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Editorial

Dear readers,

There are various ways of estimating future requirements for potash fertilization. One major one is that, in general, current potash fertilization rates - in contrast to nitrogen and phosphorus - fall short of crops' needs to enable yield potential to be fulfilled.

For agronomic, economic and other reasons, regions like the Indian sub-continent, newly converted savannah to arable lands in Brazil, parts of Asia and, above all, sub-Saharan Africa, all suffer from levels of potash application that are significantly too low.

In this edition of *e-ifc*, we provide reports on IPI experiments in Brazil, Indonesia and Pakistan. In these trials, crops tested are all heavy users of potash: cassava, cotton, maize, and soybean.

It is IPI's mission to assist researchers and farmers in realising crop yield potential through optimal use of potash fertilizers.

I wish you an enjoyable read.

Hillel Magen
Director

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Experimental site for Polyhalite, LEM, Bahia State, Brazil. Photo by F. Vale.

Research Findings

Photo 1. Fully opened cotton bolls. Photo by authors.

Impact of Potassium Fertilization Dose, Regime, and Application Methods on Cotton Development and Seed-Cotton Yield under an Arid Environment

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Abstract

Modern cotton cultivars require more potassium (K) and its deficiency during peak bloom and boll setting period adversely affects the seed-cotton yield. The objectives of the present study were to determine the adequate K dose for the modern, transgenic cotton cultivar (*Bt*.CIM-616) grown on an arid light soil, to evaluate the effects of a split K application, and to quantify the contribution of additional foliar K applications on seed-cotton yield and its components. Two-year (2014-15) field experiments were conducted at the Central Cotton Research Institute, Multan, Pakistan, in two sets. In set-I, three K doses (0, 100 and 200 kg K_2O ha^{-1}) were applied at sowing or were split into two or four equal applications of 50 kg K_2O ha^{-1} (pre-planting and 45 days after sowing or pre-planting, 30, 45 and 60 days after sowing)

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respectively. In set-II, the impact of pre-planting applications of 0, 100 and 200 kg K_2O ha^{-1}, followed by four foliar sprays of 2% K_2SO_4 were evaluated for plant structure and yield components. The results revealed that supplemental K is a prerequisite for modern transgenic cotton grown on poor arid soils, as it ensures sufficient plant growth and development and subsequently increases the seed-cotton yields to considerable levels. However, basal K application alone would not fulfil the cotton yield potential. Splitting the annual dose to 2-4 mid-season side-dress applications significantly improved seed-cotton yield. Nevertheless, a basal K application, followed by four foliar sprays of 2% K_2SO_4 during the season resulted in the highest yield, obtaining up to 40% more yield than the non-fertilized control, and 10-15% more than that of the split soil-applied K. These results demonstrate the importance of matching plant K status to the dynamic crop demands for this nutrient, particularly in modern transgenic cotton cultivars.

Introduction

Cotton (*Gossypium hirsutum* L.) is a world leading fiber crop and Pakistan ranks fourth among cotton producing countries (Indexmundi, 2015) with 12.8 million bales produced during 2014, generating 1.4% of the GDP (Economic Survey of Pakistan, 2014). In arid environments, crop nutrition has always been a key component of high cotton yields (Ahmed *et al.*, 2013; Karim *et al.*, 2016). While nitrogen (N), phosphorus (P) and potassium (K) are key nutrients required in large quantities by all crop plants, the use of K fertilizers for cotton is very low in Pakistan. Nevertheless, K is essential for obtaining high seed-cotton yield and fiber quality (Bennett *et al.* 1965; Mullins *et al.*, 1997; Zhao *et al.*, 2001; Oosterhuis, 2002; Aneela *et al.*, 2003; Sardar *et al.*, 2003; Pervez *et al.*, 2004; Pettigrew *et al.*, 2005).

Cotton genotypes differ significantly in their response to K fertilization (Pettigrew, 2008). The genotypic differences in K-response are probably due to the bigger root system of the more responsive genotypes, enabling faster or more efficient K up-take (Cassman *et al.*, 1989a; Brouder and Cassman, 1990). Furthermore, new high yielding and early maturing cotton varieties demand a significantly high K supply (Baily and Gwathmey, 2007; Pettigrew, 2008; Abaye, 2009; Xia *et al.*, 2013). Cotton has been recognized as very sensitive to K deficiency (Rosolem *et al.*, 2003). Deficiency symptoms occur even in soils that are not considered generally as K-deficient (Cassman *et al.*, 1989b). Potassium deficiency causes low boll weight (Kerby *et al.*, 1985), reduced sugar translocation from leaves (Pettigrew, 1999), low seed-cotton yield and poor fiber quality (Mallarino *et al.*, 1999; Pettigrew *et al.*, 2005). Although it is not a constituent of any plant compound, K plays an integral role in enzyme activation (Usherwood, 2000) involved in numerous metabolic processes.

Potassium availability from soils of arid environments is generally inadequate to fulfil potential crop yields. Light-textured soils are mostly favored for cotton production. However, in addition to the low nutrient availability in these soils, the accessible K is often rapidly leached down below the root zone. Thus, K availability might diminish at the boll setting period, when cotton requirements for this nutrient drastically increase (Halevy, 1976). Hence, supporting a steady K supply through fertilizer application seems critical in order to guarantee sufficient yield levels. Application regimes and methods may have significant impacts on K-uptake in cotton, which is challenged due to its sparse tap root system (Cappy, 1979) and the relatively low plant density in a row (Oosterhuis, 2002). The most common (and low-cost) practice for K administration is pre-planting application of the whole seasonal K fertilizer dose to the shallow soil level (basal application). In cases of K-fixing soils, or rapid nutrient leaching, this dose may be split during the season to several applications, with K fertilizers applied as a side-dressing on the soil surface along the row. The approach of foliar sprays of liquid K fertilizers is a useful deficiency correcting tool (Halevy and Markovitz, 1988), when K soil supply or plant uptake are poor, and plant growth and development are at risk (Pettigrew *et al.*, 2000). Nevertheless, only a few studies have addressed ways to combine soil and foliar K applications in cotton in order to suit an appropriate regime for K fertilization.

In recent years, scientists from the Central Cotton Research Institute (CCRI), Multan, Pakistan, have developed a series of *Bt.*-transgenic modern cotton cultivars, aimed at reducing insecticide use. The objectives of the present study were to determine the adequate K dose required to grow one of these cultivars, *Bt.*-CIM-616, on an arid light soil, to evaluate the effects of a split K application, and to quantify the contribution of additional foliar K applications on seed-cotton yield and its components.

Materials and methods

The two-year field studies were conducted at CCRI, Multan (30°12'N, 71°28'E and altitude 123 m above sea level) during the 2014 and 2015 cropping seasons. Soil properties were determined at 30 cm depth (Table 1). The experiments consisted of two sets. In set-I, the treatments comprised of K_0 (control), K_1, K_1s, K_2, and K_2s, focusing on basal or split K applications. Set-II comprised of K_0

Table 1. Soil properties for the experimental fields at 30 cm depth.

Soil property	
Texture	Silt loam
pH	8.4
Organic matter (%)	0.52
ECe (dS m^{-1})	1.71
NO_3-N (mg kg^{-1})	7.0
P (mg kg^{-1})	8.2
K (mg kg^{-1})	130

(control 1), K_0fw (control 2), K_1fK, and K_2fK, focusing on basal and additional foliar applications. A detailed description of the treatments is provided in Table 2.

Both experimental sets were carried out in a randomized complete block design with four replications. Treatments were laid out permanently and the plots received the same treatment in both years. The soil was prepared with cross wise chiseling followed by cultivation and planking. Seeds (cultivar *Bt*.CIM-616) were manually dibbled in dry conditions on bed-furrows on the third week of April in each year. Water was applied through furrow-flood irrigation. Irrigation, weeding, fungicides and insecticide application measures were kept uniform in all plots.

Plant structure and yield components were recorded at maturity. The plant height, nodes, total fruiting points, intact fruits and boll numbers were recorded from five randomly selected plants from

Table 2. A detailed description of treatments.

Set	Treatment	Seasonal dose	Application regime and methods
		-----*kg ha*$^{-1}$-----	
I	K_0	0	
I	K_1	100	A single basal application
I	K_1s	100	Split: 50% at sowing; the rest at 45 days after sowing (DAS)
I	K_2	200	A single basal application
I	K_2s	200	Split: 25% at sowing; the rest at 30, 45, and 60 DAS
II	K_0	0	
II	K_0fw	0	Foliar spray of water at 30, 45, 60, and 75 DAS
II	K_1fK	100	A single basal application and foliar sprays of 2% K_2SO_4 at 30, 45, 60, and 75 DAS
II	K_2fK	200	A single basal application and foliar sprays of 2% K_2SO_4 at 30, 45, 60, and 75 DAS




Photos 2. From upper left, clockwise: Seed dibbling into the dry bed-soil; furrow flood irrigation after germination; furrow maintenance; rows of young cotton plants. Photos by authors.

each plot. The boll weight was worked out from two randomly selected plants. The data recorded was subjected to Fischer's technique of analysis of variance (ANOVA) and the treatment means were compared at 5% probability level using least significance difference (LSD) test (Steel *et al.*, 1997).

Results

Set-I: Effects of dose and K application regime on cotton

Potassium application had a remarkable impact on cotton plant development and structure. A basal K dose of 100 kg ha^{-1} (K_1) gave rise to a significant increase (17-21%) in plant height, compared to the control (K_0) (Table 3). Doubling this basal dose (K_2) resulted in a stronger response, about 35% more than the control. Splitting the seasonal K dose, at both 100 (K_1s) and 200 kg ha^{-1} (K_2s) significantly enhanced these effects, increasing plant height by 30% and 45% above the control, respectively. The increase in plant height could be attributed to the rise in the number of nodes on the main stem (10-30%), and also to nodal elongation by up to 20% more than the control (Table 3).

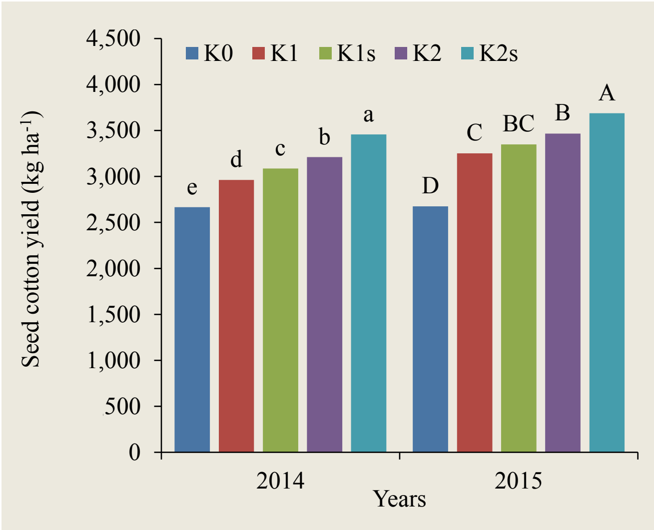

Fig. 1. Effects of K application dose and regime on seed-cotton yield in 2014 and 2015. Fertilizer (SOP) was applied as a single basal dose incorporated into topsoil, or evenly split as basal and mid-season side-dressing applications. For detailed description of treatments refer to Table 2. Columns with the same letters do not significantly differ at 5% probability level, using the LSD test.

Potassium influence on seed-cotton yield was obvious (Fig. 1); seed-cotton yield increased gradually in response to K application dose as well as regime, probably due to some relative improvement in soil K status. While the basal K application of 100 kg ha^{-1} (K_1) resulted in a yield increase of 11-22%, a split application of the same dose (K_1s) gave rise to a significant yield increase of 16-25%, compared to the control. Nevertheless, a doubled basal dose (K_2) enhanced the yield by 20-30%, and, when split into four even applications (K_2s), enhanced yield by 30-38%, compared to the non-fertilized control.

Table 3. Effect of K application dose and regime on plant development at maturity in experimental set-I (see Table 2 for description of treatments).

Treatment	Main stem height		Nodes on main stem		Node length	
	2014	2015	2014	2015	2014	2015
	------------cm------------				------------cm------------	
K_0	88.3	90	31	30	2.85	2.99
K_1	107	105	34	35	3.15	3.01
K_1s	115	118	34	37	3.38	3.20
K_2	119	122	35	37	3.40	3.31
K_2s	128	131	38	39	3.46	3.38
LSD 5%	7.56	12.42	2.11	4.88	0.03	NS

The seed-cotton yield increase may be attributed to the improvement in every yield-determining component involved (Table 4). In respect to the non-fertilized control (K_0), the number of bolls per plant increased by 16-50%, boll weight increased by 2-10%, and the total number of fruiting points was boosted by 20-30%. Fruit retention was significantly improved, as expressed by

Table 4. Effect of K application dose and regime on seed-cotton yield components at maturity in experimental set-I (see Table 2 for description of treatments).

Potassium Fertilizer	Number of bolls $plant^{-1}$		Boll weight		Total fruiting points		Total intact fruit		Shedding	
	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015
kg K_2O ha^{-1}			------------g------------		---------------------------m^{-2}---------------------------				------------%------------	
K_0	25	24	2.54	2.51	387	391	114	112	70.5	71.4
K_1	29	32	2.59	2.61	463	479	156	159	66.3	66.8
K_1s	30	31	2.64	2.65	473	487	163	170	65.5	65.1
K_2	32	34	2.69	2.68	485	498	172	179	64.5	64.0
K_2s	33	36	2.74	2.75	497	509	184	193	63.0	62.1
LSD 5%	2.80	3.11	0.10	0.12	8.7	23.3	11.4	14.7	3.49	3.46

the declining fruit shedding rates from about 70% in the control down to 62% in the K_2s treatment. Overall, the total number of intact fruit increased by 37-72%. In all yield components, the response was gradual, with a direct linkage to K dose and regime. Thus, the smallest improvements were obtained with the lower basal K input (K_1), whereas the best values were recorded in the higher K dose split into four applications (K_2s) (Table 4).

Set-II: The additive effects of foliar K applications on cotton development and yield components

Basal K application fortified with foliar applications of K_2SO_4 (2%) resulted in significant enhancement of plant growth and development (Table 5), giving rise to a 20-40% increase in plant height, 7-28% more nodes on the main stem, and 12-15% longer nodes. Excluding node length, growth response to the higher K dose (K_2fK) was twice that of K_1fK. Consequently, the yields of K_1fK and K_2fK were 24-27%, and 32-38% higher, respectively, than those of K_0fw, the water-sprayed control (Fig. 2).

The influence of the foliar K applications on the cotton yield components (Table 6) was quite similar to those of the split K doses in set-I (Table 4). In respect to the water-sprayed control (K_0fw), the number of bolls per plant increased by 19-42%, boll weight increased by about 9-13%, and the total fruiting points boosted by 21-38%. Fruit retention was also improved, as expressed by the declining fruit shedding rates from about 70% in the control down to about 63% in the K_2fK treatment. Overall, the total number of intact fruit was increased by 32-52%. Similar to set-I, in all yield components, the response was gradual with a direct linkage to K dose (Table 6).

Discussion

Potassium is required in large amounts by cotton for normal crop growth and fiber development, with a typical high yielding crop containing about 200 kg K ha^{-1} (Oosterhuis, 2002). Plant K uptake follows a pattern similar to dry weight accumulation, except that K uptake peaks from 2.2 to 5 kg ha^{-1} day^{-1} a few weeks after the start of flowering (Halevy *et al.*, 1987). Cotton is more sensitive to low K availability than most other major field crops and often shows signs of K deficiency on

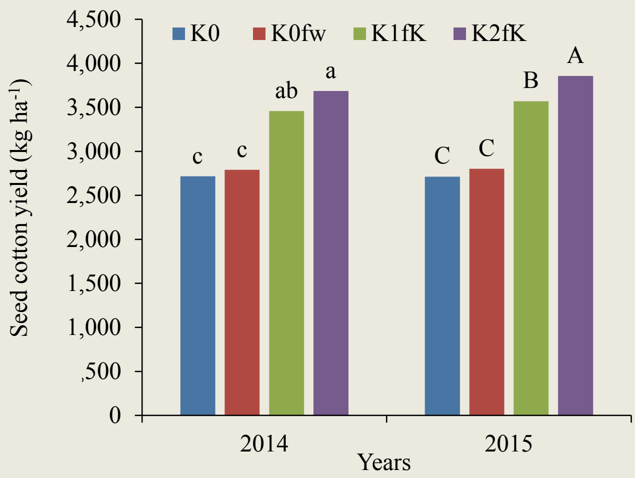

Fig. 2. Effect of basal K dose fortified with foliar application of K_2SO_4 (2%) on seed-cotton yield at maturity in experimental set-II (see Table 2 for description of treatments).

Table 5. Effect of basal K dose fortified with foliar application of K_2SO_4 (2%) on plant development until maturity in experimental set-II (see Table 2 for description of treatments).

Treatment	Main stem height		Nodes on main stem		Node length	
	2014	2015	2014	2015	2014	2015
	-------------*cm*-------------				-------------*cm*-------------	
K_0	97	94	30	29	3.23	3.25
K_0f_w	101	99	31	30	3.25	3.31
K_1f_k	121	124	33	33	3.66	3.80
K_2f_k	132	136	37	38	3.57	3.60
LSD 5%	4.99	4.62	4.69	4.75	0.31	0.54

Table 6. Effect of basal K dose fortified with foliar application of K_2SO_4 (2%) on seed-cotton yield components at maturity in experimental set-II (see Table 2 for description of treatments).

Potassium Fertilizer	Number of bolls plant^{-1}		Boll weight		Total fruiting points		Total intact fruit		Shedding	
	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015
kg K_2O ha^{-1}			-------------*g*-------------		---------------------------*m^{-2}*---------------------------				------------*%*------------	
K_0	26	25	2.58	2.51	391	396	121	120	69.1	69.6
K_0f_w	26	26	2.60	2.54	401	403	127	124	68.3	69.2
K_1f_k	31	35	2.84	2.81	487	496	168	174	65.5	64.9
K_2f_k	33	37	2.91	2.87	503	517	187	189	62.8	63.4
LSD 5%	4.7	3.2	NS	0.072	10.2	23.9	5.7	16.4	NS	4.1

soils not considered K deficient (Cassman *et al.*, 1989b). When soil K levels are insufficient, the cotton crop moves more quickly (earlier) from the vegetative to the reproductive phase (Gwathmey and Howard, 1998; Pettigrew, 1999) resulting in a decline in yield (Pettigrew, 2008). In the present study, cotton plant growth and development, as well as seed-cotton yield, were significantly enhanced by K application, compared to non-fertilized controls. When two doses were examined through basal application, 100 and 200 kg K_2O ha^{-1}, plant performance and yield seemed to respond linearly to K dose (Fig. 1). These results provide additional evidence for the critical role of K fertilization for enhancing cotton yields grown on poor arid soils in Pakistan (Ahmed *et al.*, 2013; Karim *et al.*, 2016).

In spite of the significant increase in yield, the efficiency of basal K application is of great concern. Considering the low cation exchange capacity characterizing light soils, the high leaching rate in flooded soils, and the poor K-acquiring ability of cotton root system (Cappy, 1979; Gerik *et al.*, 1987), one may assume that a substantial proportion of the basal K dose would not reach the plant.

