Research Findings

General view of the experimental site at the Main Agricultural Research Station, University of Agricultural Sciences, Dharwad, India, at harvest. Photo by authors.

Effects of Soil and Foliar Potassium Application on Cotton Yield, Nutrient Uptake, and Soil Fertility Status

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Abstract

A field experiment was carried out to study the effect of graded levels of potassium fertilizers on Bt cotton hybrid MRC-7351 at the Main Agricultural Research Station, University of Agricultural Sciences, Dharwad, India, on a Vertisol under rainfed conditions during 2012-13 and 2013-14. The experiment layout was a randomized complete block design with nine treatments and three replications. A basal application of 75 kg K_2O ha^{-1}, 50% more than the recommended dose, gave a yield increase of 13.4%. Foliar potassium nitrate (KNO_3) applications at the reproductive phase (70, 90, and 110 days after sowing), doubled the yield increment. Petiole K concentrations were highly correlated with seed cotton yields, suggesting a potential for monitoring tools for plant K status. Improved plant K status also promoted the uptake of other macro and micronutrients, indicating an improved capacity of

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the root system. Nevertheless, the very low efficiency of the soil K application (20%) calls for an alternative approach of K fertilization practice, such as splitting the dose into several applications during the season. Foliar applications are instrumental in correcting nutrient deficiencies during the reproductive phase, whenever required. Thus, the potential of K fertilizers to enhance cotton production has been clearly demonstrated but is still far from being fully exploited. To maintain profitable production, cotton producers may need to change from traditional soil fertility programs to an integrated system consisting of soil and foliar applied nutrients.

Keywords: *Gossypium hirsutum*, foliar spray, potassium nitrate, petiole K test, soil fertility.

Introduction

India is the world's second largest consumer and exporter of cotton (*Gossypium hirsutum*); in 2013-14, India exported and consumed 7.5 and 23 million bales, respectively (Anon., 2014b). Cotton enjoys a predominant position amongst all of India's cash crops; its production in 2013-14 increased 3.5 times from the previous decade, reaching a peak of 39 million bales with a productivity of 565.4 kg ha^{-1} (Anon., 2014a).

Nutrient management of cotton is complex due to the simultaneous production of vegetative and reproductive structures during the active growth phase. High and sustainable cotton productivity is associated with the application of balanced nutrients and their availability to plants (Singh *et al.*, 2006). Balanced use of plant nutrients corrects nutrient deficiency, improves soil fertility, increases nutrient and water use efficiency, enhances crop yields and farmer's income, and maintains crop and environmental quality. Cotton, being a deep-rooted crop, removes large quantities of nutrients from the soil profile. For every 100 kg of seed cotton produced, the crop depletes the soil by 6-7 kg nitrogen (N), 1.9-2.5 kg phosphorus (P), 6-8 kg potassium (K) and 1.2-2.0 kg sulfur (S) (Cassman *et al.*, 1989; Pettigrew, 2008). Generally, farmers tend not to apply these nutrients in a balanced proportion. Consequently, the soil nutrient balance is quite often degraded. By and large, the cotton growers apply mainly N and P, and application of K is usually ignored, as well as S and micronutrients (Singh and Blaise, 2000). Potassium has been recognized as an important plant nutrient in cotton because of its high uptake rate and the relative efficiency of cotton as a K absorber (Kerby and Adams, 1985). An adequate K supply is crucial throughout the period of cotton growth and development (Makhdum *et al.*, 2007) mainly due to its vital role in: biomass production (Zhao *et al.*, 2001); enzyme activation; sucrose transport; starch and fat/oil synthesis; leaf area expansion; carbon dioxide (CO_2) assimilation (Reddy *et al.*, 2004); photosynthesis; leaf pressure potential; transpiration and water use efficiency (Pervez *et al.*, 2004); boll weight and size; and lint yield (Akhtar *et al.*, 2003). The need for K increases dramatically when bolls are set on the plant because they are the major sink for K (Leffler and Tubertini, 1976). The total K quantity taken up by the plant is related to the K available from soil and fertilizer (Kerby and Adams, 1985). Gormus (2002) reported that splitting K applications decreased yields and boll weight as compared with applying the whole rate. Hence, K nutrition in cotton appears to be indispensable. Potassium requirements of cotton can be met by pre-plant soil application and/or by mid-season side dress applications of K fertilizers. Foliar K applications offer an opportunity to correct the deficiency more quickly (within 20 hrs) and efficiently, especially late in the season, when soil K application is much less effective (Abaye, 2009).

The petiole test is highly instrumental in evaluating the current requirement for foliar K fertilizer application, providing a useful tool for keeping up plant health, to evaluate soil fertility status, and to guide farmers through nutrient management decisions aimed at obtaining profitable crop yields. Petiole analysis allows for an early, pre-symptom monitoring of emerging nutrient deficiencies, and subsequent corrective measures as and when required in a timely manner. A complete petiole testing program can be designed to predict nutrient deficiencies up to two weeks in advance, before any yield reduction occurs. Based on petiole nutrient contents, critical decisions can be made for supplemental applications of fertilizer (Kichler, 2006). The present study was aimed to study the effect of graded levels of soil and foliar applied K fertilizers on yield, to determine K concentrations in cotton leaf petiole, estimate nutrient uptake by Bt cotton, and to evaluate soil fertility status at harvest.

