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Optimizing Crop Nutrition

Editorial

Dear readers,

Everybody has different preferences for one food or another, usually on the basis of taste, appearance and cost - and how hungry they are feeling! However, in today's world, should we not introduce some further criteria when choosing what to eat, considering factors such as the way the crop is grown, including its environmental and energy costs? I strongly believe we should.

But how do we make the right food choices, based on a wider range of criteria? In helping us towards an answer, Eshel *et al.* (2014) provide an interesting insight into the environmental costs of producing various types of protein in the US. One of the striking findings is that beef production demands about ten times more resources than the other categories examined (dairy, eggs, poultry and pork). Thus, the quest for more sustainable food systems is not only achieved by increasing the efficiency of production and supply, but also by adjusting our preferences concerning the types of food we choose to eat.

Lastly, I wish to draw your attention to an interesting initiative called Cool Farm Tool (http://www.coolfarmtool.org/). Under this initiative, large food and fertilizer companies, universities and other NGOs have created a new web-based tool that provides a greenhouse gas calculator for various crops under a range of different management practices.

I wish you a good read.

Hillel Magen
Director

Reference

Eshel, G., A. Shepon, T. Makov, and R. Milo. 2014. Land, Irrigation Water, Greenhouse Gas, and Reactive Nitrogen Burdens of Meat, Eggs, and Dairy Production in the United States. PNAS 111(33):11996-12001.

Photo cover page: Mango orchard in the Jordan valley, south of the Dead Sea, Israel. Irrigation and nutrients (fertigation) are applied in special deep tunnels along the trees, filled with tuff, to avoid problems of salinity and low soil fertility. Photo by H. Magen.

Research Findings

Wheat experiment setup. Photo by authors.

Effects of Potassium and Nitrogen Applications on the Yield and Yield Components of Bread and Durum Wheat

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Abstract

This study reports on an investigation made at the Ege University experimental farm (Izmir, Turkey), with soil low in available potassium (K), on the effects of different rates of potassium (K_2O) and nitrogen (N) fertilization on two different wheat varieties, one bread wheat (Galil) and the other a durum wheat (Ege 88). Measurements were made on yield, yield components, elemental composition, N use efficiency (NUE %) and the N derived from the N fertilizer (Ndff %). In general, grain and straw yields were higher for the bread than the durum wheat for corresponding N and K applications. However, the highest yield was found at the highest N and K rates applied to durum wheat. NUE % was also high in the highest rate of K application, at 1% level in the bread wheat and 5% in the durum wheat. The N derived from the N fertilizers increased as the N and K rates increased. It can be concluded that the N_1 level (150 kg ha^{-1}) of the studied N doses can be accepted as the most economic dose for both bread and durum wheat varieties in terms of N fertilization. For the bread

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variety, the lowest dose of K fertilization (K_0), i.e. soil K, could be considered adequate under rainfed (244 mm) conditions in the Ege region of Turkey. On the other hand, the grain and straw yields of the durum wheat significantly increased with increasing doses of K up to $N_{1.5}$ (225 kg N ha^{-1}) application. The highest K fertilization level (225 kg K_2O ha^{-1}) at the highest N level (225 kg N ha^{-1}) can thus be recommended for this variety provided that it is economically viable.

Introduction

Bread is the main staple food in Turkey where both bread and durum wheat are cultivated. Durum wheat is used in the production of pasta and biscuits, which are consumed extensively. In all, about 22 million tons of wheat is produced annually (Anonymous, 2014a). The average yield of bread wheat is about 7 t ha^{-1} but under conditions of water shortage (150-200 mm), yield decreases greatly to less than 3 t ha^{-1}. In the case of durum wheat, yields of just over 3 MT ha^{-1} have been reported under 400 mm of rainfall conditions (Ayçiçek and Yıldırım, 2006). Most of the standard fertilizers are used in wheat production including: diammonium phosphate (DAP), NP (20:20:0), urea, calcium ammonium nitrate (CAN) or ammonium nitrate (AN). These are generally used under rainfed conditions. Above 500 mm precipitation, NPK (15:15:15 KCl based with or without Zn), and CAN fertilizers are also included in the fertilization recommendations.

The objective of this work was to study the effect of increasing rates of K supplied together with increasing rates of N application on the yield of two different wheat varieties (one bread wheat and the other durum wheat) on their main agronomic properties, including nutrient concentrations and N fertilizer use efficiencies (NUE).

Materials and methods

Two different N and K field experiments for bread and durum wheat varieties were established under rainfed conditions (244 mm) in the year 2012 at the Ege University experimental farm (38° N and 27° E; 44m above sea level). The soil was Typic Xerofluvent with the following characteristics: slightly alkaline reaction, sandy loam texture, rich in $CaCO_3$, poor in organic matter and without any problem of salinity. Regarding available plant nutrients, total-N was medium, K low and phosphorus (P) poor (Table 1).

Table 1. Physical and chemical properties of the experimental soil.

	Unit	Value
Element		
Water soluble salts	%	0.027
pH		7.64
Organic matter	%	1.27
Texture		Sandy loam
$CaCO_3$	%	11.90
Total N	%	0.09
Available nutrients		
P	*mg kg^{-1}*	0.16
K	*mg kg^{-1}*	183
Na	*mg kg^{-1}*	71
Ca	*mg kg^{-1}*	2,802
Mg	*mg kg^{-1}*	186

The soil analytical methods used were as follow: pH (Jackson, 1967), water soluble salts (Anonymous, 2004), $CaCO_3$ (Çağlar, 1949), texture and organic matter (Black, 1965), total-N (Bremner, 1965), water extractable P (Bingham, 1949), exchangeable K (1 N NH_4OAc; pH=7), extractable K, calcium (Ca), sodium (Na) and magnesium (Mg) (Pratt, 1965; Thomas, 1982). The two varieties used in this experiment were Galil bread wheat and Ege 88 durum wheat. Galil has a mean 1,000 grain weight of 42 g, is resistant to drought, yields well and produces good quality bread. For Ege 88, the mean 1,000 grain weight is somewhat higher at 45-48 g, it is resistant to winter conditions, drought and lodging and is an early variety. It also responds well to fertilization and does not drop grains (Unsal *et al.*, 2009; Anonymous, 2014b).

The study was carried out with four replications using a random block design. The four N treatments were: N_0 (0), $N_{0.5}$ (75 kg ha^{-1}), N_1 (150 kg ha^{-1}) and $N_{1.5}$ (225 kg ha^{-1}). There were three rates of K: K_0 (0), K_1 (150 kg K_2O ha^{-1}) and $K_{1.5}$ (225 kg K_2O ha^{-1}). Fertilizers were applied in the form of ammonium sulfate ($(NH_4)_2SO_4$) and potassium sulfate (K_2SO_4). The N_1 and K_0 rates are the recommended doses according to soil analysis for wheat in this region. One third of the N was applied at sowing and two thirds at tillering. Phosphorus, together with K and with one third of N fertilizer, was given as 100 kg ha^{-1} P_2O_5 in the form of triple superphosphate (TSP) during soil preparation. In two of the treatments (75 and 225 kg ha^{-1} N) labelled $(NH_4)_2SO_4$ (^{15}N) was used to detect the NUE of the plants. Detailed findings can be found in the proceedings of the 2013 International Plant Nutrition Colloquium (IPNC) meeting (Çolak Esetlili *et al.*, 2013).

Grains were analyzed for their N, P, K and zinc (Zn) concentrations (Kacar, 1972). Crude protein concentrations were calculated according to the N concentration of the grains multiplied by the coefficient 6.25. Protein fractions were classified based on their differential solubility according to the MAES method (Maes, 1962). Estimation of NUE requires knowledge of the amount of plant N derived from the fertilizer. This was achieved using ^{15}N labeled nitrogen fertilizer; determination of ^{15}N in the dried plant material was determined by mass spectrometry after dry combustion (Axmann *et al.*, 1990; Halitligil *et al.*, 2009).

Statistical analyses were performed using SPSS 15.0 software for Windows.

Results and discussion

Yield and yield components

The lowest grain yield of Galil bread wheat variety (1,590 kg ha^{-1}) was found in the $N_0K_{1.0}$ treatment where no N was given and 150 kg ha^{-1} K_2O applied. The lowest straw yield (1,750 kg ha^{-1}) was also found in the same treatment (Table 2). The highest grain yield (4,610 kg ha^{-1}) of this variety was recorded in the $N_{1.5}K_0$ (225 kg ha^{-1} N and no K) treatment. Similarly, the highest straw yield (4,900 kg ha^{-1}) was also found in the same treatment ($N_{1.5}K_0$) as well as in the $N_{1.5}K_{1.0}$ treatment (Table 2). For the Ege 88 durum wheat variety, the lowest grain and straw yields were determined as 1,600 kg ha^{-1} in N_0K_0 treatments (Table 2). The highest grain yield was 4,690 kg ha^{-1} in the $N_{1.5}K_{1.5}$ application and the highest straw yield was 4,500 kg ha^{-1} in the same treatment (Table 2).

Table 2. Grain and straw yields of bread and durum wheat varieties.

N level	Grain			Straw		
	K_0	$K_{1.0}$	$K_{1.5}$	K_0	$K_{1.0}$	$K_{1.5}$
	kg ha^{-1}					
	Bread wheat (*cv.* Galil)					
N_0	1,840 c	1,590 c	1,840 c	2,040 b	1,750 c	2,190 c
$N_{0.5}$	2,590 b	2,820 b	3,100 b	3,010 b	2,900 b	3,290 b
$N_{1.0}$	4,150 a	4,410 a	4,140 a	4,360 a	4820 a	4,330 ab
$N_{1.5}$	4,610 a	4,460 a	4,290 a	4,900 a	4,900 a	4,400 a
N_{LSD}	56.67(2)			80.98(2)		
K_{LSD}	ns(3)			ns(3)		
NxK_{LSD}	73.12(1)			104.49(1)		
	Triticum durum (*cv.* Ege 88)					
N_0	1,600 b	1,670 c	2,010 c	1,600 b	1,740 b	1,930 c
$N_{0.5}$	2,330 b	2,700 b	3,030 b	2,080 b	2,520 b	2,810 b
$N_{1.0}$	3,380 a	3,960 a	4,050 a	3,380 a	3,960 a	3,720 a
$N_{1.5}$	3,830 a B	4,320 a AB	4,690 a A	3,490 a B	4,110 a AB	4,500 a A
N_{LSD}	64.19(2)			67.09(2)		
K_{LSD}	55.59(2)			43.28(1)		
NxK_{LSD}	82.83(1)			86.57(1)		

Note: Lowercase letters refer to increasing N treatments; capital letters refer to K treatments.
(1)$P<0.05$; (2)$P<0.01$; (3)ns=not significant

Grain yields of both varieties increased in parallel with the increasing levels of N under all the increasing K levels and the differences between treatments were statistically significant. However, when yield results were examined in relation to increasing K levels under each of the increasing N applications the responses found in bread wheat were not statistically significant. In this regard, durum grain yield increased (Table 2). Our findings with respect to the yields of durum wheat were more or less similar to the reports of other scientists who studied the same variety in different localities of the same region (Dinçer, 1972; Alpaslan, M., 2001; Ünsal *et al.*, 2009). Therefore, to achieve higher grain and straw yields for bread wheat, 150 kg ha^{-1} ($N_{1.0}$ rate) can be recommended as the most economical dose in the Ege region. On the other hand, for durum wheat, since the yields responded to higher rates of N and K fertilization, higher doses should be considered.

Table 3. ’000 grain weights of bread and durum wheat varieties.

N level	’000 grain weight					
	Bread wheat (*cv.* Galil)			*Triticum durum* (*cv.* Ege 88)		
	K_0	$K_{1.0}$	$K_{1.5}$	K_0	$K_{1.0}$	$K_{1.5}$
	g					
N_0	42.8 c	42.7 b	43.4 a	47.4 b	49.3 b	48.2 c
$N_{0.5}$	43.3 bc B	46.6 a A	46.2 a B	53.0 a	52.0 ab	51.6 b
$N_{1.0}$	46.0 ab	48.1 a	45.6 a	53.7 a	55.1 a	55.0 a
$N_{1.5}$	47.1 a	45.2 ab	46.2 a	54.1 a	55.0 a	56.1 a
N_{LSD}	2.39(2)			2.49(2)		
K_{LSD}	ns(3)			ns(3)		
NxK_{LSD}	3.08(1)			3.22(1)		

Note: Lowercase letters refer to increasing N treatments; capital letters refer to K treatments.
(1)$P<0.05$; (2)$P<0.01$; (3)ns=not significant

Enhanced doses of N application increased the 1,000 grain weights under almost all of the K levels in both of the varieties. The effect of enhanced K rates was not so clear but the weights for the durum wheat were generally higher compared to the bread variety. In this respect the highest weight was obtained with the $N_{1.5}$ and $K_{1.5}$ treatment. The 1,000 grain weights ranged between 42.7-48.1 g for bread and 47.4-56.1 g for durum wheat (Table 3). Our findings indicate that the variety effect was more clearly expressed than N and K fertilization and these results are in agreement with other reports (Hussain *et al.*, 1996).

Crude protein concentrations in the grains of the bread wheat variety ranged between 11.8-13.2% and in durum wheat between 10.8-14.4%. In both varieties, no significant response to K fertilization was observed. However in the case of durum wheat, N fertilization was significantly effective in increasing the crude protein values (Table 4).

There is some indication that rates of N fertilization or high temperatures during growth can induce changes in the proportions of gliadins and glutenins in the grain but the reports are inconsistent and leave many unanswered questions

Table 4. Concentration (%) of crude protein in the grains of bread and durum wheat varieties.

N level	Crude protein					
	Bread wheat (*cv.* Galil)			*Triticum durum* (*cv.* Ege 88)		
	K_0	$K_{1.0}$	$K_{1.5}$	K_0	$K_{1.0}$	$K_{1.5}$
	%					
N_0	12.2 ab	12.1	13.2 a	11.8 b	12.5 ab	12.3 ab
$N_{0.5}$	12.1 ab	11.8	11.6 b	11.7 b	11.0 b	10.7 b
$N_{1.0}$	11.2 b B	12.8 A	12.0 ab AB	13.4 ab	12.5 ab	12.4 ab
$N_{1.5}$	13.1 a	13.1	12.9 ab	14.2 a	13.8 a	14.4 a
N_{LSD}	0.88(1)			1.87(2)		
K_{LSD}	ns(3)			ns(3)		
NxK_{LSD}	1.57(1)			2.41(1)		

Note: Lowercase letters refer to increasing N treatments; capital letters refer to K treatments.
(1)P<0.05; (2)P<0.01; (3)ns=not significant

Table 5. Nitrogen concentration in bread and durum wheat varieties (N %).