Indeed, a further increase in plant development (Table 3) and yield was achieved whenever the basal dose was split (Fig. 1). Applying 100 kg K_2O ha^{-1} as two equal splits, and 200 kg K_2O ha^{-1} as four equal splits produced 3.6% and 7% higher seed-cotton yield, respectively, compared to the full K fertilizer dose applied at sowing. The need for K rises dramatically when bolls are set because developing bolls have a high K requirement (Abaye, 2009; Sekhon and Singh, 2013). It is crucial that K is made available when the plant begins to set fruit. In modern varieties, such as *Bt*.-CIM-616, the length of the flowering period has been reduced from 5-7 to 3-5 weeks, thus the current varieties produce a larger crop during a shorter period of time (Abaye, 2009). Even a high K level in the topsoil may not be adequate for some of the new high-yielding cotton varieties (Cassman *et al.*, 1989a; Oosterhuis, 2002). Therefore, the increasing K requirements during the boll set period can be met by strengthening the basal application with mid-season side-dressing. Silva (1984) showed that a 10% seed-cotton yield improvement obtained through basal K application was further increased by 40% more than the non-fertilized control by splitting the K dose. In fact, mid-season side-dressing with K fertilizers has become a common practice in the 'Cotton Belt' in the US (Oosterhuis, 2002). Despite this, the increase in yields in set-I of the present study was predominantly linked to the basal K dose, whereas the split application provided only a marginal contribution. The cost of multiple K side-dressings during the crop season compared with the benefit in yield might raise economic debates.

Foliar K applications offer the opportunity of correcting deficiencies quickly and efficiently, especially late in the season when soil contribution of K may not be effective or possible (Oosterhuis, 2002). Foliar feeding of a nutrient may actually promote root absorption of the same nutrient (Keino *et al.*, 1999). In the present study, foliar applications of K_2SO_4 (2%) gave rise to 24-38% yield increases, as compared to the non-fertilized control, and depending on the basal K dose (Fig. 2). This increase was comparable to that obtained by the split soil applications (Fig. 1). The major effects of soil-applied K were manifested in plant development and subsequent increase in the number of intact fruit, having only a small influence on boll weight (Tables 3 and 4). In the foliar applications, however, boll size increased significantly, while plant structure and other yield components were less affected (Tables 5 and 6). Fruit retention, an important indicator of the cotton plant fitness as well as a yield factor, was similarly improved by soil or foliar K application (Tables 4 and 6). These results are in agreement with previous studies linking a steady K-soil availability with improved plant development and yielding capacity (Mullins *et al.*, 1997; Pettigrew *et al.*, 2005). Supported by recent studies in cotton (Brar *et al.*, 2008; Sawan *et al.*, 2008; Kaur *et al.*, 2011; Dewdar and Rady 2013; Sekhon and Singh 2013), these results also demonstrate the ability of foliar K applications to correct temporary deficiencies directly where and when required, obtaining maximum benefits of soil with supplemental foliar-K applications.

For technical constraints, the two experimental sets were carried out separately, in neighboring fields, and therefore analyzed individually. Nevertheless, results were quite similar in both years. Merging the two sets provided a better view of the results, particularly regarding possible differences between the two approaches, e.g. split soil-applied dose vs. the basal and foliar K application (Fig. 3). The advantage of the second approach is quite obvious; foliar applications of 2% K_2SO_4 produced 30 and 40% increases in seed-cotton yield, while the respective split soil-applied doses of 100 and 200 kg ha^{-1} resulted in only about 20 and 33% more yield, compared to non-fertilized controls, respectively. Thus, in addition to being significantly less expensive than the split soil application, the combined basal and foliar K applications provide 10-15% more yield.

In conclusion, supplemental K is a prerequisite for cotton grown on poor arid soils, as it ensures sufficient plant growth and development and subsequently increases seed-cotton yields by considerable levels. However, basal K application alone would not fulfil the cotton yield potential due to the diminishing available K in the soil in relation to the increasing K demands during the critical period of boll set and development. Splitting the annual dose to 2-4 mid-season side-dress applications significantly improved seed-cotton yield. Nevertheless, a basal K application,

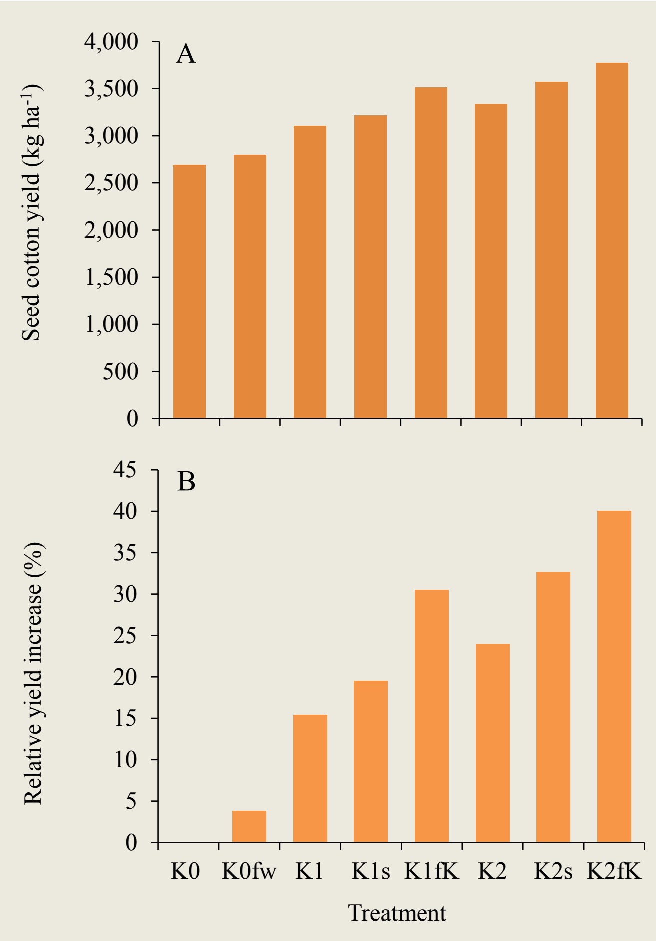

Fig. 3. A comparative analysis of the absolute (A) and relative (B) seed-cotton yields of the two experimental sets. Columns represent the mean yearly seed-cotton yield over 2014 and 2015. For detailed description of treatments refer to Table 2.

followed by four foliar sprays of 2% K_2SO_4 during the season resulted in the highest yield. These results demonstrate the relevance of matching plant K status to the dynamic crop demands for this nutrient, particularly in modern transgenic cotton cultivars. Further improvements in nutrient use efficiency in cotton would require the consideration of technologies enabling the monitoring of petiole K status during the season (Roberts *et al.*, 1993; Oosterhuis, 2002), as well as more precise delivery of water and nutrients to the plant roots, e.g., fertigation.

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Regional activities/WANA

Research Findings

Brazilian rainfed agriculture in the Cerrado, West Bahia State: No-Tillage production system. Photo by T. Wiendl.

Potassium Fertilizer Application Methods in a Medium Texture Soil in Western Bahia State, Brazil

Wiendl, T.A.[1], and I. Döwich[2]

Abstract

In recent decades, the Brazilian field crops industry has been expanding into the Cerrado region, which has poor sandy oxisoils. In addition to heavy lime and phosphorus (P) applications, potassium (K) requirements are also difficult to meet. The objectives of this long-term (2005/06-2014/15) study were to assess application methods, timing, and doses of K applied to no-tillage soybean-maize rotation systems, and generate information supporting the establishment of new criteria for K fertilization on light soils in Western Bahia. The results shared here refer to the soybean crop cultivated during the 2014/15 harvest season. The experiment included eight treatments that were applied on plots throughout the nine years, as follows: non-fertilized control; P fertilized control; low, basal K dose; farmers' practice (N-P-K, 2-15-20); high, basal K; high, top-dressed K; high, split K dose;

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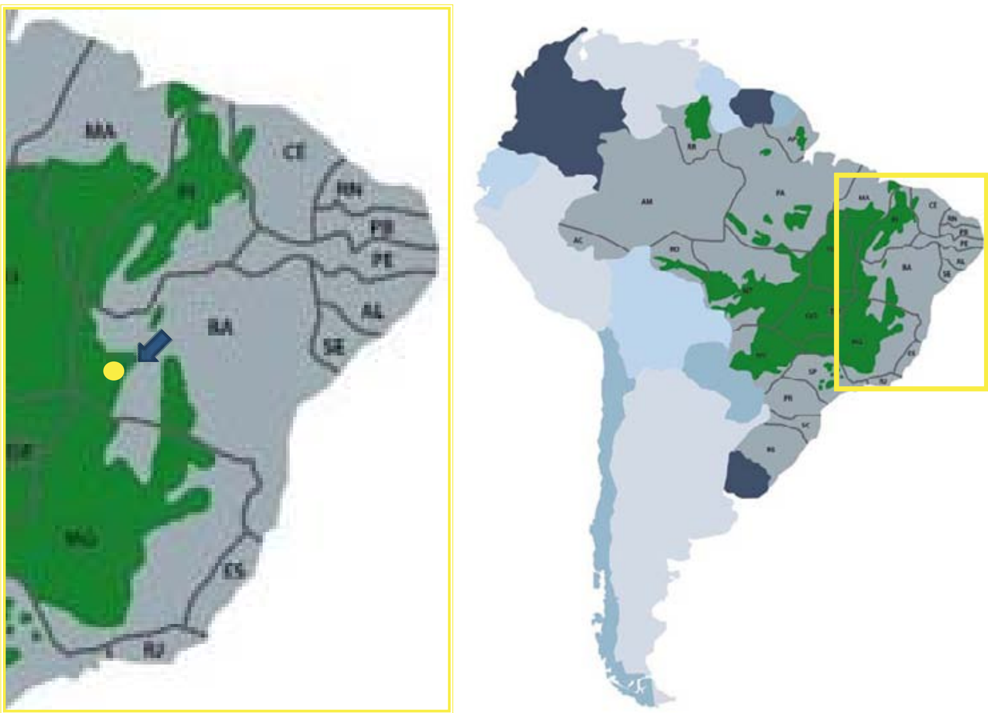
and farmers' practice and additional top-dressed K dose, with seasonal K doses of 0, 0, 60, 83, 120, 120, 120, and 203 kg K_2O ha^{-1}, respectively. All treatments, excluding the non-fertilized control, received a basal P dose of 62.3 (farmers' practices) or 96 kg P_2O_5 ha^{-1}. Soybean yields from the controls varied between 750-900 kg ha^{-1}, whereas K-applied treatments yielded 3,300-3,650 kg ha^{-1}, with no significant differences between application regimes or doses. It is concluded that K supply is essential for sustainable soybean production, as poor sandy oxisoils cannot meet soybean K demands. Degrading straw residues alone fails to support K crop requirements for high yields. When a high K dose was applied as basal, top-dress or split to two applications, K uptake remained constant at 60-70 kg K_2O ha^{-1}, K retrieval from the applied dose was less than 40-45 kg K_2O ha^{-1}, and the rest was wasted. One suggestion is to consider splitting K application when higher doses are used in order to benefit from higher pH, OM and K_2O soil content, and lower Al+H.

Introduction

Brazil's field crops industry is continuously expanding. Rotation of maize (*Zea mays*) and soybeans (*Glycine max* (L.) Merr.) is very common in Brazil, having significant economic importance. During recent decades, maize and soybean production in the Cerrado region has been challenged by poor sandy soils. Most soils of the Cerrado are highly weathered, presenting serious limitations for crop production in terms of low natural soil fertility. These soils are acidic and have low availability of nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), boron (B), copper (Cu), molybdenum (Mo) and zinc (Zn). Such soils are also highly saturated in aluminum (Al^{3+}), which makes them toxic to most crop plants (Lopes *et al*., 2012). Oxisoil (Latossolo Amarelo) and typical sandy soils (Neossolo Quartzarênico) that are predominant in the agricultural region of Western Bahia, in the Cerrado region, are characterized by low fertility and low organic matter (Silva *et al*., 1994).

In Brazil, sandy and medium texture soils have been increasingly steered to intensive soybean, maize and cotton cropping systems. A major challenge of these production systems is the establishment of an efficient management of fertilizers. Due to its major role in maize and soybean production (Pettigrew, 2008), and its interactions and mobility in the soil profile, K in particular requires special focus. KCl, the most common K fertilizer in Brazilian agriculture, is highly soluble and mobile in Cerrado soils. Therefore, the risk of rapid K leaching and consequent loss of this nutrient below the crop rhizosphere is very high. A factor that is usually perceived to contribute to K loss in cultivated crops in these soils is that most K fertilization is made through basal application of NPK formulations, at sowing. The most common NPK fertilizers employed use the formulations 02-20-18 (50%), 08-20-18 (19%) and 02-23-10 (12%) (COMIGO, 2007). These composite fertilizers are usually applied directly to the furrow, creating a temporary but extremely ion-concentrated environment in the proximity of the germinating seed and young plant. This practice might lead to several undesirable processes and subsequently limit crop development and yield: 1) chloride (Cl^-) toxicity during crop establishment, endangering the initial vegetative stages of the plant (Moraes and Menezes, 2003); 2) inhibited root expansion and a consequent poor ability of the root system to explore the soil profile (Roder *et al*., 1989); 3) imbalanced cationic ratios (K/Ca and K/Mg) in the soil sorption complex (Muñoz-Hernandez and Silveira, 1998).

Another aspect of K nutrition is the underestimated K availability in soil sampled from no-tillage fields. The straw that remains in the soil after the preceding crop may hold large quantity of



Map 1. South America and distribution of the Cerrado region in Brazil (marked in green). Site of the experiment is located near Luis Eduardo Magalhães city, Western Bahia State (marked with yellow circle). *Source:* Adapted from Lopes and Guilherme, 1994. The Brazilian Cerrado is 2.04 million km², 23 percent of the total area of Brazil.

nutrients including K, which can be released rapidly into the soil during the first rains (Rosolem *et al*., 2003; Benites *et al*., 2010). Since straw K content is often ignored, the fertilizer recommendation may often be overestimated.

This long-term (2005/06-2014/15) study aimed to assess application methods, timing, and doses of K applied to no-tillage soybean maize rotation systems, and generate information supporting the establishment of new criteria for K fertilization on light soils in Western Bahia. The results shared here refer to the soybean crop cultivated during the 2014/15 harvest season.

Material and methods

The experiment was conducted in Alvorada Farm, located in the Luis Eduardo Magalhães city, Western Bahia State, Brazil (Map 1), in the period of 2005/06-2014/15. The climate is classified as Aw (Köppen classification), with a yearly average temperature and rainfall of 24°C and 1,200 mm, respectively. There are two well defined seasons: a rainy season between November and March with 94% of the yearly total rainfall, and a dry season between April and September.

The soil of the experimental area was characterized as Oxisoil (Latossolo Amarelo), with sandy-loam texture at the upper horizon of the soil profile (0-25 cm depth), shifting to sandy clay loam at the deeper horizons (Table 1a). Acidity, which is generally high, increases significantly below 25 cm from soil surface (Table 1b). Most soil fertility parameters, such as cation exchange rate (CEC) (Table 1b) as well as organic matter, N, and P contents (Table 1c) considerably decline below horizons Ap. In fact, the horizon B of the native soil seems too compact, poor, and acidic to support plant roots. The area was cropped in annual rotation with soybeans and maize.

Table 1a. Pre-experiment soil texture and structure at horizons Ap1 to Bw3 of the soil profile.

Horizon	Depth	Soil textural composition (particle size, mm)					Clay dispersed in water	Flocculation	Silt/clay
		Gravel 20-2	Coarse sand 2-0.2	Fine sand 0.2-0.05	Silt 0.05-0.002	Clay <0.002			
	-----cm-----	*g kg⁻¹*						*---------%---------*	
Ap1	0-5	0	422	398	60	120	80	33	0.5
Ap2	6-12	0	432	392	35	141	60	57	0.25
AB	12-25	0	422	382	35	161	120	25	0.22
Bw1	25-50	0	426	341	32	201	60	70	0.16
Bw2	50-65	0	386	322	51	241	0	100	0.21
Bw3	>65	0	372	318	69	241	0	100	0.29

Table 1b. Pre-experiment soil acidity and adsorptive complex characteristics at horizons Ap1 to Bw3 of the soil profile.

Horiz.	pH (1:2.5)		Adsorptive complex							
	Water	KCl 1N	Ca^{2+}	Mg^{2+}	K^+	Na^+	Base satur. (sum)	Al^{3+}	H^+	CEC
			$cmol_c\ kg^{-1}$							
Ap1	6.3	5.3	1.7	1.0	0.13	0.01	2.8	0.1	2.2	5.1
Ap2	6.1	4.9	0.9	0.5	0.17	0.01	1.6	0.1	1.7	3.4
AB	6.1	4.8	0.6	0.5	0.05	0.01	1.2	0	1.8	3.0
Bw1	5.2	4.3	0.6		0.05	0.01	0.7	0.2	1.9	2.8
Bw2	4.7	4.3	0.4		0.02	0.01	0.4	0.3	2.0	2.7
Bw3	5.1	4.6	0.5		0.01	0.01	0.5	0.1	1.7	2.3

Table 1c. Organic carbon, N, and P contents in the pre-experiment soil profile.

Horiz.	Organic carbon	N	C/N	Available P
	g kg⁻¹			*mg kg⁻¹*
Ap1	9.2	1.0	9	24
Ap2	4.9	0.5	10	9
AB	3.7	0.4	9	1
Bw1	3.3	0.4	8	1
Bw2	3.1	0.3	10	1
Bw3	3.2	0.3	11	1

The experiment was established in the 2005/06 season with soybeans as the first crop of a yearly seasonal rotation with maize. The experiment comprised of eight treatments - fertilization practices - that were consistently preserved in fixed plots throughout the nine years of the trial. These included two controls, a farmers' practice, four practices with differing K dose or application time, and another farmers' practice fortified with an additional late K application. A detailed description of the treatments is given in Table 2.

The experimental design consisted of two blocks, each comprising eight 250 x 18 m plots, with one plot per treatment. Soil sampling was carried out in 2014, right

Table 2. A detailed description of eight fertilization practices (treatments) carried out during the long-term experiment from 2005/6-2014/15. The order of treatments follows an ascending K dose and timing of application.

Treatment	N	P_2O_5	K_2O	Commercial fertilizer	Time of application	Notes
	--------kg ha^{-1}--------					
Pr1	0	0	0			Non-fertilized control
Pr2	0	96	0	SSP 300 STP 100	P - basal	P fertilized control
Pr3	0	96	60	SSP 300 STP 100 KCl 100	P - basal K - top dressing	Low K dose
Pr4	8.3	62.3	83	2-15-20, 415	Basal	Farmers' practice
Pr5	0	96	120	SSP 300 STP 100 KCl 200	P - basal K - basal	High, basal K dose
Pr6	0	96	120	SSP 300 STP 100 KCl 200	P - basal K - top dressing	High, late K dose
Pr7	0	96	120	SSP 300 STP 100 KCl 200	P - basal K - 50% basal, and 50% top dressing	Split K dose
Pr8	8.3	62.3	203	2-15-20, 415 KCl 100	Basal K - top dressing	Farmers' practice and additional K

Note: SSP: single super phosphate; STP: super triple phosphate; 2-15-20: a composite fertilizer comprising of N-P-K (%).