Materials and methods

In order to investigate the effect of soil and foliar K application on yield, nutrient uptake, and soil fertility status at harvest of Bt cotton hybrid MRC-7351, a field experiment was conducted at Main Agricultural Research Station (MARS), University of Agricultural Sciences (UAS), Dharwad, India, during 2012-13 and 2013-14. The experimental field was situated at 15°29'647"N; 74°59'254"E, 695 m above sea level. The surface soil (Vertisol type) was characterized as of clay texture, neutral pH (7.3), non-saline, low in available N (230.5 kg ha^{-1}), medium in available P_2O_5 (31.60 kg ha^{-1}) and medium in available K_2O (334.0 kg ha^{-1}). The spacing adopted was 90 cm x 60 cm, as recommended for hybrid cotton cultivars. The experiment was arranged in a randomized complete block design with three replications and nine treatments, T_1-T_9, as detailed in Table 1. T_1 resembled situations of K deficiency but with recommended N and P doses. T_2 served as a control, resembling the standard recommended N-P-K doses. In T_3 and T_4, soil K application was increased by 25 and 50% above the recommended dose, respectively. The set of T_5-T_8 was similar

Table 1. Detailed description of the fertilization treatments.

Treatment	Soil-applied $N:P_2O_5:K_2O$ (kg ha^{-1})	Description
T_1	100:50:50	RDNP (recommended dose of N and P)
T_2	100:50:0	RDF (recommended dose of N, P, and K) - Control
T_3	100:50:62.5	RDNP + 125% RDK (recommended K dose)
T_4	100:50:75	RDNP + 150% RDK
T_5	100:50:0	RDNP + foliar sprays of KNO_3 (2%) at 70, 90, and 110 DAS
T_6	100:50:50	RDF + foliar sprays of KNO_3 (2%) at 70, 90, and 110 DAS
T_7	100:50:62.5	RDNP + 125% RDK+ foliar sprays of KNO_3 (2%) at 70, 90, and 110 DAS
T_8	100:50:75	RDNP + 150% RDK+ foliar sprays of KNO_3 (2%) at 70, 90, and 110 DAS
T_9	100:50:50	RDF + water sprays at 70, 90, and 110 DAS

and respective to T_1-T_4, with additional foliar sprays of KNO_3 (2%) at 70, 90, and 110 days after sowing (DAS). T_9 provided an additional control for T_2 and T_6, testing the influence of water spray at the three application dates. Farm-yard manure (FYM) was spread evenly to all treatments, at a dose of 5 t ha^{-1}.

To avoid a patchy crop stand, gap filling was carried out after 7 DAS. To maintain the desired plant density, thinning of seedlings was carried out at around 20 DAS. The entire recommended P and K doses and 50% of N dose were applied after germination by ring method. The remaining N dose was applied at 60 DAS (Photo 1), according to the common practice. Adequate plant protection measures were applied evenly to all treatments as recommended for Bt cotton cultivars, upon the requirements at various growth stages. During growth of the crop, and at maturity, different yield parameters like sympodial branches, number of bolls and boll weight were recorded.

Twenty fully expanded main stem leaves (fourth mature leaf from the top) (Howard *et al.*, 1997; Lopez *et al.*, 2010) were collected from three replications for petiole K analysis, before and a week after KNO_3 foliar spray. In the laboratory, the petioles were separated, washed with distilled water, dried under shade and then oven dried at 60°C until constant weight, ground to a fine powder and stored in butter paper bags. Whole plant samples were also collected at 60, 90, 120 DAS and at harvest; plants were uprooted carefully and underwent a similar process and the fine powder samples were analyzed for N, P, and K using standard procedures and micronutrients content using the DTPA method (Lindsey and Norvell, 1978).

Photo 1. General view of experimental site on Vertisol at 60 DAS (block E, MARS, UAS, Dharwad). Photo by authors.

Results and discussion

Yield attributes

Yield parameters were higher in the second season: the mean boll numbers per plant were 36.0 and 38.6; boll weights were 6.23 and 6.49 g; and seed cotton yields were 2,141 and 2,356 kg ha^{-1} in 2012-13 and 2013-14, respectively. However, plant performance and the response of the yield parameters to the different fertilization treatments were very similar in both experimental seasons, and therefore pooled data from both years are presented throughout this report.

An adequate soil K application is indispensable to obtain considerable cotton yields under the present experimental conditions. All yield parameters of T_1 and T_5, which received an RDNP soil application with no, or solely foliar K application, respectively, had the smallest number of bolls per plant, the lowest boll weight, and consequently, the lowest yields (Fig. 1). Seed cotton yield of T_1 and T_5 declined by 12 and 8.6%, respectively, as compared to T_2, the control. Potassium deficiency results in early abscission of leaves and carbohydrates accumulation in main stem leaves, so the top cotton bolls suffer incomplete development (Gormus, 2002).