N level	Nitrogen concentration					
	Bread wheat (*cv.* Galil)			*Triticum durum* (*cv.* Ege 88)		
	K_0	$K_{1.0}$	$K_{1.5}$	K_0	$K_{1.0}$	$K_{1.5}$
	%					
N_0	1.95 ab	1.93	2.11 a	1.88 b	2.00 ab	1.97 ab
$N_{0.5}$	1.93 ab	1.88	1.86 b	1.87 b	1.76 b	1.72 b
$N_{1.0}$	1.80 b A	2.04 A	1.91 ab AB	2.15 ab	2.00 ab	1.98 ab
$N_{1.5}$	2.10 a	2.09	2.06 ab	2.28 a	2.21 a	2.30 a
N_{LSD}	0.14(1)			0.30(2)		
K_{LSD}	ns(3)			ns(3)		
NxK_{LSD}	0.24(1)			0.38(1)		

Note: Lowercase letters refer to increasing N treatments; capital letters refer to K treatments.
(1)P<0.05; (2)P<0.01; (3)ns=not significant

Table 6. Potassium concentration in bread and durum wheat varieties (K %).

N level	Potassium concentration					
	Bread wheat (*cv.* Galil)			*Triticum durum* (*cv.* Ege 88)		
	K_0	$K_{1.0}$	$K_{1.5}$	K_0	$K_{1.0}$	$K_{1.5}$
	%					
N_0	0.34	0.33 b	0.33	0.37	0.37 b	0.38
$N_{0.5}$	0.32	0.32 b	0.32	0.39	0.40 ab	0.41
$N_{1.0}$	0.34 AB	0.36 a A	0.33 B	0.39	0.41 ab	0.41
$N_{1.5}$	0.32	0.33 ab	0.34	0.40	0.41 a	0.41
N_{LSD}	0.016(1)			0.021(1)		
K_{LSD}	ns(3)			ns(3)		
NxK_{LSD}	0.027(1)			0.037(1)		

Note: Lowercase letters refer to increasing N treatments; capital letters refer to K treatments.
(1)P<0.05; (2)P<0.01; (3)ns=not significant

(Dupont *et al.*, 2006). There is, however, good evidence that the proportion in which these two storage proteins are present in the endosperm does affect grain quality. The gliadins are low in molecular weight, do not possess di-sulphide bridges and engender a poor baking quality. By contrast, the glutenins are large heterogeneous molecules which contain many di-sulphide bridges which provide elasticity and resulting dough of high tenacity to improve baking quality (see Mengel and Kirkby, 2001).

Elemental composition

Nitrogen concentrations in the grain of bread wheat ranged between 1.80-2.11% and for durum wheat between 1.72-2.30%. Durum wheat crude protein concentrations increased in parallel with the N concentrations in the grain. However, no definite response to K fertilization was seen either in N concentrations of both varieties or in their crude protein concentrations (Table 4 and 5).

The P concentrations in the grain of both varieties declined with increasing N applications and the highest P concentration for durum wheat was observed in the N_0 plot. Phosphorus concentration in bread wheat grains ranged between 0.26-0.27% and of the durum wheat between 0.27-0.29%.

Potassium concentrations in durum wheat grain were enhanced by increasing doses of N as well as K applications. Results showed that K ranged between 0.32-0.36% in bread wheat and between 0.37-0.41% in durum wheat (Table 6). In general, the concentrations of K were greater in the grains of durum wheat and ran parallel with increasing grain yields.

Zinc concentrations generally decreased in relation to increasing N treatments and ranged between 23-61 mg kg^{-1} in the grain of bread wheat and 25-40 mg kg^{-1} in the grain of durum wheat. On the other hand, concentrations generally increased as the K rates were enhanced. It is important to record that all of the measurements were above the critical value of Zn (15 ppm) for wheat grain concentration (IPNI, 2014). This critical value relates to the important link between Zn grain concentration and the maintenance of human health because wheat is a major source of dietary Zn for human populations in large parts of the world, including Turkey.

Protein fractions

Results showed that in bread wheat, the albumin-N varied between 128-198 mg 100 g^{-1} flour, and in the durum wheat variety between 181-404 mg 100 g^{-1} flour. With respect to globulin-N, the range in bread wheat was between 70-287 mg 100 g^{-1} flour, and in durum wheat between 182-308 mg 100 g^{-1} flour (Table 7).

Table 7. Protein fractions of bread and durum grains (mg 100 g^{-1} flour).

N level	Albumin-N			Globulin-N		
	K_0	$K_{1.0}$	$K_{1.5}$	K_0	$K_{1.0}$	$K_{1.5}$
	---*mg 100 g^{-1} flour*---					
	Bread wheat (*cv.* Galil)					
N_0	128	152	140	70	189	196
$N_{0.5}$	187	163	169	140	196	224
$N_{1.0}$	187	198	198	266	161	189
$N_{1.5}$	146	187	175	252	259	287
	Triticum durum (*cv.* Ege 88)					
N_0	217	277	300	182	238	245
$N_{0.5}$	270	239	226	273	238	183
$N_{1.0}$	326	464	314	224	280	306
$N_{1.5}$	181	270	251	265	252	308

In general, no well defined steady responses in the protein fractions were observed in relation to increasing N and K fertilization. However, in both wheat varieties, globulin-N was found to be lowest in the K_0N_0 treatment and highest in $N_{1.5}K_{1.5}$. Here it is worth emphasizing that the highest yield in durum wheat was also obtained in the $N_{1.5}K_{1.5}$ treatment. Albumin-N was highest in the grains of the wheat of both varieties in the N_1K_1 treatment.

Table 8. Ndff (%) by the grain and straw of bread and durum wheat varieties and their NUE (%).

Treatments	Ndff		NUE
	---%---		
	Grain	Straw	
	Bread wheat (*cv.* Galil)		
$N_{0.5}K_0$	25.79 b	25.28 bc	19.20 bc
$N_{0.5}K_{1.0}$	26.38 b	28.03 ab	22.16 ab
$N_{0.5}K_{1.5}$	26.81 b	29.44 a	24.74 a
$N_{1.5}K_0$	29.68 a	19.97 d	15.20 cd
$N_{1.5}K_{1.0}$	29.84 a	23.19 cd	15.84 cd
$N_{1.5}K_{1.5}$	30.47a	22.41 cd	13.87 d
Treatments LSD	$1.39^{(2)}$	$4.60^{(2)}$	$5.07^{(2)}$
	Triticum durum (*cv.* Ege 88)		
$N_{0.5}K_0$	26.42 b	26.10 a	16.24 ab
$N_{0.5}K_{1.0}$	26.18 b	27.28 a	19.35 a
$N_{0.5}K_{1.5}$	24.84 bc	28.44 a	21.14 a
$N_{1.5}K_0$	22.48 c	20.13 b	9.61 c
$N_{1.5}K_{1.0}$	29.72 a	16.22 c	12.60 bc
$N_{1.5}K_{1.5}$	31.01 a	19.77 b	16.82 ab
Treatments LSD	$2.86^{(2)}$	$2.48^{(2)}$	$6.00^{(1)}$

Note: Lowercase letters refer to increasing N treatments.
$^{(1)}P<0.05$; $^{(2)}P<0.01$

Nitrogen fertilizer use efficiency and nitrogen derived from the fertilizer

NUE is defined as the ratio between the N derived from the fertilizer (Ndff) and the amount of N fertilizer applied to the crop. In the current study, NUE was found to be high under the low doses of N in both varieties. On the other hand, NUE increased in both varieties in parallel to the increasing doses of K fertilization. The highest NUE was obtained at 225 kg ha^{-1} K_2O (the highest dose of $K=K_{1.5}$) supplied with a low dose (75 kg ha^{-1}) of N fertilizer. As can be seen from Table 8, this result could be related to the low Ndff of the wheat straw because the Ndff of the grains were high and increased as the rate of N and K fertilization increased (Table 8). In this current study, even though different rates of fertilizers were supplied to the wheat in the treatments, NUE was generally higher in bread wheat than durum (Table 8).

As well as determining the levels of N crops require, the time and method of application should also be optimized (depending on rainfall conditions) to avoid nitrate leaching and to minimize environmental pollution (Limon-Ortega *et al.*, 2000; Velasco *et al.*, 2012; Silva *et al.*, 2014). It is thus important to increase the efficiency of N usage and the amount of N derived from the fertilizer (Kacar, 1984).

Potassium is an important essential primary plant nutrient which acts synergistically with N in various physiological processes, playing an outstanding role in water relationships as well as in stimulating the uptake and metabolism of both nutrients. If necessary, K should therefore be included in fertilizer recommendations according to soil analysis and crop requirements (Mengel and Kirkby, 2001).

Conclusion

It can be concluded that 150 kg ha^{-1} of N is the statistically significant economic dose for bread as well as durum wheat varieties in terms of N fertilization. For the K fertilization of the bread variety grown under Ege region's arid conditions, soil K could be considered as sufficient. On the other hand, since durum wheat yields significantly increased with increasing doses of K, higher K rates (150-225 kg ha^{-1} K_2O) could be recommended provided that this is economically viable. Results also showed that globulin-N was highest in this specified K dose. It is also worth stating that grains removed more from the fertilizer N (Ndff) compared to the straw and that the Ndff increased as the N and K rates increased.

Acknowledement

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Regional activities/WANA

Research Findings

Experimental setup at Jamia Hamdard University. Photo by S. Umar.

Managing Nitrate Accumulation in Forage Sorghum by Potassium Fertilization

Khanum Al Akbari, W.M.(1), **and S. Umar**(1)(1a)

Abstract

Excessive nitrogenous fertilization or environmental stress due to drought, cold, frost, hail, leads to nitrate (NO_3^-) accumulation in forages. Elevated nitrate levels are a major concern because they can be detrimental to animal health and have caused several mass cattle-death incidents. A pot culture experiment was conducted under greenhouse conditions to screen 16 genotypes of sorghum (*S. bicolor* L.) for leaf nitrate reductase activity (NRA) and, hence, also potential nitrate accumulation. Marked differences in NRA and nitrate concentrations were observed among the genotypes, many of which accumulated nitrate to very high concentrations. From this screening experiment a high nitrate reductase (HNR) genotype and a low nitrate reductase (LNR) genotype viz. POP-52 (V9) and EB-15 (V7), respectively, were selected to study the effect of potassium (K) application on NRA and nitrate accumulation. The two sorghum genotypes were grown in specially designed PVC drums and the plants supplied with increasing levels of K, supplied as KCl at rates of 0, 30, 60 and 120 mg K_2O kg^{-1} soil. Measurements made for leaf NRA and nitrate concentration at 30 and 60 days after

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sowing (DAS). Regardless of K treatment, NRA values increased from the 30 to the 60 day harvest and, correspondingly, nitrate concentrations decreased. At both harvests, K treatment up to 60 mg K_2O kg^{-1} soil, (K_{60}) increased leaf NRA and depressed leaf nitrate accumulation. An approximately three-fold decrease in nitrate concentration was observed in the K_{60} treatment in both genotypes from 30 to 60 DAS. Leaves of the 60 day old (K_{60}) treated plants, V9, the genotype with the higher NRA (9.916 µmol NO_2^{-1} h^{-1} g^{-1} fresh wt.), showed the lower nitrate accumulation (816.6 mg kg^{-1} fresh wt) and vice versa with the V7, the genotype with the lower NRA (5.018 µmol NO_2^{-1} h^{-1} g^{-1} fresh wt.), which showed the higher nitrate accumulation (2691.8 mg kg^{-1} fresh wt.). K application also substantially lowered the nitrate concentration in the leachate indicating that K is effective in mitigating nitrate pollution in plants and soil. The results emphasize the importance of K in increasing nitrogen use efficiency (NUE) and of balanced fertilization in combating detrimental effects of nitrate on human beings, animals and the environment.

Introduction

Production and consumption of fertilizers is the main requirement for agricultural development but addition of fertilizers alone does not ensure enhanced crop production. Mineral nutrient fertilizer constituents, particularly nitrogen (N) and phosphorus (P) can leach into ground and surface waters due to excessive fertilizer input and poor application methods (EPA, 2010), which results in environmental damage including eutrophication. In order to feed the burgeoning population and maintain sustainable development, the amount of N needs to be double that currently applied, unless the N use efficacy of crops is improved (Anjana *et al.*, 2011). In view of the close interrelationship between N and K uptake, application of N has to be balanced by adequate K supply in order to be effective in increasing crop yields (Zhang *et al.*, 2010).

Annual crops growing in well aerated soils take up and assimilate N mainly in the form of nitrate (NO_3^-). In many parts of the world, nitrate concentrations in ground water exceed the maximum limit of 50 mg l^{-1}, equivalent to 11.3 mg l^{-1} as NO_3^--N as recommended by the (WHO, 2011). The main sources of nitrate contamination in water are intensive agricultural production, domestic and industrial wastes, sewage and atmospheric nitrogen pollution. When the N input exceeds the demand by plants, it builds up in the soil, mostly as nitrates, and leaches into the groundwater (Gairola *et al.*, 2009). Nitrate leaching, due to excessive N fertilization, leads to eutrophication of freshwater bodies and marine ecosystems. Any factor that slows down the rate of plant growth can lead to increased nitrate levels in well-fertilized plants. Accumulation of nitrate in plants is thus commonly observed during drought, long periods of cloudy or cool weather, or following heavy fertilization with manures and nitrogen-containing fertilizers or herbicide applications (Tuncay *et al.*, 2011). Nitrate accumulation in plants in extreme cases has been known to induce toxicity in animals which feed on them. Intrinsically, however, nitrate is not very toxic to animals. Once within the animal body, nitrates are converted to nitrites and then to nitrosamines that are believed to be associated with gastric cancer and other complications like methemoglobinemia (condition affecting oxygen carrying capacity of red blood cells) (Fahmy *et al.*, 2010).

Sorghum is the fifth most important cereal crop grown in the world and is also valued for its fodder and stover. It is a known accumulator of toxic levels of nitrate even at moderate N fertility levels. In India, forage sorghum is grown on 2.6 million ha predominantly in the states of western Uttar Pradesh (UP), Haryana, Punjab, Rajasthan and Delhi, which fulfills over two thirds of the fodder demand during the Kharif (summer) season.

Sorghum plant grown in the experimntal drum (column). Photo by S. Umar.

K is one of the essential mineral elements for plant growth and development and plays a key role both in the uptake of nitrate and at various steps during N assimilation and metabolism, as well as in numerous other biochemical and physiological processes (Marschner, 2012). It thus has a major impact on agricultural ecosystems. According to Shrotriya (1998), balanced application of N, P and K could increase sorghum yield in India by up to 122%. Thus, imbalanced fertilization with an increase in N at the cost of a decrease in K has a major detrimental impact on the utilization of N itself.