According the crop rotation, soybean was grown on 2014/15, the last season of the experiment. Plant density was 320,000 per ha^{-1}, with 0.50 m space between rows. Seeds were sown on a no-till system with 'boot opener' at depth of 3-4 cm at the furrow bottom. At harvest, yield was sampled from each experimental plot, harvested from 3 x 5 m random patches (Photo 2), avoiding border effects, at three replications. Grain yield was calibrated to 14% humidity.

Potassium Use Efficiency (KUE) is defined as "the amount of increase in grain yield per unit of fertilizer nutrient applied" (Barber, 1976; Fageria and Baligar, 2001; Fageria and Baligar, 2005). The following formula was employed to calculate KUE:

$$KUE = (GY_F - GY_{NF})/K_{DOSE}$$

Where:
KUE = Potassium use efficiency (kg kg^{-1});
GY_F = treatment grain yield (kg ha^{-1});
GY_{NF} = grain yield of non-fertilized control (kg ha^{-1});
K_{DOSE} = applied K quantity (kg K_2O ha^{-1}).

after the last maize harvest. Soil was collected in the internal part of each plot to avoid border effects. Soil samples were from 2.75 m deep trenches dug perpendicularly to the planting lines (Photo 1). The samples were sieved in a 2 mm sieve after being dried in the air. Chemical characteristics were assessed according to Embrapa methodologies (1997).

This calculation is valid for treatments Pr3-Pr8 that were fertilized with K. Pr1 served as the relevant non-fertilized control.

Statistical analyses included the ANOVA F-test (5%) for soybeans grain yield, and T test ($p < 0.05$) to compare the means between treatments. All statistical analyses were performed using the 'Assistat' version 7.7 beta.

Photo 1. Trench opened for soil sampling. Photo by authors.

Photo 2. Overview of harvested soybean from treatment Pr1. Photo by authors.

Results and discussion

Genetic and physiological improvements as well as amended irrigation practices brought about a steady increase in soybeans yields, from less than 500 kg ha^{-1} in 1924 to 8,000 kg ha^{-1} towards the end of the 20th century (Specht *et al*., 1999; Grassini *et al*., 2014; Koester *et al*., 2014). Recent estimations of soybean's potential yield range from 7,000 to 11,000 kg ha^{-1} (van Roekel *et al*., 2015). This potential is characterized by physiological traits and environmental factors impacting seed number and average mass per seed. However, the realization of soybean's yield potential largely depends on local, often transient conditions, and on agronomic practices. Thus, the USA average soybean yield in 2015 was much smaller than the estimated potential, at about 3,200 kg ha^{-1} (Indexmundi, 2015). In Brazil, the second largest world soybean producer, with a mean yield of 3,000 kg ha^{-1}, soil fertility appears to be the major factor limiting further yield increases.

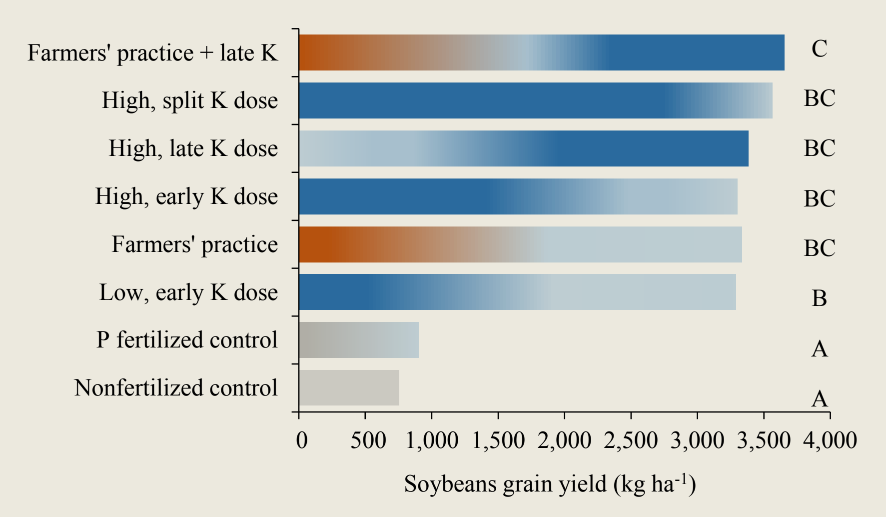


Fig. 1. Soybean grain yield from the 2014/15 harvest season, as affected by the different fertilization regimes. Different letters indicate the statistical difference at p <1% according to the T-test.

In the present study, soil analyses executed after nine years of experiment indicated that the non-fertilized control treatment (Pr1), did not differ significantly from most other treatments, in regard to mineral contents and other assessed characteristics (Table 3). This finding may suggest that this soil can provide very poor nutritional support to crop plants, as the yields obtained by the non-fertilized controls were much lower than those of the fertilized treatments (Fig. 1). Under no fertilization, the poor cropping systems maintain a certain minimum balance with the soil weathering rate, so over-exploiting symptoms do not occur even after nine years. In counterpart, treatments with high fertilizer dose produced significantly higher grain yields (Fig. 1; Photo 3), suggesting complete crop dependence on fertilizer supplies. The effects of the different fertilization regimes on soil fertility parameters are unequivocal (Table 3). However, several

Photo 3. General overview of treatment Pr5 (96 kg P_2O_5 and basal 120 kg K_2O) (left), and treatment Pr2 (96 kg P_2O_5) (right). Photo by authors.

Table 3a. Soil analyses at 0-20 cm depth, following eight years of fixed fertilization regimes: pH, OM, macronutrients, CEC, and base saturation.

Treatment		pH	OM	P	K	Ca	Mg	CEC	S	Base Satur.
			%	------------------g m^{-3}------------------			--------cmol$_c$ L^{-1}--------		g m^{-3}	%
Pr1	Nonfertilized control	4.97	1.72	26.82	22.05	1.65	0.57	4.36	5.07	52.06
Pr2	P fertilized control	5.08	2.03	29.93	21.00	1.47	0.52	3.95	5.55	51.13
Pr3	Low, early K dose	5.27	1.98	30.22	48.23	1.93	0.60	4.47	5.38	59.18
Pr4	Farmers' practice	5.31	1.87	22.22	33.23	2.05	0.73	4.70	6.28	60.47
Pr5	High, early K dose	4.71	1.70	40.47	63.83	1.18	0.48	4.25	4.33	42.68
Pr6	High, late K dose	5.03	1.83	31.03	29.07	1.75	0.58	4.42	5.68	54.19
Pr7	High, split K dose	5.28	2.07	31.70	66.60	1.93	0.63	4.49	5.65	60.45
Pr8	Farmers' practice and late K	4.83	1.60	20.77	23.53	1.50	0.53	4.34	4.92	47.94

Table 3b. Soil micronutrients content at 0-20 cm depth, following eight years of fixed fertilization regimes.

Treatment		Al	H+Al	Zn	B	Cu ³	Fe	Mn
		-----------$cmol_c\ L^{-1}$-----------		-----------$g\ m^{-3}$-----------				
Pr1	Nonfertilized control	0	2.08	1.65	0.24	0.91	61.32	1.35
Pr2	P fertilized control	0	1.92	1.70	0.18	0.89	60.62	1.48
Pr3	Low, early K dose	0	1.82	1.92	0.23	0.92	58.08	1.85
Pr4	Farmers' practice	0	1.83	1.82	0.22	0.90	57.87	1.67
Pr5	High, early K dose	0.12	2.42	1.48	0.12	0.83	62.25	1.25
Pr6	High, late K dose	0	2.02	1.80	0.23	0.94	60.87	1.48
Pr7	High, split K dose	0	1.75	1.87	0.18	0.86	57.15	1.65
Pr8	Farmers' practice and late K	0	2.25	1.40	0.16	0.77	62.02	1.15

trends could be observed. Among the treatments with a high K dose (Pr5-Pr8), the practice of split K application (Pr7) seemed to better preserve soil fertility; values of pH, and organic matter (OM), K, and Ca contents were the highest (Table 3a). Also, the risk of Al toxicity, as indicated by the H+Al value (Table 3b), was the lowest. On the contrary, a single application of a high K dose increased soil acidity, reduced the contents of OM and Ca, reduced base saturation values, and increased the risk of Al toxicity. These phenomenon were not observed with the low K dose treatment (Pr3).

Interestingly, P application did not have any significant influence on soybean grain yield, when applied alone (Fig. 1). On the contrary, substantial yield increases were obtained in response to any K application, compared to the controls (Pr1 and Pr2). Furthermore, while the yield response to the lower K dose (60 kg K_2O ha^{-1}) was dramatic, 337% more than the control, a double dose gave rise to a much smaller further impact.

Illustrating soybean yield response to K application dose (Fig. 2A) shows that between K doses of 60 to 213 kg K_2O ha^{-1}, the marginal grain production of K is extremely poor, 2.56 kg kg^{-1}. This contribution, whether significant, does not justify any K input within this dose range. Moreover, when inputs exceeded 60 kg K_2O ha^{-1}, KUE declined according to a power function (Fig. 2B), also indicating the ineptness of K application at a higher dose under the terms of the present study. However, in spite of the remarkable surge in soybean grain yield in response to 60 kg K_2O ha^{-1}, the yield response function to K dose below that level is obscure. The significant discrepancy between the yield responses to the lower and higher K dose ranges raise possible hypotheses for further research.

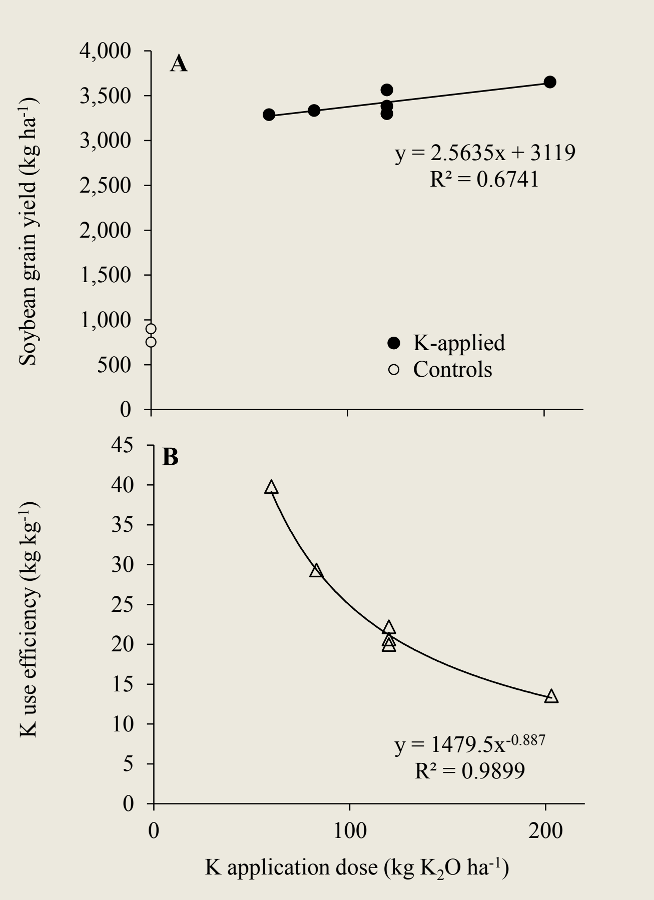


Fig. 2. Soybean yield (A) and KUE (B) as functions of K application dose.

According to Liebig's law, plant growth and development would be limited by the least available nutrient. Somewhere below the dose of 60 kg K_2O ha^{-1}, K is obviously the limiting nutrient. Is there another nutrient that might have become restrictive above that K dose? Nitrogen can be excluded from the list of candidates as when supplied as part of the farmers' practice (Pr4 and Pr8) it did not yield any exceptional results. In addition it is widely reported that *Bradyrhizobium spp*, which is associated with the crop roots, is able to provide the necessary N for the crop (Mendes *et al*., 2008; Aratani *et al*., 2008; Embrapa Soja, 2011). Also assuming that the high supplemental P doses applied to treatments Pr2-Pr8 were available and effective, this nutrient does not appear to be a limiting factor. There is no other evidence in the data provided here that could support a hypothesis regarding any macro- or micronutrient other than K, which might limit soybean yield.

Table 4. Potassium supply vs. uptake by soybean grain yield.

Treatment	K application regime	K application dose	K uptake by soybean grain yield
		---------------------*kg K_2O ha^{-1}*	---------------------
Pr1	Non-fertilized control	0	15.1
Pr2	P fertilized control	0	18.0
Pr3	Low, early K dose	60	65.8
Pr4	Farmers' practice	83	66.7
Pr5	High, early K dose	120	66.0
Pr6	High, late K dose	120	67.7
Pr7	High, split K dose	120	71.3
Pr8	Farmers' practice and late K	203	73.0

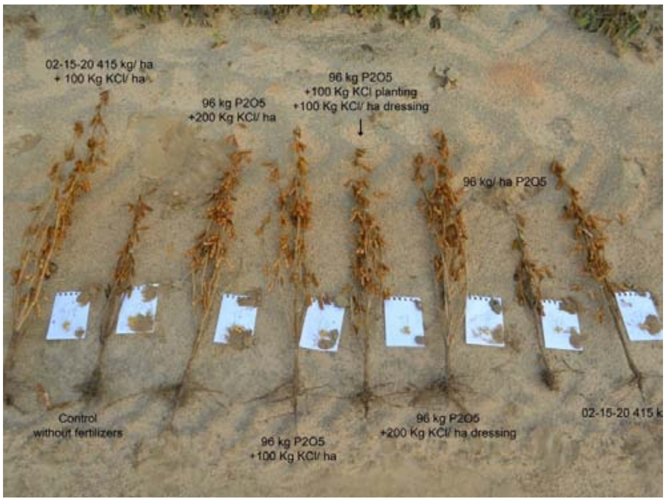


Photo 4. Effects of fertilization practice on plant size and reproductive status, demonstrated by representative plant samples at harvest. Photo by authors.

The idea that K availability might limit soybeans growth, development, and yield, despite the high doses applied, requires further thought. Soybean K demands are functions of plant growth and biomass, but they increase significantly during pod set and grain filling (Pettigrew, 2008). Considering removal of 20 kg K_2O ha^{-1} as verified by Oliveira Jr. *et al.* (2013), while checking K balance in soybean crop, the Cerrado soil was not able to supply more than 15-18 kg K_2O ha^{-1} (Table 4). Indeed, severe K deficiency symptoms were observed in plants of Pr1 and Pr2, such as empty pods, malformed seeds, and green leaves at harvest (Photo 4). As already shown for maize production (Wander *et al*., 2015), the extremely poor yields obtained under practices lacking K application do not allow for any sustainable long-term production system. Nevertheless, the significant yield increase obtained in response to K application, is unsatisfactory due to the substantial gap from an achievable yield potential, and moreover, the clear inefficiency of K doses above the 60 kg K_2O ha^{-1} threshold to produce further yield increase.

In more fertile soils, with a higher CEC range, a single basal application of the seasonal K dose should establish an adequate K reserve available throughout the season (Clover and Mallarino, 2013; IPI, 2014). Here, when a high K dose was applied as basal, top-dress or split to two applications, K uptake remained constant at 60-70 kg K_2O ha^{-1} (Table 4), some of which may be attributed to nutrients released from straw (Wilhelm *et al*., 1986; Silva *et al*., 1994). Thus, K retrieval from the applied dose was less than 40-45 kg K_2O ha^{-1}, and the rest vanished below the rhizosphere. This interpretation suggests that soybean plants grown on sandy acidic soils have a short opportunity to exploit K fertilizer whenever applied, before the latter is leached away by rainfall. Splitting the annual K dose into several applications may provide the crop with more opportunities to utilize the nutrient. This way, root expansion might improve and K retrieval may increase. Additionally, precise nutrient delivery, at the right time and quantity, is more likely to be attained. Thus, it becomes more likely that soybean yield will be significantly more responsive to further K doses. Alternatively, foliar K applications may be considered. This approach was tested experimentally and seemed promising (Garcia and Hanway, 1976) but provided ambiguous results when tested on fertile soils (Poole *et al*., 1983; Haq and Mallarino, 1998). Yet, foliar nutrient application can be beneficial and deserves careful consideration in soybean grown on poor sandy oxisoils.

Conclusions

Spreading in recent decades from the South States to Southwest Bahia, the successful maize-soybean industry also brought the paradigm that 'fertilization works for any situation'. It has been postulated that a generous application of lime and P is key for success in the region as this worked elsewhere. However, K supply is essential for sustainable soybean production, as the poor sandy oxisoils cannot meet soybean K demands. Degrading straw residues alone fail to support K crop requirements for high yields. When a high K dose was applied as basal, top-dress or split to two applications, K uptake remained constant at 60-70 kg K_2O ha^{-1}, K retrieval from the applied dose was less than 40-45 kg K_2O ha^{-1}, and the rest was wasted. One suggestion is to consider splitting the K application when higher doses are used in order to benefit from higher pH, OM and K_2O soil content, and lower Al+H.

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Regional activities/Latin America

Research Findings

Measuring results from cassava field experiment in Kalipare, East Java, Indonesia. Photo by IPI.

Response of Cassava (*Manihot esculenta* Crantz.) to Potassium Application on Various Soil Types in East and Central Java, Indonesia

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Abstract

East and Central Java are among the major cassava producers in Indonesia. Assuming that potassium (K) availability is a limiting factor for cassava cropping under the given conditions, the effects of K fertilizer at six seasonal doses (0, 30, 60, 90, 120, and 180 kg K_2O ha^{-1}) applied twice (one and three months after planting), and one treatment attributed to farmers' practice, were examined at four locations: Malang, Tulungagung, Wonogiri, and Karanganyar districts. The soils of the different regions vary from neutral (pH 6.2-6.8) silt loam to acid (pH 4.6-5.1) clay, and from high to very low exchangeable K (exch-K) contents. All K fertilizer treatments were combined with nitrogen (N) - 135 kg N ha^{-1}, and phosphorus (P) fertilizers - 36 kg P_2O_5 ha^{-1}, except one treatment with 200 kg N ha^{-1}, and 60 kg P_2O_5 ha^{-1}. Urea (46% N), SP36 (36 kg P_2O_5), and KCl (60% K_2O) were used as

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the source of N, P, and K fertilizer, respectively. Potassium doses hardly affected soil properties at harvest. Crop response to K dose was small to negligible at three sites, and significant only at Tulungagung, where tuber yield increased from 19 to 35 Mg ha^{-1}. The highest yields, 40-50 Mg ha^{-1}, were obtained at Malang on a rather fertile soil, but this is still below the recognized cassava yield potential. Nevertheless, some evidence indicates that there is considerable potential for K fertilization and other means to improve cassava production in these regions. The major problem of K nutrition, common to all four regions at varying significance, seemed to be the rapid depletion of the soluble K pool, including the applied fertilizer, from the rhizosphere before reaching the uptake zone of the roots. The tropical precipitation regime that promotes soil weathering and nutrient leaching must be taken into account. Measures such as division of the seasonal K dose into many frequent applications and supplementation of composted organic matter in order to enhance soil fertility and cassava crop performance are discussed.