Nevertheless, it appears that the recommended K dose is also inadequate; additional soil-applied K at 25 or 50% of the recommended dose gave rise to significant increases in boll number and weight, and consequently, to 8 and 13.4% higher seed cotton yield, as compared to T_2 (Fig. 1). The sequential KNO_3 sprays on 70, 90, and 110 DAS brought about much smaller but significant increases in seed cotton yields. The foliar spray increased the seed cotton yields by 3.9, 3.2, 12.6, and 11.7% in $T_{5\text{-}8}$, as compared to their respective treatments, $T_{1\text{-}4}$. This yield increase may be attributed mainly to the significant rise in the number of bolls but

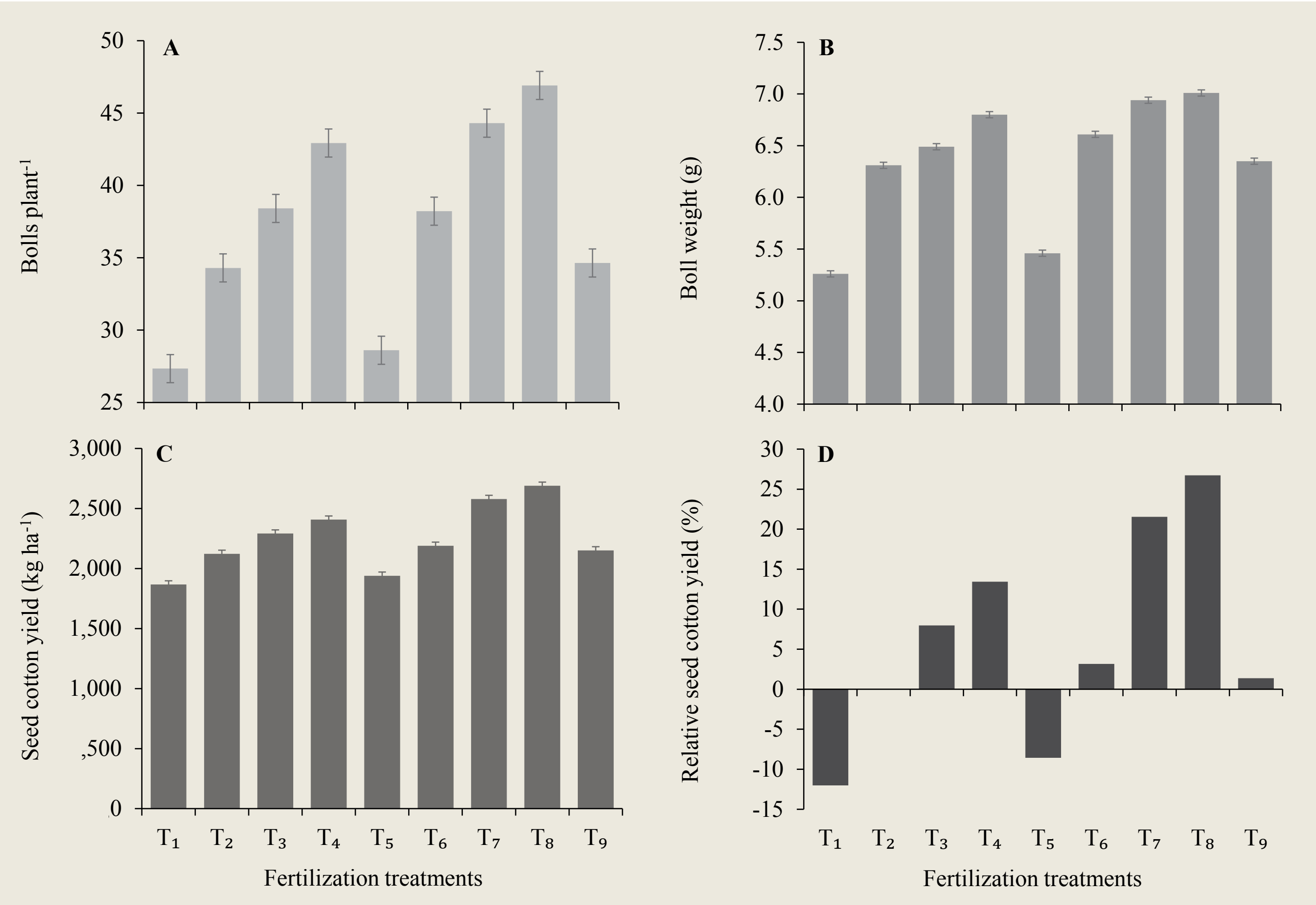

Fig. 1. Bt cotton yield parameters, pooled from seasons 2012-13 and 2013-14. D: values are relative to the T_2 control. Bars indicate LSD at 5%. T_1-T_9 are detailed in Table 1.

