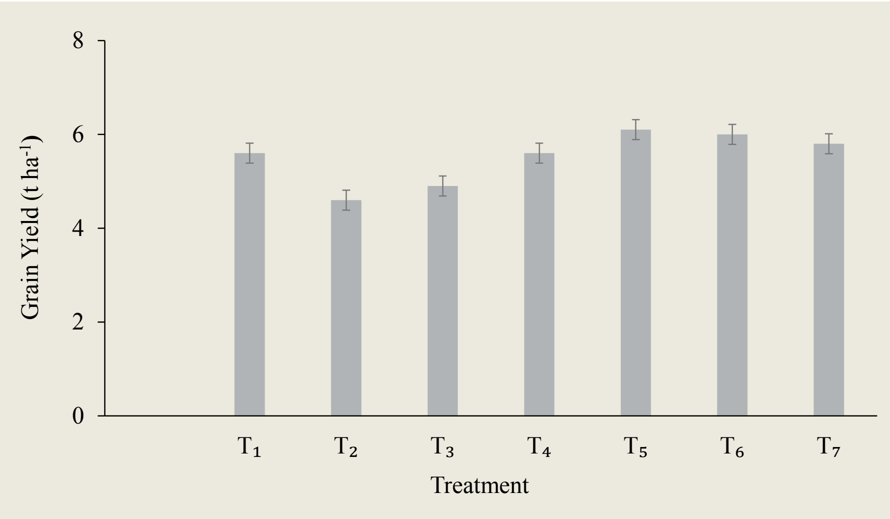


Fig. 3. Effect of different nursery nutrient treatments on grain yield of Swarna-Sub1 (grain was harvested 93-97 days after desubmergence). Bars represent the corresponding SD values.

Note: T_1: 40-40-40 kg N-P-K ha^{-1}, T_2: 40-0-0 kg N-P-K ha^{-1}, T_3: 0-40-40 kg N-P-K ha^{-1}, T_4: 0-40-0 kg N-P-K ha^{-1}, T_5: 0-0-40 kg N-P-K ha^{-1}, T_6: 0-60-40 kg N-P-K ha^{-1}, T_7: 0-60-0 kg N-P-K ha^{-1}.

15 days after transplanting, plants were completely submerged for 13 days in an outdoor pond under natural conditions.

doses alone, or together with K, (T_7; 0-60-0 kg N-P-K ha^{-1} and T_6; 0-60-40 kg N-P-K ha^{-1}) produced higher yields than lower doses of P (T_4; 0-40-0 kg N-P-K ha^{-1} and T_3; 0-40-40 kg N-P-K ha^{-1}). Difference in yield due only to a higher P dose, however, was not significant whereas yield differences resulting from different K doses were significant (Fig. 3). Lowest grain yield was recorded in T_2 (40-0-0 kg N-P-K ha^{-1}). These findings clearly indicate that nursery application of N fertilizer alone produced a detrimental effect after desubmergence, by decreasing the survival and/or initial crop stand (Table 2). This was associated with a slower recovery and growth, which might have influenced the yield attributing traits (data not shown), ultimately affecting yield. The influence of K supply during seeding growth before transplanting was shown to have a major positive impact on subsequent plant development. The K concentration of the seedlings and K uptake showed correlation coefficients with survival (0.95 and 0.92 respectively) and with grain yield (0.60 and 0.45 respectively). By contrast, the N concentration of the seedlings and N uptake were negatively correlated with survival (-0.58 and -0.36 respectively).

Conclusions

The results of the experiment indicated that 40 kg K_2O ha^{-1} alone or supplied together with 60 kg ha^{-1} P_2O_5 fertilizer produced significantly higher survival rates, and thereafter helped in rapid regeneration, which was reflected in the form of higher yield. Proper nursery nutrient management using K can contribute considerably to maximizing submergence tolerance and grain yield of the rice crop in the field. A slightly higher dose of P, along with the normal K dose, also produced a higher yield than the normal P dose used in nursery management. These results, however, need further validation on farmers' fields applying lower N doses with K and P.

Acknowledgement

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References

Bhowmick, M.K., M.C. Dhara, S. Singh, M.H. Dar, and U.S. Singh. 2014. Improved Management options for Submergence-Tolerant (SUB1) Rice Genotype in Flood-Prone Rainfed Lowlands of West Bengal. Amer. J. Plant Sci. 5:14-23.

Cakmak, I. 2005. The Role of Potassium in Alleviating Detrimental Effects of Abiotic Stresses in Plants. J. Plant Nutr. Soil Sci. 168:521-530.

Dey, M.M., and H.K. Upadhyaya. 1996. Yield Loss Due to Drought, Cold and Submergence in Asia. *In:* Evenson, R.E., R.W. Herdt, and M. Hossain (eds.), Rice Research in Asia: Progress and Priorities. CAB International, Wallingford. p. 291-303.

Ella, E.S., and A.M. Ismail. 2006. Seedling Nutrient Status Before Submergence Affects Survival After Submergence in Rice. Crop Sci. 46:1673-1681.

Gomez, K.A., and A.A. Gomez. 1984. Statistical Procedures for Agricultural Research. Second Edition. A Wiley-Inter-Science Publication (John Wiley and Sons), New York.

Haefele, S.M., and R.J. Hijmans. 2007. Soil Quality in Rice-Based Rainfed Lowlands of Asia: Characterization and Distribution. *In:* Aggarwal, P.K., J.K. Ladha, R.K. Singh, C. Devakumar, and B. Hardy (eds.), Science, Technology, and Trade for Peace and Prosperity. Proceedings of the 26th International Rice Research Conference, 9-12 October 2006, New Delhi, India. Los Baños (Philippines) and New Delhi (India): International Rice Research Institute, Indian Council of Agricultural Research, and National Academy of Agricultural Sciences. p. 297-308.

Herdt, R.W. 1991. Research Priorities for Rice Biotechnology. *In:* Khush, G.S., and G.H. Toenniessen (eds)., Rice Biotechnology. CAB International, UK, pp. 19-54.

Jackson, M.B., and P.C. Ram. 2003. Physiological and Molecular Basis of Susceptibility and Tolerance of Rice Plants to Complete Submergence. Ann. Bot. 91:227-241.

Jackson, M.L. 1973. Soil Chemical Analysis. Prentice Hall Inc. India. p. 281-285.

Lindner, R.C. 1944. Rapid Analytical Method for Some of the More Common Inorganic Constituents of the Plant Tissues. Plant Physiol. 19:76-89.

Mackill, D.J., A.M. Ismail, U.S. Singh, R.V. Labios, and T.R. Paris. 2012. Development and Rapid Adoption of Submergence-Tolerant (SUB1) Rice Varieties. Adv. Agron. 115:299-352.

Neeraja, C., R. Maghirang-Rodriguez, A. Pamplona, S. Heuer, B. Collard, E. Septiningsih, G. Vergara, D. Sanchez, K. Xu, A. Ismail, and D. Mackill. 2007. A Marker-Assisted Backcross Approach for Developing Submergence-Tolerant Rice Cultivars. Theor. Appl. Genet. 115:767-776.

Olsen, S.R., C.V. Cole, F.S. Watanube, and L.A. Dean. 1954. Estimation of Available Phosphorus in Soil by Extraction with $NaHCO_3$. USDA circ. 939:19-33.

Ram, P.C., M.A. Mazid, A.M. Ismail, P.N. Singh, V.N. Singh, M.A. Haque, U.S. Singh, E.S. Ella, and B.B. Singh. 2009. Crop and Resource Management in Flood Prone Areas: Farmer's Strategies and Research Developments. *In:* Haefele, S.M., and A.M. Ismail (eds.), Proceedings Natural Resource Management for Poverty Reduction and Environmental Sustainability in Fragile Rice-Based Systems, Los Baňos (Philippines), International Rice Research Institute, 2009. p. 82-94.

Septiningsih, E.M., A.M. Pamplona, D.L. Sanchez, C.N. Neeraja, G.V. Vergara, S. Heuer, A.M. Ismail, and D.J. Mackill. 2009. Development of Submergence-Tolerant Rice Cultivars: The SUB1 Locus and Beyond. Ann. Bot. 103:151-160.

Shabala, S., and I. Pottosin. 2014. Potassium Transport in Plants Under Hostile Conditions: Implications for Abiotic and Biotic Stress Tolerance. Physiol. Plant. 151(3):257-279.

Singh, H.P., B.B. Singh, and P.C. Ram. 2001. Submergence Tolerance of Rainfed Lowland Rice: Search for the Physiological Markers Traits. J. Plant Physiol. 158:883-889.

Singh, K.N., B. Hassan, B.A. Kanday, and A.K. Bhat. 2005. Effect of Nursery Fertilization on Seedling Growth and Yield of Rice. Indian J. Agron. 50(3):187-189.

Singh, P. 2011. Nutrient Management in Nursery for Improving Submergence Tolerance in Swarna-Sub1 Rice (*Oryza sativa* L.). M.Sc. Dissertation, Narendra Deva University of Agriculture and Technology, Kumarganj, Faizabad (U.P.).

Singh, S., D.J. Mackill, and A.M. Ismail. 2009. Responses of SUB1 Introgression Lines to Submergence in the Field: Yield and Grain Quality. Field Crops Res. 113:12-23.

Srivastava, A.K., P.N. Singh, S. Kumar, P.C. Ram, and A. Ismail. 2007. Physiological Changes Associated with Submergence Tolerance in Genetically Diverse Lowland Genotypes. Tropical Agric. Res. 19:240-253.

Subbiah, B.V., and G. L. Asija. 1956. A Rapid Procedure for Estimation of Available N in Soils. Curr. Sci. 25:259-260.

Wade, L.J., S.T. Amarante, A. Olea, D. Harnpichitvitaya, K. Naklang, A. Wihardjaka, S.S. Sengar, M.A. Mazid, G. Singh, and C.G. McLaren. 1999. Nutrient Requirements in Rainfed Lowland Rice. Field Crops Res. 64:91-107.

Winkel, A., T.D. Colmer, A.M. Ismail, and O. Pedersen. 2013. Internal Aeration of Paddy Field Rice (*Oryza sativa*) During Complete Submergence - Importance of Light and Floodwater O_2. New Phytol.197:1193-203.

Winkel, A., O. Pedersen, E. Evangelina, A.M. Ismail, and T.D. Colmer. 2014. Gas Film Retention and Underwater Photosynthesis During Field Submergence of Four Contrasting Rice Genotypes. J Exp. Bot. 65:3225-3233.

Xu, K., X. Xia, T. Fukao, P. Canlas, R. Maghirang-Rodriguez, S. Heuer, A.M. Ismail, J. Bailey-Serres, P.C. Ronald, and D.J. Mackill. 2006. SUB1A is an Ethylene-Response-Factor-Like Gene that Confers Submergence Tolerance to Rice. Nature 442:705-708.

Yoshida, S. 1981. Mineral Nutrient of Rice: *In:* Yoshida, S. (ed.), Fundamentals of Rice Crop Science. International Rice Research Institute (IRRI), Los Baňos. p. 111-146.

The paper "The Beneficial Effects of Applying Potassium Alone or with Phosphorus During Nursery Management in Enhancing the Survival and Yield of the Rice Variety Swarna-Sub1 in a Flood-Prone Ecosystem" also appears on the IPI website at:

Regional activities/India

Research Findings

Photo by E. Sokolowski.

Effect of Graded Doses of Potassium on Yield, Profitability and Nutrient Content of Vegetable Crops in the Central Plain Zone of Uttar Pradesh, India

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Abstract

Field experiments were carried out at the vegetable research farm, Kalyanpur, Kanpur Nagar, Chandra Shekhar Azad University of Agriculture and Technology, Kanpur, Uttar Pradesh, during the rabi seasons of 2011-12 and to 2012-13 to evaluate the potassium (K) requirement of four vegetable crops i.e. cauliflower, cabbage, brinjal (aubergine) and tomato on a soil moderately supplied in K. Five rates of K application 0, 40, 60, 80 and 100 kg K_2O ha^{-1} were tested with recommended doses of nitrogen (N) and phosphorus (P) of 120 kg N ha^{-1} and 60 kg P_2O_5 ha^{-1} for all four crops. Significant responses in increasing yield occurred for all four vegetables, the lowest yield for all crops being found in the treatment without K application. Yields and net profit from added potash to cauliflower, brinjal and tomato increased to the maximum level

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of K applied (100 kg K_2O ha^{-1}), while that for brinjal was achieved with less K applied, at 80 kg ha^{-1}. These yield responses indicate that even though the soil was moderately well supplied with K, it was inadequate to meet the K demands required to obtain the maximum yield in any of the four crops. In all four crops, the benefit cost ratio (BCR) due to potash application was very high, and varied between 25 to 69 presenting a very low financial risk for potash application. N, P and K concentration in the dry matter of all crops tested increased significantly up to 60 kg K_2O ha^{-1}, indicating a higher nutrient use efficiency (NUE) of N and P. Nutrient balance calculations showed that N was insufficiently provided to cauliflower and cabbage, resulting in a negative balance. Similarly, in all crops, except tomato, levels of applied K were not sufficient to avoid a negative K balance. We conclude that potash application to the crops tested was highly profitable with very little risk in this investment, especially in brinjal and tomato crops. The N levels applied to cauliflower and cabbage were not sufficient to realize full yield potential, however, increasing rates of K applied raised the NUE of N and P. Additional experiments in these crops are needed with increased levels of N and K to test for further possible potential yield increases.

Introduction

Potassium (K), an essential macronutrient taken up by the plant in very large quantities, plays a fundamental role in plant physiology and biochemistry (Marschner, 2012; Mengel and Kirkby, 2001). It is an exceptional nutrient in that it is not metabolized and is present within the plant almost exclusively as a univalent cation. It is highly mobile throughout the plant and associated with the transport of inorganic anions and metabolites. It activates more than 60 enzymes, has a direct function in protein synthesis, exerts an outstanding influence on plant water relations and is essential in the process of growth and development of cells. Potassium also plays a major role in photosynthesis in both the light and dark reactions culminating in the formation of sugar via the reduction of carbon dioxide. Potassium is also essential for the loading and transport of the sugar produced to developing fruits and roots, processes of extreme importance in the production of fruits and vegetables. It also enhances crop resistance to biotic and abiotic stresses including insects, pests and various diseases, as well as drought and frost (Cakmak, 2005) and is beneficial in extending the keeping quality of crop produce.

On many soils the application of K fertilizers is needed to increase yields and quality of crops. The aim of the work presented here was to establish the effects of increasing rates of application of muriate of potash (KCl) in a field experiment over a two year period on yields and nutrient uptake in four vegetable crops (cauliflower, cabbage, brinjal (aubergine) and tomato) growing in the soil conditions of the central plain of Uttar Pradesh, India. Our objective was also to use the data obtained to provide information in recommending K application rates for vegetable crops in the region. Additionally, the work was initiated to establish the benefit cost ratio (BCR), in relation to likely increased yields and the most profitable return to farmers when taking into account the fertilizer cost and crop sale value.

Soil fertility is very closely dependent on the presence of adequate supplies of mineral plant nutrients. Many soils, however, are unable to meet nutrient demands, particularly those supporting high yielding crops, so fertilizers have to be applied to the soil. In this work we therefore also draw up simple balance sheets relating the known increasing rates of K to the four vegetable crops (supplied together with the fixed recommended rates of N and P) and the removal of these nutrients in the harvested crops.

Materials and methods

Field experiments were carried out at the vegetable research farm, Kalyanpur, Kanpur Nagar, Chandra Shekhar Azad University of Agriculture & Technology, Kanpur, in the central plain zone of Uttar Pradesh, India. Four vegetable crops i.e. cauliflower, cabbage, brinjal and tomato were grown over two years during the rabi seasons of 2011-12 to 2012-13 to test their response to

Cauliflower crop in the experiment. Photo by E. Sokolowski.