Introduction

Cassava (*Manihot esculenta* Crantz) has multiple end-uses such as food, animal feed, and raw material for many industries. Hence, demand for this produce is likely to increase. In Indonesia, cassava has a strategic role for food security because 64% of total cassava consumption is for food. Recently, studies have been carried out to develop cassava as a raw material for biofuel.

Indonesia is the fourth cassava producer in the world after Brazil, Nigeria and Thailand. Sutyorini and Waryanto (2013) showed that during years 2009-2013, the harvested area of cassava declined by 3% (from 1.18 million ha in 2009 to 1.14 million ha in 2013), but the productivity increased by 12%, from 19.4 to 21.7 Mg ha^{-1}. In 2013, the cassava area in East and Central Java was 16% and 15% of the national area, respectively, with an average productivity of 23 Mg ha^{-1}. In East and Central Java, the cassava area declined by 15% during 2009-2013, however, the yields increased by 25% and 3%, respectively.

By using appropriate cultural practices, cassava yield could attain 25-40 Mg ha^{-1} (Wargiono *et al.* 2006). Taufiq *et al.* (2009) reported even higher yields of 63 Mg ha^{-1}, when 70, 30, and 115 kg ha^{-1} of nitrogen (N), P_2O_5, and K_2O, respectively, were applied. The amount of nutrient uptake by cassava is high. Howeler (1981) found that with a fresh tuber yield of 21 Mg ha^{-1} cassava absorbed 87, 37.6, and 117 kg ha^{-1} of N, phosphorus (P), and potassium (K), respectively. Wargiono *et al.* (2006) reported that, at a yield level of 30 Mg ha^{-1}, cassava absorbed 147.6, 20.7, and 148.8 kg ha^{-1} of N, P and K, respectively. Amanullah *et al.* (2007) showed that fresh tuber yields ranging from 20-35 Mg ha^{-1} required quite stable rates of about 6, 0.75, and 6 kg of N, P, and K, respectively, per Mg ha^{-1}. These data revealed that K uptake is as high as that of N. Putthacharoen *et al.* (1998) showed that K removed by cassava in the harvested product was as high as K removal by maize and peanut.

Cassava can be planted in various agroecosystems. The crop is adaptable to dry condition as well as marginal soil fertility. Lampung, East Java, and Central Java provinces are the main cassava producing regions in Indonesia. Soil type in the main area was dominated by Alfisol, Ultisol, and Inceptisol, which commonly had marginal soil fertility (Suryana, 2007). Until 15 years ago, the majority of cassava plantations in East and Central Java were cultivated as a monocrop. Nevertheless, due to low or unstable prices, farmers quite often tended to intercrop cassava with maize, upland rice, or with peanut.

The positive response of cassava yields to K application, particularly on poor soils, below the critical threshold of exchangeable K^+ at 0.15 meq per 100 g soil (Howeler, 1981), has been well documented (Maduakor, 1997; Suyamto, 1998; Nguyen *et al.*, 2002; Ispandi and Munip, 2005). Also, the significant reduction in cassava yield in the absence of K fertilization during five consecutive cropping years was clearly demonstrated (El-Sharkawy and Cadavid, 2000). Furthermore, this yield reduction was considerably restrained by K application. Nevertheless, cassava response to fertilizer application may largely depend on local soil properties and on farmers' practices. In the past, the majority of Indonesian cassava growers did not apply any fertilizer (FAO, 2005). Those who did, used to apply high levels of N, less P, and no K fertilizer. Almost all of cassava biomass is taken away from the field at harvest, thus soil fertility, especially K, is rapidly degraded. Therefore, it is important to optimize the K dose to the local soil properties and cassava plant requirements.

The objectives of the present three-year (2011/12 - 2013/14) study were: to examine cassava response to elevated K dose on four typical soils of East and Central Java, Indonesia; to demonstrate the contribution of K application to the cassava yield, as compared to the common K-deficient practices; and, to create awareness among farmers and extension workers on balanced nutrient management and cost:benefit ratio analyses. This paper focuses on the results obtained during the last two or three consecutive years of the experiment in relation to the previous years' results.

Materials and methods

Location and Planting Date

An on-farm trial was conducted at four sites (Map 1):

1. Sukowilangun village, Kalipare sub-district, Malang district, East Java Province (8°11'03" S, 112°26'51" E; 296 m asl). Planting date: 12 Nov, 2013. Harvest: 10 Sep, 2014. The trial on this site lasted three consecutive years with constant treatments and layout.

2. Ngrejo village, Tanggunggunung sub-district, Tulungagung district, East Java Province (8°14'08" S, 111°53'04" E; 198 m asl). Planting date: 19 Nov, 2013. Harvest: 1 Sep, 2014. The trial on this site lasted three consecutive years with constant treatments and layout.

3. Molokokulon village, Ngadirojo sub-district, Wonogiri district (7°47'26.23'' S, 111°0'42.97" E; 325 m asl), Central Java Province. Planting date: 19 Nov, 2013. Harvest: 3 Nov, 2014. The trial in this area lasted two years, but not in the same field.

Map 1. A general map of Indonesia (A), with the regions of experimental work in the yellow square; the four experiment sites in Malang (1), Tulungagung (2), Wonogiri (3), and Karanganyar (4) districts in East and Central Java, Indonesia (B); Köppen-Geiger climate classification of Java: Eqatorial (Af, dark blue), Monsoon (Am, blue), and Tropical savanna (Aw, light blue). Yellow circles indicate experiment sites (C). *Sources:* Google Maps (A and B); derived from: World Koppen Classification.Svg, https://creativecommons.org/compatiblelicenses/by-sa/4.0/# (C).

4. Jatipuro village, Jatipuro sub-district, Karanganyar district, Central Java Province (7º44'31.22" S, 111º55'95" E; 430 m asl). Planting date: 20 Nov, 2013. Harvest: 5 Nov, 2014. The trial on this site lasted two consecutive years with constant treatments and layout.

Climate

The climate of Java island, Indonesia is tropical, however, significant differences occur between regions (Map 1C), particularly regarding precipitation (Fig. 1).

In all four regions, there is a clear distinction between the rainy (November - April) and the dry (May - October) seasons. Malang is the driest district, with about 1,300 mm yearly. The Central Java districts have significantly more rain, with more than 2,100 mm a year, while Tulungagung is intermediate with about 1,640 mm a year (Fig. 1).

Soil characteristics

Soil properties at the four experimental sites at the beginning of the last growing season are presented in Table 1. Soil texture differed significantly between sites, with silt-loam in Kalipare-Malang, light clay in Tulungagung, silty clay loam to clay in Wonogiri, and heavy clay in Karanganyar. Soil pH was slightly acidic to nearly neutral in the East Java sites, and quite acidic in the Central Java sites, but in all cases within the range suitable for cassava (4.5 - 7.0), as classified by Howeler (2002). Organic Carbon (C) and total N content were very low at all sites even in the topsoil layer, indicating that addition of organic matter and N fertilizer might have a positive effect on cassava growth. This was the reason why farmers usually applied high rates of N fertilizer. Critical levels of P and K for cassava were 8 ppm P (18 ppm P_2O_5) and 0.15 meq K 100 g^{-1} (Howeler, 1981). Phosphorous availability in the topsoil and in the subsoil layer in the East Java sites was high, except in the subsoil layer at Tulungagung. On the contrary, in the Central Java sites, P availability was below the critical level.

Potassium availability at Malang site was high in both layers, while at Tulungagung it was just above or at the critical level in the topsoil and subsoil layers, respectively. Exchangeable K (exch-K) was high in both sites of Central Java (Table 1).

Experimental set up

The trial consisted of seven treatments that were arranged in a randomized complete block design with three replications. The treatment consisted of six rates of K fertilizer (0, 30, 60, 90, 120, 180 kg K_2O ha^{-1}), and one treatment representing local farmers' practice. Detailed descriptions of the treatments at each region are given in Table 2. Urea (46% N), SP36 (36 kg P_2O_5), and KCl (60% K_2O) served as the source of N, P, and K, respectively. Nitrogen was applied one, three, and five months after planting (MAP) with proportionally 25%, 50%, and 25% of each dose, respectively. Phosphorus and K were applied one and three MAP, split into two equal doses. Phosphorus and K Fertilizers were dibbled at 7-10 cm distance (P) or next to the plant (K) and covered with soil. Fertilizer rates applied by farmers varied among individuals and sites (Table 3).

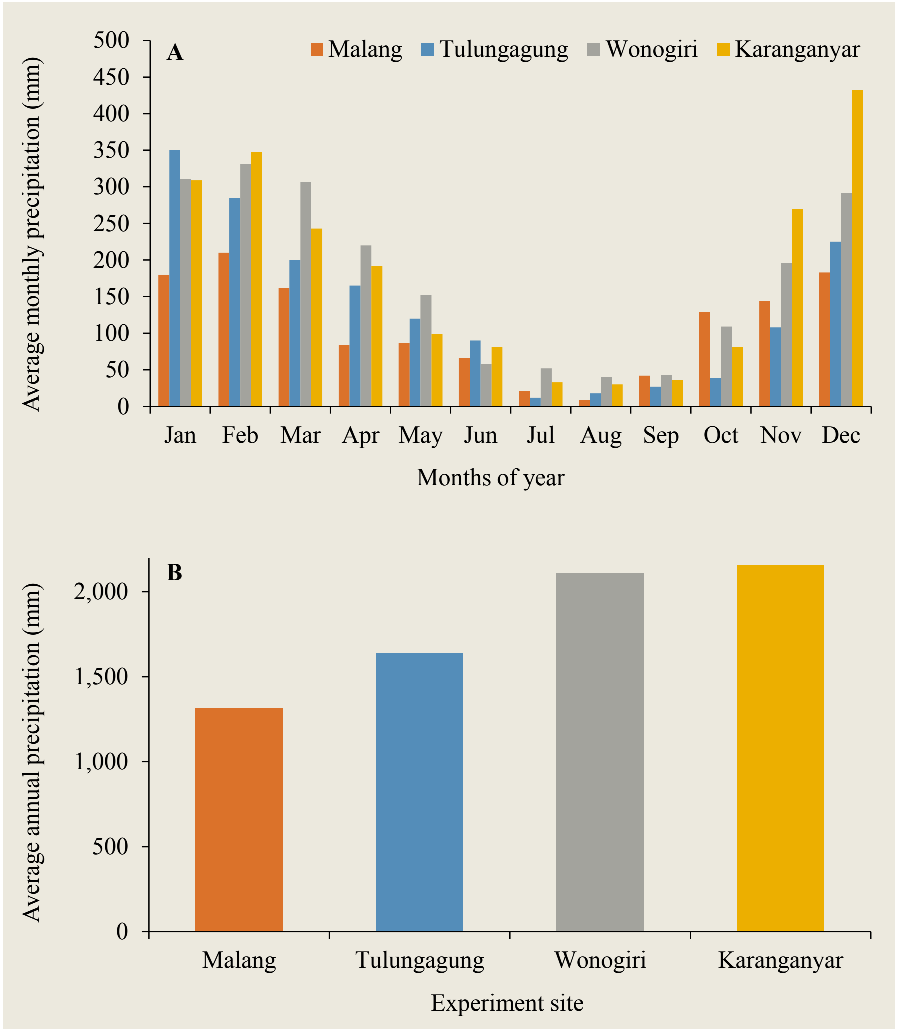

Fig. 1. Average monthly (A) and average annual (B) precipitation in the four experiment sites during years 2000-2012 in East and Central Java, Indonesia. Source: http://www.worldweatheronline.com/.

Table 1. Soil characteristics at four sites in East and Central Java at the beginning of the experiments.

Soil variables	East Java				Central Java			
	Kalipare-Malang		Tanggunggunung-Tulungagung		Ngadirojo-Wonogiri		Jatipuro-Karanganyar	
	0-20 cm	20-40 cm	0-20 cm	20-40 cm	0-20 cm	20-40 cm	0-20 cm	20-40 cm
Sand (%)	28	35	19	17	14	5	8	6
Silt (%)	55	54	39	27	54	33	39	35
Clay (%)	17	19	42	44	32	62	53	59
Texture	Silt loam	Silt loam	Clay	Clay	Silty clay loam	Clay	Clay	Clay
pH-H_2O (1:2.5)	6.6	6.8	6.2	6.2	4.6	5.0	5.1	5.2
C-organic (%)	1.09	1.39	1.67	1.66	1.46	1.40	1.06	1.08
N-total (%)	0.08	0.07	0.12	0.12	0.11	0.09	0.07	0.07
P_2O_5 (ppm)	26.9	30.3	28.5	4.78	13.5	3.20	5.05	4.78
Exch-K (cmol$^+$ kg^{-1})	0.98	0.93	0.21	0.15	0.27	0.28	0.34	0.38
Exch-Ca (cmol$^+$ kg^{-1})	2.03	13.1	28.6	29.4	2.31	2.34	3.94	2.02
Exch-Mg (cmol$^+$ kg^{-1})	3.65	3.30	7.30	7.11	0.72	0.75	0.60	0.63

Table 2. Detailed description of the experiment treatments in East and Central Java, 2013/2014.

Treatment	Fertilizer dose			
	N	P_2O_5		K_2O
		East	Central	
	-----------------------*kg ha^{-1}*-----------------------			
T_1 Farmer's practices[(1)]				
T_2	135	36	60	0
T_3	135	36	60	30
T_4	135	36	60	60
T_5	135	36	60	90
T_6	135	36	60	120
T_7	200	60	60	180

[(1)]Farmer's practices are described in Table 3.

Implementation

After soil cultivation and ridging, cassava stem cuttings (cultivar Malang-4) were planted along the ridge, spaced at 100 cm between rows and 100 cm within a row (plant density 10,000 plants ha^{-1}), excluding Kalipare site, where 125 x 100 cm (8,000 plants ha^{-1}) spacing was performed. Plot size at all sites was 5 x 8 m, except in Kalipare, which was 6.25 x 8 m (5 rows of 8 m length). Cassava was planted as a monocrop.

Bud reductions to maintain two buds per plant was carried out one MAP. Hand weeding was executed at one, two, and three MAP (depending on weed condition). Insect and disease control included the use of chemical pesticides as required. The crop was harvested at about 10 MAP.

Data collection

1. Initial soil analyses, 0-20 and 20-40 cm deep, consisted of pH (soil:water 1:2.5), P (Bray-1 extraction method), K, Ca, and Mg (extraction using 1 N NH_4-acetate pH 7), and C-organic (Kurmis method). Nine soil subsamples were taken systematically from the plots using a soil auger. The sub samples at each depth were merged and taken for analyses at the Soil and Plant Laboratory of ILETRI.
2. Leaf, stem, and tuber dry matter contents (three plants per plot) were determined at harvest. Samples were oven-dried at 105°C (for leaf and stem) and at 60°C (for tuber) till reaching a constant weight.
3. Leaf (including petiole), stem and tuber K concentration were determined at harvest.
4. Soil samples (0-20 cm deep at the root zone) were taken from each plot at harvest and K concentration was determined.
5. Fresh tuber yields were determined for each plot at harvest.
6. Tuber starch content was determined at harvest at the Food Science Laboratory of ILETRI, employing the hydrolysis method.

Table 3. Fertilizer applied in farmer's practice treatment at the four experimental sites in 2013/2014.

Site	Fertilizer rate			Equivalent to		
	Urea (46% N)	SP36 (36% P_2O_5)	Phonska 15-15-15	N	P_2O_5	K_2O
	--*kg ha^{-1}*--					
Malang	400	0	200	214	30	30
Tulungagung	500	0	200	260	30	30
Wonogiri	600	300	0	276	108	0
Karanganyar	0	0	550	83	83	83

Analysis of variance and mean comparison of collected data were performed using Statistix 3.0 statistical software and MSTAT-C.

Soil analyses at the 2013/14 harvest revealed interesting changes that had occurred in the top soil fertility during the experimental years as a result of the different K doses applied (Fig. 2). In the

East Java sites, the exch-K remained constant or even slightly decreased under K doses less than 60 kg K_2O ha^{-1}, this parameter tended to increase or remain constantly high under higher K doses. Despite any fertilization management, exch-K in Tulungagung was much lower than in Malang. In Karanganyar, Central Java, exch-K increased considerably in the first year of the experiment (2012/13) from 0.17 to 0.46 $cmol^+$ kg^{-1}, but declined in the second year to 0.15-0.29 $cmol^+$ kg^{-1} and was much less responsive to K fertilization (Fig. 2). In the second site of Central Java, Wonogiri, two different fields were employed, each in a season, thus no comparison could be made between consecutive years. However, in the 2013/14 trial, exch-K at harvest increased linearly from 0.22 to 0.66 $cmol^+$ kg^{-1}, under no K and 180 kg K_2O ha^{-1}, respectively. In 2012/13, on a much more fertile soil, exch-K ranged at 0.83-1.08 $cmol^+$ kg^{-1}, with a very slight response to K application dose.

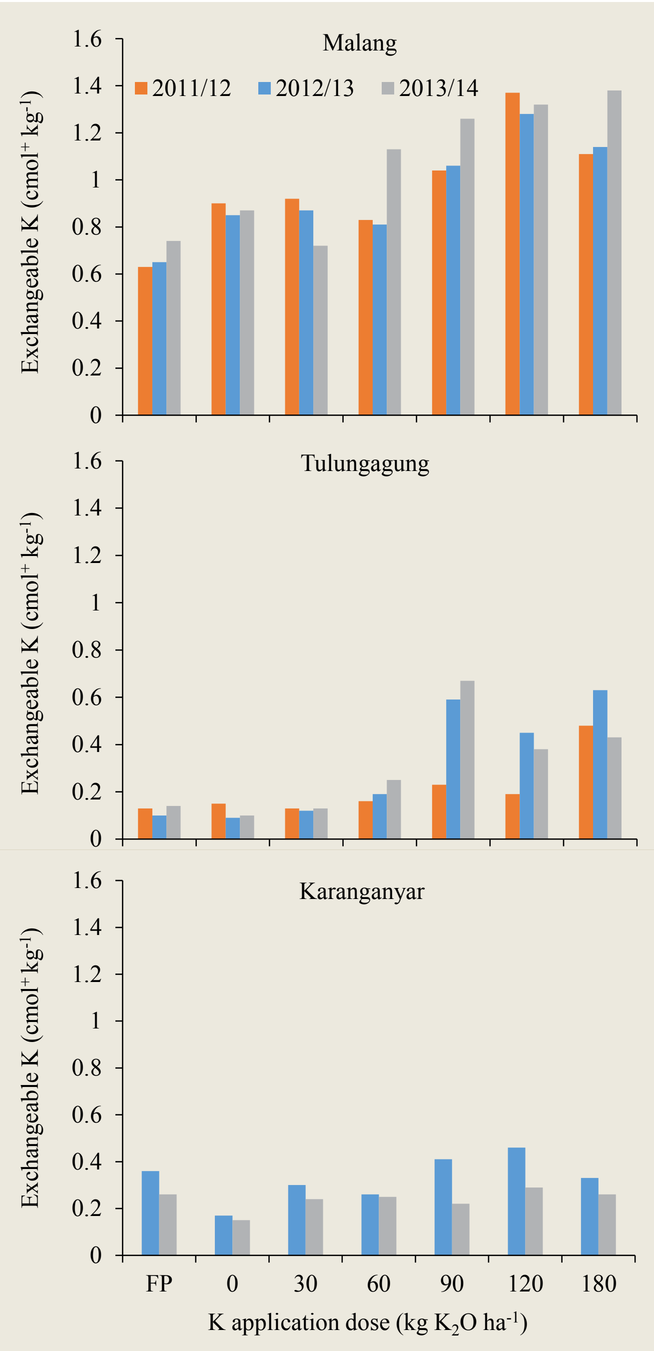

Fig. 2. Effects of K application dose on the exch-K of the top soil at root zone (0-20 cm) during the experimental years in three sites in East and Central Java, Indonesia.