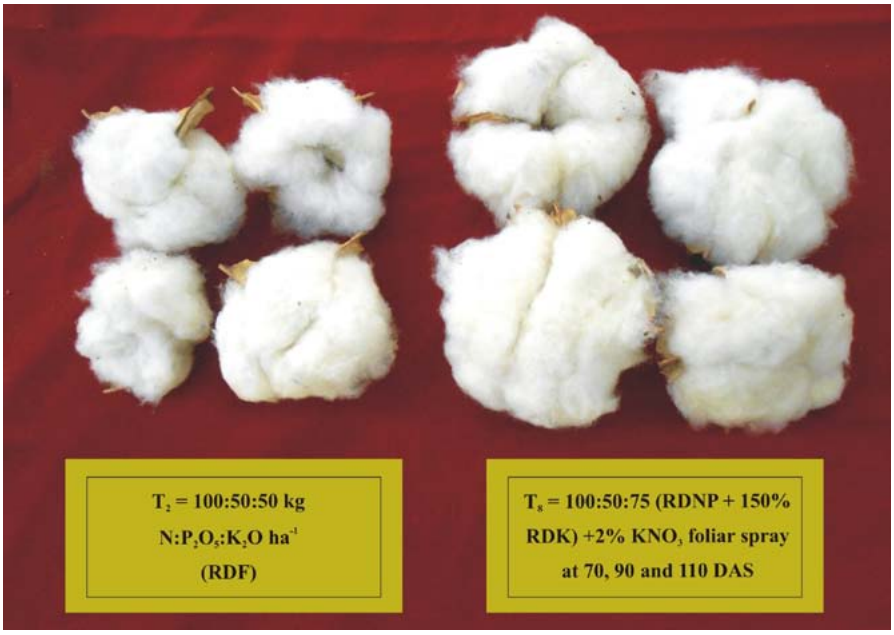

Photo 2. Differences in cotton boll size and quality between the highest level of K application (T_8) and the control (T_2). Photo by authors.

also to the slighter surge in boll weight (Fig. 1). Beyond the direct influence of the foliar K applications, it appears that this treatment is more constructive where adequate soil K application are provided.

The highest seed cotton yield, 2,689 kg ha^{-1}, was obtained at T_8 (RDNP+150%RDK+foliar KNO_3 sprays), 26.7% more than the control (T_2, RDF). The difference lies in the number of bolls per plant, 46.9 vs. 34.3, and boll weight, 7.11g vs. 6.33g, in T_8 vs. T_2, respectively (Photo 2). The supply of sufficient K quantities at critical periods, particularly during the boll development stage, resulted in retention of greater numbers of bolls per plant, as compared to the non-sprayed controls (Channakeshava *et al.*, 2013). The higher boll weight is also attributed to additional nutrition due to the foliar KNO_3 spray that might have enhanced dry matter translocation and accumulation in bolls (Kumar *et al.*, 2011). These results demonstrate the significance of synchronizing the nutrient supply at different developmental stages using foliar application to enhance growth and consequent higher yields.

Effect of soil and foliar K application on K concentration in cotton leaf petiole

Petiole K concentrations declined gradually from an average of 3.89% to 3.55%, 2.98%, and 0.98%, from 70 to 90, 110 DAS, and at harvest, respectively. This constant decrease could be observed even at a daily time scale: in treatments with no foliar KNO_3 applications (T_1-T_4, T_9), petiole K concentrations were consistently lower at the latter of two subsequent tests (Table 2). Petiole K concentrations were tightly and positively associated with soil K application rates. However, foliar KNO_3 applications brought about significant increases in petiole K concentration at the immediate as well as the longer time scale (Table 2). While only decelerating the declining petiole K in the K deficient T_5, petiole K concentration responded to the KNO_3 sprays with an immediate rise of

Table 2. Potassium concentration (% of dry matter, DM) in leaf petioles sampled before, and after KNO_3 sprays at 70, 90, 110 DAS, and after harvest. For detailed description of treatments please refer to Table 1.

Treatment	Days after sowing						
	70		90		110		
	Before	After	Before	After	Before	After	At harvest
T_1	3.23	3.16	3.11	3.04	2.39	2.31	0.81
T_2	3.67	3.62	3.24	3.18	2.65	2.57	0.92
T_3	4.26	4.21	3.55	3.51	3.16	3.10	1.01
T_4	4.51	4.46	3.92	3.83	3.47	3.41	1.07
T_5	3.23	3.20	3.15	3.09	2.45	2.34	0.83
T_6	**3.66**	**3.85**	**3.45**	**3.52**	**2.77**	**2.93**	**1.04**
T_7	**4.28**	**4.66**	**4.11**	**4.30**	**3.54**	**3.83**	**1.12**
T_8	**4.51**	**4.76**	**4.16**	**4.46**	**3.74**	**3.93**	**1.16**
T_9	3.65	3.59	3.24	3.18	2.67	2.60	0.90
SEm	0.06	0.03	0.04	0.04	0.05	0.02	0.02

Note: SEm = standard error of means.