Improving crop performance through balanced fertilization by application of K is a prerequisite for minimizing environmental risks due to N losses as well as nitrate poisoning in ruminants. In this work we report on a greenhouse study on sorghum to investigate the influence of increasing supply of K on two selected genotypes differing greatly in leaf nitrate reductase activity (NRA) and nitrate accumulation. We also report on the effects of increasing K supply on nitrate leaching.

Materials and methods

The experiments

A greenhouse pot experiment was conducted in the Herbal Garden of Jamia Hamdard, New Delhi, during the Kharif (summer) season of 2010-2011 in order to screen 16 genotypes of sorghum (*S. bicolor* L.) for both nitrate reductase activity (NRA) and nitrate concentration in the leaves. Seeds for the 16 genotypes, namely: CSV 15, CSV 21F, CSV23, E-68-1, E73, E77, EB-15 (V7), HC-308, POP-52 (V9), SPSSV 5, SPSSV 6, SPSSV 7, SPSSV 20, SPSS 422, SPV 462, and SPV 913 were obtained from the Sorghum Research Institute, Hyderabad (India). The plants were grown in earthen pots of about 25 cm diameter (with 4 plants per pot) with three replicates per genotype (a total of 48 pots). Prior to sowing, the pots were lined with polythene bags and filled with 8 kg of soil taken from the Herbal Garden, which had been thoroughly mixed with a uniform basal dressing of fertilizers for all the pots. This comprised N (120 mg kg^{-1}) as urea, P (30 mg kg^{-1}) as single super phosphate, K (80 mg kg^{-1}) as muriate of potash (KCl) and Zn (25 mg kg^{-1}) as $ZnSO_4 \cdot 7H_2O$. The Herbal Garden soil (Lukhi soil series of Gurgaon) is a sandy loam (83.6% sand, 6.8% silt and 9.6% clay) with a neutral pH 7.1 and is low in available K (40 mg kg^{-1} soil) N (30 mg kg^{-1}) and P (4 mg kg^{-1}). Thirty days after sowing (DAS), fully expanded leaves from the same position were analyzed simultaneously for NRA and nitrate concentration. The genotypes POP-52 and EB-15 were identified as highest and lowest in NRA, respectively and these two genotypes were used in the second experiment.

The purpose of the second experiment was to test the effects of increasing supply of K on the activities of NRA and nitrate accumulation in the leaves of these two very different sorghum genotypes in NRA activity. The experiment also allowed a simultaneous investigation of possible differences in nitrate leaching as influenced by the two genotypes in relation to K supply. In this experiment the plants were grown in much larger containers: PVC drums 25 cm × 120 cm (diameter × height) with a total capacity of 60 liters using the same amended Herbal Garden soil as that of the pot experiment except for the K supply. Increasing levels of potassium were tested: 0, 30, 60 and 120 mg K_2O kg^{-1} soil (K_0, K_{30}, K_{60} and K_{120} respectively, applied as KCl). Three drums were used per treatment for both the genotypes at 30 and 60 DAS so that there was a total of 24 drums in the experiment. Ten seeds each of high and low NRA genotypes were sown, which were thinned down to four plants per drum. The experimental drums were fitted with drainage systems at three different sites on the drums (30, 60 and 100 cm height of the soil column). Glass wool filled the lower opening of the drum above a 10 cm height filling of washed fine gravel. Plastic funnels (10 cm diameter) with PVC tubes (5 mm diameter) were fitted to each drain to collect the leachate. Before planting, the soil was irrigated with sufficient water for seed germination. The pots were weeded and scarified weekly. Fully expanded leaves from the same position were sampled in triplicates per drum at two different stages, viz. 30 and 60 DAS. The schematic diagram of the experimental set up is given (Fig. 1).

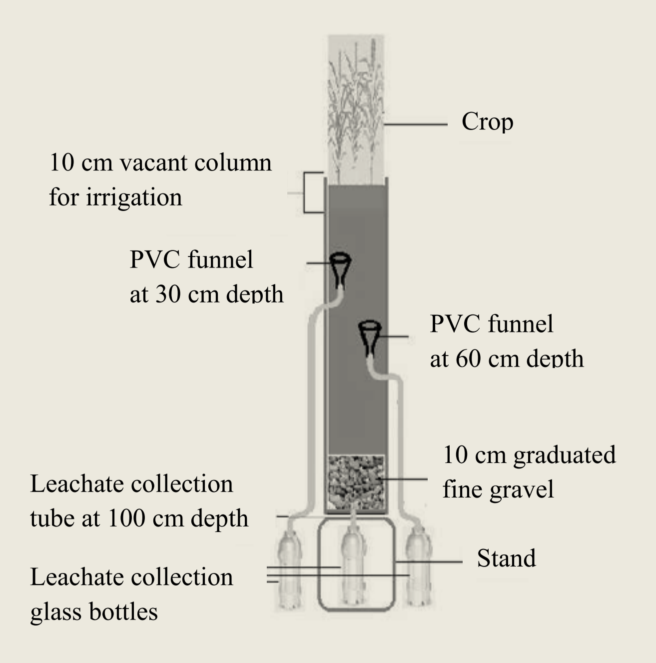

Fig. 1. Schematic sketch of the column used showing the collection of leachate at various depths of the soil.

Chemical estimations

Nitrate was extracted from ground dried leaf material using the method of Grover *et al.* (1978) followed by the reduction hydrazine method of Downes (1978). This is based on the reduction of nitrate to nitrite followed by diazotization from the addition of sulphanilamide and naphthyl ethylene diamine dihydrochloride to produce a pink colored solution - the intensity of which depends on the nitrite concentration and is measured using the spectrophotometer at 540 nm. Nitrate concentration is expressed as mg g^{-1} fresh weight of leaves. Nitrate reductase activity (NRA) in the leaves was determined by the intact tissue assay method of Jaworski (1971) using the method of estimating nitrite as described above. The estimation of NRA is dependent on the rate of formation of nitrite and is expressed as µmol NO_2^- h^{-1} g^{-1} fresh wt. Biomass nitrogen utilization efficiency was calculated using the formula: NutE = Biomass (dry matter) (g $plant^{-1}$)/Total N content (g $plant^{-1}$). Leachate was collected after each irrigation for nitrate analysis, which was determined using the same basic method as described above. Available N, P and K values in the Herbal Garden soil were determined by soil extraction methods described by Kalra and Maynard (1994), Oslen *et al.* (1954) and Hanway & Heidal (1952), respectively.

Results and discussion

Marked variation was evident in the leaf NRA in the 30 day old plants of the 16 genotypes as detailed in Table 1. POP-52 (V9) genotype had the highest level of NR activity (7.024 µmol NO_2^{-1} h^{-1} g^{-1} fresh wt.) with minimum nitrate concentration, while the lowest level of NR activity was observed in EB-12 (V7) genotype (1.813 µmol NO_2^{-1} h^{-1} g^{-1} fresh wt.) with the maximum nitrate concentration. Leaf nitrate concentrations also varied significantly among the 16 sorghum genotypes in the 30 day old plants. This observation is in keeping with the inter- and intra-species variations in leaf nitrate content reported in many crop plants (Anjana *et al.*, 2007). A significant negative relationship (r = -0.913) between the NRA level and leaf nitrate concentration was found among the 16 genotypes (Fig. 2).

Leaf nitrate concentration under K application

There is evidence in the literature that K stimulates N assimilation so that increased K fertilization can depress nitrate accumulation as observed, for example, by Nurzynska-Wierdak *et al.*, (2012) in rocket leaves. Our study findings also confirm that K application decreased nitrate accumulation significantly ($p<0.05$) and that the decrease was substantial in the leaves of both the sorghum genotypes studied (Table 2). A reduction in nitrate concentration at $K_{60,}$ 35.24% (V9) and 26.0% (V7), occurred over the control (K_0) at 30 DAS. An approximately three-fold difference was observed between leaf nitrate concentrations at 30 and 60 DAS. Genotype V9 (816.6 mg of nitrate kg^{-1} fresh wt.) showed the lowest nitrate concentration at K_{60} (Table 2).

Leaf NRA under K application

Strategies for improving nitrogen assimilation require an understanding of the N-assimilation pathway. NRA, which reduces nitrate to nitrite, is assumed to be the rate-limiting step for nitrate assimilation in plants. A positive and linear relationship was shown to occur between NRA and K-fertilization up to K_{60} in both genotypes at 30 and 60 DAS. At the highest K application (K_{120}), activity appeared to be depressed in both genotypes. The

Table 1. Variation in nitrate reductase activity (NRA) (µmol nitrite h^{-1} gm^{-1} fresh wt. of leaves) and nitrate concentration (mg kg^{-1} fresh wt. of leaves) in leaves of 30 day old plants of 16 *Sorghum bicolor* L. genotypes.

Sl. no.	Code no.	NRA	Nitrate
1	V1	3.536±0.097	3726.67±29.72
2	V2	5.063±0.079	2406±27.18
3	V3	4.448±0.096	2870.33±36.11
4	V4	2.905±0.092	4508.67±36.42
5	V5	2.582±0.12	5397±46.01
6	V6	2.152±0.095	6492±40.19
7	V7	1.813±0.031	7121.33±22.63
8	V8	3.573±0.049	3466.67±32.8
9	V9	5.989±0.096	2308.67±24.25
10	V10	2.380±0.067	6107.67±44.4
11	V11	4.360±0.039	2643.33±25.3
12	V12	2.449±0.046	5731.67±36.4
13	V13	4.288±0.087	2476±12.5
14	V14	4.039±0.046	3218.67±33
15	V15	2.635±0.05	5147.67±26.74
16	V16	2.778±0.057	4880±27.60

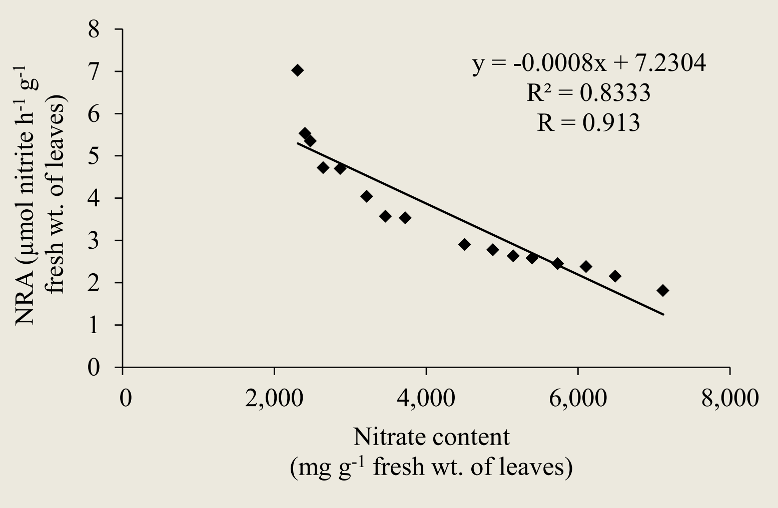

Fig. 2. Relationship between nitrate concentration and nitrate reductase activity in leaves of sixteen sorghum genotypes in 30 day old plants.

Table 2. Effect of applied potassium on nitrate reductase activity (NRA) (*in vivo*) (μmol nitrite h^{-1} gm^{-1} fresh wt.), nitrate concentration (mg kg^{-1} fresh wt.) at 30 and 60 DAS, nitrate concentration (mg l^{-1}) of leachate at 30 cm, 60 cm and 100 cm depths and biomass nitrogen utilization efficiency (NUE) (g $plant^{-1}$).

Treatments	NR activity at 30 days		NR activity at 60 days	
	HNR	LNR	HNR	LNR
K_0	3.21±0.035d	1.646±0.022d	7.203±0.203c	3.154±0.065d
K_{30}	3.416±0.032c	1.814±0.028c	7.462±0.104c	3.738±0.059c
K_{60}	5.978±0.042a	2.174±0.039a	9.916±0.212a	5.018±0.053a
K_{120}	4.918±0.026b	1.984±0.037b	8.142±0.078b	4.178±0.059b

	Nitrate at 30 days		Nitrate at 60 days	
	HNR	LNR	HNR	LNR
K_0	3,272.04±215.169a	9,600.97±313.494a	1,726.8±46.067a	5,179±49.79a
K_{30}	2,533.96±116.899b	8,073.31±405.298b	1,507.4±41.966b	3,627.8±43.22b
K_{60}	2,118.89±114.216c	7,104.06±235.615c	816.6±45.181d	1,969.4±38.47d
K_{120}	2,112.80±147.157c	7,096.18±346.563c	1,050.8±40.59c	2,199.4±39.20

	Leachate nitrate concentration at 30 cm		Leachate nitrate concentration at 60 cm		Leachate nitrate concentration at 100 cm	
	HNR	LNR	HNR	LNR	HNR	LNR
K_0	20.49±0.38a	23.11±0.19a	26.65±0.23a	28.75±0.25a	20.45±0.31a	21.67±0.15a
K_{30}	18.11±0.22b	21.56±0.16b	23.38±0.27b	25.36±0.39b	16.54±0.33b	20.04±0.34b
K_{60}	14.17±0.18c	17.69±0.23c	20.46±0.26c	23.12±0.46c	14.1±0.25c	17.80±0.20c
K_{120}	13.90±0.25d	14.76±0.14d	20.12±0.22d	22.00±0.27d	12.52±0.21d	14.86±0.15d

	Biomass NUE	
	HNR	LNR
K_0	37.1±0.55d	31.05±0.24d
K_{30}	41.43±0.43c	33.86±0.24c
K_{60}	45.93±0.36a	39.09±0.37a
K_{120}	44.68±0.25b	38.18±0.28b

Note: Values represent mean ± SE. Rows showing different letters (a-d) indicate significant differences according to Duncan's test at $p<0.05$.

increase in NRA was significant at ($p<0.05$) with increasing levels of K application. The V9 genotype showed the highest NRA at K_{60} at 30 and 60 DAS, anthe lowest at K_0 (Table 2).

Biomass NUE in leaves at 60 DAS

The most effective way to improve the efficiency of N fertilizers is adequate and balanced use of fertilizer nutrients. Biomass nitrogen utilization efficiency (NUE) significantly ($p<0.05$) increased from K_0 to K_{60} in both genotypes. In V9, biomass NUE of (45.93) was greater than V7 (39.09) at K_{60}. The minimum biomass NUE was recorded at K_0 both in V9 (37.1) and V7 (31.05) (Table 2). Brar *et al.* (2012) also reported that application of K effectively increased the NUE of maize. A higher NUE implies a more efficient utilization of N and little wastage. Improving NUE with K means that a lower amount of N can be applied without affecting yield, thereby preventing land and water contamination.