Plant growth and production

Cassava dry matter production during the 2013/14 season was the highest at Malang and Wonogiri, ranging from 17 to 22.5 Mg ha^{-1}, intermediate in Karanganyar (14-16 Mg ha^{-1}), and the lowest at Tulungagung (7-15 Mg ha^{-1}) (Fig. 3A). With the exception of Tulungagung, cassava dry matter production did not display any consistent response to K application dose. In Tulungagung, however, dry matter production increased steadily with increasing K dose (Fig. 3A).

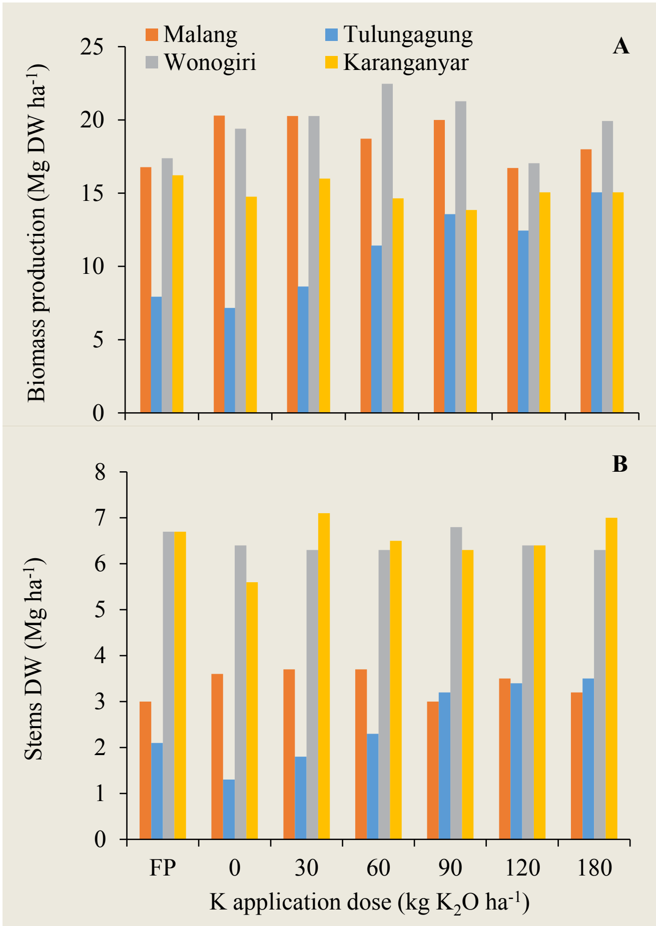

Fig. 3. Total dry matter (A) and stems dry weight (B) in response to K application dose at the four sites of the experiment at the 2013/14 harvest.

Stems biomass at harvest was significantly greater at the Central Java sites, ranging from 6-7 Mg ha^{-1}, while at Malang and Tulungagung in East Java, it ranged from 3-3.7 and 1.3-3.5 Mg ha^{-1}, respectively (Fig. 3B). A clear response of stems biomass to K dose was observed only in Tulungagung.

Tuber yields and dry matter allocation

Large differences in tuber yield occurred between the experimental sites (Fig. 4). The highest fresh weight yields, above 40 Mg ha^{-1}, were obtained at Malang. Here, despite some significant differences between treatments, no consistent response to K dose could be observed. Fresh tuber yield at Wonogiri ranged from 31 to 47 Mg ha^{-1}, second to Malang, and again, showed no significant response to K dose. A significant and positive response was observed at Tulungagung, where fresh tuber yield increased from 19-35 Mg ha^{-1}, as K dose rose from 0-180 kg K_2O ha^{-1}. On the contrary, at Karanganyar, fresh tuber yields were at the lowest level and tended to decline in response to elevated K dose (Fig. 4A).

Examination of the dry tuber yields does not change the impression arising from the fresh tuber yield results. However, a clearer response could be observed in Wonogiri, where dry tuber yield increased as the K dose rose up to 60 kg ha^{-1}, but declined with further increase in K dose (Fig. 4B).

The harvest index (HI) expresses the allocation of dry matter between the product (tubers) and other plant organs (stems and leaves), calculated as: HI = $Tuber_{DM}$ / (Stems + Leaves + $Tubers)_{DM}$. There were significant differences in HI between the districts, nevertheless, no certain effect of K dose on HI could be elucidated from the present results (Fig. 4C).

Tuber yields over consecutive years of the experiment provide a better insight into the influence of K application on both short and long-term perspectives (Fig. 5). Yields from the first year were higher, reaching even 89 and 38 Mg ha^{-1} under 90 K_2O ha^{-1}, at Malang and Tulungagung, respectively. Nevertheless, in the second year yields declined in Malang by 16% and dropped further in the third year to about 66% of the first year. Yield reduction in the second year in Tulungagung was even sharper (28%), but it slightly recovered in the third year. Also in Karanganyar, tuber yields were high in the first year and declined by 13% in the second (Fig. 5). Throughout the experiment, significant tuber yield response to K dose was obvious only in Tulungagung.

Starch and K concentrations

Starch accumulation in cassava tubers averaged 28-30% of fresh weight (Fig. 6). While no significant effect of K dose could be observed at Malang, starch concentration in tubers harvested at Tulungagung and Wonogiri tended to increase with the rising K dose up to 120 kg K_2O ha^{-1} reaching 32-37%, but usually declined back to 28-30% under the highest K dose. Despite significant differences in starch concentration between treatments at Karanganyar, no consistent effect of K dose could be clarified (Fig. 6).

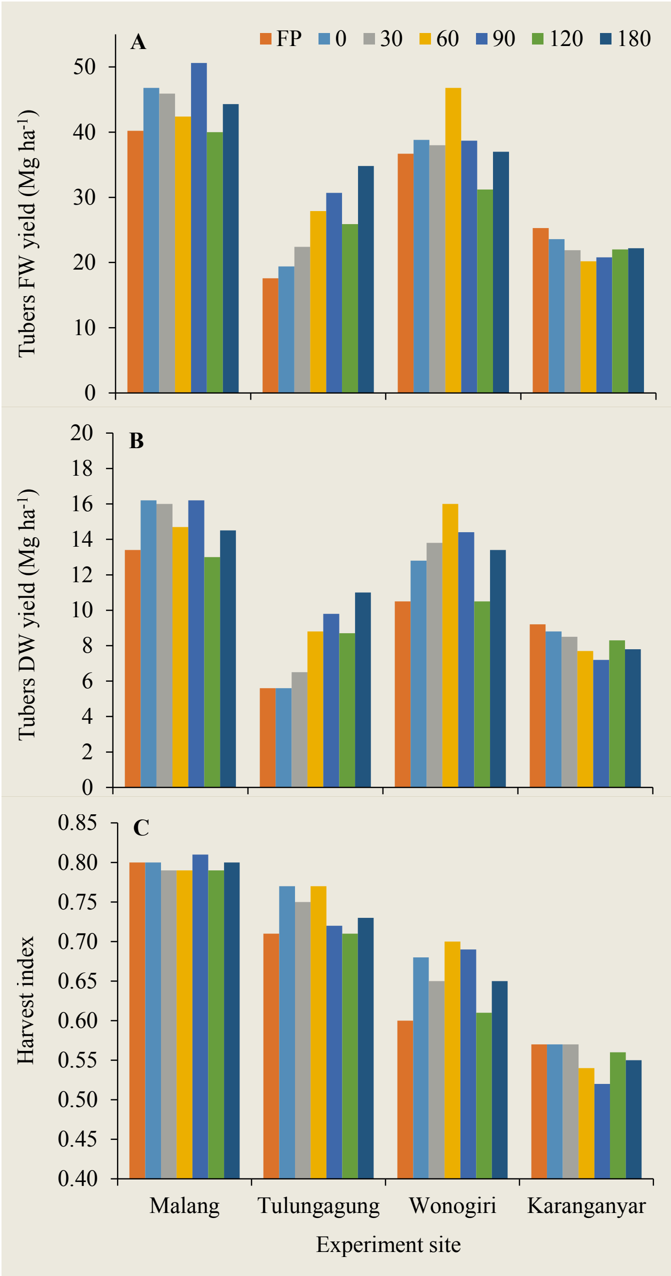

Fig. 4. Tubers, fresh (A) and dry (B) weight yields, and harvest index (C), as affected by K application dose at the four sites of the experiment in the 2013/14 harvest.

Potassium concentrations in the above-ground organs varied significantly among the experimental sites (Fig. 7). In the leaves, Potassium concentration varied from 0.35-2.31% and from 0.26-

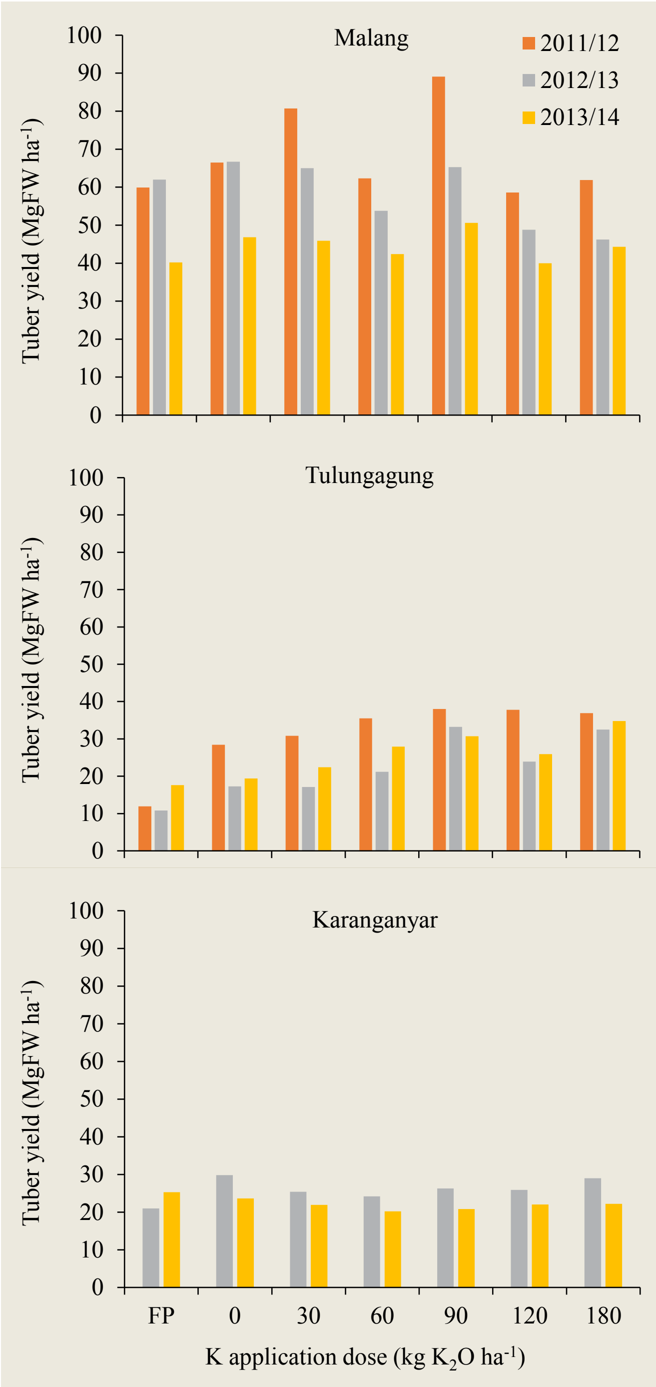

Fig. 5. Effects of K application dose on fresh tuber yields over three (or two) consecutive years of experiment at East Java (Malang and Tulungagung) or Central Java (Karanganyar), respectively.

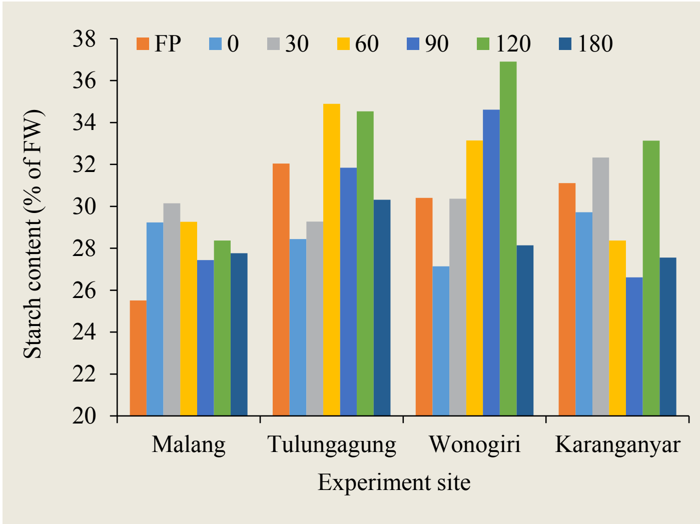

Fig. 6. Influence of K application dose on starch concentration in tubers at the four sites of experiment in 2013/14.

1.89 in the leaves and the stem, respectively. The highest leaf K concentrations, above 2%, were obtained at Malang under K dose ranging from 0-60 kg K_2O ha^{-1} but those dropped to about 1.5% under higher K doses. The lowest leaf K concentrations were recorded at Tulungagung (0.31-0.56%) displaying a significant tendency to increase in response to the rising K dose above 60 kg K_2O ha^{-1}. In Wonogiri, the differences in leaf K were very small (1.4-1.56%), with a slight but significant tendency to rise with the K dose. A similar trend, but at a much lower range (0.83-1.07), was observed at Karanganyar (Fig. 7). The differences in stem K concentration among the experiment sites were quite similar to those shown for leaf K (Fig. 7). Noteworthy was the significant decline in stem K concentration observed at Malang in response to elevated K dose at the lower range.

Tuber K concentration ranged from 0.2 to 0.77% (Fig. 7). The highest values were recorded at Malang, with a very slight response to K application dose. At the other three sites, tuber K was lower but increased significantly in response to elevated K application dose. That response was clear at Tulungagung above 90 kg K_2O ha^{-1}, slighter at Wonogiri under 30-60 kg K_2O ha^{-1}, and dramatic at 30 kg K_2O ha^{-1}, at Karanganyar.

Potassium removal by the crop

The crop biomass and K concentration measurements in the different plant organs provided a rough calculation of K removal by the cassava crop (Table 4). Obviously, K removal at Malang was significantly higher than K inputs under most of the K application doses. Furthermore, K removal even tended to decline with the rising K dose. On the contrary, at Tulungagung, where K removal under zero K was about 17 kg K ha^{-1}, only 10% of the removal at the respective situation in Malang, it steadily increased with rising K doses up to 59 kg K ha^{-1}, about 40% of K input. Also at the Central Java sites, K removal by the cassava crops exceeded inputs at most K application doses; only at 120 kg K_2O ha^{-1} or above did K application exceed K removal. At

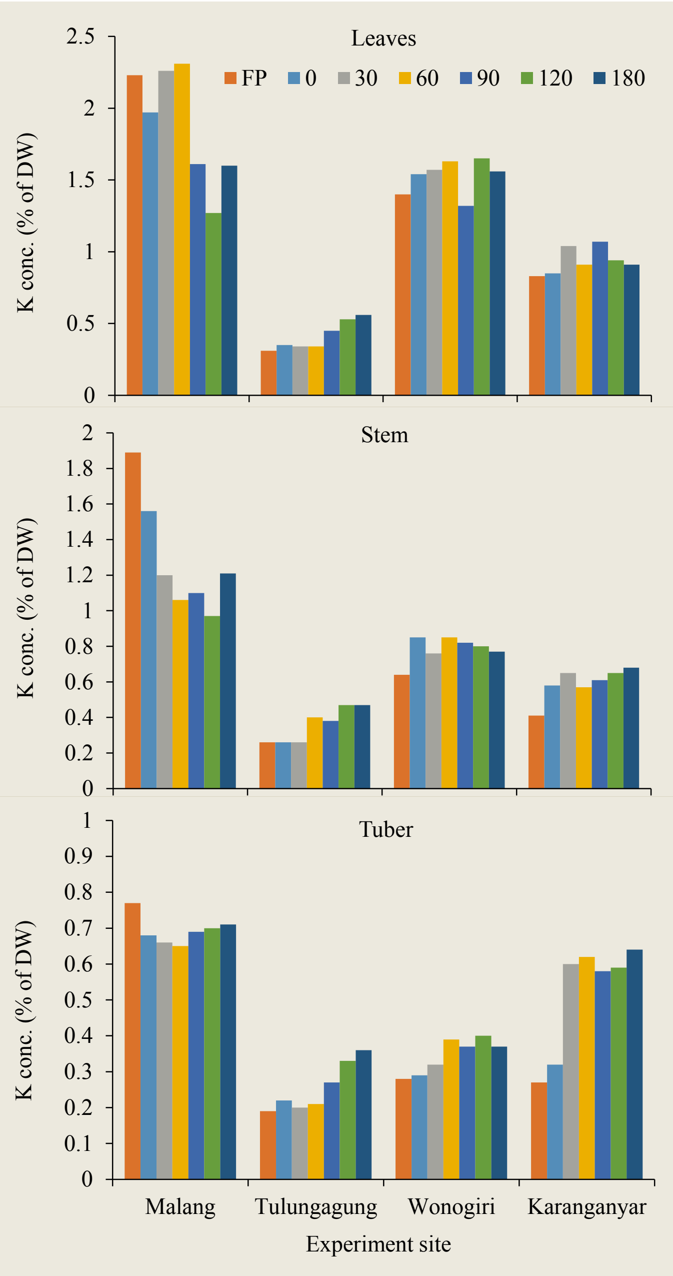

Fig. 7. Effects of K application dose on K concentrations in the leaves, stem, and tubers at harvest.

both sites, K removal rate seemed to respond only at the lower K application range of 30 or 60 kg K_2O ha^{-1} (Table 4).

Discussion

Indonesia is an important cassava producer, however, the average yields obtained are lower than the potential production for this crop. It was hypothesized that farmers' practices that frequently ignore cassava K requirements were responsible for the poor performance of this crop in many regions of Indonesia. Hence, optimizing K supply should result in higher yields. In the present study, a wide range of K application doses, up to 180 kg K_2O ha^{-1}, were examined during two to three consecutive years on various soil types and climate conditions. The maximum cassava yields that were obtained on the third consecutive crop season (2013/14) at Malang, East Java, ranged at 40-50 Mg ha^{-1} (Fig. 4). These are generally within the upper range of yields reported for cassava under various conditions of soil and fertilization regimes (Wargiono *et al.*, 2006). Nevertheless, reports of much higher yields (Taufiq *et al.*, 2009), and yields obtained in the present study on the first or second years of the experiment (Fig. 5) point to reasonably higher potential. Furthermore, tuber yields at the other three sites were fairly small (Wonogiri, Central Java), or significantly low (Tulungagung and Karanganyar, Fig. 4). Apparently, among the four experimental sites, K application was found to be effective and economically beneficial only at Tulungagung, and even there, tuber yields remained relatively poor. Can K application still be a considerable solution and what measures should be taken to realize its potential?