K application on yield and nutrient uptake. Five doses were compared 0, 40, 60 80 and 100 kg K_2O ha^{-1} in the form of muriate of potash given as a basal application. The recommended rates of N and P application of 120 kg N ha^{-1} and 60 kg P_2O_5 ha^{-1} were supplied as urea and diammonium phosphate (DAP) respectively. All the DAP and half the urea was applied as a basal dressing, with the remaining half of the urea being applied in two equal splits as top dressing. The five treatments for the four crops were replicated three times, giving a total of 60 plots with a plot size of 40 m^2.

Soil samples were collected randomly from the top soil (0-15 cm) and analyzed for physico-chemical properties prior to the onset of the experiment. The experimental soil was alkaline in reaction (pH 7.3) and low in organic carbon (C) (0.41%). Available N, P and K values obtained from sampling the experimental fields were 173.5, 11.92 and 171.5 kg ha^{-1} respectively, indicating a deficiency in N and medium levels of available P and K. During the experiments all necessary agronomic practices were followed when and where required. At maturity, the crops were harvested and fresh and dry matter yields determined as per treatment. Soil pH, EC, and available NPK were analyzed by standard procedures (Jackson, 1973). Organic C was measured using the Walkley and Black (1934) method. N, P and K concentrations in the vegetables (% dm) were determined as follows: N by the micro Kjeldahl method, and P and K by wet digestion using a (9:4) mixture of nitric:perchloric acid followed by suitable dilution. P was estimated colorimetrically as phosphomolybdate and K by flame photometry. The NPK concentrations of vegetables under test were expressed on a dry matter basis and the values computed.

Results and discussion

Yields

All four vegetable crops responded to a varying extent to K application as shown in Table 1 and Fig 1. In cauliflower and brinjal, fresh weight yield significantly increased up to 80 kg K_2O ha^{-1} from 21.8 to 27.85 t ha^{-1}, an increase of 27%, and from 27.8 to 43.35 t ha^{-1}, an increase of 59%, respectively. The lesser effect of K in cauliflower may be explained by an insufficiency of applied N, as evident from the negative N balance (Fig. 2). In cabbage, fresh weight yield increased up to only 60 kg K_2O ha^{-1} from 23.10 to 29.80 t ha^{-1}, a 29% increase. N applied to this crop was also probably insufficient in meeting only half of the crop's requirement (Fig. 3), with a large negative N balance at higher rates of

Table 1. Effect of K application on fresh weight yield, profit and BCR in vegetables (mean over two years).

K doses	Cauliflower			Cabbage			Brinjal			Tomato		
	Yield	Added net profit	BCR	Yield	Added net profit	BCR	Yield	Added net profit	BCR	Yield	Added net profit	BCR
kg K_2O ha^{-1}	*t ha^{-1}*	*US\$ ha^{-1}*		*t ha^{-1}*	*US\$ ha^{-1}*		*t ha^{-1}*	*US\$ ha^{-1}*		*t ha^{-1}*	*US\$ ha^{-1}*	
K_0	21.80	-	-	23.10	-	-	27.80	-	-	22.10	-	-
K_{40}	24.55	458	25	26.40	550	29	33.50	950	51	26.35	708	38
K_{60}	27.15	892	32	29.80	1,117	40	40.00	2,033	73	32.60	1,750	62
K_{80}	27.75	992	27	29.75	1,108	30	43.35	2,583	69	34.70	2,100	56
K_{100}	27.90	1,017	22	30.05	1,158	25	43.05	2,542	54	35.75	2,275	49
CD (P=0.05)	0.42			0.25			0.23			0.85		

Note: Calculation based on exch. rate USD=Rs.60; cost of vegetables 166.67 US\$ t^{-1}; cost of potash 466.67 US\$ t^{-1}.

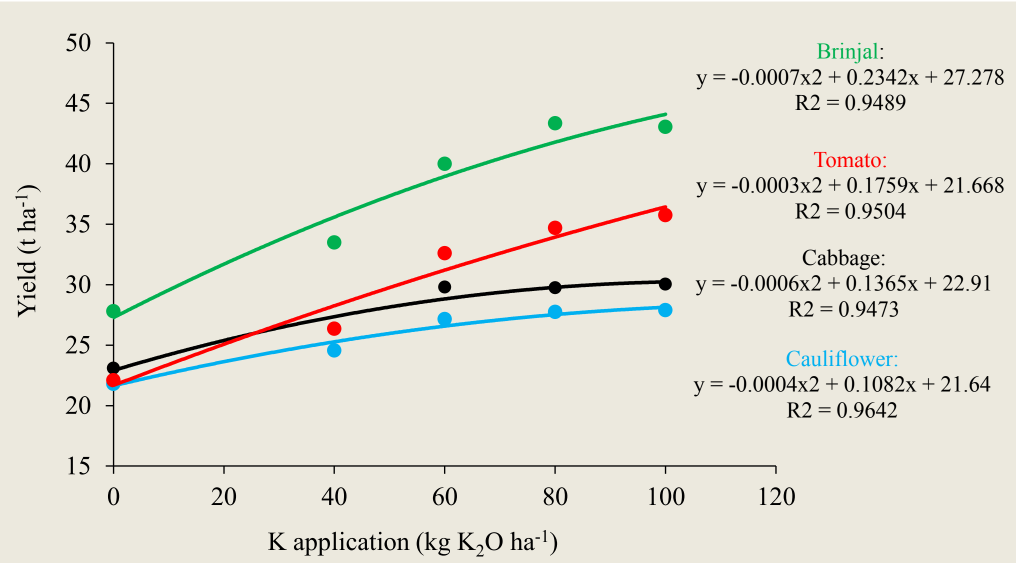


Fig. 1. Response of fresh weight vegetable yield to K application.

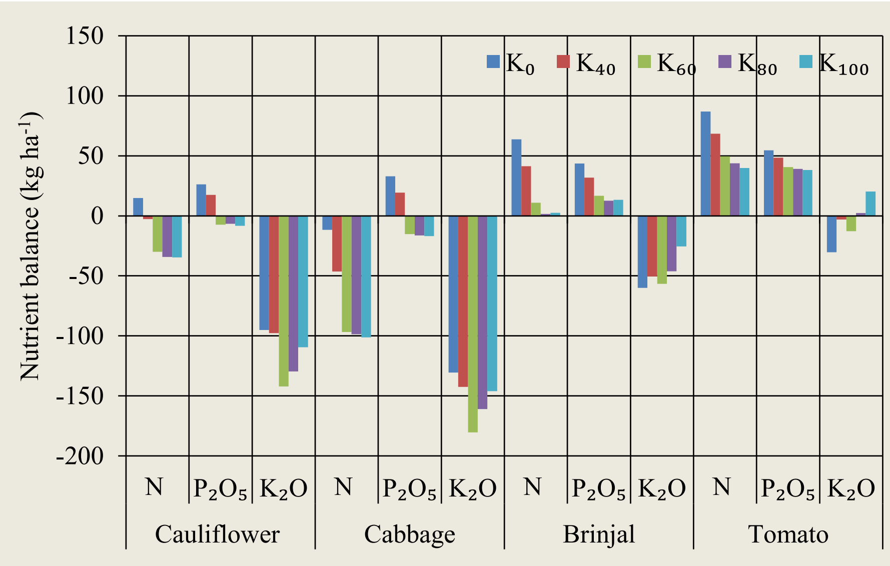


Fig. 2. Nutrient balance in crops.

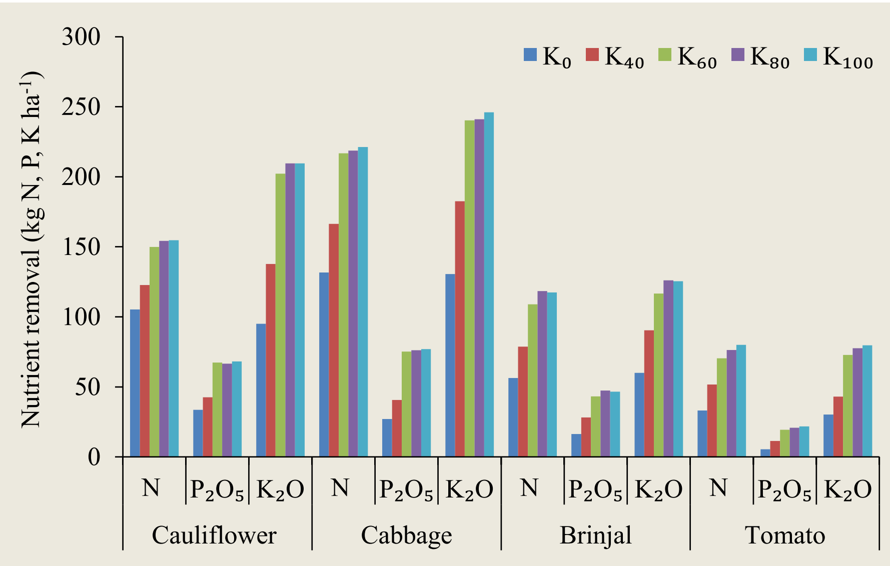


Fig. 3. Nutrient removal by crop with increased K application.

Table 2. Effect of K application on dry matter yield of various vegetables (mean over two years).

K doses	Cauliflower	Cabbage	Brinjal	Tomato
kg K_2O ha^{-1}		------------t ha^{-1}------------		
K_0	3.71	3.47	1.39	0.88
K_{40}	4.17	3.96	1.68	1.05
K_{60}	4.62	4.47	2.00	1.30
K_{80}	4.72	4.46	2.17	1.39
K_{100}	4.74	4.51	2.15	1.43

Note: Dry matter yield calculated on the basis of 17, 15, 5 and 4% dry matter in cauliflower, cabbage, brinjal and tomato respectively.

K supply (Fig. 2). The greatest response at 100 kg K_2O ha^{-1} occurred in tomato with a yield increase of 13.65 t ha^{-1}, a 61.76% increase. The fresh yield response curves of the four vegetables against the rate of K_2O application (Fig. 1) illustrate the response order in terms of fresh yield produced: brinjal (aubergine) > tomato > cabbage > cauliflower. From this data, we also assume that the tomato crop might have increased further with applications higher than 100 kg K_2O ha^{-1}. The response of increasing yield to K application above the zero application for all four vegetable crops provides evidence of an inadequate supply of available K in the farm soil for the growth and development of all of these crops. It is interesting that the order of fresh weight yield for the four crops as shown above differs markedly from the dry weight yield order of: cauliflower > cabbage > brinjal (aubergine) > tomato. This difference is dependent on the large variation in dry matter weights (of 17, 15, 5 and 4% for the four crops respectively - see Table 2).

Nutrient removal and balance

The concentrations of all three nutrients, N, P and K, in the dry matter were lowest in the treatment which did not receive any K fertilizer for all four vegetables (Table 3). This result provides further evidence that, despite the presence of adequate amounts of N and P fertilizer, the unamended soil K, although of medium status, was an insufficient source of K and restricted the uptake of all three nutrients by the crops. This observation also reflects the high K requirement in all four crops. Comparing the various rates of K application, K concentrations in the dry matter varied between the four crops. Brinjal, showed the highest K concentration above tomato and cabbage (with somewhat similar figures), followed by cauliflower with by far the lowest K concentration (about 25% lower than brinjal, Table 3). These differences may, to some extent, reflect differences in K requirement between the crops. Additionally, however, from a physiological viewpoint, fruits (brinjal

Table 3. Effect of graded doses of K on percent nutrient concentration in the dry matter of vegetables (mean over two years).

K doses	Cauliflower			Cabbage			Brinjal			Tomato		
	N	P	K	N	P	K	N	P	K	N	P	K
kg K_2O ha^{-1}	*% of DM*											
K_0	2.84	0.40	2.14	3.80	0.34	3.14	4.05	0.52	3.60	4.20	0.27	2.85
K_{40}	2.94	0.45	2.75	4.20	0.45	3.84	4.70	0.74	4.50	4.90	0.48	3.40
K_{60}	3.25	0.64	3.65	4.85	0.74	4.48	5.45	0.95	4.86	5.40	0.65	4.65
K_{80}	3.27	0.62	3.70	4.90	0.75	4.50	5.46	0.96	4.85	5.50	0.66	4.66
K_{100}	3.26	0.63	3.68	4.91	0.75	4.55	5.46	0.95	4.86	5.60	0.67	4.65
CD (P=0.05)	0.08	0.04	0.52	0.35	0.09	0.61	0.58	0.19	0.34	0.45	0.18	0.44

Table 4. Effect of K application on removal and balance of N by vegetables (mean over two years).

K doses	Cauliflower		Cabbage		Brinjal		Tomato	
	Removal	Balance	Removal	Balance	Removal	Balance	Removal	Balance
kg K_2O ha^{-1}	*kg N ha^{-1}*							
K_0	105.23	+14.77	131.70	-11.70	56.30	+63.70	33.12	+86.88
K_{40}	122.74	-2.74	166.35	-46.35	78.70	+41.30	51.64	+68.36
K_{60}	149.94	-29.94	216.75	-96.75	109.00	+11.00	70.40	+49.60
K_{80}	154.19	-34.19	218.70	-98.70	118.35	+1.65	76.32	+43.68
K_{100}	154.70	-34.70	221.25	-101.25	117.50	+2.50	80.08	+39.92

Note: Calculation based on 120 kg N ha^{-1} application.

Table 5. Effect of K application on removal and balance of P_2O_5 by vegetables (mean over two years).

K doses	Cauliflower		Cabbage		Brinjal		Tomato	
	Removal	Balance	Removal	Balance	Removal	Balance	Removal	Balance
kg K_2O ha^{-1}	*kg P_2O_5 ha^{-1}*							
K_0	33.72	26.28	27.02	32.98	16.42	43.58	5.47	54.53
K_{40}	42.64	17.36	40.70	19.30	28.27	31.73	11.49	48.51
K_{60}	67.44	-7.44	75.24	-15.24	43.32	16.68	19.33	40.67
K_{80}	66.67	-6.67	76.27	-16.27	47.42	12.58	20.88	39.12
K_{100}	68.22	-8.22	76.95	-16.95	46.63	13.37	21.80	38.20

Note: Calculation based on 60 kg P_2O_5 ha^{-1} application.

Table 6. Effect of K application on removal and balance of K_2O by vegetables (mean over two years).