Nitrate content in the leachate

Imbalanced nitrogen fertilization leads to nitrate leaching as it shows a negligible interaction with the negatively charged matrix of most topsoil, especially in sandy soils with minimum nutrient retention capacity. As evident from Table 2, the leachate nitrate decreased significantly ($p<0.05$) with increasing K levels (from K_0 to K_{60}) at all soil depths (30, 60 and 100 cm). The lowest nitrate concentrations were recorded with K_{60} in both the genotypes at all soil depths; however, the value was comparatively lower in V9. This decrease in nitrate concentration in the leachate can be attributed to the greater utilization of the available nitrate as a consequence of K application.

Conclusions

Nitrate concentration in the leaves was the highest at the younger stage (30 DAS). However, with K application, especially at K_{60}, leaf nitrate concentration decreased considerably, while the NRA appeared at the highest level in both the genotypes (V9 and V7). Genotype V9 showed better growth seemingly through higher NRA and lower nitrate concentration in the leaves and leachate compared to V7 at both the growth stages. K application showed the greatest effect after 60 DAS. Thus, balanced nutrient management with K application at 60 mg K_2O kg^{-1} soil (K_{60}) appears to lower nitrate accumulation and sustain growth and productivity of sorghum. This lowering of nitrate is of benefit in preventing toxicity in animals and decreasing the load on ground water. Furthermore, it is advantageous to the farmer to attain a cost effective strategy for fertilizer management without wastage of fertilizers. Further studies are required to validate these findings on a larger scale in the field using different crops at various locations under different climatic conditions.

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The paper "Managing Nitrate Accumulation in Forage Sorghum by Potassium Fertilization" also appears on the IPI website at:

Regional activities/India

Research Findings

SoilCares mobile lab in action. Photo by SoilCares.

Soil Fertility Status and NPK Blends at Planting for Maize Growing in the Western Kenyan Counties Uasin Gishu and Busia

van Erp, P.J.[(1)(1a)], T. Terhoeven-Urselmans[(1)], and R. van der Meer[(2)]

Abstract

Crop production on smallholder agricultural land must increase considerably if the growing world population is to be fed. To achieve this, affordable soil testing methods, fertilizer recommendations and the accessibility of optimal fertilizers containing the required nutrients are required. The SoilCares mobile laboratory offers affordable soil testing using infrared spectroscopy and slightly modified Quantitative Evaluation of the Fertility of Tropical Soils (QUEFTS) for fertilizer recommendations (through the use of blends) to smallholders. SoilCares soil testing results from 2,107 samples from Uasin Gishu and Busia counties in Kenya were analyzed using archetype analysis and QUEFTS to derive: i) more accurate soil fertility classification; and ii) to optimize the formulation of NPK planting blends for maize. The study showed that eight soil archetypes could be distinguished of which four

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were dominant. Additionally, four fertilizer-blend archetypes were distinguishable for all counties which comply reasonably well with the NPK fertilization at planting necessary for 5 t ha^{-1} maize production. These blends are 12:25:0, 6:22:14, 0:40:0, and 13:33:0 (N-P_2O_5-K_2O). Median relative difference between the advised and optimally needed N, P_2O_5 and K_2O application rates at planting were 36, -10 and 0 %, respectively. The method described, including mapping, may be useful in assisting decision-making by the fertilizer industry, traders and policymakers on the production and availability of crop or region specific NPK blends.

Introduction

In order to feed a fast-growing world population ways must be found to increase crop yields, particularly for smallholder farmers in developing countries (FAO, 2009). Many of these smallholders are confronted with an enormous yield gap in crop production, i.e. a difference between potential yield and actual yield. The key factors in determining this potential yield difference are soil nutrient management and soil fertility status (Licker *et al.*, 2010). Nitrogen (N), phosphorus (P) and potassium (K) are macronutrients that play a major role in plant growth and crop yields (Marschner, 2012). In smallholder farming systems, export of N, P and K from fields and farms often exceeds input via e.g. fertilizers. Such negative N, P, K balance sheets lead to a gradual and unsurmountable decrease in N, P and K soil fertility status (Roy, 2003; Smaling, 1993). Restoration of soil fertility status and the provision of crop specific N, P and K recommendations are prerequisites to increase crop yields. Closing the yield gap must therefore begin with precise and affordable soil testing, followed up with the development of fertilizer recommendations, and making such fertilizers accessible to farmers. Shepherd *et al.* (2007) have shown that infrared technology can be used for soil testing. It is an indirect method that requires calibration and validation studies. However, when this is achieved, the method gives precise results and it then becomes a promising and cheap tool for routine soil testing for smallholders.

The QUEFTS fertilization model (Quantitative Evaluation of the Fertility of Tropical Soils, Janssen *et al.*, 1990) has been developed for N, P and K fertilization of maize in Kenya. It calculates the optimal nutrient rates taking into account the measured fertility status of the soil, interactions between soil pH and N-, P-, K-supply, fertilizer nutrient efficiency, and the (desired) yield level. The QUEFTS model has also been applied and tested for the other main staple crops throughout the world (Sattari *et al.*, 2014).

The accessibility of organic and mineral fertilizers to smallholders is often limited even though long-term fertilizer subsidy programmes have been set up in many African countries to promote fertilizer use. Additionally, the repeated use of e.g. urea and (ammonium) N and P containing fertilizers has led to soil acidification, decrease of K status and low use efficiency of N or P, or both of these nutrients. The major reason for these side-effects is that nutrient application is not tuned to the specifically measured soil nutrient status and crop nutrient demand for optimal production.

Negative side effects of blanket fertilizer recommendations are well known, and prescribed blends cannot be applied before: i) the actual and specific soil nutrient status in different regions/countries has been identified; ii) the recommended N, P and K rates for optimal crop production are calculated; and iii) techniques have been established to optimize a limited number of appropriate NPK blends. In this context, 'appropriate' implies that deviations from actual demand are acceptable.

Archetypal analysis is an empirical, data-driven classification algorithm yielding a few typical and representative combinations of the underlying multivariate data set (Cutler and Breiman, 1994). These typical combinations are called archetypes. Once archetypes are established, any new instance represented by the underlying data set can be classified to one archetype. Archetypal analysis has been used in economics (Porzio *et al.*, 2008) and can also be used to classify soil or fertilizer blend archetypes. This is the basis for optimizing appropriate NPK fertilizer blends.

During the first three months of 2014, SoilCares analyzed 2,107 soil samples from agricultural land from the two Western Kenyan counties, Uasin Gishu and Busia (Fig. 1). The goal of the work reported in this paper was to determine for these counties:

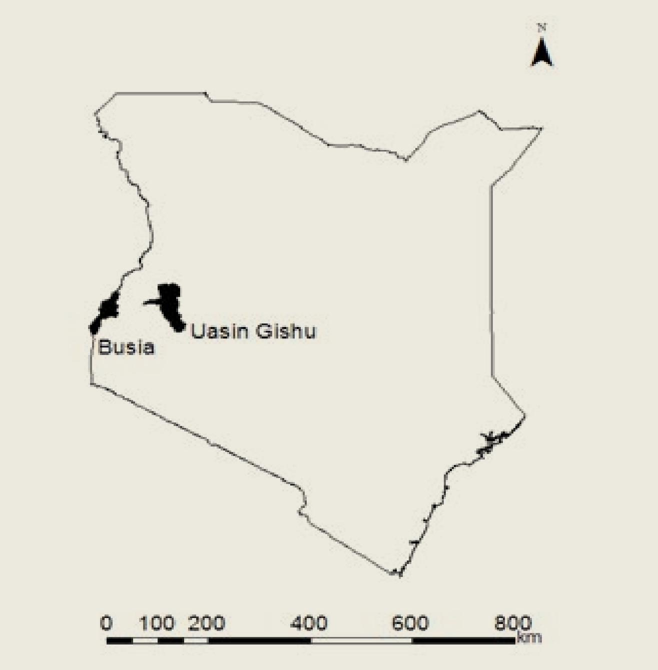

Fig. 1. Location of the two Western Kenyan counties, Uasin Gishu and Busia.

- archetypes of soil fertility status
- archetypes of NPK blends to apply at planting for maize

Materials and methods

The field study was carried out in the two Western Kenyan counties, Uasin Gishu and Busia (Fig. 1).

Soil sampling was carried out by the smallholders themselves. They were provided with an auger, sample bag, registration form, and top soil (0-20 cm) sampling protocol. Mandatory information was inter alia the spatial origin of the soil sample and crop type to be planted. Spatial origin of a sample was defined by sub-location (level 5 of Kenya from the Global Administrative Areas version 2 database). There were 117 sub-locations in total in the Uasin Gishu and Busia counties.

In total, 2,107 soil samples were collected and handed over to the SoilCares Mobile soil testing laboratory (Fig. 2). After receipt, the (moist) soil samples were crushed and sub-sampled using a combined grinder/sub-sampler device. The sub-sample was dried with a forced air flow for about 1 hour at 40^{o}C until dry. Subsequently, the dried samples were crushed, sieved to 2mm, and subdivided to obtain a representative 15 ml sub-sample. This sub-sample was finely ground using a ball-mill followed by determination of the diffuse reflection mid-infrared spectrum. Spectra were analyzed and soil testing data were derived using the SoilCares calibration set for Kenyan soils. Data flows in the system were continuously checked to internal quality standards, and soil testing data were only released when checks were passed. Data presented are Organic Carbon (Org C), Total Nitrogen (Tot N), acidity (pH-CaCl$_2$), phosphorus stock (P stock), exchangeable calcium (exch. Ca), magnesium (exch. Mg) and potassium (exch. K), and contents of clay and sand (Table 1).

Fig. 2. SoilCares mobile soil testing laboratory.

The QUEFTS model (Janssen *et al.*, 1990), including modifications (Sattari *et al.*, 2014) was used to carry out scenario studies to calculate: i) the potential N, P and K supply from soil; ii) the N, P and K demand of different yield levels; and iii) the remaining fertilizer nutrient demand.

Scenario calculations were made for two maize yield levels (2 and 5 t ha^{-1}) and two levels of nutrient recovery fractions of applied fertilizer (normal and high). It was assumed that 22 kg N, 3.7 kg P, and 14.6 kg K need to be taken up by maize plants to produce 1 t of maize grains. If the necessary nutrients could not be supplied by the soil, the remaining nutrients were assumed to be applied by fertilizer (expressed as kg ha^{-1}). Calculated amounts of fertilizer nutrients were converted to N, P$_2$O$_5$ and K$_2$O for ease of comparison to blend compositions. For the two yield levels, at the normal level, it was assumed that fertilizer nutrient recovery by the crop was 50% of applied N, 10% of applied P, and 50% of applied K, whereas at the higher level it was 50% of applied N, 20% of applied P, and 75% of applied K. For fertilizer advice, calculations of soil pH values below 4.9 were set to 4.9 - assuming that lime was applied by the farmer prior to fertilization. This was done in order to exclude the effects of strongly acidic soils on nutrient supply and fertilizer use efficiency. In relation to calculations of potential soil nutrient supply, soil pH values determined in water were increased by 0.3 pH units above the original 0.01M CaCl$_2$ pH values.

Archetypal analysis was done using the archetype-package (Eugster & Leisch, 2009) within the R statistical environment (R core team, 2013). Input data were scaled (mean centred and divided by their standard deviation) before use. All named soil property data were taken as input for soil archetypal analysis. After the model building phase, each of the 2,107 soil samples was classified to one of the soil archetypes. Blend archetypes were calculated for the basal fertilizer application of 5 t yield aim and normal recovery fraction of applied fertilizer only; 30% of the total N rate was subtracted for the top-dressing application. Prior to blend archetypal analysis, the calculated amounts of N, P$_2$O$_5$ and K$_2$O (kg ha^{-1}) were converted to the blend ratios used for the blended products (e.g. NPK 16:23:7) subject to the assumption that the sum of N, P$_2$O$_5$ and K$_2$O should not exceed 46% in the blend (when urea is the leading N product with the highest nutrient content, any addition of other fertilizer will dilute the total nutrient content in the blend). After the model building phase, each of the 2,107 soil samples was classified to one of the blend archetypes. To assess the impact of not using the optimal nutrient rate but the selected archetype blend, for N, P$_2$O$_5$ and K$_2$O we calculated: i) the absolute nutrient residuals (fertilizer - plant need at planting); and ii) the relative nutrient residuals (absolute residuals plant^{-1}

Table 1. Soil characteristics (median and range) of the total dataset and for Uasin Gishu and Busia counties separately.

Soil characteristic	Unit	Total (n=2,107)		Busia (n=1,139)		Uasin-Gishu (n=968)	
		Median	Range	Median	Range	Median	Range
Organic C	g kg^{-1}	17	4-87	13	4-87	21	5-68
Total N	g kg^{-1}	1.5	0.3-4.9	1.2	0.3-4.5	1.9	0.5-4.9
Exch. Ca	mmol+ kg^{-1}	27	0-269	17	0-269	28	0-269
Exch. Mg	mmol+ kg^{-1}	13	0-63	12	0-63	15	2-63
Exch. K	mmol+ kg^{-1}	3.4	0-9.2	2.5	0-9.2	4.5	0.7-9.2
pH		4.9	4.0-6.6	4.9	4.0-6.6	4.8	4.1-6.0
Clay	g kg^{-1}	510	10-820	420	10-780	580	40-820
Sand	g kg^{-1}	300	70-840	340	70-840	270	70-820
P stocks	mmol P kg^{-1}	5	1-23	5	1-23	6	1-20

Table 2. Soil characteristics of each of 8 archetypes distinguished in the Uasin Gishu and Busia data set (n=2,107), division of soil samples over the 8 soil archetypes, and the number of sub-locations where a specific soil archetype is most common.

Soil characteristic	Archetypes							
	1	2	3	4	5	6	7	8
Organic C	8	73	11	6	22	28	7	27
Total N	0.7	4.3	0.8	0.5	2.1	1.3	1.0	2.6
Exch. Ca	34	157	0	12	26	231	18	8
Exch. Mg	14	36	4	6	18	56	5	8
Exch. K	1.7	8.7	0.5	2.0	5.1	5.9	1.0	5.1
pH $CaCl_2$	5.3	5.3	4.2	5.7	5.0	5.8	5.0	4.2
Clay	280	530	110	50	670	460	560	680
Sand	370	280	720	820	240	190	140	170
P stock	14	19	1	3	2	13	4	10
Number of soil samples classified to archetype	64	39	264	312	557	95	411	365
Number of sub-locations classified mainly to soil archetype	3	1	6	15	29	6	32	25

need at planting*100). Fertilizer nutrient recovery fraction was also taken into account. Knowing the N, P and K plant demand to provide 5 t of maize yield, the application rate (kg ha^{-1}) of the NPK blend was optimized. This was achieved by minimizing the sum of the N, P_2O_5 and K_2O absolute residuals over the range of possible nutrient application rates.