Potassium is essential for plant growth and development (Marschner, 1995). If not provided by a fertile soil, K must be supplied to ensure satisfactory crop performance and yield. Potassium plays a major role in sugar transport and starch accumulation in plants (Zörb *et al.*, 2014). Therefore, starch accumulating crop plants such as potato, wheat, and maize (Pettigrew, 2008), as well as cassava, are significant K consumers. Indeed, K requirements of cassava are high, as indicated by the K removal rates calculated in the present study (Table 4), and are expected to further increase in the future, in case the expectations for higher yields come true. Yet, K removal rates were often much higher than K applied; there were huge differences among sites in crop performance and yield under similar fertilization regimes, and; crop response to K application dose was very poor or unsatisfactory. These discrepancies require further in-depth explanation.

Potassium uptake by plants is strongly determined by soil properties, climate (temperature and precipitation regime), and fertilization management. The availability of K differs greatly with soil type and is affected by physico-chemical properties of the soil. To simplify the complex K dynamics in the soil, K in soil is often classified into four groups depending on its availability to plants: water-soluble, exchangeable, non-exchangeable and structural forms (Zörb *et al.*, 2014). Water-soluble K is directly available to plants, and potentially susceptible to leaching. Exchangeable K is electrostatically bound as an outer-sphere complex to the surfaces of clay minerals and humic substances (Barre *et al.*, 2008). Both fractions are often considered to be easily available to crops. However, the size of both pools is very small, only about 0.1-0.2% and 1–2% of the total K in soil,

Table 4. Estimated K removal by cassava crop during the 2013/14 season, as affected by K application dose and experiment site.

Treatment	K_2O input	Equivalent K input	Experiment site			
			Malang	Tulungagung	Wonogiri	Karanganyar
	-----	-----	-----kg ha^{-1}-----			
T_1	FP(1)	FP(1)	168.4	16.8	74.8	55.0
T_2	0	0	176.0	16.6	94.6	63.7
T_3	30	24.9	162.9	18.8	94.7	101.2
T_4	60	49.8	142.2	28.8	118.7	88.8
T_5	90	74.7	157.7	41.2	110.0	83.9
T_6	120	99.6	127.6	46.5	95.5	94.0
T_7	180	149.4	146.3	59.2	101.7	99.8

(1)FP = farmers' practices that differed among sites. K_2O inputs were: 30, 30, 0, and 83 kg ha^{-1} (equivalent to: 24.9, 24.9, 0, and 69 kg K ha^{-1}) at Malang, Tulungagung, Wonogiri, and Karanganyar sites, respectively.

respectively (Sparks, 1987). Non-exchangeable and structural forms are considered to be slowly- or non-available K sources for plants. However, these pools may also contribute significantly to the plant supply in the long term (Pal *et al.*, 2001).

The quantities of plant-available and non-available K in the soil varies greatly among soil types, and dynamic equilibrium reactions exist between the different soil K pools. Thus, a number of soil physical and chemical properties as well as plant-soil interactions and soil microbial activities affect the fixation and release of K in soils.

The degree of K fixation or release in soils depends on the type of clay mineral and its charge density, moisture content, competing ions, and soil pH. Wet soil, and moreover, frequent cycles of soil wetting may enhance soil weathering and K release. The H^+ concentration in soil solution (via soil pH) seems to play a key role in K release from clay minerals by enhancing the exchange of H^+ for K^+. The combination of heavy precipitation regime, high temperature, and acidic soils facilitates soil weathering and K release and availability to plants, but also promotes rapid K loss through leaching. These conditions also enhance the degradation and mineralization of soil organic material. Organic acids, exuded by plant roots and certain microbial flora, are known to facilitate weathering of soil minerals through the formation of metal-organic complexes, and by enhancing the exchange of H^+ for K^+ (Hinsinger and Jaillard, 1993; Wang *et al.*, 2011). The depletion of K in rhizosphere soil solution below a threshold level (10-20 µM) has been reported to be a key signal which activates the root exudation mechanisms (Hosseinpur *et al.*, 2012; Schneider *et al.*, 2013).

Photo 2. The highest fresh tuber weight of cassava at Wonogiri site in 2013/2014 . Photo by A. Taufiq.

Fertilizer application is required not only to ensure but also to sustain an adequate supply of soluble K to crops. Thus, for optimized K fertilizer management practices, it is crucial to recognize and understand the dynamic factors regulating soil K availability, as well as the shifting crop requirements that occur under specific local conditions. Therefore, and due to the large differences in yields and in crop response to fertilizers application, the results of each experiment site are discussed separately, as case studies.

The Kalipare-Malang site is characterized by a silt loam soil with neutral pH, relatively high exch-K (Table 1), and the lowest annual precipitation, only 1317 mm (Fig. 1). The high, K-irresponsive tuber yields obtained here (Fig. 4), the high HI, and the very high K removal rates (Table 4) indicate that soil fertility can provide most of the crop K requirements and only a small dose (30 kg K_2O ha^{-1}) would be required to maintain this situation. Presumably, with the dose applied twice, in December and February, at the beginning of the crop cycle and at the middle of the rainy season (Fig. 1), most of the excess K fertilizer had been leached away from the rhizosphere before reaching the plant. Moreover, the declining rates of K removal with the rising K application dose may suggest that excess concentrated K fertilizer, the way it has been applied, interrupts the fragile balance between soil-K release and K uptake by the crop. However, in order to further increase cassava tuber yields under these conditions a higher K dose, divided and applied 5-6 times during the season, should be considered. Noteworthy is the limited stem fraction in the crop biomass (Fig. 3) under the high K availability at Malang (Fig. 2) demonstrating K role in governing dry matter production and allocation.

On the contrary, the soil of Tanggunggunung-Tulungagung site is clayish, more acidic (pH 6.2), very low exch-K (Table 1), and receives 1640 mm of annual precipitation. In this site, the lowest tuber yields were obtained. However, the response to K application dose was significant and positive for all parameters, including biomass production (Fig. 2), tuber yield and HI (Fig. 4), and starch (Fig. 6) and K contents (Fig. 7). Potassium removal was in close correlation with K application dose, indicating significant crop dependence on fertilization. Nevertheless, K use efficiency declined steeply from 75 to 39% with increasing K dose (Table 4). These results suggest that the opportunity the crop has to utilize applied K is very limited, and a large proportion of fertilizer is wasted. The same as the previous case study, distribution of the K dose during the cropping season might broaden the opportunity for K uptake, thus increasing K use efficiency, and furthermore, enhancing crop performance and yields.

The low soil pH (4.6-5.2) in Central Java, combined with high annual precipitation (2150 mm) promote rapid weathering of the clay soil, releasing significant K from the fixed to the soluble pool. Thus, with relying on soil available K, considerable (though unsatisfactory) tuber yields are obtained (Fig. 4). Large proportions of the soluble K pool are prone to be leached away during the rainy season. Moreover, any additional K applied during that period (November-April, Fig. 1) is presumably washed away before reaching plant roots (Lambin and Meyfroidt, 2010), explaining the poor response to K application dose. High imbalanced N/K nutrition ratio might have promoted stem growth (Fig. 3) at the expense of tubers, leading to the declining HI (Fig. 4). Undoubtedly, more efficient K supply should improve cassava crop performance. Under the Central Java circumstances, first K application should take place about 30 days after planting, when the new fibrous roots penetrate into the soil and begin functioning (Alves, 2002). The rest of the annual dose should be divided into small portions and applied frequently throughout the season, preferably during April to June, under an intermediate precipitation regime.

Careful attention to two issues, not necessarily associated with K nutrition, may contribute to improving cassava cultivation in the tropics: soil amendment and crop rotation. Lack of organic material is often associated with loosening of soil particles and consequent soil erosion and poor cation exchange capacity (Don *et al.*, 2010; Prabowo and Nelson, 2015). The common practice to remove all above ground residues from cassava fields after harvest, although done for phytosanitary reasons, accelerates soil degradation processes. In cassava, organic manurial treatments were shown to result in higher nutrient uptake by plants, higher tuber yields, and the least depletion of soil nutrients (Amanullah *et al.*, 2007). Embedding composted organic matter in ridges along the rows and application of supplemental fertilizers and soil amendments (e.g. gypsum to reduce soil acidity) directly to that strip would enhance root expansion into the new fertile soil space, thus improving nutrient uptake and crop performance. In the long term, reiteration of such practices is expected to restore soil properties.

Cassava is often grown as a monocrop system in consecutive years. Evidence of exch-K buildup, whenever it occurs at the high K dose treatments (Fig. 2) requires further examination; soil sampling is necessary also during the cropping season. The consistent reduction in tuber yields after the first year (Fig. 5) should give rise to significant concerns. Crop species, including cassava, might have specific requirements, and essential nutrients might be depleted during consecutive monocropping, causing suppressed crop performance. Therefore, crop rotation, whenever possible, is recommended.

In conclusion, cassava response to elevated K dose was rather disappointing in three of the four experimental sites in East and Central Java. In most cases, tuber yields were far below the potential, and yield increases compared to the farmers' practices were too small or negligible. However, there were considerable indications that K application, if appropriately carried out, might result in substantial enhancement of cassava performance and yield. Cost and benefit ratio analyses of K application programs are premature, as further research is still required. A fundamental principle of plant K nutrition must be obeyed: maintenance of the soil's exch-K pool at a constant available level to match the current crop requirements. Thus, the annual K dose should be divided and distributed throughout the season taking into account precipitation regime, crop phenology (e.g., tuber growth), and soil properties. Special care should be paid to acid soils (Taufiq *et al.*, 2015) where K depletion rates are rapid.

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The paper "Response of Cassava (*Manihot esculenta* Crantz.) to Potassium Application on Various Soil Types in East and Central Java, Indonesia" also appears on the IPI website at:

Regional activities/Southeast Asia

A Short Report

SoilCares Lab Initiative in Bungoma County, Kenya

Lilian Wanjiru Mbuthia[1]

Increasing smallholder crop production to feed growing populations is an urgent challenge which requires affordable soil testing methods, fertilizer recommendations, and accessible fertilizers with the required nutrients. However, soil analysis for small-scale farmers in Kenya has been difficult and mostly non-existent, primarily due to inaccessibility, high costs and lack of awareness on the need to conduct soil analysis. The launch of the SoilCares mobile laboratories in 2013 is one approach that has brought significant awareness to smallholder farmers of the need for soil analysis, as well as making soil analysis more accessible. SoilCares offers affordable soil testing - using infrared spectroscopy and slightly modified Quantitative Evaluation of the Fertility of Tropical Soils (QUEFTS) - to provide fertilizer recommendations to smallholders.

In 2014, SoilCares soil testing results from 2,107 samples from Uasin Gishu and Busia counties in Kenya, using archetype analysis and QUEFTS, showed that eight soil archetypes could be distinguished, of which four were dominant. Additionally, four fertilizer-blend archetypes were distinguishable for all counties which complied reasonably well with the NPK fertilization necessary at planting to produce 5 tonnes/ha maize. These blends are 12:25:0, 6:22:14, 0:40:0, and 13:33:0 (N-P_2O_5-K_2O). The median relative difference between the advised and optimally needed nitrogen (N), phosphorus (P_2O_5) and potash (K_2O) application rates at planting were 36, -10 and 0%, respectively. This exciting soil analysis and mapping method will help the fertilizer industry, traders and policymakers to make important decisions about production and availability of crop or region-specific NPK blends.

At the beginning of 2015, Bungoma County local government in western Kenya took the initiative to purchase three SoilCares mobile labs to provide affordable soil testing services to farmers in the region and promote balanced fertilization. IPI has partnered with the local government to support the promotion of soil testing to small-scale farmers by subsidizing the cost of analysis to the first 500 farmers by 40%. IPI is also running fertilizer trial plots on individual farmer's fields within the county whereby field days will be held to demonstrate to farmers the need for balanced fertilization. In addition, the IPI team will offer technical advice to the county and facilitate a monitoring and evaluation process to determine the effectiveness of the soil testing technique and factors influencing the adoption of soil analysis by farmers.

See also the new IPI video "Increasing Crop Yields through Advanced Soil Testing and Fertilizer Recommendation for Small Scale Farmers in Kenya" on the IPI website.

Bungoma county extension service personnel preparing soil samples for analysis. Photo by Lilian Wanjiry Mbuthia.

This report also appears on the IPI website at:

Regional activities/Eastern Africa

[1]IPI Coordinator for Eastern Africa

Events

International Symposia and Conferences

August 2016

5th Sustainable Phosphorus Summit (SPS 2016), 16-20 August 2016, Kunming, Yunnan, China.

SPS 2016 is the fifth in a successful series of Sustainable Phosphorus Summits that was launched in Linköping (Sweden) in 2010, and then went to Tempe (USA) in 2011, Sydney (Australia) in 2012 and Montpellier (France) in 2014, related to the Global Phosphorus Research Initiative. It is a global multidisciplinary event to discuss phosphorus production and utilization, management and sustainability. The conference will be hosted by China Agricultural University and Yuntianhua Group. See First Circular on the IPI website/Events. For details go to the P Summit website.

The 2nd International Conference on Agriculture and Sustainability (ICAS 2016), 24-26 August 2016, Xi'an, China.

This Conference will cover issues on Agriculture and Sustainability. It is dedicated to creating a stage for exchanging the latest research results and sharing the advanced research methods. For more information go to the conference website.

September 2016

The European Mineral Fertilizer Summit, 14-15 September 2016, London, UK.

The two day event will provide an exclusive platform in collaboration with Fertilizers Europe for discussion between a variety of industry perspectives including manufacturers, suppliers, distribution/logistics, academia and regulators homing in on the latest opportunities arising from plant technology and best practices within operational production. For more information see the agenda here.

October 2016

CropWorld Global, 24-25 October 2016, Amsterdam RAI, Netherlands.

CropWorld Global is Europe's leading event dedicated to the latest developments & innovations on crop production, protection and agricultural technology. The event's new format connects a Congress and Expo. Leading global suppliers, buyers, scientists, regulators and key policy makers from the agriculture and crop industry will benefit from two days of first-rate networking and exposure to new business opportunities. See more details on the congress website.

December 2016

7th International Nitrogen Conference (INI 2016) "Solutions to Improve Nitrogen Use Efficiency for the World", 4-8 December 2016, Melbourne Cricket Ground, Victoria, Australia.

More information on this triennial event, which is supported by both IPNI and IFA, is available online on the conference website.

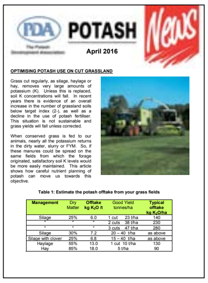
January 2017

Frontiers of Potassium - an International Conference, 25-27 January 2017, Rome, Italy.

The understanding of potassium behavior in soil and its vital role in plant health has been expanding rapidly. This conference will allow global experts to gather and discuss the frontiers of potassium science. IPNI will organize the conference to facilitate discussion of key technical questions and develop a pathway for additional potassium research and for improved nutrient management. See First Conference Announcement on the conference website.

Publications

Publication by the PDA


POTASH News
April 2016
OPTIMISING POTASH USE ON CUT GRASSLAND

Optimising Potash Use on Cut Grassland

POTASH News, April 2016.

Grass cut regularly, as silage, haylage or hay, removes very large amounts of potassium (K). Unless this is replaced, soil K concentrations will fall. In recent years there is evidence of an overall increase in the number of grassland soils below target index (2-), as well as a decline in the use of potash fertiliser. This situation is not sustainable and grass yields will fall unless corrected. Read more on the PDA website.

Potash Development Association (PDA) is an independent organisation formed in 1984 to provide technical information and advice in the UK on soil fertility, plant nutrition and fertilizer use with particular emphasis on potash. See also www.pda.org.uk.

Scientific Abstracts

K in the Literature

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Physiology of Intracellular Potassium Channels: A Unifying Role as Mediators of Counterion Fluxes?

Checchetto, V., E. Teardo, L. Carraretto, L. Leanza, and I. Szabo. 2016. Biochimica et Biophysica Acta (BBA) - Bioenergetics 1857(8):1258-1266. DOI 10.1016/j.bbabio.2016.03.011.

Abstract: Plasma membrane potassium channels importantly contribute to maintain ion homeostasis across the cell membrane. The view is emerging that also those residing in intracellular membranes play pivotal roles for the coordination of correct cell function. In this review we critically discuss our current understanding of the nature and physiological tasks of potassium channels in organelle membranes in both animal and plant cells, with a special emphasis on their function in the regulation of photosynthesis and mitochondrial respiration. In addition, the emerging role of potassium channels in the nuclear membranes in regulating transcription will be discussed. The possible functions of endoplasmic reticulum-, lysosome- and plant vacuolar membrane-located channels are also referred to. Altogether, experimental evidence obtained with distinct channels in different membrane systems points to a possible unifying function of most intracellular potassium channels in counterbalancing the movement of other ions including protons and calcium and modulating membrane potential, thereby fine-tuning crucial cellular processes. This article is part of a Special Issue entitled 'EBEC 2016: 19th European Bioenergetics Conference, Riva del Garda, Italy, July 2-7, 2016, edited by Prof. Paolo Bernardi.

Evaluate Regional Potassium Fertilization Strategy of Winter Oilseed Rape under Intensive Cropping Systems: Large-Scale Field Experiment Analysis

Rihuan Cong, Hui Li, Zhi Zhang, Tao Ren, Xiaokun Li, and Jianwei Lu. 2016. Field Crops Research 193:34-42. DOI 10.1016/j.fcr.2016.03.004.

Abstract: Potassium (K) fertilization is essential for winter oilseed rape (*Brassica napus* L.) especially in the intensive cropping systems. To evaluate the yield response to K fertilization and economic optimum K rate (EOKR) under different levels of soil indigenous K supply (IKS), we collected 1437 site-year experiments with four K application rates at the regional scale in Yangtze River Basin, with large yield range of 665-4470 kg ha^{-1}. The four treatments were K0 (without K fertilization), LK (half K rate of MK), MK (recommended K rate by local technicians), and HK (1.5 times' K rate of MK) in this study. We used K uptake under no K fertilization to represent IKS. Four IKS levels (i.e., L1, L2, L3, and L4 from lower to higher) were grouped based on the relationship between the relative yield and IKS. The results indicated that the rapeseed yield and yield increase rate of K fertilizer under the current recommended K rate by local technicians (MK) was higher than that under other K treatments across different IKS levels. However, the K application rate could be further optimized regionally. The MK rate was similar to EOKR in 44.3%-55.6% of the experimental sites (K rate difference in the range of ±10 kg ha^{-1}). And in 29.6%-42.5% sites, the MK rate could be reduced across the four IKS levels. The EOKR values were 92, 85, 80 and 75 kg K_2O ha^{-1} in the L1, L2, L3 and L4 groups of IKS, respectively, which were significant lower than the MK rate in the four IKS levels. Our results can be used to evaluate soil provided the feasible method and valuable data to evaluate soil indigenous K supply and determine the regional K fertilizer rates of winter oilseed rape, especially in those countries that also plant multiple cropping systems and/or small-scale sites across the world.