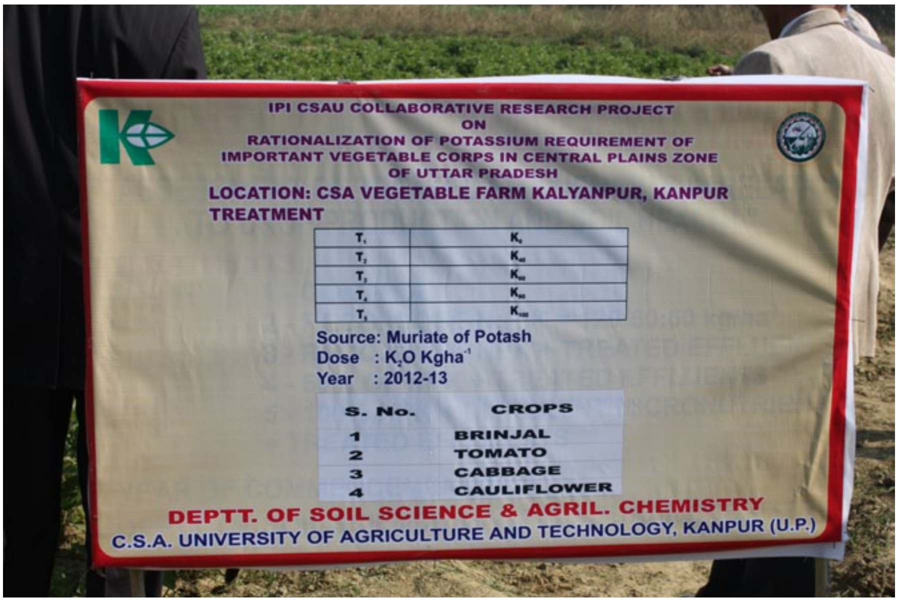
K doses	Cauliflower		Cabbage		Brinjal		Tomato	
	Removal	Balance	Removal	Balance	Removal	Balance	Removal	Balance
kg K_2O ha^{-1}	*kg K_2O ha^{-1}*							
K_0	95.06	-95.06	130.50	-130.50	60.06	-60.06	30.24	-30.24
K_{40}	137.70	-97.70	182.52	-142.52	90.42	-50.42	43.01	-3.01
K_{60}	202.16	-142.16	240.30	-180.30	116.64	-56.64	72.77	-12.77
K_{80}	209.51	-129.51	241.02	-161.02	126.12	-46.12	77.62	2.38
K_{100}	209.51	-109.51	246.06	-146.06	125.52	-25.52	79.78	20.22

and tomato) as K sinks in the plant might be expected to contain higher concentrations of K than leafy vegetables. Phosphorus concentrations of the dry matter were particularly high in brinjal followed by cabbage, tomato and cauliflower (Table 3).

The effects of K application on the four vegetable crops on the removal and balance of the three nutrients are shown for N (Table 4), P_2O_5 (Table 5) and K_2O (Table 6). The results are also expressed graphically (Fig. 2 and 3). A negative balance of N (Table 4) was recorded in all the K treatments for cauliflower and cabbage (except the controls) indicating that a lack of N probably limited plant growth. The positive balance of phosphorus (Fig. 2 and Table 5) was noted in all four vegetables (cauliflower, cabbage, brinjal and tomato), except at the higher rates of K application with cauliflower and cabbage. The negative balance of K was found in all crops regardless of K levels applied, except for tomato (Fig. 2, Table 6) for which a positive K balance was recorded at each level of K application. In all crops tested, NUE, e.g. increasing removal of N and P (Fig. 3) increased with K application over that without K use.

Profit and benefit cost ratio

Increased yield and profit with no risk to the farmer are not synonymous. To determine profit, the added costs for potash application were deducted from the additional income (Table 1, added net profit). Benefit cost ratio (BCR) reflects the risk by presenting the ratio between the added profit and the cost of the input (KCl in this case). It is factors such as net profit (USD ha^{-1}) and BCR that farmers take into account. The effect of K application on the net profit in each crop is described in Table 1 and Fig. 4. The highest additional net profit was achieved in brinjal and tomato, at USD 2,583 and USD 2,275 per ha while in cauliflower and cabbage it was only half of this amount. The high profitability of brinjal and tomato is also supported by a very high BCR of well over 50, while that of cauliflower and cabbage varies between 30 to 40. While maximum BCR was recorded at applications of 60 kg K_2O ha^{-1} for all four vegetables, the decision for which K application rate is needed, especially



Field board with the experiment set-up. Photo by E. Sokolowski.

at such high BCR values which pose no risk to farmers, brings into account the additional net profit.

Conclusions

On the basis of two years results of a vegetable research farm trial using cauliflower, cabbage, brinjal and tomato as test vegetables in their response to K fertilization as KCl, it was concluded that brinjal and tomato crops responded significantly in yield up to 80 and 100 kg K_2O ha^{-1} with maximum additional net income of over USD 2,000 ha^{-1}, and cauliflower and cabbage responded significantly in yield up to 80 and 60 kg K_2O ha^{-1} respectively, with maximum additional net income of over USD 1,000 ha^{-1}. These substantial responses, which were observed on a soil of medium K supply, indicate the high K requirements by all four vegetable crops and the

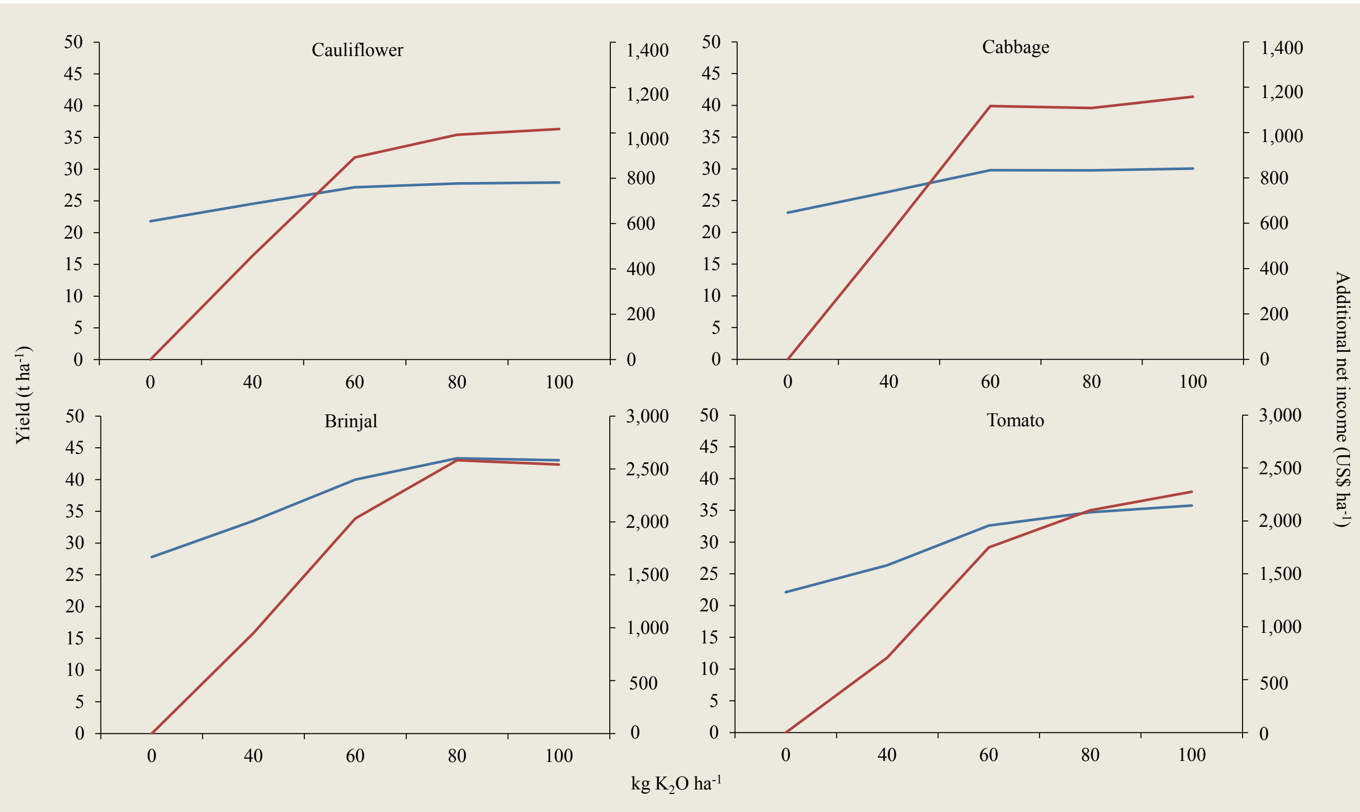


Fig. 4. Effect of increasing levels of K application on fresh weight yield (blue) and net profit of vegetables.

need for fertilizer application. High K applications must be accompanied by appropriate N levels, to avoid yield stagnation due to N deficiency, as reported here for cauliflower and cabbage crops. More experiments are required to optimize rates of N and K application to reduce or eliminate negative N and K nutrient balances and possible loss of fertility. Considering the BCR, which takes into account the cost of fertilizer and the value of the crop, K application offers little risk and therefore should be widely adopted.

Acknowledgement

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References

Cakmak, I. 2005. The Role of Potassium in Alleviating the Detrimental Effects of Abiotic Stresses in Plants. J. Plant Nutr. Soil Sci. 168:521-530.

Jackson, M.L. 1973. Soil Chemical Analysis. Prentice Hall of India Pvt. Ltd., New Delhi, India. p. 187.

Marschner, P. (ed). 2012. Marschner's Mineral Nutrition of Higher Plants. 3rd edn. Academic Press, Elsevier Ltd., London, UK.

Mengel, K., and E.A. Kirkby. 2001. Principles of Plant Nutrition. 5th edn. Kluwer Academic Publishers, Dordrecht, The Netherlands; Springer.

Olsen, S.R., C.V. Cole, F.S. Watanabe, and L.A. Dean. 1954. Estimation of Available Phosphorus in Soils of Extraction with Sodium Bicarbonate. USDA 93:9-19.

Pathak, R.K., T.P. Tiwari, and K.N. Tiwari. 1999. Effect of Potassium on Crop Quality in Uttar Pradesh. *In:* Use of Potassium in Uttar Pradesh Agriculture; Proceedings of workshop. p. 112-113.

Singh, J.P., S. Singh, and V. Singh. 2010. Soil Potassium Fractions and Response of Cauliflower and Onion to Potassium. J. Indian Soc. Soil Sci. 58:(4)384-387.

Subbiah, B.V., and G.L. Asija. 1956. A Rapid Procedure for the Estimation of Available Nitrogen in Soil. Current Sci. 25:259-260.

Walkley, A., and I.A. Black. 1934. An Examination of the Degtjareff Method for Determining Soil Organic Matter, and a Proposed Modification of the Chromic Acid Titration Method. Soil Sci. 37(1):29-38.

The paper "Effect of Graded Doses of Potassium on Yield, Profitability and Nutrient Content of Vegetable Crops in the Central Plain Zone of Uttar Pradesh, India" also appears on the IPI website at:

Regional activities/India

Scientific Paper

Typical symptoms of potassium deficiency in cotton leaves. Photo by D.M. Oosterhuis.

Potassium and Stress Alleviation: Physiological Functions and Management in Cotton

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Summary

Potassium (K) plays a major role in the basic functions of plant growth and development. In addition, K is also involved in numerous physiological functions related to plant health and tolerance to biotic and abiotic stress. However, deficiencies occur widely resulting in poor growth, lost yield and reduced fiber quality. This review describes the physiological functions of K and the role in stress relief and also provides some agronomic aspects of K requirements, diagnosis of soil and plant K status, and amelioration. The physiological processes described include enzymes and organic compound synthesis regulation, water relations and stomatal regulation, photosynthesis, transport, cell signaling, and plant response to drought stress, cold stress, salt stress, as well as biotic stresses. The agronomic aspects of K fertilization include the K requirements of cotton, K uptake and soil characteristics, genotypic variation in K uptake and use, and characteristics of K deficiency in cotton. In addition, diagnosis and amelioration of K soil and plant status is discussed.

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Introduction

Potassium (K) plays a major role in plant metabolism, growth, development, and yield. Deficiencies of K result in perturbations of numerous physiological functions, including water relations, enzyme activation, charge balance, poor growth, reduced yield, and decreased resistance to stress. Furthermore, K is also involved in numerous physiological functions related to plant health and tolerance to biotic and abiotic stress. For optimal growth and productivity, modern crop production requires a large amount of K, particularly during reproductive development. Potassium is the mineral element, after nitrogen (N), required in the largest amount by plants. The K requirement for optimal plant growth is 2 to 5% of the plant dry weight (Marschner, 1995). However, this requirement is often not met due to adverse soil and plant factors, and deficiencies occur with resulting yield reductions. Furthermore, the concentration of K available to the plant is often influenced by the availability/abundance of other essential elements.

Farmers in the USA and elsewhere are using substantially more commercial fertilizer than 20 years ago and major improvements have been made in how these fertilizers are managed. However, despite soil analyses and subsequent soil applications of fertilizer prior to planting, K deficiencies have occurred sporadically and somewhat unpredictably. This has prompted a renewed focus on K management in cotton with some emphasis on understanding K fertilizer requirements and use by the cotton plant. An efficient fertilizer regime requires an accurate knowledge of the nutrient status of the soil, as well as a reliable tissue analysis during the season to fine tune the fertility status and avoid any unforeseen deficiencies. Fundamental to this is an understanding of the role of the nutrient in plant metabolism, yield formation and in amelioration of stress. This review describes the general agronomic characteristics of K, the physiological functions and mitigation of stress by K, and common methods of deficiency diagnosis and amelioration using cotton as a model crop.

Physiology of potassium

Potassium is an essential macronutrient for plant growth and development that affects many fundamental physiological processes (Clarkson and Hanson, 1980). It is the most abundant cation in plant cells and it can be stored either in the cytoplasm and/or in the vacuole, while the distribution of K concentrations between those compartments determines its function in the plant (Marschner, 1995). Additionally, K is characterized by high mobility not only within short distance transport, such as between individual cells and neighboring tissues, but also within long distance transport, such as through the xylem and phloem. These characteristics convey K as a major nutrient responsible for controlling many physiological and biochemical processes in the plant, such as: enzyme activation, cell osmotic potential regulation, soluble and insoluble molecular anions neutralization, and cell pH stabilization (Marschner, 1995). Potassium plays an integral role in plant-water relations, and is involved in numerous physiological functions where water is involved including transpiration, cell turgor maintenance, stomatal opening and closing, assimilate translocation, enzyme activation, and leaf movements. Lastly, plant photosynthesis, as well as the translocation of carbon (C) and N compounds from production sites into sink organs is greatly dependent on K.

Agronomic aspects of potassium

Importance of potassium in cotton

From an agronomic standpoint, K deficiencies and excesses are financially and environmentally inefficient and have negative yield-impacting consequences. General characteristics of excessive K in cotton (*Gossypium hirsutum* L.) include increased boll rot (Bennett *et al.*, 1965), increased plant height (Bennett *et al.*, 1965; Pettigrew and Meredith, 1997), and delayed maturity (Bennett *et al.*, 1965; Clement-Bailey and Gwathmey, 2007; Gwathmey and Howard, 1998; Gwathmey *et al.*, 2009). Deficiencies of K enhance water deficit stress (Coker *et al.*, 2000), reduce lint percentage (Pettigrew *et al.*, 1996), dry matter production (Gerardeaux *et al.*, 2010; Rosolem *et al.*, 2003; Zhao *et al.*, 2001), plant height (Zhao *et al.*, 2001), leaf area (Gerardeaux *et al.*, 2010; Zhao *et al.*, 2001), internode length (Gerardeaux *et al.*, 2010), seed mass (Pettigrew *et al.*, 1996), boll mass (Pettigrew *et al.*, 1996), N use efficiency (Pettigrew and Meredith, 1997), and lint yield (Gormus, 2002; Pettigrew *et al.*, 1996; Stromberg, 1960). Deficiencies of K also effect crop maturity by stopping reproductive growth prematurely and increasing early season flowering rate (Pettigrew, 2003).

Potassium requirements of cotton

Normal cotton growth and fiber development requires K in quantities second only to N. An average mature cotton crop is estimated to contain between 110-250 kg K ha^{-1} (Hodges, 1992) or about 2 to 5 kg K ha^{-1} day^{-1} (Bassett *et al.*, 1970; Halevy, 1976; Mullins and Burmester, 1991), i.e. about 13 kg K/100 kg lint (Mullins and Burmester, 2009), with 50% of the K in the boll (Rimon, 1989) and 24% in the seed and lint (Mullins and Burmester, 2009). At maturity, the capsule wall of the boll accounts for over 60%, the seed about 27% and the fiber about 10% of all the K accumulated by the boll (Leffler, 1986). Large quantities of K in non-harvested tissues results in only about 20 kg of K required to produce one 218 kg bale of cotton fiber, with about 2.5 to 6 kg being removed mainly by the seeds (Hodges, 1992; Rimon, 1989).