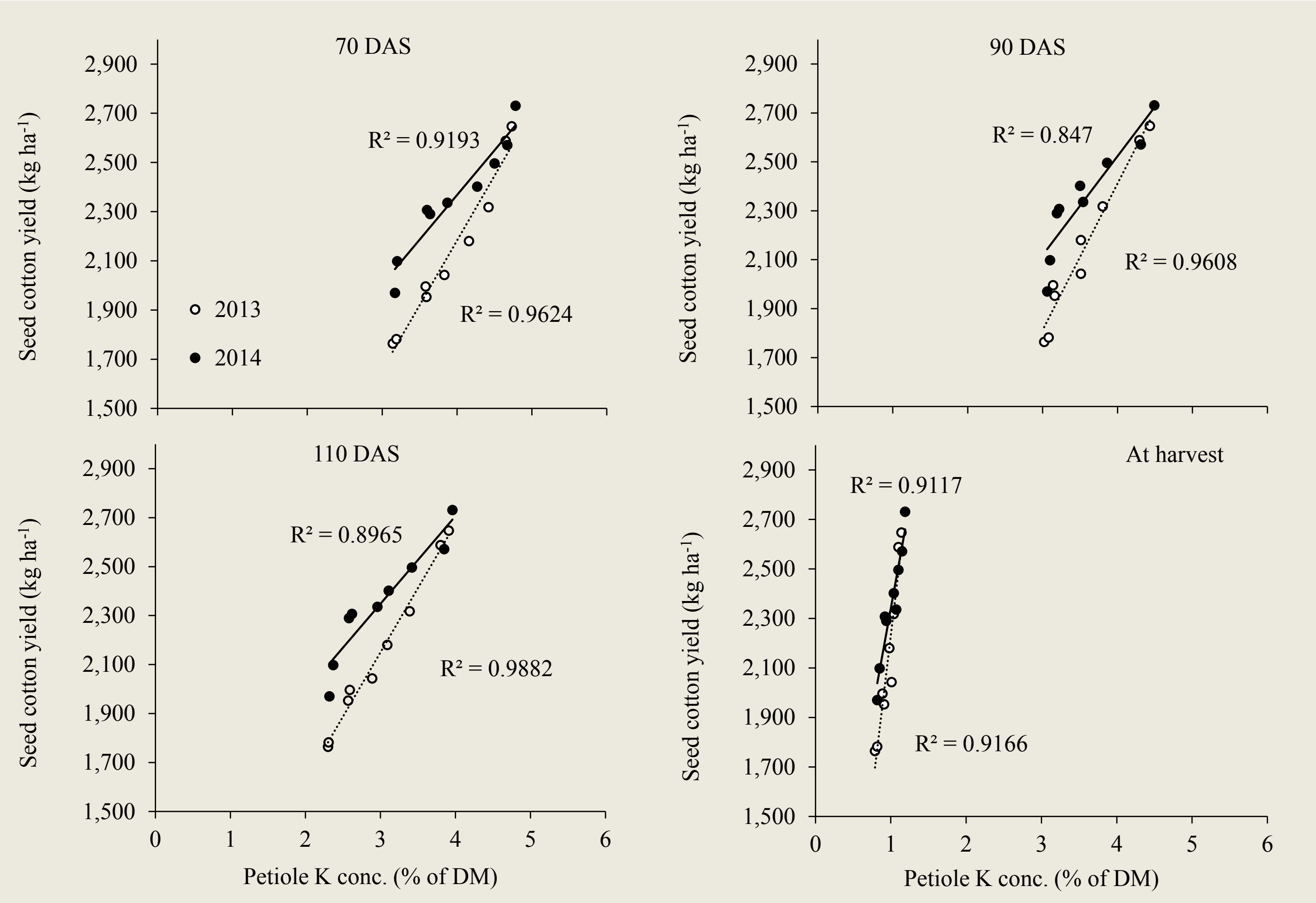

Fig. 2. Correlations between petiole K concentration and seed cotton yield at 70, 90, 110 DAS and at harvest during the two successive experiments which ended in 2013 and 2014.

2-9%. Furthermore, the foliar applications supported consistently higher petiole K levels throughout the season, until harvest (Table 2). The developing cotton bolls are the largest K and carbon sink in the cotton plant (Howard *et al.*, 1998). During the critical period of simultaneous boll set, growth, and development, K supply from the roots might be inadequate, causing boll abortion and shedding (Pettigrew, 2008). In agreement with Oosterhuis *et al.* (1990), combined soil and foliar K applications increase K availability within the canopy, as indicated by petiole K concentration, thus enhancing boll survival and growth.