Phosphorus and Potassium Fertilizer Recommendations for High-Yielding, Profitable Soybeans

Staton, M. 2014. Michigan State University Extension.

Abstract: The keys to maximizing the economic returns from phosphorus (P) and potassium (K) fertilizer applications are a comprehensive soil testing program and maintaining P and K soil test levels above their respective critical levels. The critical level for a given nutrient is the soil test level at which 95 to 97 percent of the crop's yield potential will be reached with no additional inputs of the nutrient.

Effect of Potassium Fertilization on Leaf Physiology, Fiber Yield and Quality in Cotton (*Gossypium hirsutum* L.) under Irrigated Mediterranean Conditions

Tsialtas, I.T. , S. Shabala, D. Baxevanos, and T. Matsi. 2016. Field Crops Research 193:94-103.

Abstract: The aim of this work was to study the physiological, yield and quality responses of two upland cotton cultivars (Greek and Australian), grown on light-textured soil under irrigated, Mediterranean conditions, to three potassium levels (0, 80, 160 kg K_2O ha^{-1}). Despite its pivotal role in plant physiology and growth, K supplementation is often neglected by growers due to high cost and complexity with identifying optimal K levels. A rate of 80 kg K_2O ha^{-1} was adequate to increase both seed cotton and lint yield and improve fiber length. This was

despite the absence of any response of leaf cation concentrations (K, Na, Ca, Mg, their sum and ratios) to K fertilization. On a contrary, K application affected leaf gas exchange physiology by increasing CO_2 assimilation rate and stomatal conductance thus leading to reduced leaf temperature and higher leaf water potential and carbon isotope discrimination (Δ). Cultivars did not differ in the leaf gas exchange characteristics and yield but the Australian (Carmen) had markedly better fiber quality, was water conservative and sustained higher leaf K concentrations compared to Greek (Elina). Growth stage (first open flower, full bloom, first open bolls) impacted significantly leaf gas exchange physiology and cation concentrations resulting in reductions of CO_2 assimilation rate, stomatal conductance, leaf water potential, specific leaf area (SLA) and N and K concentrations through the growing season. Regardless the growth stage, the lint yield was negatively correlated with Δ, Na and Na/Mg ratio highlighting the importance of the conservative use of water on cotton yield and the detrimental role of Na despite the theoretical cotton's tolerance. Fiber length was closely correlated to leaf K at the first open boll stage indicating a putative deficiency of K which possibly accelerates cotton maturity. Overall, results of the present work emphasize the essentiality of adequate K supply for cotton physiology, growth, yield and quality, highlight the interactions of K with other nutrients and stress the cultivar selection as a means to encounter soil K inadequacy.

Chlorophyll Fluorescence Induction Kinetics and Yield Responses in Rainfed Crops with Variable Potassium Nutrition in K Deficient Semi-Arid Alfisols

Srinivasarao, Ch., Arun K. Shanker, Sumanta Kundu, and Sharanbhoopal Reddy. 2016. J. Photochemistry and Photobiology, B: Biology 160:86-95. DOI 10.1016/j.jphotobiol.2016.03.052.

Abstract: Optimum potassium (K) nutrition in semi-arid regions may help crop plants to overcome constraints in their growth and development such as moisture stress, leading to higher productivity of rainfed crops, thus judicious K management is essential. A study was conducted to evaluate the importance of K nutrition on physiological processes like photosynthesis through chlorophyll a fluorescence and chlorophyll fluorescence induction kinetics (OJIP) of rainfed crops viz., maize (*Zea mays* L.), pearl millet (*Pennisetum glaucum*), groundnut (*Arachis hypogaea*), sunflower (*Helianthus annuus*), castor (*Ricinus communis* L.) and cotton (*Gossypium hirsutum*) under water stress conditions by studying their growth attributes, water relations, yield, K uptake and use efficiency under varied K levels. Highest chlorophyll content was observed under K60 in maize and pearl millet. Narrow and wide Chl a:b ratio was observed in castor and groundnut respectively. The fluorescence yield decreased in the crops as K dosage increased, evidenced by increasing of all points (O, J, I and P) of the OJIP curves. The fluorescence transient curve for K60 was lower than K0 and K40 for all the crops. Potassium levels altered the fluorescence induction and impaired photosynthetic systems in all the crops studied. There was no distinct trend observed in leaf water potential of crops under study. Uptake of K was high in sunflower with increased rate of K application. Quantitatively, K uptake by castor crop was lesser compared to all other crops. Our results indicate that the yield reduction under low K was due to the low capacity of the crops to translocate K from non-photosynthetic organs such as stems and petioles to upper leaves and harvested organs and this in turn influenced the capacity of the crops to produce a high economic yield per unit of K taken up thus reducing utilization efficiency of K.

Estimating On-Farm Wheat Yield Response to Potassium and Potassium Uptake Requirement in China

Ai Zhan, Chunqin Zou, Youliang Ye, Zhaohui Liu, Zhenling Cui, and Xinping Chen. 2016. Field Crops Research 191:13-19. DOI 10.1016/j.fcr.2016.04.001.

Abstract: Understanding grain yield response to potassium fertilizer supply and potassium uptake requirements is essential for devising optimized potassium fertilizer management policies in China. Currently, potassium fertilization is often ignored due to high natural levels of potassium in the soil. We conducted 836 on-farm experiments at 209 sites in China to quantify wheat (*Triticum aestivum* L.) grain yield response to potassium application rates, and evaluate potassium uptake requirements with increasing grain yield. Across all 209 sites, wheat grain yield increased by 70% from 3.3 Mg ha^{-1} at a control level to 5.6 Mg ha^{-1} for recommended potassium treatments (RKR, 102 kg K_2O ha^{-1}). With 150% RKR treatments, no yield gains were achieved, while there was a notable decrease in potassium use efficiency. The potassium uptake requirements per Mg of grain (K_{req}) increased from 21.1 kg with RKR treatments to 21.9 kg with 150% RKR treatments, which indicated that a luxury potassium uptake occurred under excessive potassium application. Under RKR treatments, K_{req} decreased from 23.8 kg with <4.5 Mg ha^{-1} to 20.2 kg with >7.5 Mg ha^{-1}, which was attributed to the increase of the harvest index (from 45.5% to 48.6%) and decline in grain potassium concentrations (from 4.7 g kg^{-1} to 4.0 g kg^{-1}). When the grain yield was <7.5 Mg ha^{-1}, potassium accumulation during post-anthesis was lower than that at pre-anthesis, by -78.5 kg ha^{-1} and -30.8 kg ha^{-1} with <6 Mg ha^{-1} and 6-7.5 Mg ha^{-1} yield ranges, respectively, but higher than that at pre-anthesis when the grain yield was >7.5 Mg ha^{-1} and by 18.2 kg ha^{-1}. In summary, potassium fertilization can increase wheat grain yield in China and total potassium uptake requirements were shown to decrease with increasing grain yield. This suggests that potassium optimization must be taken into account in management decisions for high-yielding wheat production in China.

Beneficial Effects of Potassium Application in Improving Submergence Tolerance of Rice (*Oryza sativa* L.)

Priyanka Gautam, B. Lal, R. Tripathi, M. Shahid, M.J. Baig, S. Maharana, C. Puree, and A.K. Nayak. 2016. Environmental and Experimental Botany 128:18-30. DOI 10.1016/j.envexpbot.2016.04.005.

Abstract: The rainfed lowland rice ecosystem is affected by not only water deficit but also excess water. Although the rice plant is well adapted to aquatic environments, it is unable to survive if it is completely submerged in water for an extended period. The impact of submergence on survival, chlorophyll, photosynthesis, post-recovery growth and anti-oxidant capacities in four rice cultivars namely IR 64, IR 64-Sub1, Swarna and Swarna-Sub1 having differential response to potassium application were examined. All the cultivars showed inhibition of photosynthesis, this was accompanied with decrease in stomatal conductance, chlorophyll and carbohydrate contents; the decrease was more pronounced in non-sub1 cultivars. The activity of anti-oxidants was found to be significantly high and lipid peroxidation was low in sub1 cultivars. Potassium application improved the survival mainly because of maintenance of carbohydrates, chlorophyll and contributing to less lodging and leaf senescence. Furthermore, K application resulted in inhibition of lipid peroxidation and increase in catalase and Peroxidase activities. Potassium at higher levels was more beneficial in terms of improving survival, photosynthesis and growth after recovery. The germplasm improvement is beneficial if provided with best management practices, modification in plant nutrition by K application enhance the survival, recovery and growth of rice during complete submergence.

A Potential Role of Flag Leaf Potassium in Conferring Tolerance to Drought-Induced Leaf Senescence in Barley

Hosseini, S.A., M.R. Hajirezaei, C.Seiler, N. Sreenivasulu, and N. von Wirén. 2016. Front. Plant Sci. DOI 10.3389/fpls.2016.00206.

Abstract: Terminal drought stress decreases crop yields by inducing abscisic acid (ABA) and premature leaf senescence. As potassium (K) is known to interfere with ABA homeostasis we addressed the question whether there is genetic variability regarding the role of K nutrition in ABA homeostasis and drought tolerance. To compare their response to drought stress, two barley lines contrasting in drought-induced leaf senescence were grown in a pot experiment under high and low K supply for the analysis of flag leaves from the same developmental stage. Relative to the drought-sensitive line LPR, the line HPR retained more K in its flag leaves under low K supply and showed delayed flag leaf senescence under terminal drought stress. High K retention was further associated with a higher leaf water status, a higher concentration of starch and other primary carbon metabolites. With regard to ABA homeostasis, HPR accumulated less ABA but higher levels of the ABA degradation products phaseic acid (PA) and dehydro-PA. Under K deficiency this went along with higher transcript levels of ABA8′-HYDROXYLASE, encoding a key enzyme in ABA degradation. The present study provides evidence for a positive impact of the K nutritional status on ABA homeostasis and carbohydrate metabolism under drought stress. We conclude that genotypes with a high K nutritional status in the flag leaf show superior drought tolerance by promoting ABA degradation but attenuating starch degradation which delays flag leaf senescence. Flag leaf K levels may thus represent a useful trait for the selection of drought-tolerant barley cultivars.

Potassium for Crop Production

Rehm, G., and M. Schmitt. 2002. Nutrient Management. University of Minnesota Extension.

Abstract: Potassium (K) is an essential nutrient for plant growth. Because large amounts are absorbed from the root zone in the production of most agronomic crops, it is classified as a macronutrient. Minnesota soils can supply some K for crop production, but when the supply from the soil is not adequate, K must be supplied in a fertilizer program. This publication provides information important to the basic understanding of K nutrition of plants, its reaction in soils, its function in plants, and its role in efficient crop production.

Extending the Fall Harvest Window of Switchgrass on the Basis of Phosphorus and Potassium Tissue Concentrations

Bacon, J.L., A.J. Ashworth, F.L. Allen, C.E. Sams, D.D. Tyler, W.E. Hart, and J.F. Grant. 2016. Crop Science 56(3):1288-1295. DOI 10.2135/cropsci2015.08.0506.

Abstract: It is hypothesized that switchgrass (*Panicum virgatum* L.) remobilizes phosphorus (P) and potassium (K) to belowground plant organs during maturation and senescence. Consequently, recommended biomass harvests occur after the first killing frost or early November, although field curing conditions at that time may be undesirable. Therefore, the objectives of this study were to determine i) if harvests can occur earlier based on removal of P and K (in leaves and stems) for two standard (‘Alamo’ and ‘Kanlow’) and eight new upland and lowland cultivars during the fall (i.e., mid-September, mid-October, late October, and early November) in Exp. 1, and ii) changes in P and K concentration in aboveground versus belowground biomass (roots, crowns, and shoots) in standard cultivars during mid-September, late October, and mid-November in Exp. 2. Both experiments were performed in a randomized complete design with three blocks at Knoxville and Springfield, TN, USA, in 2009 and 2010. Shoot P and K concentrations in cultivars did not decline from mid-September to late October, nor did P and K in crowns and roots increase

from mid-September to mid-November (P >0.05). However, leaf concentrations of P (across locations and years) were greatest for OK NSL-2001-1 (lowland cultivar), which did not differ from Blackwell (upland cultivar). Cultivar Kanlow had the lowest P concentrations across all plant parts and cultivars. Similarly, stem P was greatest for the cultivar Blackwell. Harvest timing of upland and lowland switchgrass cultivars may therefore be extended to earlier in the fall (mid-September) based on lack of attenuating declining trends of P and K in shoots of switchgrass cultivars in the Southeast.

Impact of Nitrogen, Phosphorus and Potassium on Brown Planthopper and Tolerance of its Host Rice Plants

Md Mamunur Rashid, Mahbuba Jahan, and Khandakar Shariful Islam. 2016. Rice Science 23(3):119-131. DOI 10.1016/j.rsci.2016.04.001.

Abstract: The brown planthopper (BPH), Nilaparvata lugens (Stål), appeared as a devastating pest of rice in Asia. Experiments were conducted to study the effects of three nutrients, nitrogen (N), phosphorus (P) and potassium (K), on BPH and its host rice plants. Biochemical constituents of BPH and rice plants with varying nutrient levels at different growth stages, and changes in relative water content (RWC) of rice plants were determined in the laboratory. Feeding of BPH and the tolerance of rice plants to BPH with different nutrient levels were determined in the nethouse. Concentrations of N and P were found much higher in the BPH body than in its host rice plants, and this elemental mismatch is an inherent constraint on meeting nutritional requirements of BPH. Nitrogen was found as a more limiting element for BPH than other nutrients in rice plants. Application of N fertilizers to the rice plants increased the N concentrations both in rice plants and BPH while application of P and K fertilizers increased their concentrations in plant tissues only but not in BPH. Nitrogen application also increased the level of soluble proteins and decreased silicon content in rice plants, which resulted in increased feeding of BPH with sharp reduction of RWC in rice plants ultimately caused susceptible to the pest. P fertilization increased the concentration of P in rice plant tissues but not changed N, K, Si, free sugar and soluble protein contents, which indicated little importance of P to the feeding of BPH and tolerance of plant against BPH. K fertilization increased K content but reduced N, Si, free sugar and soluble protein contents in the plant tissues which resulted in the minimum reduction of RWC in rice plants after BPH feeding, thereby contributed to higher tolerance of rice plants to brown planthopper.

Spatial Distribution of Potassium Uptake Across the Cotton Plant Affects Fiber Length

Yuan Chen, Yabing Li, Dapeng Hu, Xiang Zhang, Yujin Wen, and Dehua Chen. 2016. Field Crops Research 192:126-133. DOI 10.1016/j.fcr.2016.04.025.

Abstract: To enhance whole plant fiber quality of cotton, the relationship between the spatial distribution of potassium (K) absorption and fiber length was investigated. In 2007, a field experiment was conducted to assess genotypic differences among 17 cultivars for potassium absorption and fiber length. Differences in both K uptake and fiber length existed among cultivars in field conditions. The cultivars could be categorized into three classes: moderate K uptake and high fiber length; high K uptake and moderate fiber length; and both low K uptake fiber length. In 2008, single cultivars representative of each of these three classes were selected to further investigate spatial distribution patterns of K absorption and cotton fiber length, respectively. In 2009, differences among the three selected cultivars in K uptake and fiber length were further studied under three K fertilizer regimes and by foliar spraying of KCl. Higher K uptake at upper and distal positions of the plant was associated with longer fiber; however, at lower and proximal positions no such association was observed. The change of K uptake and fiber length is related to cultivar and K fertilizer application as well. For all three cultivars, without K fertilizer application, K uptake and fiber length decreased from lower to upper sections and from proximal to distal positions. With increasing K application, K uptake increased for all positions, especially upper and distal positions. For cultivar Siza3, higher fiber lengths were consistent with greater K uptake at upper and distal sections. For cultivar Xuza3, fiber length declined markedly when K application rate increased from 225 to 450 kg hm^{-1} even if K absorption was enhanced. For Sumian9, fiber lengths were no longer increased when K rate increased from 225 to 450 kg hm^{-1}. These results suggested that rational K fertilizer management could improve whole plant fiber length of cotton cultivars that have intermediate K absorption potential with high uptake ability at upper and distal positions.

Effect of 35 Years Inorganic Fertilizer and Manure Amendment on Structure of Bacterial and Archaeal Communities in Black Soil of Northeast China

Jianli Ding, Xin Jiang, Mingchao Ma, Baoku Zhou, Dawei Guan, Baisuo Zhao, Jing Zhou, Fengming Cao, Li Li, and Jun Li. 2016. Applied Soil Ecology 105:187-195. DOI 10.1016/j.apsoil.2016.04.010.

Abstract: Black soil is common in northeast China and plays an important role in Chinese crop production. However, in the past three decades, inappropriate use of fertilizer has caused a sequence of agroecological issues. The objective of this research was to evaluate the effect of long-term fertilizer on the microbial communities in black soil. The soil was subjected to four fertilization regimes: without fertilizer (CK); manure (M); nitrogen, phosphorus and potassium inorganic fertilizer (NPK); and inorganic fertilizers with manure (MNPK). The soil pH was decreased by inorganic fertilizers and increased by manure. Quantitative PCR analysis of microbial community size and Illumina platform-based analysis of the V4 16S rRNA gene region were performed to characterize soil microbial abundance and to compare community structure and diversity. Microbial community size was enhanced by the incorporation of inorganic fertilizer and manure. Microbial diversity was decreased by inorganic fertilizer and increased by the incorporation of inorganic fertilizer and manure. The predominate phyla in all samples were Proteobacteria (29.39-33.48%), Acidobacteria (13.14-16.25%) and Actinobacteria (9.32-10.77%). The relative abundance of different classes significantly differed among the different treatments, especially MNPK and NPK. Acidobacteria and Deltaproteobacteria were relatively stable in organic fertilizer treated soil. Gammaproteobacteria, Alphaproteobacteria and Betaproteobacteria were sensitive to all the fertilization regimes. Comparatively, Spartobacteria was stable in response to fertilization practices. Principal coordinate analysis indicated that microbial communities were primarily clustered into three groups: CK and M were clustered together; MNPK was improved by manure and separated from NPK. Shannon and Simpson indexes were significantly correlated with soil pH and the concentrations of available phosphorus and total phosphorus. Redundancy analysis indicates that microbial communities were closely positively correlated with soil nitrate nitrogen concentration (P = 0.002) and pH (P = 0.002). These results indicate that inorganic fertilizer plus manure increased microbial size and diversity and changed microbial composition.