Characteristics of potassium deficiencies in cotton

Cotton is more sensitive to low K availability than most other major field crops, and often shows signs of K deficiency on soils not considered K deficient (Cassman *et al.*, 1989). Visual symptoms of K deficiencies in cotton have traditionally been noted in the lower, more mature leaves and progress from the bottom of the canopy to the top (Dong *et al.*, 2004) due to the nutrient's very mobile nature in the plant. The traditional symptoms often begin with interveinal chlorosis of leaves and necrosis of the leaf margins. Leaves become brittle and become bronze in color as the deficiency progresses, and because of these characteristics K deficiencies have been commonly referred to as 'cotton rust' (Maples *et al.*, 1988).

Although traditional deficiency symptoms are still occasionally noted, more recent characterization of K deficiencies describe symptoms later in the growing season during boll development in younger leaf deficiencies, and include interveinal leaf chlorosis which turns to a gold-like color as deficiency worsens, causing necrosis of leaf tissues. The occurrence of these K deficiency symptoms was first recognized in California during the early 1960s (Brown *et al.*, 1973). These deficiencies manifested themselves during the latter half of the season in a range of soils and cotton cultivars. Visual deficiency symptoms on younger tissues are similar to the traditional symptoms on older leaves, with leaf-edge curl and early defoliation. In contrast to traditional symptoms, however, the deficiencies progress from the top of the canopy to the bottom (Maples *et al.*, 1988; Stromberg, 1960).

It is commonly suggested that the two major contributing factors to these shifts in K deficiency characteristics are: (1) an inefficiency of cotton roots to utilize K in the surface exacerbated by genetic shifts to earlier-maturing cultivars which fail to develop as expansive of a root system; and (2) higher yielding, earlier maturing cultivars which require much more K and other nutrients than lower yielding traditional cultivars (Oosterhuis, 1976). Understanding the nature and reasons for late-season cotton K deficiencies should result in reduced frequencies and severities of in-field K deficiencies (Bednarz and Oosterhuis, 1998).

Potassium uptake and soil characteristics

The main mechanisms of plant K uptake from the soil are mass-flow and diffusion (Barber, 1962). Under normal conditions, the vast majority of K uptake occurs through diffusion, as mass-flow may only represent 1-3% of total K uptake (Marschner, 1995; Rosolem *et al.*, 2003). Still, the importance of these two mechanisms varies with soil and plant parameters such as root characteristics, plant K requirements, and water flux rates (Baligar, 1985). Cotton uptake of K during the season follows a pattern similar to dry weight accumulation until peak flower, at which time maximum K uptake is reached and begins to decline (Bassett *et al.*, 1970; Halevy *et al.*, 1987; Schwab *et al.*, 2000). This is also the period in which K demand rises dramatically due to the developing boll load as the bolls are the major sinks for this element (Halevy, 1976; Leffler and Tubertini, 1976).

Close up on mild K deficiency in cotton leaf. Photo by D.M. Oosterhuis.

Plants can, in the most basic sense, be considered as nutrient (and more specifically K) wicks. Cotton removes K from the exchangeable sites on soil colloids and organic matter at various soil depths and concentrates the nutrient in above-ground tissues (Brouder and Cassman, 1990). In contrast to crops harvested for their biomass, cotton returns much of the K back to the soil in leaves, stems, and capsule walls (burs). These tissues are either incorporated in the soil's surface or in no-till and conservation tillage systems allowed to decompose on the soil's surface. Due to the negative charge of medium to heavy textured soils and the characteristics of K as a cation, it is not common for K to leach out of these upper soil layers. Many examples of this can be found in the San Joaquin Valley (SJV) in the US. Although this region generally possesses high fertility soils with respect to K (Brown *et al.*, 1973) it was one of the first to characterize modern cotton K deficiencies (Stromberg, 1960) due to stratification of K through the profile in the SJV with more K located in the vermiculitic topsoil than subsoil. Depletions of subsoil K have also been noted in America's mid-southern and south-eastern regions (Maples *et al.*, 1988).

Mimicking the K stratified characteristics of the SJV, Gulick *et al.* (1989) examined the response of cotton and barley (*Hordeum vulgare* L.) to soil K in layered profiles. Results suggested cotton rooting pattern was very similar to barley in all layers except the topsoil, in which barley had 2.7 times greater root length density than cotton. As a result, cotton K uptake from the topsoil was much lower than barley. Long-term fertility trials conducted in the south-eastern US comparing nutrient uptake of cotton to soybeans (*Glycine max* L.) and maize (*Zea mays* L.) found cotton to be much more sensitive to K deficiencies than the other two crops (Cope, 1981). Research by Brouder and Cassman (1990) in this region examined root growth of two cultivars, one sensitive to K deficiency and a K deficiency tolerant cultivar. The tolerant cultivar was characterized by a larger mean root diameter and increased root extension after peak bloom, at which point most K deficiencies become visually apparent. Furthermore, results from examination of root zone densities suggested neither cultivar utilized nutrients in the topsoil.

Genotypic variation in K uptake and use

It has been suggested that the increasing reports of K deficiencies in modern cultivars may be due to their earlier maturity or increased yields as compared to traditional cultivars (Oosterhuis, 1995). In theory, earlier maturing cultivars will require more K earlier in the growing season than their late-season isolines. Although it seems logical that an earlier maturing cultivar would not have the time to grow as expansive of a root system or store as much K as a later maturing cultivar, experiments testing these theories have shown mixed results.

Scientists began examining differences in K uptake due to maturity (earliness) as early as the mid 1970s. Halevy (1976) found an earlier maturing cultivar to be more sensitive to K deficiencies due to greater K demands by reproductive parts earlier in the growing season and have a relatively smaller root system compared to the later maturing cultivar. The aforementioned characteristics of the earlier cultivar resulted in earlier translocation of K from the leaves to the fruit than in the later maturing cultivar. As a result, the earlier maturing cultivar displayed visual deficiency symptoms earlier than the later maturing cultivar. Clement-Bailey and Gwathmey (2007) reported similar findings. The authors only noted significant increases in yields from additional K for the earlier maturing cultivar (no yield response to additional K was noted in the later maturing cultivar). Results are also in agreement with findings of Tupper *et al.* (1996), who concluded that earlier cultivars required higher levels of soil test K as applications of fertilizer K increased earlier maturing cultivars' yields but failed to greatly impact the yields of later maturing cultivars. Cassman *et al.* (1989) observed differences in K uptake between two cultivars and suggested K uptake from soil was the main factor determining efficiency as partitioning was not different between the two. Furthermore, the author only noticed differences in K efficiency at low K levels; at high K levels differences were not noted. Similar results were noted under controlled growing conditions by López *et al.* (2008). Further uptake research was conducted by Keino *et al.* (1996), who examined the response of K uptake from two cultivars of differing maturities after foliar K was applied. The authors found foliar K doubled the root uptake of K from both the early and late maturing cultivars, although increases in number of squares and shoot tissue and decreases of root length tended to be elevated in the later maturing cultivar.

Still, other research examining cultivars of varying maturity has not shown significant differences in response to K fertility. Pettigrew (1999) and Pettigrew *et al.* (1996) examined the responses of early, mid and late maturing cotton cultivars to varying K fertilizer rates and found genotype to be insignificant. Concern that the previously examined cultivars included genetic differences beyond maturity led the investigator to conduct further research examining the response in two okra and normal leaf-type isogenic pairs (Pettigrew, 2003). This approach was chosen due to the earlier maturity of okra leaf-type cultivars as compared to normal leaf-type cultivars while maintaining more similar genotypic traits than cultivars examined in earlier experiments. Significant responses to K deficiencies were noted, but earlier maturing cultivars did not significantly increase this response. Gwathmey *et al.* (2009) also found no significant differences in K utilization or uptake ratios between cultivars of differing maturity, but suggested differences may be significant under lower K statuses. Although inconsistent, earlier maturing cultivars did have greater K uptake in one out of three years and greater K accumulation in the fruit in two of the three years of the study.

Potassium and relief of stress

Potassium is involved in numerous physiological functions related to plant health and resistance to biotic and abiotic stress, and because of this, K plays an important role in the metabolic and agronomic alleviation of stress.

Drought stress

All plants are subjected to water shortages at some time during their life cycles, resulting in numerous detrimental effects on plant growth. Alleviation of drought stress is therefore a fundamental aspect of crop management. Water-stressed chloroplasts have been observed to suffer increased leakage of K, resulting in further suppression of photosynthesis (Sen Gupta and Berkowitz, 1987). Water-deficit stressed plants, where higher than optimum quantities of K were supplied, were reported to be able to maintain efficient photosynthetic activity (Berkowitz and Whalen, 1985; Pier and Berkowitz, 1987) with higher K concentrations compared to plants where optimal quantities of water was applied (Cakmak and Engels, 1999). This was due to K's ability to maintain CO_2 assimilation rates by regulating stomatal function and balancing cell water relations (Mengel and Kirkby, 2001; Sangakarra *et al.*, 2000). High K levels have also been associated with maintenance of optimum pH values in the chloroplasts' stroma and optimal function of photosynthetic mechanisms (Pier and Berkowitz, 1987).

Cold stress

A positive correlation has been reported between K availability and cold stress tolerance, with lower than optimum K concentrations escalating the negative effects of cold stress (Kafkafi, 1990) while increased K levels enhance plant defense against cold stress, not only promoting production of antioxidative enzymes but also by acting as an osmolyte and lowering the freezing point of sap (Hankerlerler *et al*., 1997; Kafkafi, 1990; Kant and Kafkafi, 2002).

Salt stress

High sodium (Na) levels in the soil solution significantly reduce K uptake from the plant in the cytoplasm and drives water out of the cell vacuole resulting in decreased cell turgor (Yeo *et al*., 1991; Zhu *et al*., 1997). High concentrations of Na cations compete in the soil with K cations, substantially reducing its uptake by the plants (Zhu, 2003). Higher K levels as well as increased capacity of plants to accumulate K have been associated with increased salt-tolerance in a number of crops such as Arabidopsis (Liu and Zhu, 1997; Zhu *et al*., 1998), wheat (Rascio *et al*., 2001; Santa-Maria and Epstein, 2001), cucumber (*Cucumis sativus* L.) and pepper (*Piper nigrum* L.) (Kaya *et al*., 2001) due to K's ability to enhance plants' antioxidative mechanism.

Potassium and biotic stress

High concentrations of K have been reported to alleviate detrimental effects of disease and pest infestations (Bergmann, 1992; Perrenoud, 1990; Prabhu *et al*., 2007). This has been attributed to the regulation by K of primary metabolic plant functions. High levels of K in the plant promote the synthesis of high molecular weight compounds, such as proteins, starch and cellulose while simultaneously suppressing the formation of soluble sugars, organic acids and amides, compounds indispensable for feeding pathogens and insects (Amtmann *et al*., 2008; Marschner, 1995). In cotton, K application has been reported to significantly reduce Fusarium wilt and root rot caused by *Fusarium oxysporum* sp. (Prabhu *et al*., 2007).

Diagnosis and amelioration of plant potassium status

The nutrient demands of current high-yielding varieties are not entirely met by natural soil fertility. The application of fertilizer is therefore required, yet spatial and temporal variability of abiotic and biotic factors results in varying nutrient demands of different fields across seasons. For K, two methods are currently used to determine optimum fertilizer applications.

Soil sampling and analysis

Soil sampling is the traditional method to determine necessary fertilizer applications (Baker *et al*., 1992). Recommendations for sampling are created by cooperative extension services in each cotton-growing state in the US (in cooperation with the United States Department of Agriculture). Generally, soil sampling should be conducted at the depth of tillage (typically 15 cm) in a zig-zag pattern through uniform areas of each field every three to four years. Mixed soil samples are dried and analyzed for mg K kg^{-1}. Soil testing laboratories typically calibrate their recommendations based upon the type of analysis utilized, type of soil, crop to be grown and estimated yields. Still, deficiencies have been noted under laboratory-determined 'sufficient' levels (Oosterhuis and Weir, 2010). These unanticipated deficiencies may be due to sampling shallow soil depths which cotton may fail to fully exploit (Brouder and Cassman, 1990) or seasonal factors which require a mid-season measurement to accurately determine nutrient demands.

Tissue sampling and analysis

Although the most practical method to detect K deficient areas is through pre-plant soil testing, in-season plant tissue analysis has the potential to also be a valuable tool (Baker *et al*., 1992). Unfortunately, the characteristics of plant K have complicated the establishment of critical values.

Potassium is generally concentrated in the leaves and stems early in the growth season and is then transferred to the reproductive structures, which become the dominant K sinks, later in the growth season (Bassett *et al*., 1970; Cassman *et al*., 1989; Halevy, 1976). These shifts result in a moving target depending upon growth stage. Inability to accurately characterize the sampled plant growth stage and/or failure to accurately describe tissue concentrations at differing locations on the target cotton development curve are major difficulties in tissue sampling programs. Many other genetic and environmental conditions and stresses can also influence K tissue concentrations through shifts in uptake and translocation. Furthermore, cotton takes up K in luxury amounts (Kafkafi, 1990) and this could possibly confuse tissue diagnostic recommendations (Oosterhuis, 1995). All of these properties of K have led to inconsistent and often conflicting reports of critical leaf K values (Reddy and Zhao, 2005).

Contrasting reports on the sensitivities of specific tissues have also been reported. Rosolem and Mikkelsen (1991) suggested that tissue sensitivity to K stress increases in the following order: leaves < bolls < roots < stems. These results suggest that only a severe deficiency would result in decreased leaf K concentrations. In contrast, Bednarz and Oosterhuis (1995) noted the following degrees of sensitivity: bolls < stems < leaves < roots. Still, many reports have suggested petiole sampling is more useful due to its more sensitive nature, noting declines in petiole K concentrations as early as seven days after treatment establishment (Coker *et al.*, 2003).

Amelioration with fertilizer

Although research in SJV stratified soils seemed to suggest that deep-placed K fertilizer would increase K uptake and yields, research from the south-eastern and mid-southern regions of the US often found no consistent yield responses. Mullins *et al.* (1997) examined the response of cotton yield to subsoil and surface applications of K and found no significant difference associated with application method. Further research by Mullins and Burmester (2009) in Alabama - examining subsoil, banded, and broadcast applications of K fertilizer - also noted no significant differences between methods of applications. Adeli and Varco (2002) examined broadcast and banded applications of K in Mississippi and found similar results. The authors only noted consistent yield increases from banded K applications in dry growth seasons. There has been some interest in deep placement of K (Tupper *et al.*, 1988) although yield responses from this method of K placement have been inconsistent (Reeves and Mullins, 1995).

Failure of these banded and subsoil applications to affect yield regardless of soil depth may be best explained by research conducted by Brouder and Cassman (1994). They examined the response of cotton roots and shoots to localized supplies of N, phosphorus (P), and K. Results suggested that although root proliferation and compensatory growth were typically observed after N and P enrichment, neither were observed after K enrichment. Therefore, the quantity and distribution of N through the profile can greatly influence K uptake by influencing root proliferation. This may be one reason why increasing the amount of N fertilizer increases the amount of K uptake (Halevy *et al.*, 1987), but that increasing the amount of K fertilizer does not increase N uptake (Pettigrew and Meredith, 1997).