Geographical representations of the results were obtained using ArcGIS software.

Results

Soil

In total, 1,139 and 968 samples originated from Busia and Ushia Gishu counties, respectively. Table 1 provides a summary of the soil test values obtained.

The range within the soil characteristics measured was huge but seemed to be comparable for the sub-locations of Busia and Uasin Gishu counties. Nevertheless, soils in Uasin Gishu seemed to be more fertile, because median values for contents of Org C, Tot N, clay and exch. Ca, Mg and K were higher at a comparable pH value.

When archetypal analysis was applied to the whole soil data set, 8 different soil archetypes could be distinguished. Table 2 shows the soil characteristics per archetype. In most cases, 2 to 6 soil characteristics are decisive in differentiating between 2 archetypes. For example, archetype 5 has a lower Org C content, Tot N and exch. Ca, Mg and K as compared to archetype 7. The pH of these archetypes are the same.

When the 2,107 soil samples were classified according to the archetypes, fewer than 100 samples were classified to each of the soil archetypes 1, 2 and 6. Between 200 and 400 samples were classified to each of the soil archetypes 3, 4 and 8, and more than 400 samples to each of the soil archetypes 5 and 7.

The maps in Fig. 3 illustrate that in the sub-locations of the two counties, soil archetypes 3, 4, 6 and 7 were mainly present in Busia, whereas soil archetypes 5 and 8 were predominant in Uasin Gishu. Only 12% of the 117 sub-locations had only one soil archetype. In the other sub-locations, 2-7 archetypes were present. The distribution was as follows: 23% had 2 archetypes, 26% had 3 archetypes, 20% had 4 archetypes, 14% had 5 archetypes, 4% had 6 archetypes and 1% of sub-locations had 7 soil archetypes.

QUEFTS scenario studies

Fig. 4 and Table 3 present the result of the QUEFTS scenario studies in which the effect of maize yield level and P and K fertilizer efficiency on total N, P_2O_5 and K_2O fertilizer application rate were simulated for each of the 8 soil archetypes.

It is clearly visible that samples belonging to one soil archetype are restricted to a specific location in the three dimensional representation of the nutrient application rates. Nevertheless, there is an overlap between different soil archetypes. Yield levels and rates of nutrient recovery have a strong influence on recommended amounts of nutrients. For example, high nutrient use efficiency at yield level 5 t ha^{-1} (Fig. 4d) showed reduced total

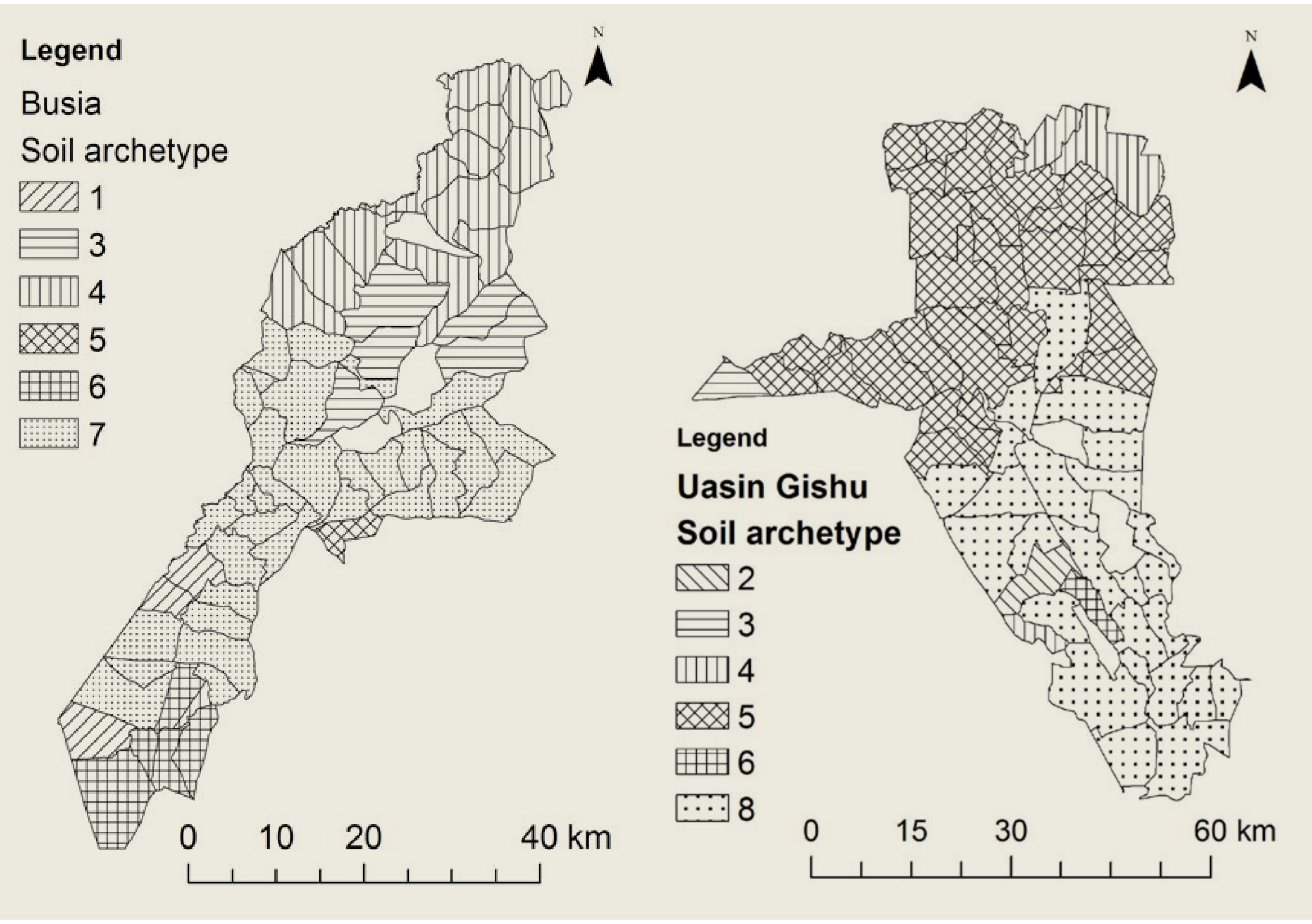

Fig. 3. Main soil archetypes represented in each of the counties of Uasin Gishu and Busia (defined by Global Administrative Areas (GADM); http://www.gadm.org/).

Table 3. Total maize fertilizer nutrient needs per soil archetype with a projected 5 t ha^{-1} maize yield per ha and normal nutrient recovery fraction of applied fertilizer (50% of N, 10% of P and 50% of K taken up by the plant). Median, minimum and maximum nutrient needs for all soil samples belonging to one soil archetype are presented.

Soil archetype	Total fertilizer N			Total fertilizer P_2O_5			Total fertilizer K_2O		
	Median	Min	Max	Median	Min	Max	Median	Min	Max
	---kg ha^{-1}---								
1	159	97	186	306	144	359	0	0	81
2	78	0	111	255	90	320	36	0	97
3	172	88	200	398	307	411	40	0	176
4	170	71	199	377	276	411	0	0	172
5	146	5	178	366	276	411	0	0	31
6	106	0	158	273	121	339	0	0	103
7	139	69	193	368	290	411	7	0	172
8	135	0	166	334	253	388	0	0	98

P_2O_5 and K_2O nutrient needs compared to normal nutrient use efficiency at the same yield level (Fig. 4c).

Further analysis was restricted to the 5 t of maize per ha yield scenario with normal nutrient recovery rates (Table 3). The study showed that total N, P_2O_5 and K_2O application rates ranged from 78-159, 90-411 and 0-176 kg N, P_2O_5 and K_2O ha^{-1} respectively. Distinct differences existed between the soil archetypes, again with overlap occurring between soil archetypes.

Four NPK blend archetypes could be distinguished for fertilization at planting (Table 4). Archetype 3 is a pure P fertilizer. Archetypes 1 and 4 are NP blends and archetype 2 is an NPK blend. 49% of soil samples were classified as archetype 1; 38% as archetype 4; 8% as archetype 3; and 6% as archetype 2. Blend archetype 1 was the

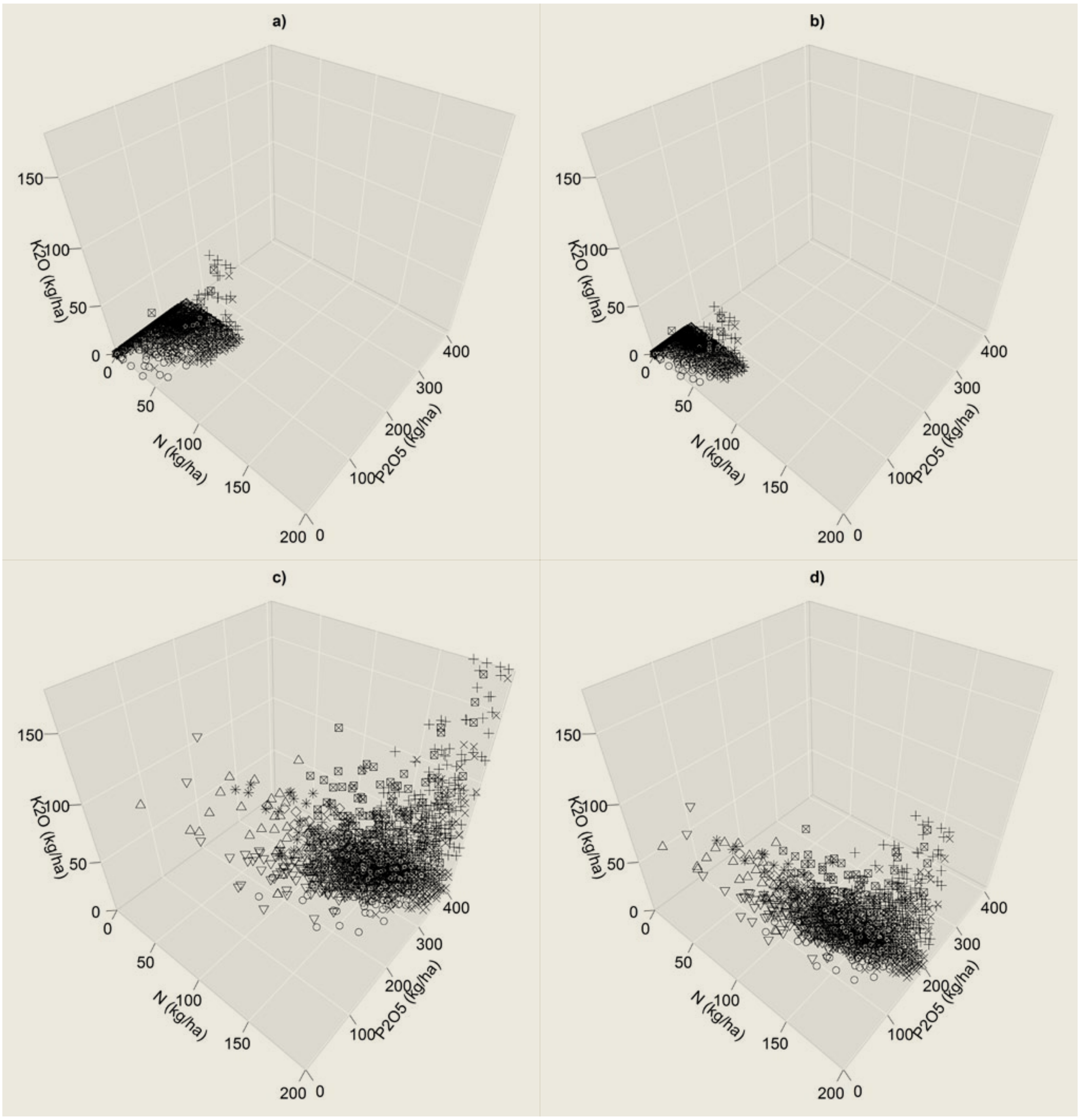

Fig. 4. 3D total fertilizer nutrient application rates for: i) 2 t maize yield (graph a and b); ii) 5 t maize yield (graph c and d); iii) normal nutrient recovery fraction (graph a and c); and iv) high nutrient recovery fraction (graph b and d). Different symbols refer to soil archetypes as mentioned in Table 2 and Fig, 3.

major blend in 59% of the sub-location areas. Nevertheless, in one sub-location more than one blend archetype was advised (Fig. 5). Only in 6% of the sub-locations did all soil samples from this sub-location have the same blend archetype. All the other sub-locations had two to four blend archetypes; 38% of sub-locations had two blend archetypes; 33% of sub-locations had three blend archetypes; and all four blend archetypes were present in 22% of the sub-locations.

When the classified blend archetype at planting is applied in a per sample optimized amount to the field, a shortage or excess amount of N, P_2O_5 or K_2O may occur because the blend composition does not fit perfectly to the specific NPK fertilizer demand of maize on that field. For all samples, the excess/shortage of N, P_2O_5 and K_2O was calculated. Table 5 gives the summary statistics of the calculated absolute nutrient residuals at planting in kg N, P_2O_5 and K_2O ha^{-1} for the soil samples leaving out the 10% lowest and 10% highest residues (10-90% percentiles). In addition, the relative nutrient residuals at planting (residuals/plant need at planting*100%) are presented for this 10-90% percentile.

Table 4. Description of blend archetypes at planting for 5 t maize yield per ha and normal nutrient recovery fraction.

Fertilizer	Blend archetype			
	1	2	3	4
N	12	6	0	13
P_2O_5	25	22	40	33
K_2O	0	14	0	0
Number of samples classified to blend archetype	1,032	130	153	792
Number sub-locations classified mainly to blend archetype	67	2	7	41

When the recommended blend archetype was applied in an optimized amount, the analysis showed the median residual N, P_2O_5 and K_2O was 37, -37 and 0 kg ha^{-1} respectively. Eighty percent of the soil samples (10-90% percentile) had deviations from the recommended N application rate between -30 and 59 kg ha^{-1}. For P_2O_5 and K_2O, this ranged between -57 and 0, and -36 to 0 kg ha^{-1}, respectively. This translated into median relative residuals of 36%, -10% and 0% for N, P_2O_5 and K_2O.