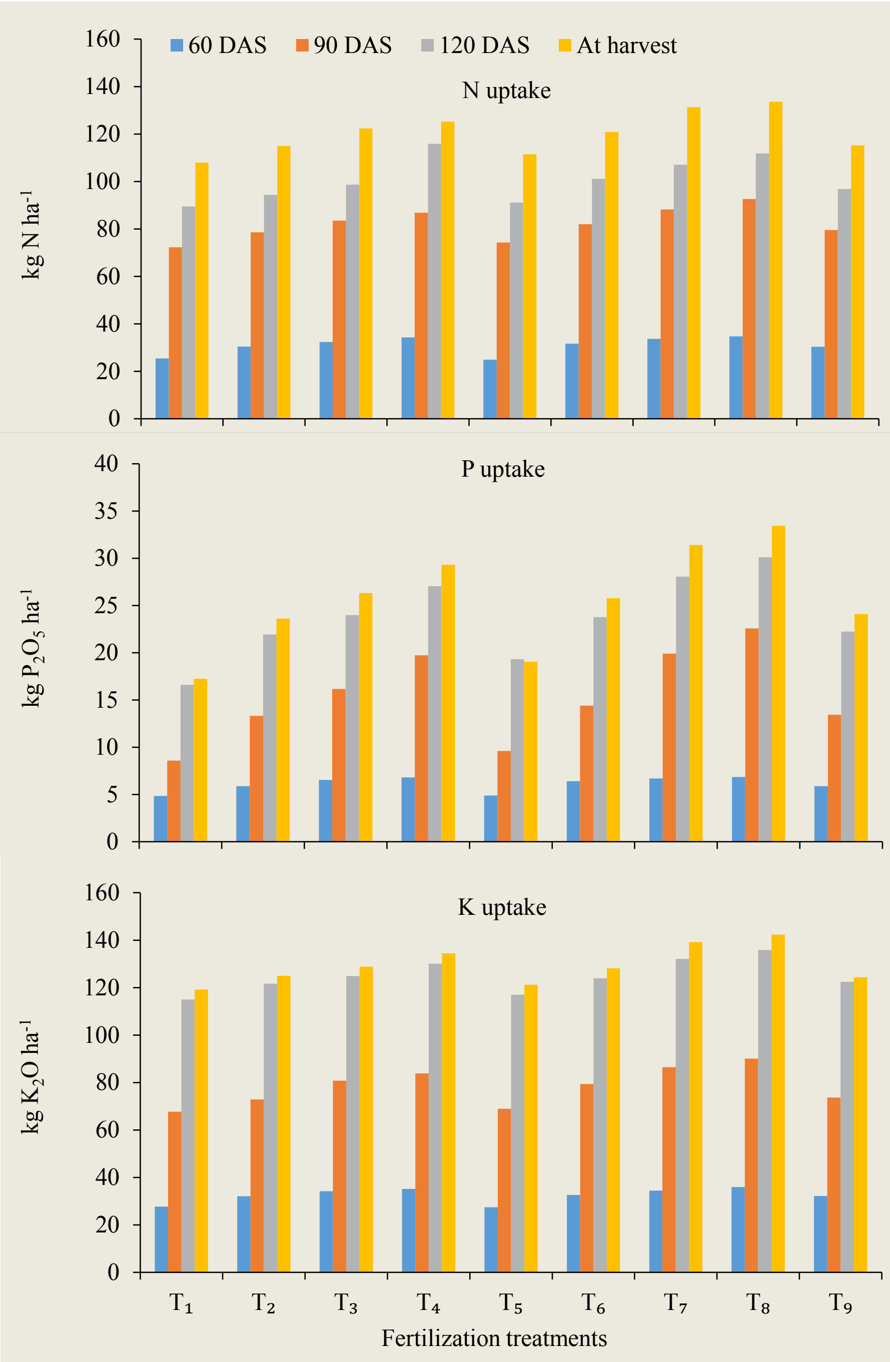

Fig. 3. Effect of K fertilization treatments on N, P, and K uptake by Bt cotton at 60, 90, and 120 DAS, and at harvest. For detailed description of treatments please refer to Table 1.

Petiole K concentrations were highly and significantly correlated with the final seed cotton yields (Fig. 2), supporting previous findings by Lopez *et al.* (2010). Apparently, such correlations may suggest using this parameter for yield prediction. Nevertheless, the relationships change among plant developmental stages and between years (Fig. 2). In as much, petiole K concentration may be employed to monitor the plant nutritional status at particular phenological phases and within certain limits (Bennett *et al.*, 1965; Kafkafi, 1990).