When soil analysis calls for K, the cotton crop is usually fertilized with a single preplant broadcast application of K fertilizer. Potassium chloride, commonly referred to as muriate of potash, is the most common source of fertilizer K due to its cost and high K composition (IPNI, 2011a). The contained chloride (Cl^-) typically leaches with the application of water and is not considered to negatively affect cotton growth in most humid regions. Still, in arid regions where application of Cl is of concern or where sulfur is needed, potassium sulfate, commonly referred to as sulfate of potash, is another acceptable K source (IPNI, 2011b). Under these conditions research has shown significant cotton yield penalties associated with the use of muriate of potash as compared to sulfate of potash (Pervez *et al.*, 2005). Other sources of K include potassium magnesium sulfate, commonly referred to as Langbeinite, and potassium nitrate, but use of these fertilizers is typically restricted to high value crops and not commonly used in cotton production (IPNI 2011c; IPNI, 2011d).

Mid-season applications are infrequently applied, and foliar applications are only used occasionally to correct K deficiencies during fruiting. Foliar applications of K offer the opportunity of correcting mid-season deficiencies quickly and efficiently, especially late in the season when soil application of K may not be effective. The practice of foliar fertilization has only caught on in cotton production in the last two decades, but there is still considerable speculation about the benefits and correct implementation of this practice. While there are many reports on research involving soil-applied K (e.g. Kerby and Adams, 1985), there are no definitive studies available on the usefulness of foliar-applied K. Earlier research (Oosterhuis, 1976; Oosterhuis *et al.*, 1991) indicated that foliar-applications of K significantly increased seed yield of cotton. There have also been reports of foliar-applications of K improving both lint quality and yield (Oosterhuis *et al.*, 1990; Pettigrew *et al.*, 1996). With the current emphasis on lint quality (Sasser, 1991) and the introduction of high-volume instrumentation classification, the positive effect of K on lint quality may be of paramount importance.

Conclusions

This review has described the major role that K plays in plant physiological processes fundamental to normal growth and yield development of cotton. Potassium deficiency was described and related to functions in the plant. It was shown that K is also involved in numerous physiological functions related to plant health and resistance to biotic and abiotic stress. In addition, the role of K in stress relief was highlighted. Lastly, the agronomic aspects of K requirements, diagnosis of soil and plant K status, and amelioration of K soil and plant status were discussed. However, research has mainly focused on model crops such as arabidopsis or rice and maize with very little or even no information existing on the physiology, biochemistry and most importantly molecular biology of K nutrition in the cotton plant. Identification of the metabolical pathways that may be controlled by K in the cotton plant will improve our understanding of the plant's adaptation to deficiency, aiding farmers to generate more efficient fertilization strategies on marginal soils and additionally provide us with valuable information on targets for future genetic improvement efforts.

References

Adeli, A., and J.J. Varco. 2002. Potassium Management Effects on Cotton Yield, Nutrition, and Soil Potassium Level. J. Plant Nutr. 25:2229-2242.

Amtmann, A., S. Troufflard, and P. Armengaud. 2008. The Effect of Potassium Nutrition on Pest and Disease Resistance in Plants. Physiol. Plant. 133:682-691.

Baker, W.H., J.S. McConnell, R.L. Maples, and J.J. Varvil. 1992. Soil an Plant Methods for Diagnosing K Deficiency in Cotton. Proc. Beltwide Cotton Conf., National Cotton Council of America, Memphis, TN.

Baligar, V. 1985. Potassium Uptake by Plants, as Characterized by Root Density, Species and K/Rb Ratio. Plant and Soil 85:43-53.

Barber, S.A. 1962. A Diffusion and Mass-Flow Concept of Soil Nutrient Availabilty. Soil Sci. 93:39-49.

Bassett, D.M., W.D. Anderson, and C.H.E. Werkhoven. 1970. Dry Matter Production and Nutrient Uptake in Irrigated Cotton (*Gossypium hirsutum*). Agron. J. 62:299-303.

Bednarz, C.W., and D.M. Oosterhuis. 1998. Development of a Protocol to Study the Effects of Potassium Deficiency in Cotton under Controlled Environmental Conditions. J. Plant Nutr. 21:329-339.

Bennett, O.L., R.D. Rouse, D.A. Ashley, and B.D. Doss. 1965. Yield, Fiber Quality and Potassium Content of Irrigated Cotton Plants as Affected by Rates of Potassium. Agron. J. 57:296-299.

Bergmann, W. 1992. Nutritional Disorders of Plants: Development, Visual and Analytical Diagnosis. Gustav Fischer Verlag, New York.

Berkowitz, G.A., and C. Whalen. 1985. Leaf K^+ Interaction with Water Stress Inhibition of Nonstomatal Controlled Photosynthesis. Plant Physiol. 79:89-193.

Brouder, S.M., and K.G. Cassman. 1990. Root Development of Two Cotton Cultivars in Relation to Potassium Uptake and Plant Growth in a Vermiculitic Soil. Field Crops Res. 23:187-203.

Brouder, S.M., and K.G. Cassman. 1994. Cotton Root and Shoot Response to Localized Supply of Nitrate, Phosphate and Potassium: Split-Pot Studies with Nutrient Solution and Vermiculitic Soil. Plant and Soil 161:179-193.

Brown, S.M., A.L. Quick, and G.J. DeBoer. 1973. Diagnosing Potassium Deficiency by Soil Analysis. California Agriculture 27:13-14.

Cakmak, I., and C. Engels. 1999. Role of Mineral Nutrients in Photosynthesis and Yield Formation. *In:* Rengel, Z.: Mineral Nutrition of Crops: Mechanisms and Implications. The Haworth Press, New York, N.Y. p. 141-168.

Cassman, K.G., T.A. Kerby, B.A. Roberts, D.C. Bryant, and S.M. Brouder. 1989. Differential Response of Two Cotton Cultivars to Fertilizer and Soil Potassium. Agron. J. 81:870-876.

Clarkson, D.T., and J.B. Hanson. 1980. The Mineral Nutrition of Higher Plants. Annu. Rev. Plant Physiol. 31:239-298.

Clement-Bailey, J., and C.O. Gwathmey. 2007. Potassium Effects on Partitioning, Yield, and Earliness of Contrasting Cotton Cultivars. Agron. J. 99:1130-1136.

Coker, D.L., D.M. Oosterhuis, and R.S. Brown. 2000. Potassium Partitioning in the Cotton Plant as Influenced by Soil and Foliar Potassium Fertilization under Water Deficit Stress. *In:* Oosterhuis, D.M.: Summaries of Arkansas Cotton Research. Arkansas Agricultural Experiment Station, Fayetteville, AR. p. 81-88.

Coker, D.L., D.M. Oosterhuis, M. Arevalo, and M. Mozaffari. 2003. Critical Petiole Potassium Levels as Related to Physiological Responses of Chamber-Grown Cotton to Potassium Deficiency. Summaries of Arkansas Cotton Research 2003 AAES Research Series 521:81-86.

Cope, J.T. 1981. Effects of 50 Years of Fertilization with Phosphorus and Potassium on Soil Test Levels and Yields at Six Locations. Soil Sci. Soc. Am. J. 45:342-347.

Dong, H.W., Z.L. Tang, and D. Zhang. 2004. On Potassium Deficiency in Cotton-Disorder, Cause and Tissue Diagnosis. Agric. Consp. Sci. 69:77-85.

Gerardeaux, E., L. Jordan-Meille, J. Constantin, S. Pellerin, and M. Dingkuhn. 2010. Changes in Plant Morphology and Dry Matter Partitioning Caused by Potassium Deficiency in *Gossypium hirsutum* (L.). Environ. Exp. Bot. 67:451-459.

Gormus, O. 2002. Effects of Rate and Time of Potassium Application on Cotton Yield and Quality in Turkey. J. Agron. Crop Sci. 188:382-388.

Gulick, S.H., K.G. Cassman, and S.R. Grattan. 1989. Exploitation of Soil Potassium in Layered Profiles by Root Systems of Cotton and Barley. Soil Sci. Soc. Am. J. 53:146-153.

Gwathmey, C.O., and D.D. Howard. 1998. Potassium Effects on Canopy Light Interception and Earliness of No-Tillage Cotton. Agron. J. 90:144-149.

Gwathmey, C.O., C.L. Main, and X. Yin. 2009. Potassium Uptake and Partitioning Relative to Dry Matter Accumulation in Cotton Cultivars Differing in Maturity. Agron. J. 101:1479-1488.

Hankerleler, H., M. Oktay, N. Eryuce, and B. Yagmur. 1997. Effect of Potasium Sources on the Chilling Tolerance of Some Vegetable Seedlings Grown in Hotbeds. *In:* Johnston, A.E.: Food Security in the WANA Region, The Essential Need for Balanced Fertilization. International Potash Institute, Switzerland. p. 317-327.

Halevy, J. 1976. Growth Rate and Nutrient Uptake of Two Cotton Cultivars Grown under Irrigation. Agron. J. 68:701-705.

Halevy, J., A. Marani, and T. Markovitz. 1987. Growth and NPK Uptake of High-Yielding Cotton Grown at Different Nitrogen Levels in a Permanent-Plot Experiment. Plant and Soil 103:39-44.

Hodges, S.C. 1992. Nutrient Deficiency Disorders. *In:* Hillocks, R.: Cotton Diseases, CAB International, Wallingford, UK.

Kafkafi, U. 1990. The Functions of Plant K in Overcoming Environmental Stress Situations. 22nd Colloquium, International Potash Institute, Switzerland. p. 81-93.

Kant, S., and U. Kafkafi. 2002. Potassium and Abiotic Stresses in Plants. *In*: Pasricha, N.S. and S.K. Bansal: Plant Roots: The Hidden Half. Marcel Dekker Incorporated, New York. p. 435-449.

Kaya, C., H. Kimak, and D. Higgs. 2001. Enhancement of Growth and Normal Growth Parameters by Foliar Application of Potassium and Phosphotus in Tomato Cultivars Grown at High (NaCl) Salinity. J. Plant Nutr. 24:357-367.

Keino, J.K., C.A. Beyrouty, D.M. Oosterhuis, and E.E. Gbur. 1996. Potassium Uptake Kinetics of Cotton as Influenced by Foliar-Applied K. Proc. Beltwide Cotton Conf. National Cotton Council of America, Memphis, TN. p. 1167.

Kerby, T.A., and F. Adams. 1985. Potassium Nutrition of Cotton. Potassium in Agriculture, American Society of Agronomy, Madison, WI.

Leffler, H.R. 1986. Mineral Compartmentation within the Boll. *In:* Mauney, J.R. and J.M. Stewart: Cotton Physiology. Cotton Foundation, Memphis, TN. p. 301-309.

Leffler, H.R., and B.S. Tubertini. 1976. Development of Cotton Fruit II. Accumulation and Distribution of Mineral Nutrient. Agron. J. 68:858-861.

Liu, J., and J.K. Zhu. 1997. Proline Accumulation and Salt Stress-Induced Gene Expression in a Salt-Hypersensitive Mutaution of Arabidopsis. Plant Physiol. 114:591-596.

López, M., M.A.A. El-Dahan, and E.O. Leidi. 2008. Genotypic Variation in Potassium Uptake in Dryland Cotton. J. Plant Nutri. 31:1947-1962.

Maples, R.L., W.R. Thompson Jr., and J. Varvil. 1988. Potassium Deficiency in Cotton Takes on a New Look. Better Crops Plant Food 73:6-9.

Marschner, H. 1995. Mineral Nutrition of Higher Plants. Academic Press, Inc., London. p. 651.

Mengel, K., and E.A. Kirkby. 2001. Principles of Plant Nutrition. Kluwer Academic Publishers, Dordrecht, The Netherlands. p. 833.

Mullins, G.L., C.H. Burmester, and D.W. Reeves. 1997. Cotton Response to In-Row Subsoiling and Potassium Fertilizer Placement in Alabama. Soil Tillage Res. 40:145-154.

Mullins, G.L., and C.H. Burmester. 2009. Relation and Development to Mineral Nutrition. *In:* Stewart, J.M., D.M. Oosterhuis, J. Heitholt, and J.R. Mauney: Physiology of Cotton. National Cotton Council of America. Springer, London, Memphis, TN, USA. p. 563.

Oosterhuis, D.M. 1976. Foliar Application of Fertilizer. *In:* Annual Report Cotton Research Institute 1974-75. Government Printer, Salisbury, Rhodesia. p. 11-12.

Oosterhuis, D.M., and B.L. Weir. 2010. Foliar Fertilziation of Cotton. *In:* Stewart, J.M., D.M. Oosterhuis, J. Heitholt, and J.R. Mauney (eds.): Physiology of Cotton. National Cotton Council of America. Springer, London, Memphis, TN, USA. p. 272-288.

Oosterhuis, D.M. 1992. Foliar Feeding with Potassium Nitrate in Cotton. Proc. Beltwide Cotton Conferences, Nashville, TN. National Cotton Council of America, Memphis, TN. Vol 1. p. 71-72.

Oosterhuis, D.M., S.D. Wullschleger, R.L. Maples, and W.N. Miley. 1990. Foliar Feeding of Potassium Nitrate in Cotton. Better Crops with Plant Food. Potash and Phosphate Institute, Atlanta, GA, USA. p. 8-9.

Oosterhuis, D.M. 1995. Potassium Nutrition of Cotton with Emphasis on Foliar Fertilization. *In:* Constable, C.A.N. and W. Forrester: Challenging the Future. Proc. World Cotton Research Conference 1. CSIRO, Australia. p. 133-146.

Perrenoud, S. 1990. Potassium and Plant Health. IPI-Research Topics No. 3,. International Potash Institute, Switzerland. p. 365.

Pettigrew, W.T., J.J. Heitholt, and W.R. Meredith. 1996. Genotypic Interactions with Potassium and Nitrogen in Cotton of Varied Maturity. Agron. J. 88:89-93.

Pettigrew, W.T., and W.R. Meredith. 1997. Dry Matter Production, Nutrient Uptake, and Growth of Cotton as Affected by Potassium Fertilization. J. Plant Nutr. 20:531-548.

Pettigrew, W.T. 1999. Potassium Deficiency Increases Specific Leaf Weights and Leaf Glucose Levels in Field-Grown Cotton. Agron. J. 91:962-968.

Pettigrew, W.T. 2003. Relationships Between Insufficient Potassium and Crop Maturity in Cotton. Agron. J. 95:1323-1329.

Pier, P.A., and G.A. Berkowitz. 1987. Modulation of Water Stress Effects on Photosynthesis by Altered Leaf K^+. Plant Physiol. 85:655-661.

Prabhu, A.S., N.K. Fageria, D.M. Huber, and F.A. Rodriguez. 2007. Potassium and Plant Disease. *In:* Datnoff, L.E., W.H. Elmer, and D.M. Huber: Mineral Nutrition and Plant Disease. The American Phytopathological Soc. Press, Saint Paul. p. 57-78.

Rascio, A., M. Russo, L. Mancuzzo, C. Platani, G. Nicastro, and N. Di Fonzo. 2001. Enhanced Osmotolerance of a Wheat Mutant Selected for Potassium Accumulation. Plant Sci. 160:441-448.

Reddy, K.R., and D. Zhao. 2005. Interactive Effects of Elevated CO_2 and Potassium Deficiency on Photosynthesis, Growth, and Biomass Partitioning of Cotton. Field Crop Res. 94:201-213.

Reeves, D.W., and G.L. Mullins. 1995. Subsoiling and Potassium Effects on Water Relations and Yield of Cotton. Agron. J. 87:847-852.

Rimon, D. 1989. Functions of Potassium in Improving Fiber Quality of Cotton. Methods of Potassium Research in Plants. Proc. 21st Colloquium, International Potash Institute, Switzerland.

Rosolem, C.A., and D.S. Mikkelsen. 1991. Potassium Absorption and Partitioning in Cotton as Affected by Periods of Potassium Deficiency. J. Plant Nutri. 14:1001-1016.

Rosolem, C.A., R.H.D. Silva, and J.A.F. Esteves. 2003. Potassium Supply to Cotton Roots as Affected by Potassium Fertilization and Liming. Pesquisa Agropecuária Brasileira 38:635-641.