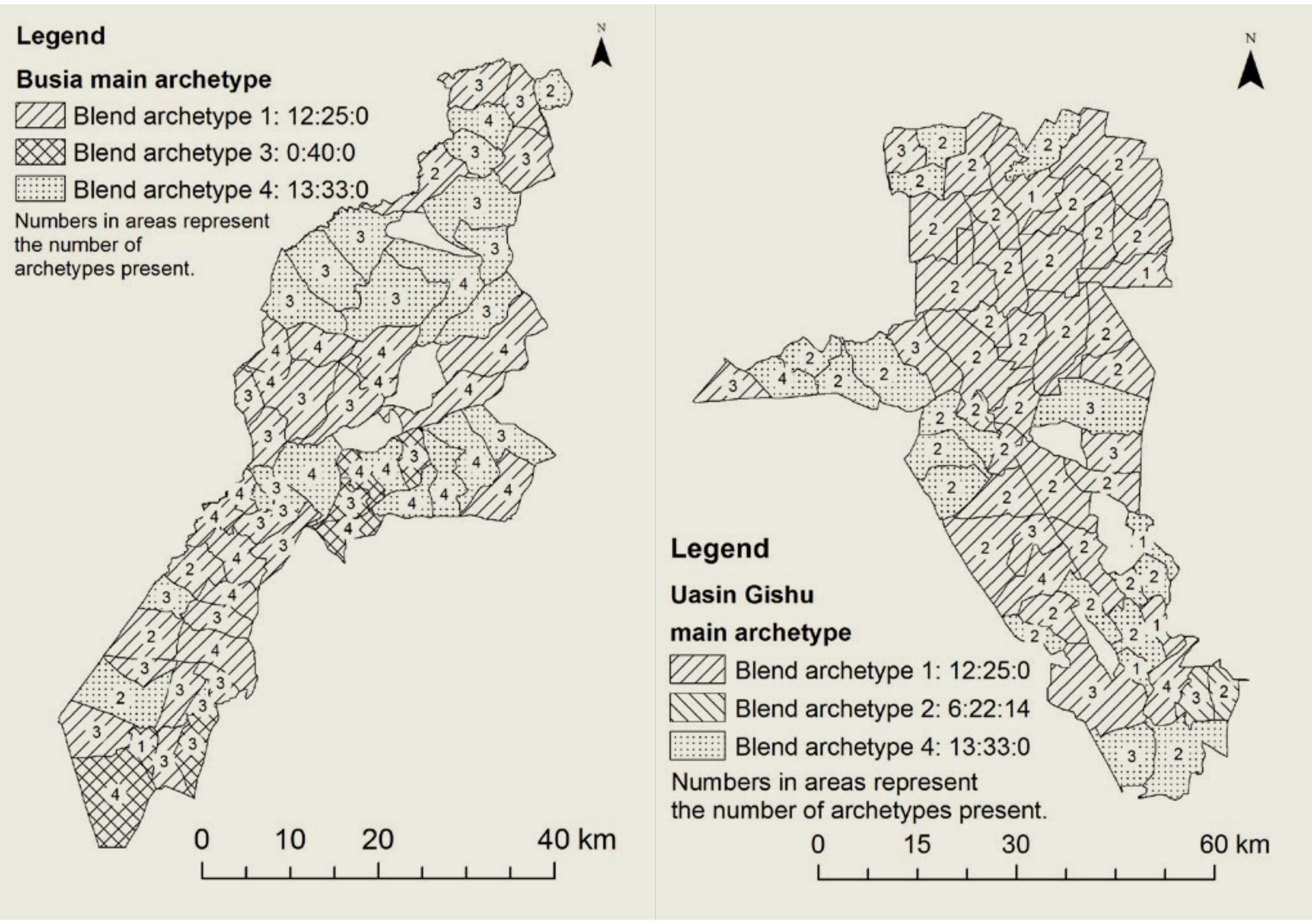

Fig. 5. Distribution of main planting blend archetypes in the sub-locations of Busia and Uasin Gishu.

Table 5. Summary statistics on absolute and relative nutrient fertilizer residuals at planting.

Type of residual	Population characteristic	N	P_2O_5	K_2O
Absolute nutrient residuals: fertilizer – plant needs (kg ha^{-1})	10% percentile	-30	-57	-36
	Median	37	-37	0
	Mean	35	-29	-4
	90% percentile	59	0	0
Relative nutrient residuals: absolute residuals/plant needs (%)	10% percentile	-27	-16	-100
	Median	36	-10	0
	Mean	34	-8	-26
	90% percentile	63	0	0

Discussion

Routine soil testing using infrared technology in combination with the SoilCares mobile laboratory is a promising first step to decreasing the crop yield gap experienced by smallholders. In this Uasin Gishu - Busia project, more than 2,100 samples provided by smallholder farmers were analyzed by one bus run by a team of three people within eight weeks. All smallholders received a field and crop specific fertilizer recommendation within about three hours of presenting their samples.

The data plotted at the sub-location level of Uasin Gishu and Busia are useful to obtain recent, detailed information on actual soil fertility status. Soil test data of soil samples, in combination with the calculated optimal NPK application rate according to the QUEFTS fertilization model, provide a data set which can be used to derive optimal fertilizer blend compositions using the archetype approach.

The soil samples from Uasin Gishu and Busia could be classified to eight soil archetypes with unique soil property combinations. Mainly different soil archetypes were found in the two counties. Nevertheless, huge soil variability was encountered even at sub-location level. There appeared to be no direct relationship between the soil archetypes and the well-known soil types on soil maps. The reason for this is probably that on common soil maps only general static soil characteristics are included. When dynamic soil characteristics are incorporated, more detailed and precise soil fertility maps can be produced. These changes in the dynamic soil characteristics are probably the outcome of recent farm, fertilizer or crop residue management, but this statement needs further investigation.

Soil archetypes, as derived in this study, provide a very useful starting point for assessing soil fertility status and advising on fertilizers and their rates of application. However, this is only possible when the soil archetypes remain constant for a long period. If this is not the case, communication and knowledge transfer on soil fertility status and fertilizer application rates becomes more challenging. Future research should also address this point.

Fig. 4 and Table 4 (exemplary for the maize yield of 5 t ha^{-1} assuming normal nutrient recovery fraction) showed the huge variation that can be expected in the optimal N, P_2O_5 and K_2O application rates because of differences in soil archetype. However, when the archetype approach is used for the calculated N, P_2O_5 and K_2O rates of all samples. An optimization step needs to be included to derive the optimal amount of blend that should be applied to a single field. Each of the 2,107 soil samples was classified to one blend archetype. Calculations showed that, although N, P_2O_5 and K_2O residuals existed, the magnitude (absolute and relative) was acceptable.

This study showed that the SoilCares mobile soil testing concept is a good starting point for minimizing the yield gap. The infrared technology is an affordable soil testing method for smallholders and the QUEFTS calculation model has a good scientific basis for deriving field and crop specific N, P_2O_5 and K_2O recommendations. Results are returned within three hours. As described in this paper, data can also be analyzed in more detail to define soil advice and blend archetypes. This new information is a good basis for knowledge transfer to smallholders, as well as for the economic production of NPK blends potentially of use for large areas of agricultural land and crops.

Acknowledgement

Soil testing in the Busia county was carried out in cooperation with the Programme for Agriculture and Livelihoods in Western Communities (PALWECO) funded by the Governments of Finland and Kenya. In Uasin Gishu, the soil testing project was carried out in cooperation with the local authorities.

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The paper "Soil Fertility Status and NPK Blends at Planting for Maize Growing in the Western Kenyan Counties Uasin Gishu and Busia" also appears on the IPI website at:

Regional activities/SSA

Research Findings

Soybean crop in Brazil - grown to new horizons. Alvorada farm, Brazil. Photo by T. Wiendl.

Influence of Brachiaria (*Urochloa brizantha*) as a Winter Cover Crop on Potassium Use Efficiency and Soybean Yield under No-Till in the Brazilian Cerrado

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Introduction

Brazil is the world's third largest consumer of potash (fertilizers, with an annual consumption of more than 4.7 million metric tons of K_2O (ANDA, 2013), of which less than 10% is produced within the country. Most of this potash fertilizer is applied to grain production, mainly soybean and maize, but the large amounts of potassium (K) exported in grain crops make its replacement essential in order to retain high soil productivity levels, in particular for soybean. Grain production in Brazil is concentrated in areas where indigenous K soil reserves are low, and significant reductions in yield losses may be observed after three or four successive harvests if K replacement is inadequate. There is a need, therefore, to identify management strategies to increase K use efficiency. Brachiaria (*Urochloa brizantha*) is considered to be highly efficient in K recycling (Naumov *et al.*, 2011). In this short article we report the findings of a field experiment showing

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the beneficial effects of Brachiaria, used as a winter cover crop, on soybean yield and K use efficiency in a highly weathered red tropical soil.

Materials and methods

This field study was conducted in the experimental area of the Technological Center of COMIGO, Rio Verde - GO, Brazil (17° 45' 49.13" S and 51° 01' 57.47" W; 604 m above sea level). The soil in the experimental area was characterized as a clayey Red Oxisol low in exchangeable K (Table 1), and had been cultivated for grain production for over 10 years prior to the experiment being set up in 2006.

Table 1. Chemical attributes of the soil of the experimental area prior to the experiment (n=8).

Layer	pH$^{(1)}$	OM$^{(2)}$	P$^{(3)}$	Ca	Mg	Al$^{(4)}$	H+Al	K	BS	CEC$^{(5)}$	clay
cm		*g dm^{-3}*	*mg kg^{-3}*	----------------------------*cmolc dm^{-3}*----------------------------							*%*
0-20	4.93	25.51	10.47	2.56	0.54	0.05	3.13	0.10	3.20	6.33	45
20-40	4.48	20.45	1.84	1.21	0.27	0.26	3.74	0.08	1.56	5.30	48

$^{(1)}$pH in $CaCl_2$; $^{(2)}$Soil organic matter; $^{(3)}$Phosphorus (P) and K in Mehlich 3 extract; $^{(4)}$Calcium (Ca), Magnesium (Mg) and Aluminum (Al) in 1 mol l^{-1} KCl; $^{(5)}$CEC = Base saturation + H + Al.

Note: These data indicate the low availability of K in the soil, according to Embrapa (2011).

Treatments were arranged in a 2 x 4 m factorial experiment, using a split plot design with four replications. The first factor was analyzed through two different treatments (*U. brizantha* as winter cover crop and bare soil) on 240 m^2 plots (12 x 20 m). In the bare soil treatment, the weeds were desiccated with glyphosate (2 l ha^{-1} of commercial product) after soybean harvesting, so that there was no vegetative soil cover during the winter. For the second factor of K treatment, four rates of application of KCl were made: (0, 20, 40 and 60 kg K_2O ha^{-1}), the amounts being applied 15 days after seeding on the split plots of 60 m^2 (6 x 10 m).

Soybean crops were cultivated during the summer after total area desiccation. Soybean yield data and leaf K concentration data were then collected from three cropping seasons, between 2009 and 2012 (apart from the 2010/11 season when samples for leaf K were not determined). Soybean leaves were sampled at the flowering stage to estimate leaf K concentration. Soybean yield was measured in a 6 m^2 area and the grain weight adjusted to 13% moisture.

Results and discussion

Soybean sown during the summer over Brachiaria straw resulted in markedly higher yields compared to those obtained from bare soil: average yield increases of 502.8, 572.5 and 640.0 kg ha^{-1} were obtained in 2009/10, 2010/11 and 2011/12 seasons, respectively. These values show that seeding Brachiaria brings an increase in soybean yield of between 11 to 25 percent, in all K treatments tested. Across the three years, yields for K treatments averaged 18, 14 and 22 percent respectively (Fig. 1).

Potash fertilization did not significantly influence soybean yield. Nevertheless, during the 2010/2011 season, a slight increase in soybean yield was observed related to the increase of K fertilizer doses. This was probably due to high K demand in relation to the high yield (Fig. 2). Yields obtained in this experiment appear rather high, especially when Brachiaria was used as a cover crop, in comparison with the average yield of 2,680 kg ha^{-1} reported from a review of 108 studies by Salvagiotti *et al.* (2008). The higher yields achieved in our experiment, especially under bare soil, at zero K applied may possibly be explained by the high level of technology used by soybean farmers in Brazil, which includes a good genetic base, efficient control of insects and diseases, and soil management based on a no till system. The yield obtained in this experiment is comparable with the average yield obtained with commercial crops in the same region and crop season which reached more than 4,000 kg ha^{-1}.

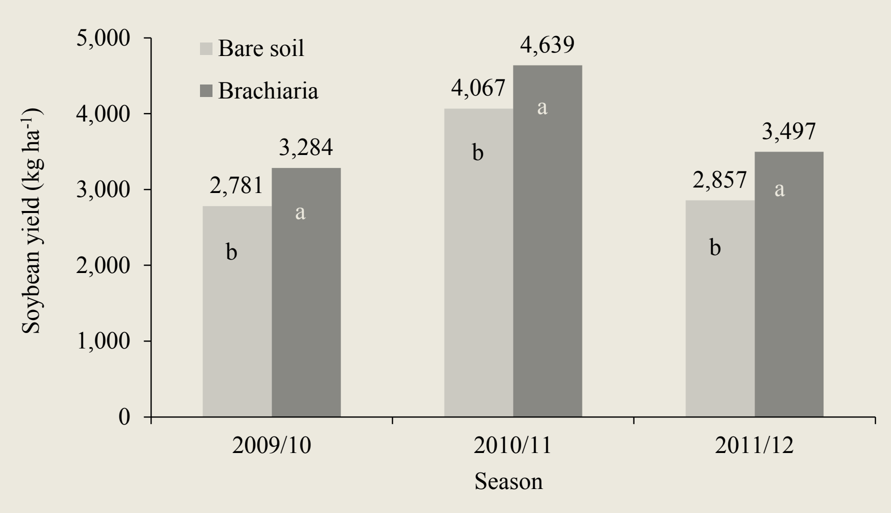

Fig. 1. Average soybean yield (for K application rates) in three cropping seasons influenced by Brachiaria as a winter cover crop (n=32).