Effect of soil and foliar K application on nutrient uptake by Bt cotton

Nutrient uptake by plants usually reflects their dry biomass. Shortage of one or more nutrients would restrict plant growth and development. In the present study, K was the limiting factor, the replenishment of which brought about a significant rise in crop biomass, and a resulting surge in N and P uptake (Fig. 3). Interestingly, the remarkable differences between treatments in soil K application did not result in proportionate increases in K uptake. The difference in K uptake between T_4, which received 75 kg K_2O ha^{-1}, and T_1, with null K application, was only 15 kg ha^{-1}. These results indicate that the cotton crop relied mostly on soil K reserves, at about 120 kg K_2O ha^{-1}. The differences between treatments was acquired during the early period of 60 DAS, with no further changes later on (Fig. 3). It can be, therefore, concluded that a basal K application predominantly supports the early vegetative phase of the cotton crop, and fades away, probably through leaching, during the most K demanding reproductive phase. This scenario of inefficient K fertilization practice calls for an alternative approach in which the annual K dose is split and broadcasted during the season. The success of the foliar KNO_3 applications to increase yield is marginal and indicative of the major concept change required.

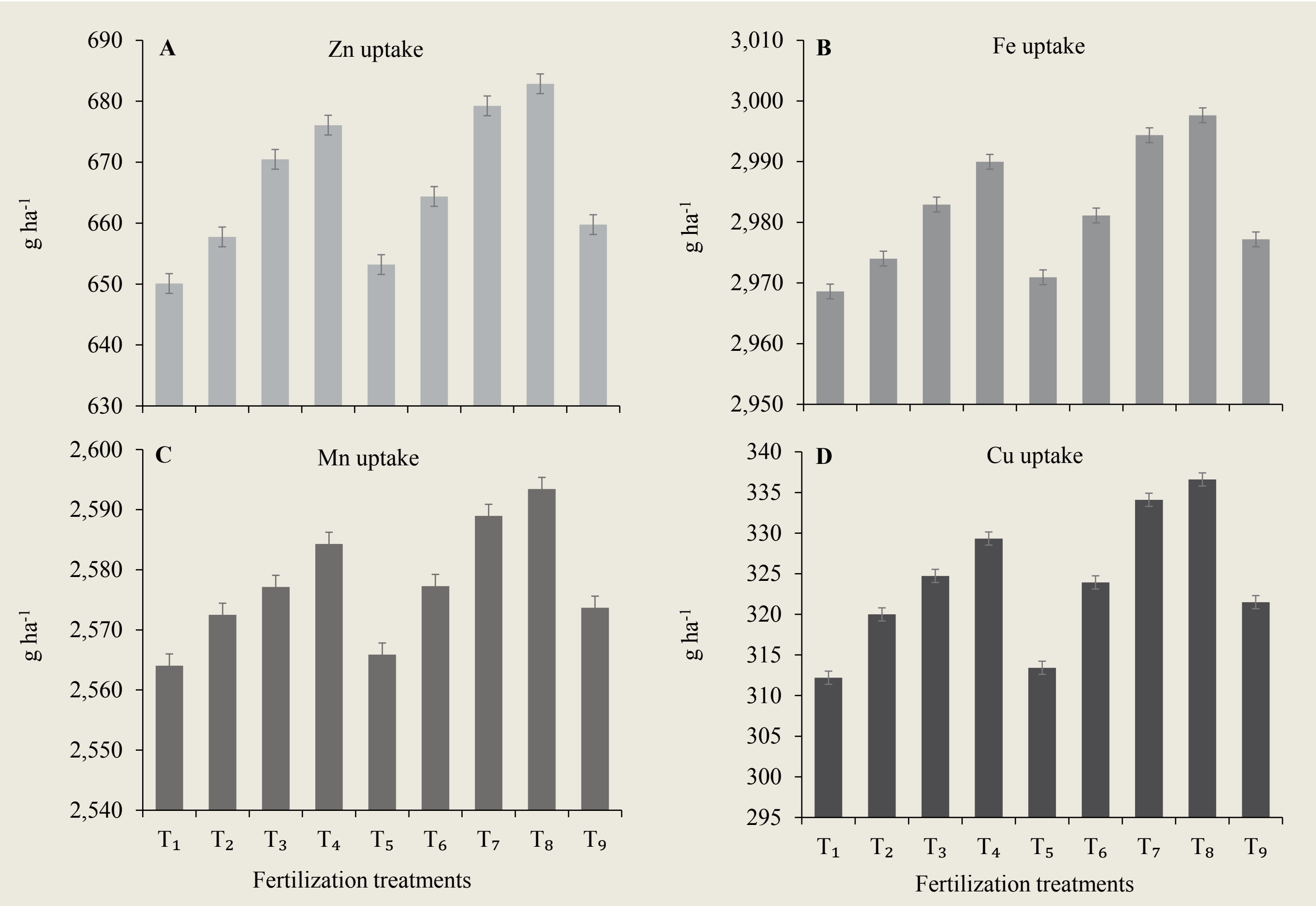

Fig. 4. Effects of K fertilization treatments on zinc (Zn), iron (Fe), manganese (Mn), and copper (Cu) uptake by Bt cotton, at harvest. For detailed description of treatments please refer to Table 1.

This is in accordance with Makhdum *et al.* (2007), who stated that shifting dry matter from vegetative to reproductive organs is dependent on sustained supply of nutrients throughout the season.