Sangakkara, U.R., M. Frehner, and J. Nosberger. 2000. Effect of Soil Moisture and Potassium Fertilizer on Shoot Water Potential, Photosynthesis and Partitioning of Carbon in Mungbean and Cowpea. J. Agron. Crop Sci. 185:201-207.

Santa-Maria, G.E., and E. Epstein. 2001. Potassium/Sodium Selectivity in Wheat and the Amphiploid Cross Wheat x Lophopyrum Elongatum. Plant Sci. 160:523-534.

Sasser, P.E. 1991. The Future of Cotton Quality: Trends and Implications - Fiber Quality Measurements. *In:* Proc. Beltwide Cotton Conf., National Cotton Council of America, Memphis, TN. p. 68-70.

Schwab, G.J., G.L. Mullins, and C.H. Burmester. 2000. Growth and Nutrient Uptake by Cotton Roots under Field Conditions. Commun. Soil Sci. Plant Anal. 31:149-164.

Sen Gupta, A., and G.A. Berkowitz. 1987. Osmotic Adjustment, Symplast Volume, and Nonstomatally Mediated Water Stress Inhibition of Photosynthesis in Wheat. Plant Physiol. 85:1040-1047.

Stromberg, L.K. 1960. Potassium Fertilizer on Cotton. California Agriculture 14:4-5.

Tupper, G.R., H.C. Pringle, and W.E. Ebelhar. 1988. Cotton Response to Deep Banding Dry Fertilizer in the Subsoil. *In:* Proc. Beltwide Cotton Conf., National Cotton Council. Memphis, TN. p. 498-501.

Tupper, G.R., D.S. Calhoun, and M.W. Ebelhar. 1996. Sensitivity of Early-Maturing Varieties to Potassium Deficiency. *In:* Proc. Beltwide Cotton Conf., National Cotton Council of America, Memphis, TN. p. 625-628.

Yeo, A.R., K.S. Lee, P. Izard, P.J. Boursier, and T.J. Flowers. 1991. Short-Term and Long-Term Effects of Salinity on Leaf Growth in Rice (*Oryza sativa* L.). J. Exp. Bot. 42:881-889.

Zhao, D., D.M. Oosterhuis, and C.W. Bednarz. 2001. Influence of Potassium Deficiency on Photosynthesis, Chlorophyll Content, and Chloroplast Ultrastructure of Cotton Plants. Photosynthetica 39:103-109.

Zhu, J., P.M. Hasegawa, and R.A. Bressan. 1997. Molecular Aspects of Osmotic Stress in Plants. Crit. Rev. Plant Sci. 16:253-277.

Zhu, J. K. 2003. Regulation of Ion Homeostasis under Salt Stress. Curr. Opin. Plant Biol. 6:441-445.

The paper "Potassium and Stress Alleviation: Physiological Functions and Management in Cotton" also appears on the IPI website at:

IPI K Center
Potassium and Stress and Plant Disease and
Basic Facts about Potassium

Events

IPI Events

August 2014

IPI-ISES Capacity Building Seminar on "Balanced Use of Fertilizers for Quality Produce and Sustainable Agriculture in Pakistan", 20 August 2014, Faisalabad, Pakistan

Report and Recommendations by
Dr. Nisar Ahmad, NFDC Planning Commission, Islamabad, Pakistan and
Dr. Abdul Wakeel, ISES, University of Agriculture, Faisalabad, Pakistan; IPI Consultant Pakistan

A capacity building seminar on "Balanced use of Fertilizers for Quality Produce and Sustainable Agriculture" was jointly organized by the International Potash Institute (IPI) and Institute of Soil and Environmental Sciences (ISES), University of Agriculture, Faisalabad, Pakistan on 20 August 2014 at the Serena Hotel in Faisalabad.

The objectives of seminar were to: 1) build the capacity of agriculture extension workers both in the public and private sector to promote balanced fertilizer use for quality produce and sustainable crop yields; and 2) highlight the significance of potassium (K) fertilization and its promotion by developing joint collaborative programs and strategies involving the public and private sector.

The seminar was attended by about 105 delegates including researchers, extension workers, the fertilizer industry, academics and policymakers. The seminar was inaugurated by Professor Dr. Iqrar Ahmad Khan vice chancellor, University of Agriculture, Faisalabad. In his opening remarks, Khan commended the efforts of ISES and IPI in organizing the seminar. He said that imbalanced and inefficient use of fertilizers is severely impacting crop yields and hampering national food security. Khan advised all stakeholders to develop programs and strategies to address this issue and wished the seminar success.

Photos: IPI-ISES Capacity Building Seminar, 20 August 2014, Faisalabad, Pakistan. Photos by A. Wakeel.

Technical presentations revealed impressive growth in nitrogen (N) and phosphorus (P) use in the past 50 years. However, growth in potash use remained stagnant. One matter of concern was that both fertilizer use and crop yields appeared to have reached a plateau. Although micronutrients are already a component of crop fertilization, the importance of balanced use of nutrients, macro, secondary and micro is stressed. Site specific use of fertilizers using the latest modeling and geographic information system (GIS) technology was shown to be a promising tool that should be refined and promoted to farmers. Presentations also showed the benefits of integrated use of mineral and organic sources on improving nutrient use efficiency and crop yield. The use of potash and its positive impact both on quality and yield of sugarcane, cotton and fruits/vegetables was highlighted by a number of presentations from field investigations.

A lively panel discussion comprising experienced and distinguished representatives from extension, research, the fertilizer industry, and academia was held to critically analyze the imbalance in NPK fertilization in Pakistan and strategies to improve potash fertilization. While the use of chemical fertilizers (N and P) after the Green Revolution increased, the panel concluded that the use of potash remained depressed due to a number of factors, such as the high economic return from N and P compared to K, a strong belief that soils are naturally supplied with K, and limited availability of K fertilizers at the right time, right place and right price compared to other fertilizers.

Detailed discussions led to the following conclusions and recommendations:

1. Applying K fertilizers improves both yield and quality of sugarcane, cotton, horticultural and vegetable crops, and increases the shelf life of fruits and vegetables which promotes export of agricultural produce.
2. To promote K fertilizer use on sugarcane, the purchase of sugarcane needs to be based on the quality of the crop.
3. Crop ecological regions with clay mineralogical information should be delineated for the precise, crop responsive potash recommendations.
4. A consortium – comprising agriculture extension workers, researchers, universities and fertilizer marketing companies, including IPI – should be created to develop research and developmental programs for K use in Pakistan.
5. The Pakistan government should be provided with empirical evidence that clearly demonstrates how the use of potash will improve the productivity and quality of crops, to encourage them to subsidize K fertilizer.

This report also appears on the IPI website at:

Regional activities/WANA

Events

IPI Events

September 2014

1st IPI-Ministry of Agriculture-Ethiopian ATA joint Symposium on "The Role of Potassium in Cropping Systems of sub-Saharan Africa: Current Status and Potential for Increasing Productivity", Addis Ababa, Ethiopia, 4-5 September 2014

Report by Hillel Magen, IPI Director

The 1st Potash Symposium jointly organized by the International Potash Institute (IPI), Ministry of Agriculture, Ethiopia (MOA) and the Ethiopian Agriculture Transformation Agency (ATA) was held in Addis Ababa during 4-5 September, 2014. More than 25 papers were presented during the first two days with more than 80 scientists, extension officers, officials and private farmers attending the event. A field trip to visit demonstration plots near the city of Debre Birhan was also held on the 6th September.

The symposium ceremony began with Prof. Tekalign Mamo, Minister's Advisor and State Minister's welcome address; Mr. Tesfay Mengiste, Director General of Extension at the Ministry gave the official opening speech on behalf of H.E. Ato Tefera Derbew, Minister of Agriculture, Ethiopia. This was followed by a key note speech by Mr. Khalid Bomba, CEO Ethiopian Agricultural Transformation Agency (ATA). Mr. Serkalem Adigeh, Embassy of Israel, addressed the audience with greetings on behalf of the Ambassador, Ms. Belaynesh Zevadia, and Mr. Hillel Magen, Director IPI delivered a speech on the role of fertilizers in improving food security.

The five sessions of the symposium included papers describing the development and challenges of agriculture in East Africa and, in particular, the fertilizer sector in Ethiopia. The Ethiopian soil mapping project, potassium (K) in soil and plant systems, experiments with

Photo 1 (top). Group photo of participants at the 1st IPI-Ministry of Agriculture-Ethiopian ATA joint Symposium, Addis Ababa, Ethiopia, 4-5 September 2014.

Photo 2 (bottom). Panel session chaired by Prof. Tekalign Mamo, MOA, Ethiopia (second from left) and other panel members, Dr. Uri Yermiyahu, ARO, Israel (left), Dr. Jeoren Huising, IITA, Nigeria (middle), Mr. Hillel Magen, IPI, Switzerland (second from right) and Dr. Kibebew Kibret, Haramaya University, Ethiopia (right). Photos by E. Sokolowski.

potash fertilization in the country and other countries of East Africa were also presented along with various aspects of soil analysis and fertilizer recommendations for the continent.

Major issues emerged from the papers and the active discussions that took place:

- During recent years, Ethiopia has significantly increased its food production. However, with additional improved practices, productivity could be substantially raised further.
- While there is existing policy for micro-credit to farmers in place, additional credit to farmers may play a significant role in improving crop productivity in Ethiopia.
- There is an efficient supply chain for fertilizers in Ethiopia.
- The livestock sector will play a much more important role in future agricultural productivity.
- Identifying appropriate cropping systems (e.g. inclusion of legumes), increased cropping intensity and improved nutrient management practices would improve productivity in many East African countries.
- More dedicated research on the nutrient demand and fertilization practices are needed for Ethiopia's unique crops (e.g. teff, coffee, enset).
- Ethiopian Soil Information System (EthioSIS) provides detailed soil fertility mapping which allows follow-up by agronomists and fertilizer suppliers to meet the site specific nutrient requirements in many parts of the country. However, cropping systems are not part of this work and their inclusion will add much value to consolidating fertilizer recommendations.
- Hundreds of demo plots, mostly in Tigray, Amhara, Oromia and SNNPS states complement the data obtained from EthioSIS soil mapping.
- Exchangeable K analysis carried out extensively by EthioSIS would benefit from additional K-intensity analysis.
- Multi-nutrients deficiency - not just N, P and K - occur in many East African countries, which highlights the need for dedicated 'balanced fertilization' programs.
- Managed balanced fertilization practices may bring very high agronomic efficiencies to K application (>20 kg/kg).
- Spectral soil analysis provides a tool to improve fertilizer recommendations; more work is needed to establish recommended levels of K in plants.
- Capacity building along the fertilizer value chain is urgently needed.

In his concluding remarks, Prof. Tekalign Mamo called for a further event in 2015 to enable follow up and provide guidelines for additional research and dissemination activities.

This report also appears on the IPI website at:

Regional activities/sub-Saharan Africa

Events (cont.)

International Symposia and Conferences

October 2014

XVII Congreso Colombiano de la Ciencia del Suelo, 8-11 October 2014, Popayán, Cauca, Colombia. See more on the congress website.

3rd Palm Oil AFRICA, 13-14 October 2014, Labadi Beach Hotel, Accra, Ghana. See more on the event website.

XXXIX Congreso Nacional de la Ciencia del Suelo, 19-24 October 2014, Ciudad Juárez, Chihuahua, Mexico. For more details contact the Organizing Committee at Congresosmcs2014@uacj.mx.

16th World Fertilizer Congress of CIEC, 20-24 October 2014, Rio de Janeiro-RJ, Brazil. See more on the congress website.

4th International Rice Congress (IRC2014), 27 October - 1 November 2014, Bangkok International Trade and Exhibition Centre (BITEC), Bangkok, Thailand. See more on the IRC2014 website.

November 2014

2nd International Symposium on Magnesium in Crop Production, Food Quality and Human Health, 4-6 November 2014, Hotel Bourbon Convention Ibirapuera, Avenida Ibirapuera, 2927, São Paulo/SP, Brazil. See more on the conference website.

XX Congreso Latinoamericano de la Ciencia del Suelo, 9-15 November 2014, Cusco, Peru. See more on the congress website.

China Fertilizer & Innovation Summit 2014, 20-21 November 2014, Shanghai, China. See more on the summit website.

December 2014

Challenges for Crop Production and Quality - Annals of Applied Biology Centenary conference, 9-10 December 2014, Rothamsted Research, Harpenden, Herts, UK. See more on the conference website.

January 2015

14th ISSPA International Symposium for Soil and Plant Analysis, 26-30 January 2015, Kona Beach, Hawaii. See more on the ISSPA 2015 website.

March 2015

Biocontrol Asia 2015 Conference, 17-18 March 2015, Taj Palace Hotel, New Delhi, India. See more on the New Ag International website.

April 2015

3rd Global Soil Week 2015, 19-23 April 2015, Berlin, Germany. See more on the Global Soil Week website.

13th New Ag International Conference & Exhibition, 18-20 March 2015, Taj Palace Hotel, New Delhi, India. See more on the New Ag International website.

July 2015

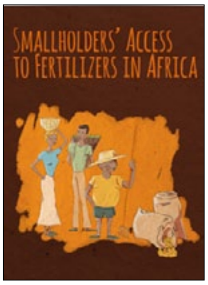
10th European Conference on Precision Agriculture, 12-16 July 2015, Volcani Center, Tel-Aviv, Israel. See more on the conference website.

October 2015

9th Symposium for the International Society of Root Research "Roots Down Under", 6-9 October 2015, Hotel Realm Canberra, Canberra, Australia. See more on the symposium website.

Publications

Smallholders' Access to Fertilizers in Africa



This is a new campaign by IFA and its partners in conjunction with the FAO 2014 International Year of Family Farming and the African Union 2014 Year of Agriculture.

The following organizations are building access to fertilizers for family farms in Africa:

- African Fertilizer and Agribusiness Partnership (AFAP)
- Alliance for a Green Revolution in Africa (AGRA)
- CNFA
- International Fertilizer Development Center (IFDC)
- International Fertilizer Industry Association (IFA)
- International Institute for Tropical Agriculture (IITA)
- International Plant Nutrition Institute (IPNI)
- International Potash Institute (IPI)
- One Acre Found (OAF)

The brochure can be downloaded from the Smallholders' Access to Fertilizers Homepage.

Scientific Abstracts

in the Literature

Follow us on Twitter on: https://twitter.com/IPI_potash
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High-Yield Maize Production in Relation to Potassium Uptake Requirements in China

Liangquan Wu, Zhenling Cui, Xinping Chen, Rongfang Zhao, Dongxia Si, Yixiang Sun, and Shanchao Yue. 2014. Agron. J. 106(4):1153-1158. DOI 10.2134/agronj13.0538.

Abstract: Understanding maize (*Zea mays* L.) grain yield in relation to K uptake requirements is essential for devising optimized K fertilizer management practices and agricultural policies to increase grain yield for food security. A database comprising 953 measurements was created using 56 on-farm and research station experiments during 2000 to 2012 in the North China Plain (NCP) to determine K uptake requirements and patterns of K accumulation pre- and post-silking with different yield levels. The K requirement Mg^{-1} grain yield ($K_{req.}$) in the K = Opt. treatment was 15.0 kg, which was lower than 20.0 kg in the K > Opt. treatment. In the Optimal K treatment, average Kreq. values were 15.0, 14.8, 14.8, and 15.7 kg for grain yields ranging from <8.0, 8 to 10, 10 to 12, and >12.0 Mg ha^{-1}, respectively. The relative consistency of $K_{req.}$ values with increasing grain yield was mainly attributed to an offset in the increase in stover K (from 14.0 to 18.1 g kg^{-1}), an increase in harvest index (HI) from 0.49 to 0.54, and the stability of grain K concentrations (about 3.2 g kg^{-1}). Higher percentages for K accumulation at the post-silking stage were observed with >12 Mg ha^{-1} (24%) and 10 to 12 Mg ha^{-1} (22%) compared to <10 Mg ha^{-1} (9%). In conclusion, maintaining adequate K supply and post-silking K accumulation is essential for achieving high-yield maize production.