Leaf K concentrations in all K treatments were higher when soybean was grown after Brachiaria, indicating higher K availability. Increasing levels of K application slightly increased leaf K in both crops, with and without Brachiaria as a cover crop,

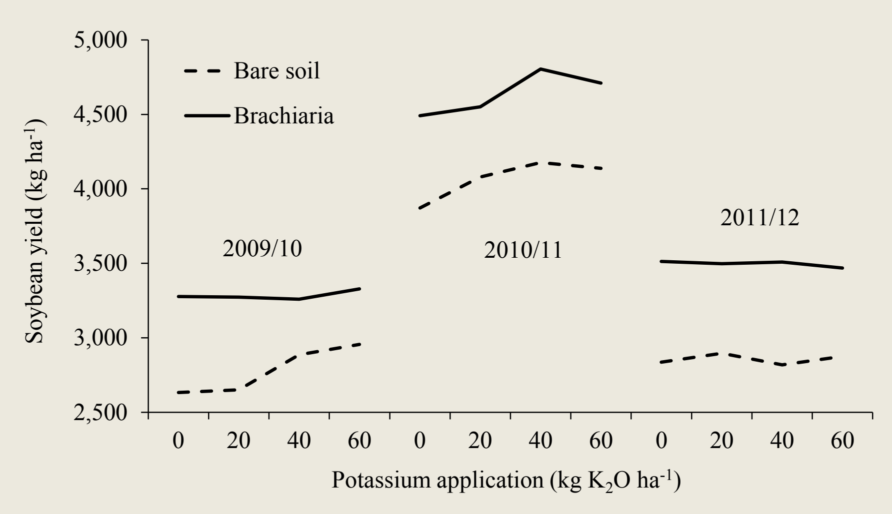

Fig. 2. Response of soybean yield to K application during three cropping seasons and the influence of Brachiaria as a winter cover crop over bare soil (n=8).

and varied between 18 and 22.8 g kg^{-1} (DM). The average offtakes of K were calculated as the product of the average yield from the data given in Table 2 and the average K bean concentration of 20 g K_2O kg^{-1} (Embrapa, 2011). Soybean K offtakes, when grown after a Brachiaria cover crop for the three seasons analyzed (2009/10 to 2011/12) were calculated as 65.7, 92.8 and 69.9 kg K_2O ha^{-1} respectively and were considerably higher compared to the respective values for the bare soil of 55.6, 81.3 and 57.1 kg K_2O ha^{-1}. The rates of K removal in the bare soil treatment were almost the same as those applied by the highest doses (60 kg K_2O ha^{-1}). In the Brachiaria treatments, K offtake was higher than the highest dose of applied K. Thus, taking into account K leaching to deep soil layers as well as K losses from Brachiaria straw via run off, there appears to be a negative K balance in the system. This would be expected to lower yields in succeeding crops, but as discussed below this is not the case. With soybean, the greater yields and offtakes of K, resulting from the Brachiaria treatment compared with bare soil, may be explained by the root system of this tropical grass species. This highly extensive and efficient system enables this plant to explore a very high soil volume, recovering K from deep soil layers to be stored in the straw for the benefit of the succeeding soybean crop (Fig. 1, Fig. 2, and Table 2). Other researchers have found similar results of the beneficial effect of this species in recycling K in Brazilian soils (Garcia *et al.*, 2008). The efficient use of indigenous K by Brachiaria is also suggested by other authors, as summarized by Benites *et al.* (2010). It has also to be considered that despite the low exchangeable K values in the soil (Table 1), the highly weathered Brazilian red clay soil may originate from a variety of parent rocks including basalt, feldspars and muscovite (Ker, 1997) thus contributing to a significant source of K. According to Melo *et al.* (2000) even in very weathered Oxisols there are significant reserves of indigenous K in the silt and sand fractions. These reserves are able to be used by crops, especially by those with aggressive root system such as Brachiaria and other grasses.

The agronomic efficiency (AE; kg soybean per kg K_2O added) was found during the 2009/10 season only in high K applications under bare soil, during 2010/11 in both bare and cover crop and in 2011/12 only with low K application under bare soil (Table 2). AE varied between 3 to 10.4 kg kg^{-1} (Table 2). When Brachiaria was used as a cover crop, AE for K application was found in only one season (2010/11). In the other crop seasons the AE was negative, indicating the use of indigenous K by soybean.

Interestingly, although slightly higher concentration of leaf K were reported, no statistical differences were observed in response

Table 2. Soybean yield and soybean leaf K concentration in response to K application over three cropping seasons with bare soil or Brachiaria as a winter cover. Agronomic efficiency data are also shown.

Season	2009/10					2010/11					2011/12				
kg K_2O ha^{-1}	0	20	40	60	Ave.	0	20	40	60	Ave.	0	20	40	60	Ave.
Winter cover	Soybean yield *(kg ha^{-1})*														
Bare soil	2,633	2,651	2,886	2,955	2,781	3,872	4,080	4,177	4,138	4,067	2,837	2,896	2,819	2,875	2,857
Brachiaria	3,277	3,273	3,259	3,328	3,284	4,491	4,551	4,804	4,710	4,639	3,513	3,498	3,509	3,468	3,497
	Leaf K concentration *(g kg^{-1})*														
Bare soil	18.0	18.6	18.8	19.9	18.8	nd	nd	nd	nd		18.1	18.4	20.2	20.2	19.2
Brachiaria	21.4	20.8	21.4	22.8	21.6	nd	nd	nd	nd		19.4	19.8	20.8	20.4	20.1
	Agronomic efficiency of K *(kg soybean kg^{-1} K_2O)*														
Bare soil	-	-	6.3	5.4	5.9	-	10.4	7.6	4.4	7.5	-	3	-	-	-
Brachiaria	-	-	-	-	-	-	3.0	7.8	3.6	4.8	-	-	-	-	-

to increasing rates of K application on yield or K leaf tissue concentration in any of the cropping seasons in either the Brachiaria or bare soil systems. The intriguing question is why there was no response to K fertilizer application on the bare soil in particular. This may be caused in part by a higher than expected soil K status of the experimental site and the type of K bearing minerals in soil. While, according to Mengel (2006), values recorded for the K concentrations of the soybean leaf samples were just at the K critical deficiency level (2% of the dry weight), these leaf concentrations at flowering are considered adequate by the Brazilian research being tested in many field experiments (Embrapa, 2011) which consider 1.7% to 2.5% K as an adequate level. Cultivation of Brachiaria as a cover crop during the winter provides farmers with a useful means for recycling soil K for the benefit of soybean and maize, which offers an explanation for the low response to K, and therefore low or negative AE achieved.

Experimental site in Rio Verde, Goiás, Brazil. Photo by T. Wiendl.

Conclusions

The use of Brachiaria as a winter cover crop results in a significant increase in summer soybean yield. This in part reflects an increased K use efficiency by utilizing K from deep soil layers and from non exchangeable forms of K. This crop succession has proven potential in the tropics, in particular where it is not possible to grow a second crop during the same season and farmers have been accustomed to maintaining bare soil during the winter. In order to ensure the long-term efficacy of the system, more precise calculations of crop response, K use efficiency and K balance are needed through additional field experiments.

Acknowledgements

We acknowledge the International Potash Institute for its financial support in the Aduba Brasil project, and also the COMIGO agricultural cooperative for its experimental facilities.

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The paper "Influence of Brachiaria (*Urochloa brizantha*) as a Winter Cover Crop on Potassium Use Efficiency and Soybean Yield under No-Till in the Brazilian Cerrado" also appears on the IPI website at:

Regional activities/Latin America

Events

IPI Events

December 2014

IPI-BZU Awareness Seminar on “Potash Use in Pakistani Agriculture”, held on 4 December 2014 at Bahauddin Zakariya University (BZU), Multan, Pakistan

Report by
Dr. Abdul Wakeel, Assistant Professor, ISES, University of Agriculture, Faisalabad, Pakistan; IPI Consultant Pakistan
Dr. Dr. Muhammad Farooq Qayyum, Assistant Professor, Department of Soil Science, BZU, Multan, Pakistan
Dr. Ahmad Naeem Shehzad, Assistant Professor, Department of Agronomy, BZU, Multan, Pakistan

Imbalanced fertilization, especially in the use of nitrogen, phosphorus and potassium, not only causes deterioration of natural resources but also results in low economic returns. In Pakistan, use of chemical fertilizers (mostly nitrogen and phosphorus) started during 1960-70; nitrogenous fertilizer use has been significantly higher than phosphorus, due to its better, quicker and more economic crop responses. However, application of potash has been discouragingly low in most crops except potato, where it has been used for increased yields and quality.

Although Pakistani soils are developed from mica minerals containing >6% potassium, most of this is strongly bound to clay minerals and is not available to plants. Previously, the available potassium was sufficient for low yielding crop varieties. More recently, development of high yielding varieties and intensive cropping have depleted the soils to a great extent and increased the demand for better yield. Canal water was also considered a significant source of potassium but the decreased availability of canal water has limited this source also. There is, therefore, a dire need to promote potassium fertilization in Pakistan for sustainable and economical agriculture.

Current research activity has targeted the cotton growing area of Pakistan, in order to highlight the significant response of cotton to potash application. The main objectives of this seminar were to highlight the significance of potassium fertilization in cotton-wheat cropping systems, and to create awareness among farmers, industry, academia, students and agriculture extension workers about the importance of balanced fertilization in food security and sustainable agriculture in Pakistan. There were about 150 participants including progressive farmers, researchers, the advisory section of the fertilizer industry, Punjab government agriculture extension officers, scientists and students of the Faculty of Agricultural Sciences and Technology, Bahauddin Zakariya University, Multan.

Photos: IPI-BZU awareness seminar on potash use in Pakistan, held at BZU, Multan, Pakistan, 4 December 2014. Photos by A. Wakeel.

The first speaker was Dr. Shehzada Manawwar Mehdi, Director of the Soil Fertility Research Institute (SFRI), who gave a review of potash use in Pakistan and highlighted the status of potassium in Pakistani soils, especially in Multan division. His presentation included reference to maps based on the soil analysis data of

SFRI. He concluded that soils in many areas of Pakistan are deficient in crop-available potassium, and potassium fertilizers are required. While most of the soils in Multan division are not deficient, according to the soil analysis reports, they are close to the acceptable margin, such that crop yields can be severely impacted if potash fertilization is not carried out.

Dr. Nadeem Tariq, Director of NIHA Technologies Private Limited, beautifully presented the importance of optimum potassium concentration in edible parts of agricultural produce for human health, and also explained the economic benefits of potassium fertilization in Pakistan. He emphasized that government should subsidize potassium fertilizers as this would bring a great return to the country's economy, based on the strong potential to improve crop yields. Dr. Anjum Ali, Director General of the Punjab Agriculture Extension and Adaptive Research showed some results of balanced use of fertilizer, including potash and mentioned up to 123% increase in crop yields achieved through balanced fertilization. He also mentioned that the Government of Punjab, Pakistan, has approved a three-year mega project for promotion of balanced fertilization in Punjab province. Each year there will be >4,000 balanced fertilization demonstration plots and more than 200,000 farmers will be trained through this project. This is a great development; a previous seminar on balanced use of fertilizers, held on 20 August 2014, may have played an important role in the approval of this project.

The significant effect of potash fertilization on cotton by use of potassium was presented by Dr. Dilbaugh Muhammad from the Central Cotton Research Institute (CCRI), Multan. There was also a good discussion with farmers. Lastly, the IPI Coordinator for Pakistan highlighted some gaps regarding potassium research and fertilizer use in Pakistan. He also highlighted the objectives of IPI and the potential role of IPI in Pakistani agriculture. Recent activities of IPI in Pakistan were mentioned and the future plan was also discussed. Prof. Alqama, Vice Chancellor of BZU, appreciated all the seminar activities and emphasized the link between agriculture and politics in Pakistan, due to the agriculture-based economy of the country.

Syed Fakhar Imam, the guest of honor for this seminar, is a progressive farmer, a former speaker of the National Assembly of Pakistan and a renowned politician. He was very much impressed by the discussions, as he mentioned in his speech. He emphasized the importance of knowledge-based agriculture for better economic returns and stressed that farmers should take the initiative to act upon the scientific findings, especially in the use of potassium. This, he believed, would ultimately attract the government's attention towards the issues.

Concluding the seminar speeches and discussions, it can be stated that now there is a great inspiration among farmers and researchers, as well as policymakers, to promote balanced fertilization for sustainable and economical agriculture in Pakistan. The Punjab government's recent action to promote balanced fertilizer use is a great achievement. The time has come to develop a consortium, including researchers, extension workers, farmers and the fertilizer industry, to suggest a single fertilizer policy for the governments of all four provinces of Pakistan. We look forward to a better future of precise nutrient management and balanced fertilizer use in the country.

This report also appears on the IPI website at:

Regional activities/WANA

Events (cont.)

IPI Events

September 2015 (tentative date, not final)

Mark your calendars: IPI will conduct the **2nd Potash Symposium in Ethiopia** in September 2015. The definite date and venue will soon be published on the IPI website. For more details contact Mr. Eldad Sokolowski, IPI Coordinator sub-Saharan Africa.

International Symposia and Conferences

January 2015

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

March 2015

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

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

April 2015

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

July 2015

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

October 2015

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

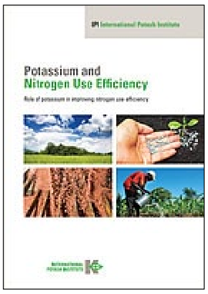
November 2015

The 2nd World Congress on the Use of Biostimulants in Agriculture, 16-19 November 2015, Florence Convention Centre, Italy. For more information visit www.biostimulants2015.com.

First quarter 2016

IFA and New Ag International join forces again to organize the **4th International Conference on Slow- and Controlled-Release and Stabilized Fertilizers in China** during first quarter 2016. For more information go to www.newaginternational.com/index.php/news/399.

Publications



Potassium and Nitrogen Use Efficiency

Role of potassium in improving nitrogen use efficiency

This 20 page IPI leaflet, compiled by M.S. Brar and P. Imas, explores the Role of Potassium in Improving Nitrogen Use Efficiency (NUE).

Nitrogen (N) and potassium (K) are essential major nutrients, which play an important role in the growth and development of plants. Plants take up N and K in almost the same quantities but application of these nutrients to crops varies widely. When N and K are applied separately, yield is increased due to application of either of the elements. But, when both N and K are applied together, the increase in yield is greater than the sum of the increase in yield due to N and K separately.

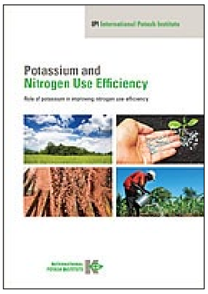
This publication is available for download from the IPI website, or can be ordered free of charge from IPI head office at ipi@ipipotash.org.

Калій - Елемент Якості в Рослинництві

Potassium - the Quality Element in Crop Production

Compiled by P. Imas. 38 p. 2013.

This publication is now available in Ukrainian on the IPI website. For hardcopies, please contact Dr. Gennadi Peskovski at g.peskovski@belpc.by.



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Potassium - a Nutrient Essential for Life

We have just published this booklet in Amharic, available for download on the IPI website. You can order hardcopies from Mr. Eldad Sokolowski, IPI Coordinator sub-Saharan Africa.

Publication by the PDA

High Yields - are we keeping up with Potash offtakes?

POTASH News, Autumn 2014.

The Fertiliser Manual (RB209) gives recommendations for phosphate and potash applications for arable crops and grass based on that needed to replace the amount that will be removed from the soil by crop offtake at harvest. 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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Potassium and Rhizobium Application to Improve Quantitative and Qualitative Traits of Lentil (*Lens culinaris* Medik.)