The basal soil K application, also supported by the second N application at 60 DAS, had an obvious effect on N uptake, which rose by up to 10%, respective to the increase in K dose (Fig. 3). However, the influence of soil K application on P uptake was dramatic; it gradually increased in direct relationship to K rates, up to 29.3 kg P_2O_5 ha^{-1} in T_4, about 90% more than T_1 (Fig. 3). Foliar KNO_3 applications further enhanced this nutrient uptake pattern (Fig.3). Moreover, a similar, and even stronger pattern was observed regarding the effect of K application on the uptake of microelements, such as zinc (Zn), iron (Fe), manganese (Mn), and copper (Cu) (Fig. 4), suggesting that improved K status can promote root expansion and exploration of larger soil volumes (Abaye, 2009). These results are consistent with previous studies suggesting that improved plant K status has a significant impact on the uptake and metabolism of macro as well as micronutrients (Mengel *et al.*, 1976; Silberbush and Lips, 1991; Brar and Brar, 2004; Pettigrew, 2008; Zörb *et al.*, 2014). The advantage of foliar application is, however, in the precise delivery of nutrients to target tissues and organs (Baloch *et al.*, 2008; Saravanan *et al.*, 2013).

Soil fertility status

The fertilization treatments did not have any significant effect on soil pH, salinity (ECe), or organic carbon (OC) (Table 3). Soil available N and P slightly increased during the two years of experiments, but this increase declined with the increasing soil K applied. This pattern may be ascribed to the more intensive nutrient uptake by plants benefiting from improved K supply (Cassman *et al.*, 1989). Soil available K displayed a similar pattern, except in T_1 and T_5, where no changes occurred from the initial levels, in spite of the two successive crops and null supply of K fertilizers.

Table 3. Effects of different K fertilization treatments on Vertisol fertility status following two successive years of Bt cotton production. For detailed description of treatments please refer to Table 1.

Treatment	pH	ECe	Organic carbon	Available			DTPA extractable micronutrients			
				N	P	K	Zn	Fe	Mn	Cu
	1:2.5	*dS m⁻¹*	*g kg⁻¹*	--------kg ha⁻¹--------			--------mg kg⁻¹--------			
Initial	**7.81**	**0.30**	**7.63**	**230.5**	**31.60**	**334.0**	**0.70**	**2.65**	**6.80**	**2.23**
T_1	7.84	0.33	7.61	257.5	38.92	333.0	0.68	2.62	6.45	2.26
T_2	7.74	0.32	7.57	253.8	36.24	358.6	0.66	1.95	6.41	2.23
T_3	7.90	0.33	7.52	248.4	34.36	353.2	0.64	1.85	6.35	1.98
T_4	7.87	0.33	7.49	244.1	33.66	347.7	0.62	1.58	6.26	1.90
T_5	7.86	0.33	7.55	255.6	36.93	332.0	0.66	2.59	6.45	2.25
T_6	7.84	0.34	7.54	250.1	35.00	356.5	0.65	1.81	6.38	2.23
T_7	7.85	0.33	7.50	241.9	33.57	342.8	0.62	1.65	6.30	1.87
T_8	7.88	0.32	7.46	239.8	32.44	341.2	0.60	1.55	6.24	1.85
T_9	7.88	0.33	7.56	252.2	36.11	357.8	0.65	1.93	6.36	2.21
SEm	0.03	0.01	0.03	0.57	0.39	1.21	0.01	0.03	0.02	0.02
CD at 5%	NS	NS	NS	1.71	1.17	3.62	0.03	0.10	0.05	0.05

Note: SEm = standard error of means; CD = critical difference.

At the harvest at the end of the second season, levels of DTPA extractable micronutrients (Zn, Fe, Mn, and Cu) were generally lower than the initial ones. The drop in Fe levels was especially significant, suggesting that this nutrient should be routinely replenished (Table 3). Also here, enhanced K supply brought about higher biomass production and yield, and consequently, led to faster soil nutrient depletion.

Conclusions

The Vertisol on which the two successive Bt cotton crop experiments took place is rather fertile. The rate at which new K is released to the available phase is sufficient to support considerable cotton yield levels. However, when commercial yield levels are anticipated, significant K supplementation is required. In the present study, a basal application of 75 kg K_2O ha^{-1}, 50% more than the recommended dose, gave rise to a yield increase of 13.4%. Foliar KNO_3 applications at the reproductive phase (70, 90, and 110 DAS), doubled the yield increment. Petiole K concentration was highly correlated with seed cotton yield, suggesting a potential for monitoring tools of plant K status. Improved plant K status also promoted the uptake of other macro and micronutrients, indicating an improved capacity of the root system. Nevertheless, the very low efficiency of the soil K application (20%) calls for an alternative approach of K fertilization practice, such as splitting the dose into several applications during the season. Foliar applications are instrumental in correcting nutrient deficiencies during the reproductive phase, whenever required. Thus, the potential of K fertilizers to enhance cotton production has been clearly demonstrated but is still far from being fully exploited.

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