Potassium Fertilization - An Effective Mitigator of Unused Nitrogen in Forage Sorghum

Khanum Al Akbari, W.M., and S. Umar. 2014. J. Plant Biochem. Physiol. 2014, 2:2. DOI 10.4172/2329-9029.1000126.

Abstract: Forages tend to accumulate elevated levels of nitrate when fields are heavily fertilized with nitrogenous fertilizers or are environmentally stressed due to drought, cold, frost, hail, etc. Elevated levels of nitrate have detrimental effects on animal health and are regarded as a causative factor for several mass cattle-death incidents. It was observed that nitrate concentration in *Sorghum bicolor* L. obtained from local fields of Uttar Pradesh (Ghaziabad and Meerut) and Haryana (Gurgaon and Faridabad) exceeded the safe limit (2,500 mg of nitrate kg^{-1} of fresh wt.) in a significant number of samples (31.7%) studied. Given this, the investigation was conducted in earthen pots to determine nitrate contents in 16 genotypes of *S. bicolor* L. A significant difference in nitrate content was observed among genotypes, many of which accumulated nitrate to toxic levels. POP-52 (V9), a high nitrate reductase (HNR) genotype and EB-15 (V7), a low nitrate reductase (LNR) genotype of sorghum were selected to study the effect of potassium (K) application on nitrate accumulation in specially designed PVC-drums. The minimum nitrate concentration (V9=816.6 mg/kg fresh wt. and V7=2691.8 mg/kg fresh wt.), coupled with maximum NR activity (V9=9.916 µmol NO_2^{-1} h^{-1} g^{-1} fresh wt. and V7=5.018 µmol NO_2^{-1} h^{-1} g^{-1} fresh wt.) were observed in 60 day old K60 treated plants. K application reduced the nitrate concentration by 35.24% in V9 and by 25.54% in V7 genotypes by increasing nitrate reductase (NR) activity by 86.23% in V9 and lesser increase of 32.07% in V7 genotype of sorghum at 30 days. A two-fold (approx.) decrease in nitrate concentration was observed at K60 in both genotypes from 30 to 60-days-after-sowing. K application also reduced considerably the nitrate in the leachate indicating that K is effective in mitigating nitrate pollution in plants and soil. The data emphasizes the importance of K in increasing the nitrogen use efficiency and of balanced fertilization in combating the nitrate-related implications on human beings, animals and environment.

Potassium Fertiliser Enhances the Salt-Tolerance of Common Bean (*Phaseolus vulgaris* L.)

Dawood, M.G., M.T. Abdelhamid, and U. Schmidhalter. 2014. J. Horticultural Science & Biotechnology 89(2):185-192.

Abstract: Sodium chloride (NaCl) is the most abundant salt that contributes to soil salinity. The response of plants to excess NaCl is complex, involving changes in their morphology, physiology, and metabolism. Potassium (K) is not only an essential macronutrient for plant growth and productivity, but it is also a primary osmoticum for maintaining the low water potential of plant tissues. A pot experiment was conducted in the wire-house of the National Research Centre, Cairo, Egypt, during the 2010-2011 season, to examine the potential role of K fertiliser in alleviating the deleterious effects of NaCl-salinity on some physiological and biochemical traits of two recombinant inbred lines (RILs) of common bean (*Phaseolus vulgaris* L.; RIL 147 and RIL 115).The results showed that salinity levels of 25 mM (S1) and 50 mM NaCl (S2) caused significant decreases in the numbers of pods per plant, the fresh weight (FW) and dry weight (DW) of pods per plant, shoot DW per plant, as well as in the level of photosynthetic pigments, compared to plants irrigated with tap water (S0). A dose of 150 mg K_2O kg^{-1} soil (K2) mitigated these harmful effects of salinity on common bean yield and on the content of photosynthetic pigments. Both salinity levels (S1

and S2) and treatment K2 caused significant increases in proline, free amino acid, and soluble carbohydrate concentrations, as well as peroxidase and polyphenol oxidase activities, relative to the corresponding control plants. In contrast, both RILs show a decrease in their phenolic compound concentrations due to salinity and/or the application of K2 compared to control plants (i.e., treatment S0K1; where K1 = 25 mg K_2O kg^{-1} soil). The K^+:Na^+ ion ratio decreased significantly as the salinity level increased, and increased significantly under treatment K2. We conclude that treatment K2 mitigated the adverse effects of salinity (NaCl) through the effect of K^+ ions enhancing the levels of photosynthetic pigments, anti-oxidant enzyme activities, osmoprotectant concentrations, and the K^+:Na ion ratio, all of which were reflected in an improvement in plant performance.

Effect of Potassium Application on Wheat (*Triticum aestivum* L. Cultivars Grown Under Salinity Stress

Safaa R. El-Lethy, S.R., M.T. Abdelhamid, and F. Reda. 2013. World Applied Sciences Journal 26(7):840-850. DOI 10.5829/idosi.wasj.2013.26.07.13527.

Abstract: Effect of potassium application on wheat plants (two cultivars), one sensitive (Gemiza 9) and the other cv. tolerant (Sakha 93) grown under salinity stress was studied. A pot experiment were carried out during two successive winter seasons (2009/2010 and 2010/2011) under greenhouse conditions at the National Research Centre, Dokki, Giza, Egypt. The treatments used were: irrigated with (tap water), 40, 80 and 120 mM NaCl and two levels of potassium fertilizers (25 and 150 mg K_2O/kg soil) in the form of potassium sulfate (48-50% K_2O) were added to soil. When plants age reached 65 days, samples were drawn for vegetative growth criteria, photosynthetic pigments (chlorophyll (a), (b) and carotenoids). Polyphenoloxidase (PPO), peroxidase (POX) and superoxide dismutase (SOD). Soluble sugar, starch and total phenols, macro elements and Na^+ as well as yield were determined. The results showed that NaCl-stress triggered significant inhibitory effects on wheat plant growth, photosynthetic pigments especially for sensitive cv. Application of 150 mg K_2O fertilizer to the soil exerted certain alleviative effects on these indices in wheat cultivars, especially tolerant one (Sakha 93). Activities of the enzymes Polyphenoloxidase (PPO), peroxidase (POX), superoxide dismutase (SOD) and soluble sugar and total phenols were significantly increased by salinity at 80 and 120 and K application at level 150 mg K_2O/kg soil. Potassium application could play an important role in alleviation of injury of wheat irrigated with salinized water depend on the level of salinity. The yield of both cultivars significantly decreased as the level of salinity increased. Potassium fertilizer level of 150 mg K_2O/kg soil was effective in lessening the harmful effect of salinity, especially at lower levels on yield.

Exogenous Application of Proline Alleviates Salt-Induced Oxidative Stress in *Phaseolus vulgaris* L. Plants

Abdelhamid, M.T., M.M. Rady, A. SH. Osman, and M.A. Abdalla. 2013. J. Horticultural Science & Biotechnology 88(4):439-446.

Abstract: Two field experiments on common bean (*Phaseolus vulgaris* L.) plants were conducted at three sites having different levels of salinity (EC = 1.84, 6.03, or 8.97 dS m^{-1}) and considered to be low, moderate, or highly saline soil, respectively. The aim was to examine the effects of three successive exogenous applications of 5.0 mM proline, applied as foliar sprays at 20, 30, and 40 d after sowing (DAS) to each plant at each site. Bean plants were sampled 50 DAS and the effects of the proline sprays on various growth parameters, levels of photosynthetic pigments, endogenous proline, ascorbic acid, nitrate, nitrite, and mineral nutrient (P, K, Na) concentrations, and anti-oxidant enzyme activities were measured in order to understand the mechanism(s) of salt tolerance in proline-treated bean plants. Exogenous applications of 5 mM proline alleviated oxidative stress and enhanced the growth of all treated common bean plants. Proline also increased the activities of the anti-oxidant enzymes, superoxide dismutase (SOD), catalase (CAT), and peroxidase (POD), as well as the concentrations of carotenoids, ascorbic acid, and endogenous proline. Spray applications of proline increased the concentrations of P and K^+, and decreased Na^+ ion concentrations, in salt-affected plants. Thus, the K^+:Na^+ ratio increased. Based on these findings, we recommend the use of proline as a commercial formulation to enhance plant growth and production in common bean plants grown under saline conditions.

Potassium Mobilization and Transformation in Red Paddy Soil as Affected by Rice

Xiaokun Li, Liping Zhan, Jianwei Lu, Zhiwen Liao, Jifu Li, Tao Ren and Rihuan Cong. 2014. Agron. J. 106(3):1011-1017. DOI 10.2134/agronj13.0347.

Abstract: A rhizobox experiment was conducted to study the effect of growing rice (*Oryza sativa* L.) on the movement and transformation of K in a red paddy soil. Results showed that K uptake by rice reduced the concentrations of soil water-soluble K (Sol-K), exchangeable K (Ex-K), and non-exchangeable K (Nonex-K) in the root zone. Soil Sol-K in non-root-zone compartment close to the root zone (0-6 cm) migrated toward the root zone, and soil Ex-K (0-4 cm) and soil Nonex-K (0-3 cm) was released into soil solution. As the rice growth progressed, soil Sol-K, Ex-K, and Nonex-K in the root zone and soil Sol-K in non-root-zone compartment close to the root zone (0-6 cm) continued to decrease. Decreases of soil Ex-K and Nonex-K in non-root-zone compartment extended from the root to 6 and 5 cm into the bulk soil, respectively. At the late grain-filling stage, soil Sol-K

concentration in the root zone and non-root-zone compartment (0-6 cm) declined, and then remained stable, whereas Sol-K in the non-root zone (6-7 cm) kept diffusing toward the root zone. Soil Ex-K and Nonex-K in the root zone and non-root-zone compartment continued to reduce, and the decrease distance of soil Nonex-K was extended to 6 cm. Within the whole season, soil Ex-K and Nonex-K were the main forms of K available to the plants, followed by Sol-K. The information obtained in this study indicated that K fertilizer should be added to the place around the root zone.

Phosphorus and Potassium Distribution and Adsorption on Two Florida Sandy Soils

Kadyampakeni, D.M., K.T. Morgan, K. Mahmoud, A. Schumann, and P. Nkedi-Kizza. 2014. Soil Sci. Soc. Amer. J. 78(1):325-334. DOI 10.2136/sssaj2013.07.0259.

Abstract: Phosphorus and K are critical nutrients in citrus production whose deficiency or excess can affect yield, fruit quality, and water quality. However, no study has been conducted to understand the nutrient distribution in the root zone using intensive fertigation practices in Florida's sandy soils. Thus, experiments were conducted to: (i) compare the performance of intensively managed drip and microsprinkler fertigation systems with conventional grower practices; and (ii) determine P and K adsorption based on recommended fertilizer application rates on Candler (hyperthermic, uncoated Lamellic Quartzipsamments) and Immokalee (sandy, siliceous, hyperthermic Arenic Alaquods) fine sands. Phosphorus and K were applied and tracked with time and distance from point of application. Soil P on Immokalee soil was 27 to 163% higher in the irrigated zone for drip and restricted microsprinkler fertigation than the unirrigated zone and up to 70% greater in the 0 to 15 cm depth of the irrigated zone than conventional microsprinkler practices. Soil K was 5 to 61% greater in the upper 0 to 15 cm of the irrigated zone with drip and microsprinkler fertigation than conventional microsprinkler practices on Immokalee fine sand. Soil P and K on Candler also differed by fertilization method, depth, and between irrigated and unirrigated zones. The linearized P sorption coefficients for Candler were three- to fourfold greater than the corresponding depths for Immokalee, while sorption coefficients for K were similar for the two soils. It is unlikely that P or K would present a water quality concern as strictly related to irrigation practice. The P application rate for Candler should be lowered for young trees (<3 yr old).

Residual Effects of Potassium to Cotton on Corn Productivity under No-Tillage

Guisu Zhou, Xinhua Yin, and David A. Verbree. 2014. Agron. J. 106(3):893-903. DOI 10.2134/agronj13.0389.

Abstract: The long-term residual effects of K applications to preceding cotton (*Gossypium hirsutum* L.) on subsequent corn (*Zea mays* L.) is largely unknown under no-tillage. A cotton field experiment was conducted on a no-tilled Loring silt loam (fine-silty, mixed, active, thermic Oxyaquic Fragiudalf) at Jackson, TN, during 1995 to 2008 with the K treatments of 0, 28, 56, 84, 112, 140, and 168 kg ha^{-1} applied to the same plots each year. From 2009 through 2011, corn was no-till planted on the previous cotton trial without further K fertilization. Incremental gains in corn leaf K responses were consistent with increases in the K application rate for previous cotton. A significant quadratic relationship was observed between corn yields and K application rates in 2010 and 2011 with corn yield peaking at the K rate of 94 kg ha^{-1} in 2010 and 84 kg ha^{-1} in 2011. Potassium removal by grain ranged from 2.54 to 3.55 kg K Mg^{-1} of grain yield. For the 28 kg K ha^{-1} rate and those higher K rates, soil K buffering capacity followed an exponential decline as the initial soil test K level increased. Surface broadcasting of K fertilizer at the recommended rate of 56 kg K ha^{-1} or above to preceding cotton for 14 yr and relying on the residual K fertilizer for the subsequent corn for at least 3 yr without further K fertilization might be a viable K management practice on high K fields under no-tillage.

Mineral Micronutrient Content of Cultivars of Field Pea, Chickpea, Common Bean, and Lentil Grown in Saskatchewan, Canada

Ray, H., K. Bett, B. Tar'an, A. Vandenberg, D. Thavarajah, and T. Warkentin. 2014. Crop Sci. 54(4):1698-1708. DOI 10.2135/cropsci2013.08.0568.

Abstract: The mineral content of pulses grown in Saskatchewan, Canada, was examined for magnesium, potassium, iron, zinc, manganese, copper, selenium, and in some cases nickel and calcium. Eight to 18 cultivars of each of field pea (*Pisum sativum*), common bean (*Phaseolus vulgaris*), chickpea (*Cicer arietinum*), and lentil (*Lens culinaris*) were grown at several locations in southern Saskatchewan in 2005 and 2006 in randomized complete block designs with three replicates. Mineral content was examined by atomic absorption spectrometry. The pulses were found to contain significant proportions of the recommended daily allowance (RDA) for all the tested minerals except calcium. In many cases a 100 g (dry weight) portion of the crop provided over 50% of the RDA. For selenium, pulses grown in some locations provided 100% of the RDA. The effect of location was highly significant in most instances, while that of year and cultivar were

generally less so. Pairwise differences among cultivars were examined by Tukey's test. Where possible, crops grown side by side were compared.

Drought Resistance of Warm-Season Putting Green Cultivars on U.S. Golf Association Root Zones with Varied Potassium

Rowland, J.H., J.L. Cisar, G.H. Snyder, J.B. Sartain, A.L. Wright, and J.E. Erickson. 2014. Agron. J. 106(5):1549-1558. DOI 10.2134/agronj14.0019.