Effects of Potassium Supply on Growth, Gas Exchange, Phenolic Composition, and Related Antioxidant Properties in the Forage Legume *Sulla carnosa*

Chokri Hafsi, Hanen Falleh, Mariem Saada, Mokded Rabhi, Khaoula Mkadmini, Riadh Ksouri, Chedly Abdelly, and Abderrazek Smaoui. 2016. Flora - Morphology, Distribution, Functional Ecology of Plants 223:38-45. DOI 10.1016/j.flora.2016.04.012

Abstract: The effects of potassium (K^+) deficiency were investigated in Sulla carnosa plants. Plants were grown hydroponically for one month in K^+-sufficient (6 mM K^+, Control) and K^+-deficient (60 µm K^+) solutions inside the greenhouse in Biotechnology Center of Borj Cedria, Tunisia. Growth, water status, pigment contents, photosynthetic gas exchange, photosystem II (PSII) photochemistry and leaf principal secondary metabolites (polyphenols, flavonoids, and condensed tannins), and their antioxidant properties (DPPH (1.1-diphenyl-2-picrylhydrazyl) scavenging capacity, ferric reducing power, chelating effect on ferrous ions, and β-carotene bleaching test) were determined. Growth of vegetative organs was decreased by some 50% by K^+ deficiency with stems more affected (-68%) than roots (-42%) and leaves (-45%). Water content decreased in the three vegetative organs. Photosynthetic gas exchange and pigment contents were affected by low K^+ conditions. In contrast to condensed tannins which remained constant, total polyphenols and flavonoids contents increased under K^+ deficiency (by 62.7 and 14.5%, respectively). Furthermore, total antioxidant activity increased by 33.5% compared to control plants. Except for β-carotene bleaching test that increased, DPPH scavenging capacity, ferric reducing antioxidant power, and chelating effect on ferrous ions decreased owing to K^+ deficiency. An increased and/or de novo synthesis of individual polyphenols was also observed by RP-HPLC analysis. As a whole, these data suggest that S. carnosa was able to modulate the metabolism of secondary metabolites and their antioxidant activity under conditions favouring reactive oxygen species (ROS) production in order to minimize the deleterious effects of these oxygen species.

Nutrient Management Recommendations for Profitable Soybean Production

Staton, M. 2016. Michigan State University Extension.

Abstract: Nutrient management is an important component for maximizing net income from raising soybeans. Soybean yields and net income can be reduced when essential nutrients are not available at the time or in the quantities required by the crop. However, net income is also reduced when applied nutrients fail to produce yield increases large enough to offset their costs. The following nutrient management recommendations by Michigan State University Extension will help you maximize your soybean income.

Diagnosis of Potassium Nutrition Level in *Solanum lycopersicum* Based on Electrical Impedance

Li Jinyang, Li Meiqing, Mao Hanping, and Zhu Wenjing. 2016. Biosystems Engineering 147:130-138. DOI 10.1016/j.biosystemseng.2016.04.005

Abstract: Potassium (K) is an essential element for crop growth. Tomato has a long growth cycle and large fertiliser requirement; thus, K stress often occurs and degrades crop yield and quality. It is the most suitable method to provide nutrition based on the actual requirement of crop growth. An accurate monitoring and diagnosis of nutrition during crop growth is key to realise a precise nutrient management. Crop K monitoring methods have

been developed to improve K fertiliser management, and most of them are based on leaf or canopy optical property measurements. However, sensitivity to environmental interference remains an important drawback of these methods. Electrical impedance has been applied to determine the physiological and nutritional status of plant tissues, but no studies related to plant K contents have been reported. This study aims to evaluate the K nutrition level based on leaf impedance spectroscopy. Five sets of tomato samples with different K contents were grown. Total K content of leaves was determined, and electrical impedance data recorded in a frequency range of 1 Hz to 1 MHz. The measured impedance data were analysed using an equivalent circuit model for cellular tissues. The change rule of equivalent parameters was obtained, and the sensitive impedance spectroscopy characteristics of K nutrition level were extracted. Moreover, the influence of moisture content on impedance measurement is discussed and the prediction model for K content is established. Results show that electrical impedance can be applied to the detection and diagnosis of plant K nutrition status.

Should Harvest Residues be Left on Site in Peatland Forests to Decrease the Risk of Potassium Depletion?

Sarkkola, S., L. Ukonmaanaho, T.M. Nieminen, R. Laiho, A. Laurén, L. Finér, and M. Nieminen. 2016. Forest Ecology and Management 374:136-145. DOI 10.1016/j.foreco.2016.05.004.

Abstract: Sufficiency of potassium (K) is one of the biggest concerns for forestry in boreal peatlands, since the rooting zone stores of K in thick peat soils are generally small and significant proportion of the K in ecosystem is bound in stand biomass. Increased demand for bioenergy may lead to intensified harvesting also in such forests. There is thus an urgent need to study the significance of the nutrients in harvest residues for the next-generation forest productivity. The specific questions in peatland forests are whether the harvest residues are an important source of K to the restock or whether the K in harvest residues is lost by leaching. We quantified K losses from drained peatland forests following management by clear-felling with stem-only harvesting (SOH), whole-tree harvesting (WTH) and whole-tree harvesting plus stump harvesting (WTHS). Calibration period - control area method and mixed modelling approach were used to analyze the ditch-outflow K-concentration and water-borne K-export data from 17 harvested and 5 control catchments in southern and central Finland. K concentrations and runoff were monitored for 1-2 years before and 3-4 years after treatment. Supplementary long-term data from one pair of harvested and non-managed catchments was used to assess the duration of the harvest impact on K export.

Mean annual K concentrations in ditch outflow were higher after than before harvesting. The concentrations started to increase during the second or third post-harvest year, reaching the peaks of 1.1-2.2 mg L^{-1} in WTHS, 0.8-1.7 mg L^{-1} in WTH, and 1.0-1.9 mg L^{-1} in SOH. The concentrations correlated positively with the amount of K in the surface peat. In nutrient-poor ombrotrophic sites, the K concentrations were higher for sites with shallower water-table level.

Using the supplementary data, the impact of harvesting on K losses was estimated to last for about eight years. The overall estimated K loss was about 28 kg ha^{-1} from minerotrophic sites, and about 9 kg ha^{-1} from ombrotrophic sites. There was no significant difference in K losses between the harvest treatments SOH, WTH and WTHS, indicating that the K in harvest residues was largely retained onsite. The role of K losses induced by harvesting in the site K stores in drained peatland forests is discussed.

The Calibration Model in Potassium Ion Flux Non-Invasive Measurement of Plants *in vivo in situ*

Lin Xue, Dong-jie Zhao, Zi-yang Wang, Xiao-dong Wang, Cheng Wang, Lan Huang, and Zhong-yi Wang. 2016. Information Processing in Agriculture 3(2):76-82. DOI 10.1016/j.inpa.2016.05.002.

Abstract: SIET (Self-referencing Ion Electrode Technique) provides a novel electrophysiological tool which can non-invasively measure the dynamic influxes and effluxes of ions caused by the diffusion along the concentration gradients *in vivo*. However, in this technique ion fluxes are converted to voltage signals using an ion selective microelectrode at a small amplitude of μV, which is easy to be interfered by the ambient noise. Hence, effective solutions to the suppression of noise and calibration of ion flux measurement system are very important for this method. A K^+-selective microelectrode was constructed using liquid ion exchangers (LIX) to investigate ion transport over plant tissue. A standard concentration gradient which simulates plant living cells was produced by an electrode with a certain tip diameter, filled with a solution containing a known K^+ concentration in 100 mmol/L. An ion diffusion simulation model was established. This model evaluated the performance of ion flux measurement system in accuracy and reliability by comparing the consistency of the measured value and the predicted curve. K^+ fluxes were measured within 25 min at each measuring point of distance 10, 20, 30, 40, 50, 80, and 100 μm from the K^+ source, respectively. It can be seen that the K^+ fluxes changes little, which indicates that ion flux measurement system has a reliable stability. The study provides a theoretical basis for a new non-invasive ion flux measurement method creation and a new sensors design.

Non-destructive Measurement of Calcium and Potassium in Apple and Pear Using Handheld X-ray Fluorescence

Kalcsits, L.A. 2016. Front. Plant Sci. DOI 10.3389/fpls.2016.00442.

Abstract: Calcium and potassium are essential for cell signaling, ion homeostasis and cell wall strength in plants. Unlike nutrients such as nitrogen and potassium, calcium is immobile in plants. Localized calcium deficiencies result in agricultural losses; particularly for fleshy horticultural crops in which elemental imbalances in fruit contribute to the development of physiological disorders such as bitter pit in apple and cork spot in pear. Currently, elemental analysis of plant tissue is destructive, time consuming and costly. This is a limitation for nutrition studies related to calcium in plants. Handheld portable x-ray fluorescence (XRF) can be used to non-destructively measure elemental concentrations. The main objective was to test if handheld XRF can be used for semi-quantitative calcium and potassium analysis of in-tact apple and pear. Semi-quantitative measurements for individual fruit were compared to results obtained from traditional lab analysis. Here, we observed significant correlations between handheld XRF measurements of calcium and potassium and concentrations determined using MP-AES lab analysis. Pearson correlation coefficients ranged from 0.73 and 0.97. Furthermore, measuring apple and pear using handheld XRF identified spatial variability in calcium and potassium concentrations on the surface of individual fruit. This variability may contribute to the development of localized nutritional imbalances. This highlights the importance of understanding spatial and temporal variability in elemental concentrations in plant tissue. Handheld XRF is a relatively high-throughput approach for measuring calcium and potassium in plant tissue. It can be used in conjunction with traditional lab analysis to better understand spatial and temporal patterns in calcium and potassium uptake and distribution within an organ, plant or across the landscape.

Nutrient Partitioning and Stoichiometry in Unburnt Sugarcane Ratoon at Varying Yield Levels

Leite, J.M., I.A. Ciampitti, E. Mariano, M.X. Vieira-Megda, and P.C.O. Trivelin. 2016. Front. Plant Sci. DOI 10.3389/fpls.2016.00466.

Abstract: Unraveling nutrient imbalances in contemporary agriculture is a research priority to improve whenever possible yield and nutrient use efficiency in sugarcane (Saccharum spp.) systems while minimizing the costs of cultivation (e.g., use of fertilizers) and environmental concerns. The main goal of this study was therefore to investigate biomass and nutrient [nitrogen (N), phosphorus (P), and potassium (K)] content, partitioning, stoichiometry and internal efficiencies in sugarcane ratoon at varying yield levels. Three sites were established on highly weathered tropical soils located in the Southeast region of Brazil. At all sites, seasonal biomass and nutrient uptake patterns were synthesized from four sampling times taken throughout the sugarcane ratoon season. In-season nutrient partitioning (in diverse plant components), internal efficiencies (yield to nutrient content ratio) and nutrient ratios (N:P and N:K) were determined at harvesting. Sugarcane exhibited three distinct phases of plant growth, as follows: lag, exponential–linear, and stationary. Across sites, nutrient requirement per unit of yield was 1.4 kg N, 0.24 kg P, and 2.7 kg K per Mg of stalk produced, but nutrient removal varied with soil nutrient status (based on soil plus fertilizer nutrient supply) and crop demand (potential yield). Dry leaves had lower nutrient content (N, P, and K) and broader N:P and N:K ratios when compared with tops and stalks plant fractions. Greater sugarcane yield and narrowed N:P ratio (6:1) were verified for tops of sugarcane when increasing both N and P content. High-yielding sugarcane systems were related to higher nutrient content and more balanced N:P (6:1) and N:K (0.5:1) ratios.

Protein Synthesis is the Most Sensitive Process when Potassium is Substituted by Sodium in the Nutrition of Sugar Beet (*Beta vulgaris*)

Faust, F., and S. Schubert. 2016. Plant Physiology and Biochemistry 107:237-247. DOI 10.1016/j.plaphy.2016.06.009.

Abstract: Potassium ions (K^+) and sodium ions (Na^+) share many physical and chemical similarities. However, their interchangeability in plant nutrition is restricted. Substitution studies showed that K^+ can be replaced by Na^+ to a large extent in the nutrition of *Beta vulgaris* L. However, the extent of substitution without negative impacts is not unlimited. The aim of the present study was to identify the process which is most sensitive during the substitution of K^+ by Na^+ in nutrition of young sugar beet plants. We focused on transpiration, growth, and net protein synthesis. Plants were grown under controlled environmental conditions. With transfer of seedlings into nutrient solution, plants were cultivated in different substitution treatments. For all treatments the sum of K^+ and Na^+ (applied as chloride) was fixed to 4 mM. The extent of substitution of K^+ by Na^+ in the nutrient solution was varied from low (0.25% substitution: 3.99 mM K^+, 0.01 mM Na^+) to almost complete substitution (99.75% substitution: 0.01 mM K^+, 3.99 mM Na^+). The supply of 3.99 mM K^+ in 0.25% substitution treatment guaranteed the absence of K^+ deficiency. Transpiration was not affected by the substitution. Growth was inhibited at a substitution level of 99.75%. Net protein synthesis was already affected at a substitution level of 97.50% (0.10 mM K^+, 3.90 mM Na^+). Hence, net protein synthesis was most sensitive to the substitution and limited the extent of substitution of K^+ by Na^+ in the nutrition of young sugar beet plants.

K-Priming Positively Modulates Growth and Nutrient Status of Salt-Stressed Cotton (*Gossypium hirsutum*) Seedlings

Huma Lubna Shaheen, Muhammad Iqbal, Muhammad Azeem, Muhammad Shahbaz, and Misbah Shehzadi. 2015. Archives of Agronomy and Soil Science 62(6):759-768. DOI 10.1080/03650340.2015.1095292.

Abstract: Being macronutrient, K^+ is involved in a number of metabolic processes including stimulation of over 60 enzymes. The present study was conducted to investigate whether K-priming could alleviate the effects of salinity on the growth and nutrient status of cotton seedlings. The seeds of two cotton cultivars, namely FH-113 and FH-87, were primed with solutions of three potassium sources (KNO_3, K_2SO_4 and K_2HPO_4) using three concentrations (0%, 1.25% and 1.5%) of each potassium source. After 1 week of germination, the seedlings were subjected to salinity (0 and 200 mM NaCl) stress. The results showed that salinity significantly affected growth and nutrients status of cotton seedlings. The K-priming alleviated the stress condition and significantly improved dry matter as well as nutrient uptake in cotton seedlings. Of the priming treatments pre-sowing treatment with KNO_3 (1.5%) was most effective in increasing shoot and root lengths and biomass of cotton seedlings. The seedlings raised from seed treated with KNO_3 (1.5%) showed varied accumulation of cations (Ca^{2+}, Na^+ and K^+) and faced less oxidative stress irrespective of cotton cultivars under salt stress. The results suggested that pre-sowing seed treatment with KNO_3 (1.5%) might be recommended for synchronized germination and sustainable production of cotton crop under saline environments.

Effect of Technological Progress on Working Time in Agriculture

Umstätter, Ch., R. Stark, D. Schmid, and M. Schick. 2016. Recherche Agronomique Suisse 7(4):204-209.

Abstract: This study addresses the influence of technological progress on the annual working hours of Swiss farmers in the years 2003 and 2012. The analysis of standard labour contracts for agricultural employees in Switzerland as well as a study of the literature revealed that the weekly working time for agricultural activities in most countries comes to over 48 hours. In addition, the working-time requirement was modelled on the basis of accounting data from 65 arable and 236 dairy farms. The data were used to calculate average farms, after which the ART Work Budget Software (Agroscope, Ettenhausen) was used for the modelling. Overall, it was noted that technological progress is definitely implemented on the farms, but that the resulting working-time reduction is being used either to farm more land or manage larger livestock numbers. In conclusion savings in working time have been offset by expansion, and working hours per person and year have tended to remain stable.

Read on

Agriculture: Future Farming
King, A. 2016. Nature. DOI 10.1038/531578a.

Seven Ways to Save our Soils
Payton, L. Soil Association.

We Must Rebuild Farmers' Resilience after Ethiopia's Catastrophic El Niño
Before this year's drought, farmers' yields were tripling in some regions. With the right investment, Ethiopia can get back on track for middle-income status. Mamo, T. 2016. The Guardian.

Keeping a Pulse on the Soil
Rossie Izlar, R. 2016. Crop Sci. Soc. Amer.

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17 Farmer Heroes for Sustainability, Equality, and Defense of Traditions
Nierenberg, D., and R. Pallin. 2016. Foodtank.

ISEI, Kadin Eye 1 Million Farmers to Join Sustainable Agriculture Scheme
Amindoni, A. 2016. The Jakarta Post.

Under the Sea: The Underwater Farms Growing Basil, Strawberries and Lettuce
Scuba divers and agricultural experts develop a project to work out if growing plants in pods on the seabed could be a viable solution to future food security. McEachran, R. 2015. The Guardian.

Uganda: Scientists Develop Technology to Guide Farmers on Use of Fertiliser
13 April 2016. The Monitor, All Africa.

Climate is Changing. Food and Agriculture must too
7 facts on climate change & food production for sustainable development. 18 May 2016. FAO.

Tissue Analysis Identifies Potash Shortage
9 June 2016. FARMINGUK.

Soil Fertility Information is Transforming Agriculture in Ethiopia
Mamo, T. 17 June 2016. Thomson Reuters Foundation News.

Clipboard

Professor Tekalign Mamo wins 2016 IFA Norman Borlaug Award

Congratulations from the International Potash Institute

Professor Tekalign Mamo, a distinguished soil scientist and former Ethiopian State Minister of Agriculture, is the recipient of the 2016 IFA Norman Borlaug Prize, awarded at the Annual IFA Meeting in Moscow. He was nominated for his outstanding contribution to improving soil health and nutrient management in Ethiopia, benefitting over 11 million smallholder farmers. His assiduous engagement for sustainable agricultural practices and tailored fertilization has contributed to tripling grain production and measurably reduce hunger and poverty in the country.

Professor Tekalign Mamo is IPI's Advisor in Ethiopia.

Find out more about his achievements in the IFA Press Release.

Prof. Mamo (in the middle) at the award ceremony. Photo: Courtesy of IFA.

Two new IPI videos

The Role of Potassium in Balanced Fertilization

The role of potassium in balanced fertilization and its impact on crop productivity and quality is gaining increasing attention from agronomists and plant nutritionists. This is particularly relevant to sub-Saharan Africa (SSA) where soils are nutrient depleted, fertilizer use is low and agricultural productivity remains the lowest in the world.

In November 2015 key researchers and senior soil fertility experts gathered at the 2nd IPI - Ministry of Agriculture - Hawassa University - Ethiopian Agricultural Transformation Agency (ATA) joint symposium. Entitled The Role of Potassium in Balanced Fertilization the symposium covered the main themes of

- Soil potassium status.
- Potassium and balanced fertilization.
- Potassium for sustainable cropping systems.
- Potassium for sustainable cropping systems
- Potassium dynamics in shrink-swell soils.
- Potassium impact on crop quality.

Some of the key speakers from the event share their thoughts on the Role of Potassium in Balanced Fertilization in sub-Saharan Africa, and in agriculture worldwide.

You can watch the video on the IPI website or on YouTube.

Increasing Crop Yields through Advanced Soil Testing and Fertilizer Recommendation for Small Scale Farmers in Kenya

Increasing smallholder crop production to feed growing populations is an urgent challenge which requires affordable soil testing methods, fertilizer recommendations, and accessible fertilizers with the required nutrients. However, soil analysis for small-scale farmers in Kenya has been difficult and mostly non-existent, primarily due to inaccessibility, high costs and lack of awareness on the need to conduct soil analysis. The launch of the SoilCares mobile laboratories in 2013 is one approach that has brought significant awareness to smallholder farmers on the need for soil analysis, as well as making it more accessible.

For more details of "SoilCares Lab Initiative in Bungoma County, Kenya" see the report on page 31 of this edition of the *e-ifc*.

You can watch the video on the IPI website here.

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