Abstract: Drought resistance of putting green cultivars is receiving increased attention due to irrigation restrictions. Potassium, which reduces turfgrass tolerance to environmental stresses when deficient, is often applied at rates equal to or greater than N in an attempt to increase its efficacy. Drought resistance for recently established 'TifDwarf' (TD) and 'TifEagle' (TE) bermudagrasses [*Cynodon dactylon* (L.) Pers. × *C. transvaalensis* Burt Davy], 'SeaDwarf' (SD) seashore paspalum (*Paspalum vaginatum* Swartz), and 'PristineFlora' (PF) zoysiagrass [*Zoysia japonica* Stued. by *Zoysia tenuifolia* (L.) Merr.] was evaluated under varied irrigation and K levels on a U.S. Golf Association (USGA)-specified research green. Irrigation treatments were applied in the spring and fall of 2009 and spring 2010, and included 25, 50, and 100% of potential evapotranspiration (ETo), as calculated using the Blaney–Criddle equation. Nitrogen at 4.9 g m^{-2} 30 d^{-1} and K (as KCl) in 1N:1K, 1N:2K, 1N:3K, and 1N:4K fertilization ratios were applied at the beginning of each experiment. All cultivars had objectionable wilting (>10%) at 25% ETo in 2009, although PF and SD had least in the fall. In 2010 PF and SD did not exhibit objectionable wilting at any irrigation level. At 50% ETo, TD and TE wilted objectionably in all experiments, as did PF in the fall of 2009. In 2010, the bermudagrasses exhibited objectionable wilting under daily irrigation at 100% ETo. Increasing K in relation to N failed to increase drought resistance for the cultivars studied. The bermudagrasses had the least drought resistance and PF and SD the most.

Farmers' Use of Nutrient Management: Lessons from Watershed Case Studies

Osmond, D.L., D.L.K. Hoag, A.E. Luloff, D.W. Meals, and K. Neas. 2014. J. Environ. Qual. DOI 10.2134/jeq2014.02.0091.

Abstract: Nutrient enrichment of water resources has degraded coastal waters throughout the world, including in the United States (e.g., Chesapeake Bay, Gulf of Mexico, and Neuse Estuary). Agricultural nonpoint sources have significant impacts on water resources. As a result, nutrient management planning is the primary tool recommended to reduce nutrient losses from agricultural fields. Its effectiveness requires nutrient management plans be used by farmers. There is little literature describing nutrient management decision-making. Here, two case studies are described that address this gap: (i) a synthesis of the National Institute of Food and Agriculture, the Conservation Effects Assessment Project, and (ii) field surveys from three nutrient-impaired river basins/watersheds in North Carolina (Neuse, Tar-Pamlico, and Jordan Lake drainage areas). Results indicate farmers generally did not fully apply nutrient management plans or follow basic soil test recommendations even when they had them. Farmers were found to be hesitant to apply N at university-recommended rates because they did not trust the recommendations, viewed abundant N as insurance, or used recommendations made by fertilizer dealers. Exceptions were noted when watershed education, technical support, and funding resources focused on nutrient management that included easing management demands, actively and consistently working directly with a small group of farmers, and providing significant resource allocations to fund agency personnel and cost-share funds to farmers. Without better dialogue with farmers and meaningful investment in strategies that reward farmers for taking what they perceive as risks relative to nutrient reduction, little progress in true adoption of nutrient management will be made.

Effects of Long-Term Fertilization on Soil Carbon and Nitrogen in Chinese Mollisols

Xiaoguang Jiao, Chongsheng Gao, Yueyu Sui, Guohong Lü, and Dan Wei. 2014. Agron. J. 106(3):1018-1024. DOI 10.2134/agronj13.0233.

Abstract: Three field experiments were conducted to examine the influence of long-term (30-31 yr) effect of fertilizer applications on soil C and N in the mollisols of Northeast China. Each experiment represented a different latitude range: low latitude (LatL), middle latitude (LatM) and high latitude (LatH). Four types of fertilizer applications were considered: (i) CK: unfertilized (control); (ii) NPK: balanced application of inorganic fertilizer nitrogen, phosphorus, potassium; (iii) M: application of organic manure; and (iv) NPKM: fertilizer nitrogen, phosphorus, potassium, plus organic manure. Compared with CK treatments, applications of fertilizers increased soil organic carbon (SOC), total nitrogen (TN), available nitrogen (AN), microbial biomass carbon (Cmic) and microbial biomass nitrogen (Nmic). On average compared with CK treatments, SOC in the NPK, M, and NPKM treatments increased by 2.74, 22.00, and 27.81%, respectively. Thus, applications of organic manure combined with inorganic fertilizers showed greater effects on the topsoil C and N content than inorganic fertilizers. Under the same fertilizer treatments, SOC, TN, Nmic, and Cmic contents were the lowest at LatM site. Available N content decreased for a latitude sequence of LatH > LatM > LatL for CK, M, and NPKM treatments and LatM > LatH > LatL for the NPK treatments. These results indicate that the magnitude of soil C and N among the three sites was not related to the latitude of the experiments.

Recommended Nutrient Management Practices in the Carbon Sequestration Potential of Cassava (Two Decades Experience from a Long-Term Fertiliser Experiment)

K. Susan John, V. Ravi, S.U. Shanida Beegum, C.S. Ravindran, M. Minikantan Nair, and J. George. 2014. Indian J. Fert. 10(4):28-33.

Abstract: Increasing CO_2 concentration in the atmosphere is considered as the predominant cause of global warming. Agricultural ecosystem has the greatest potential to sequester atmospheric CO_2 into the soil to mitigate global warming. Nutrient management practices involving crop residue and application of recommended fertilisers are viable options to acquire atmospheric CO_2. Cassava is considered as the future food security crop as regards to its biological efficiency coupled with ability to sustain under changing climate especially during drought (by shedding leaves) and to grow well in marginal soils. In this paper, a comparison between Recommended Fertiliser Practice (RFP) and an Absolute Control (AC) with respect to soil organic carbon (SOC) dynamics through leaf dry matter addition is analysed over a period of 20 years (1991-2012). The results obtained from a Long-Term Fertiliser Experiment (LTFE) under Cassava at CTCRI to highlight the C sequestering efficiency of Cassava and thereby global warming. During the first year (1991), the leaf dry matter production was 2.366 t ha^{-1} in RFP equivalent to 0.475 µg g^{-1} leaf carbon, for which 39.985 µg g^{-1} of atmospheric CO_2 was absorbed reducing its concentration to 320.015 µg g^{-1} from 360 µg g^{-1} and the then SOC status was 0.8% only. After 20 years of continuous application of recommended fertilisers, in 2012, the leaf dry matter production was increased to 5.245 t ha^{-1} equivalent to 1.053 µg g^{-1} leaf C. To produce this, the utilization of atmospheric CO_2 was 88.64 µg g^{-1}, reducing the atmospheric CO_2 status to 304.36 µg g^{-1}. Atmospheric CO_2 acquired by Cassava leaves transformed into leaf C, on leaf shedding has resulted in a concomitant increase in SOC to 0.512% by 20 years indicating the potential of Cassava to sequester atmospheric CO_2 to SOC. In the absolute control, the CO_2 acquisition and concomitant increase in SOC ranged from 25-50% of RFP only. The ultimate effect of sequestering the atmospheric CO_2 by reduction in atmospheric CO_2 and increase in SOC was manifested as increase in tuber yield to the tune of 32.13 t ha^{-1} during 2012 from 17.76 t ha^{-1} in 1991. Hence, it can be inferred that Cassava under recommended fertiliser management practices can sequester atmospheric CO_2 into SOC and mitigate global warming to a great extend.

Potassium Nutrition and Management in Indian Agriculture Issues and Strategies

Ch. Srinivasa Rao, Sharan Bhoopal Reddy, and Sumanta Kundu. 2014. Indian J. Fert. 10(5):58-80.

Abstract: Growing population in India demands more food in near future and continues further. This pressurises Indian agriculture to produce more from shrinking arable land. Balanced nutrition plays a key role in augmenting crop production. Potassium, one of the most important macronutrient, has greater influence on plant physiology and sturdiness for stress conditions. But, low status of K in Indian soils resulted from exclusion of K in balanced nutrition lead to mining of soil reserve K. Soil K status depends on soil mineralogy, fertilizer K application and through other K sources (organic manures, tank silt, irrigation water etc.). Therefore, while interpreting soil K status, non-exchangeable K is to be considered. Hence, this paper deals with categorization of soils both district wise and agro-ecological region wise for exchangeable and non-exchangeable K. Based on this crop recommendations were made and crop response also studied. Positive results were observed in different crops and cropping systems across agro-ecological regions. This further supports the inclusion of non-exchangeable K in soil K fertility interpretation and recommendation for crops based on categories of both exchangeable and non-exchangeable K.

Site-Specific Nutrient Management (SSNM) in Thailand

Attaya Phinchongsakuldit. 2012. FFTC Technical Bulletin 193.

Abstract: A site-specific nutrient management (SSNM) research project was started in Thailand in 1997 by Professor Dr. Tasnee Attanandana and colleagues. The project focused on a low-cost technology with high efficiency and the protocols that can easily be followed by farmers. Soil classification was prepared in a simple way so that Thai farmers can identify their own soil. A soil test kit has been invented which allows farmers to analyze soil nutrients (NPK) by themselves. DSSAT and PDSS models were used to generate nitrogen (N) and phosphorus (P) requirements, and a specific model for potassium (K) requirement was developed. Nutrient requirement data from crop modeling was processed by simple formulas to generate fertilizer recommendation that provides the highest return under specific conditions. After the experimental trials, the project led to the steps of technology transferring and programming of SSNM for maize (SimCorn) in 2001. After the success of SSNM for maize, in 2005, the project expanded into SSNM for rice (SimRice) and sugarcane (SimCane). During this time, the project emphasized the independency of farmers. In 2008, the Land Development Department generated the Onfarm program following the policy of the Ministry of Agriculture and Cooperatives. The Onfarm

program used the data from the SSNM projects together with the fertilizer recommendation based on soil test by the Department of Agriculture. As a result, the Onfarm program recommended fertilizers for major crops in Thailand. At present, a new research team is conducting the SSNM for chili.

Effective Fertilizer Management Practises for High Yield Rice Production of Granary areas in Malaysia

Abd Razak, H., O. Suhaimi, and M. Theeba. 2012. FFTC Technical Bulletin 194.

Abstract: High yield targets in modern rice farming should be supported by effective and efficient fertilizer management practices. Over-dependence on blanket subsidy fertilizer recommendation is unable to produce high yield. Site-specific balanced fertilizer recommendation option by FERTO package is able to enhance crop performance, subsequently achieving high yield target. The significant yield increment (up to 300%) using FERTO package recommendation is accomplished because due consideration is given to four basic principles of fertilizer management, i.e. nutrient quantity, nutrient access, indigenous soil fertility status, and balanced crop requirement. Site-specific approach of the FERTO package recommendation is complex. Therefore, FERTO package recommendation is more applicable to large-scale commercialized rice production. Thus, for policy formulation, FERTO package recommendation has to be transformed into formulation according to cropping zones. Development of fertilizer formulation according to cropping zone is more practical and can easily be managed by fertilizer suppliers and rice estate managers. The formulation can also be adopted by progressive small-scale farmers. Fourteen fertilizer formulations for specific management zones within the granary areas were identified in this study. The formulation is able to enrich proportionate vegetative and reproductive growth for high rice-yield performance. However, the application of FERTO package recommendation rate can be further enhanced by using straight fertilizers in place of the present subsidy mixture or compound fertilizers. These straight fertilizers are much cheaper compared to the mixture or compound fertilizers in the market. Therefore, the adoptions of FERTO package using straight fertilizers will reduce cost of production and ultimately increase net farm returns.

Read on

The Physiology of Channel-Mediated K^+ Acquisition in Roots of Higher Plants

Coskun, D. *et al.* 2014. Physiologia Plantarum 151:305-312.

Regulation of Potassium Transport in Plants under Hostile Conditions: Implications for Abiotic and Biotic Stress Tolerance

Shabalaa, S., and I. Pottosina. 2014. Physiologia Plantarum 151:257-279.

Rootstock Effect on Nutrient Concentration of Sweet Cherry Leaves

Hrotkó, K. *et al.* 2014. J. Plant Nutr. 37:1395-1409. DOI: 10.1080/01904167.2014.911317.

Global Plans of Action Endorsed to Halt the Escalating Degradation of Soils - Sustainable soil management is essential for healthy soils and ecosystems

FAO News Article, 24 July 2014, Rome.

Shining the Light on Family Farmers in Achieving Sustainable Development

FAO News, 30 June 2014.

Leverage Points for Improving Global Food Security and the Environment

West, P.C. *et al.* 2014. Science 345(6194):325-328. DOI 10.1126/science.1246067.

OECD-FAO Agricultural Outlook 2014-2023

in a special focus on India. See OECD website.

Global Metaanalysis of the Nonlinear Response of Soil Nitrous Oxide (N_2O) Emissions to Fertilizer Nitrogen

Shcherbak, I. *et al.* PNAS 111(25):9199-9204. DOI 10.1073/pnas.1322434111.

FAO Statistical Yearbook 2014: Latin America and the Caribbean Food and Agriculture.

FAO. 2014.

The Parched Planet: Water on Tap

Researchers are exploring unconventional sources of fresh water to quench the globe's growing thirst.

Schiermeier, Q. 2014. Nature 510:326-328. DOI 10.1038/510326a.

GM Maize Splits Mexico

Legal challenge to transgenic crops has created a rift in the country's scientific community.
Vargas-Parada, L. 2014. Nature 511:16-17. DOI 10.1038/511016a.

How to Optimize Global Food Production

2014. Food Security. Science 345(6194):280. DOI 10.1126/science.345.6194.280-f.

Darwin Who?

2014. History of Science. Science 345(6194):260. DOI 10.1126/science.1255865.

Senator, Nutrition Experts Support Research on Healthier Rice

Hon. Cynthia A. Villar. IRRI.

Clipboard

Pakistan: Potassium Fertilization and Perspectives of K Research by IPI in the Country

(see Video)

Dr. Abdul Wakeel, Assistant Professor at the Institute of Soil and Environmental Sciences, University of Agriculture, Faisalabad and IPI Consultant in Pakistan, speaks on "Potassium fertilization and perspectives of K research by IPI in the country".

Dr. Wakeel was invited to speak on 'Agri Talk', a program for farmers and the agricultural industry on a national TV channel in Pakistan (1 July 2014, 42 minutes, in Urdu and English, interviewed by Mr. Saeed Mughal).

Watch the video on the IPI video archive at http://www.ipipotash.org/en/videos.php or at http://www.suchtv.pk/program/agri-talk/item/12274-agri-talk-01-07-2014.html.

Obituary for Professor Volker Römheld (1941–2013)

Nikolic, M., E.A. Kirkby, and I. Cakmak. 2014. Plant and Soil. DOI 10.1007/s11104-014-2185-7.

This is an excerpt from the content of the obituary:
The death of Volker Römheld on the 27th November 2013 brought deep sadness to all of us who knew him. Born in Schwaig near Nürnberg, Volker was a German agricultural scientist and plant physiologist with a high international reputation. He was a Professor of Plant Nutrition at Hohenheim University, where he worked for many years in close co-operation with his mentor, and later colleague, Horst Marschner during a time of outstanding research activity and achievement, which provided a source of present internationally recognized leaders in Plant Nutrition. For the last twenty years or so, Volker was a visiting professor at China Agricultural University (Beijing) and Zheijiang Agricultural University (Hangzhou). He very much enjoyed this contact with China, where he felt at home, in co-operating in the university research programs as well as supporting many young Chinese researchers in their first steps in science.

He published over 250 scientific papers in peer-reviewed journals and book chapters, the vast majority of which focused on the various areas of his research activities.

IPI remembers Professor Volker Römheld:

We will always cherish Professor Volker Römheld's remarkable contribution to the science of plant nutrition. Typically, at this IPI conference in India in 2006 Professor Römheld challenged existing views with the goal of achieving better science.

Impressum *e-ifc*

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