Sanghmitra Suryapani, S., A.A. Malik, O. Sareer, and S. Umar. 2014. IJAAR 5(3):7-16. ISSN: 2223-7054 (Print) 2225-3610 (Online).

Abstract: In an effort to improve plant growth and productivity by increasing the amount of N_2-fixation, a two-year field experiment was designed to study the combined effect of potassium and two strains of *Rhizobium leguminosarum* (L-1897 and L-2097) on quantitative and qualitative traits of lentil (*Lens culinaris* Medikus). Bacterial inoculation and potassium application (0 kg K ha^{-1} and 50 kg K ha^{-1}) caused measurable changes in the observed characteristics in both years of study. In addition to growth characteristics, chemical- and bio-fertilizer treatments also affected the nitrogen and potassium concentration in seeds and seed protein content. Yield and yield characteristics improved more with the combined application as compared with a single treatment and control. Among the bacterial strains, L-1897 along with potassium fertilization resulted in highest yield. We conclude that optimum potassium fertilization is required for the favorable and sustained action of *Rhizobium* to influence growth characteristics and qualitative traits and hence, yield and yield components.

A Contemporary Overview of Silicon Availability in Agricultural Soils

Haynes, R.J. 2014. J. Plant Nutr. Soil Sci. 177(6):831-844. DOI 10.1002/jpln.201400202.

Abstract: Our current understanding of silicon (Si) availability in agricultural soils is reviewed and knowledge gaps are highlighted. Silicon is a beneficial rather than essential plant nutrient and yield responses to its application have been frequently demonstrated in Si-accumulator crops such as rice and sugarcane. These crops are typically grown on highly weathered (desilicated) soils where soil solution Si concentrations are low. Increased yields are the result of simultaneous increases in plant tolerance to a wide range of biotic (plant pathogens, insect pests) and abiotic (water shortage, excess salts, metal toxicities) stresses. Traditionally, soil solution Si is viewed as being supplied by dissolution of primary and secondary minerals and buffered by adsorption/desorption of silicate onto Al and Fe hydrous oxide surfaces. In recent years it has become recognized that phytogenic cycling of Si [uptake of Si by plants, formation of phytogenic silica ($SiO_2 \cdot nH_2O$) mainly in leaves and subsequent return of this silica to soils in plant litter] is the main determinant of soil solution Si concentrations in natural forests and grasslands. Considerable diminution of the phytogenic Si pool in agricultural soils is likely due to regular removal of Si in harvested products. A range of extractants (unbuffered salts, acetate-based solutions, and acids) can provide valuable information on the Si status of soils and the likelihood of a yield response in rice and sugarcane. The most common Si fertilizers used are industrial byproducts (*e.g.*, blast furnace slag, steel slag, ferromanganous slag, Ca slag). Since agriculture promotes soil desilication and Si is presently being promoted as a broad spectrum plant prophylactic, the future use of Si in agriculture is likely to increase.

Aspects that require future research include the role of specific adsorption of silicate onto hydrous oxides, the significance of phytogenic Si in agricultural soils, the extent of loss of phytogenic Si due to crop harvest, the role of hydroxyaluminosilicate formation in fertilized soils, and the effect of soil pH on Si availability.

Who Buys Organic Foods in Switzerland?

Götze, F., and A. Ferjani. 2014. Recherche Agronomique Suisse 5(9):338-343.

Abstract: Over the past years, the Swiss market for organic foods has grown considerably. However, little is known about the factors that motivate consumers to purchase organic food products. Within the framework of this analysis, data from Swiss households on the consumption of organic foods were analysed descriptively and econometrically. The evaluation of these household data confirmed the growing trend for organic foods in general and for the nine product groups under consideration, namely Bread and Grain Products; Meat; Fish; Dairy Products and Eggs; Edible Fats and Oils; Fruit;

Vegetables; Sugar and Confectionery; and Condiments and Sauces. The most popular organic products were vegetables, dairy products and eggs, and fruit, with the consumption of organic vegetables showing the strongest growth. The econometric analysis showed that the sociodemographic structure of the households influenced the decision to buy organic foods. As income increased, so did the likelihood that these households would purchase organic products. The age of the reference person of the household and the presence of children also played a role, with childless households being more likely to buy organic foods than those with children.

Response of Nitrogen Content for Some Varieties of Kenaf Fiber (*Hibiscus Cannabinus* L.) by Applying Different Levels of Potassium, Boron and Zinc

Rabar Fatah Salih, R.F., K. Abdan, A. Wayayok, A.A. Rahim, and N. Hashim. 2014. ScienceDirect. Agriculture and Agricultural Science Procedia 2:375-380. DOI 10.1016/j.aaspro.2014.11.052.

Abstract: The aim of this study was to determine the impact of the potassium, boron and zinc on the nitrogen of fiber. Two kenaf varieties namely; FHH 925 and 4383, were planted. Fertilizers (0, 100 and 150), (0, 1.0 and 1.5) and (0 and 5.0) kg/ha, for potassium, boron and zinc were added respectively. The best result was achieved for variety FHH 925 when potassium was added at level of 150 kg/ha, but regarding 4383 was when potassium, boron and zinc were applied at 150, 1.0 and 5 kg/ha, respectively. Based on the results potassium was really suitable for the kenaf.

Potassium Transporter TRH1 Subunits Assemble Regulating Root-Hair Elongation Autonomously from the Cell Fate Determination Pathway

Daras, G., S. Rigas, D. Tsitsekian, T.A. Iacovides, and P. Hatzopoulos. 2014. ScienceDirect. Plant Science 231:131-137. DOI 10.1016/j.plantsci.2014.11.017.

Abstract: Trichoblasts of *trh1* plants form root-hair initiation sites that fail to undergo tip growth resulting in a *tiny root-hair* phenotype. *TRH1* belongs to *Arabidopsis KT*/*KUP*/*HAK* potassium transporter family controlling root-hair growth and gravitropism. Double mutant combinations between *trh1* and root-hair mutants affecting cell fate or root-hair initiation exhibited additive phenotypes, suggesting that *TRH1* acts independently and developmentally downstream of root-hair initiation. Bimolecular Fluorescence Complementation (BiFC), upon *TRH1-YFP*^{C} and *TRH1-YFP*^{N} co-transformation into tobacco epidermal cells, led to fluorescence emission indicative of TRH1 subunit homodimerization. Yeast two-hybrid analysis revealed two types of interactions. The hydrophilic segment between the second and the third transmembrane domain extending from residues Q105 to T141 is competent for a relatively weak interaction, whereas the region at the C-terminal beyond the last transmembrane domain, extending from amino acids R565 to A729, strongly self-interacts. These domains likely facilitate the co-assembly of TRH1 subunits forming an active K^+ transport system within cellular membrane structures. The results support the role of TRH1 acting as a convergence point between the developmental root-hair pathway and the environmental/hormonal signaling pathway to preserve auxin homeostasis ensuring plant adaptation in changing environments.

Comparative Analysis of the Relationship Between Cs and K in Soil and Plant Parts Toward Control of Cs Accumulation in Rice

Kondo, M., T. Makino, T. Eguchi, A. Goto, H. Nakano, T. Takai, Y. Arai-Sanoh, and Takeshi Kimura. 2014. Soil Science and Plant Nutrition. DOI 10.1080/00380768.2014.973348.

Abstract: The effect of soil exchangeable potassium (K) and cesium (Cs) levels on Cs uptake and accumulation in different parts of rice (*Oryza sativa* L.) plants were examined using paddy soils with diverse exchangeable K and Cs in pot experiments. Aboveground Cs uptake decreased with higher exchangeable K and was linearly correlated with exchangeable Cs/K ratios, indicating competitive absorption of these elements by roots. Variation in Cs concentration in brown rice among soils was also related to the exchangeable Cs/K ratio. The exchangeable Cs/K ratio was positively reflected in the Cs/K concentration ratio in each plant part, with a specific slope, suggesting that Cs transport was coordinated with K transport and that there were regulated discriminations of Cs against K in the translocation process among parts. The Cs/K ratio was higher in brown rice and dead leaves than in active leaves, stems and husks. The distribution of Cs accumulation in brown rice was 14.5% on average, but it was variable and negatively related to K concentration in the stem. The Cs distribution in aboveground plant parts also decreased with higher K concentration in the root. These results imply the importance of the competitiveness with K in the root absorption and translocation of Cs within the plant. Based on the observed relationship between Cs and K, effective K management and other measures to control Cs accumulation in plant parts are discussed.

Effects of Potassium in Reducing the Radiocesium Translocation to Grain in Rice

Nobori, T., N.I. Kobayashi, K. Tanoi, and T.M. Nakanishi. 2014. Soil Science and Plant Nutrition 60(6):772-781. DOI 10.1080/00380768.2014.947617.

Abstract: This study investigated the effects of potassium (K) on the behavior of cesium 137 (^{137}Cs) in hydroponically cultured rice plants (*Oryza sativa* L. “Nipponbare”), revealing that K supply has an influence on reducing ^{137}Cs translocation from leaves to ears as well as decreasing ^{137}Cs uptake by roots. When K was omitted from the culture solution and ^{137}Cs was supplied, the ^{137}Cs content in the ears was increased 6.7-fold compared with the K-sufficient plants, while the total ^{137}Cs content in the shoot part of the K-deficient rice was only 3-fold higher than that in the K-sufficient rice. The fraction of the ears in the total shoot ^{137}Cs content was indeed 2.5 times higher in the K-deficient rice (45%) than that in the K-sufficient rice (18%), demonstrating that K supplementation has an effect on ^{137}Cs translocation to the ears. Irrespective of the K condition, >95% of the ^{137}Cs that accumulated in the ears was found to be absorbed from the culture solution before ear emergence. K supplementation after ear emergence had an influence on achieving the percentage of ^{137}Cs remobilization in the K-deficient rice close to that in the K-sufficient rice, although the effect on reducing the ^{137}Cs content in the ears could be limited. The results indicate the importance of maintaining an appropriate soil K concentration during the early growth stages to avoid ^{137}Cs contamination of rice grains.

Mineral Profile of Kaki Fruits (*Diospyros kaki* L.)

Mir-Marqués, A., A. Domingo, M. L. Cervera, and M. de la Guardia. 2014. ScienceDirect. Food Chemistry 172:291-297. DOI 10.1016/j.foodchem.2014.09.076.

Abstract: The main objective of this study was the determination of the mineral profile of 167 kaki fruit (*Diospyros kaki* L.) samples produced from different regions of Spain, including samples with the protected designation of origin (PDO) 'Kaki Ribera del Xúquer' Valencia (Spain). Samples were analysed by inductively coupled plasma optical emission spectroscopy (ICP-OES) and inductively coupled plasma mass spectrometry (ICP-MS). Consumption of one piece of kaki fruit (200-400 g) would give a mineral intake providing 1-10% of the recommended daily allowance (RDA) for calcium, 1-30% for copper and potassium, 1-15% from iron and magnesium, up to 1% of sodium, and up to 4% of zinc. ANOVA analysis indicates differences between samples from different Spanish region, thus offering a way for authentication of PDO sample origin.

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Zeng, N. *et al.* Nature 515:394-397. DOI 10.1038/nature13893.

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Stehfest, E. 2014. Nature 515:501-502. DOI 10.1038/nature13943.

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Xinping Chen *et. al.* 2014. Nature 514:486-489. DOI 10.1038/nature13609.

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Actions and accountability to accelerate the world's progress on nutrition. 2014. IFPRI.

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FAO News. 2014.

Potassium Important to Controlling Stem Rot in Rice

Miller, F. 2009. Division of Agriculture, University of Arkansas System.

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Climate Change and Smallholder Agriculture in sub-Saharan Africa. 2014. AGRA.

The Role of a Potassium Transporter OsHAK5 in Potassium Acquisition and Transport from Roots to Shoots in Rice at Low Potassium Supply Levels

Yang, T. *et al.* 2014. Plant Physiol. 166(2):945-959. American Society of Plant Biologists. DOI 10.1104/pp.114.246520.

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Lester, M. 2014. Time.

Clipboard - Position Paper

Research and policy recommendations made at the end of the 1st Potash Symposium in Ethiopia entitled:

"The Role of Potassium in Cropping Systems of sub-Saharan Africa: Current Status and Potential for Increasing Productivity"

jointly organized by the International Potash Institute (IPI), Ministry of Agriculture, Ethiopia (MoA) and the Ethiopian Agriculture Transformation Agency (ATA)

4-5 September 2014, Addis Ababa, Ethiopia

The 1st Potash Symposium in Ethiopia was held in Addis Ababa from 4-5 September, 2014. More than 25 papers were presented during the first two days with over 100 scientists, extension officers, officials and farm technicians attending the event.

The five sessions of the symposium included papers describing the development and challenges of agriculture in East Africa and in particular, the fertilizer sector in Ethiopia. Evidence was presented from the Ethiopian soil fertility mapping project, and important information was shared on the role of potassium (K) in soil and plant systems, including data from experiments in potash fertilization, both in Ethiopia and other East African countries. In addition, new fertilizer formulations that have been tested were presented and information shared with farmers, agricultural experts and other stakeholders in Ethiopia. These new formulations brought significant yield increases and were widely accepted by the farmers. The outcome has also been the reversal of the previous belief by many that Ethiopian soils are rich in K, and do not need potash fertilization.

In the concluding panel session, participants emphasized the urgent need to address several key issues within the fields of research, policy and collaboration.

1. Research

Targeted action to strengthen soil science and plant nutrition research is needed in the following areas:

a) Improved understanding of the nutrient requirements and fertilization practices for Ethiopia's leading crops (e.g. teff, coffee, enset).

b) Improved area- and crop-specific fertilizer recommendations and value addition activities to complement the results of the soil fertility mapping program within the Ethiopian Soil Information System (EthioSIS).

c) Improved use of balanced nutrition practices in Africa, including micronutrients, to obtain the maximum economic response to fertilizer inputs.

d) Validate K status in Vertisols where K availability - by routine extraction procedures - shows high values and where K response trials on the same soils also show a good crop response.

e) Measuring soil exchangeable K by different methods and correlating to plant response in order to determine the best method and critical value in areas where high clay Vertisols are predominant.

f) Use an 'omission trials' approach to identify site-specific and economic responses to all nutrients.

g) Strengthen the ongoing work to identify additional soil-specific and crop-specific fertilizer blends (formulations) for different parts of Ethiopia and other East African countries.

h) Improve the inclusion of micro-elements in bulk fertilizer blends.

i) Strengthen adoption and development of nutrient diagnostics in plants and soils by using either mobile or static laboratories.

j) Full attention to be given to research on K in plants and soils within the agricultural/soil research agenda in Ethiopia and other African countries.

2. Policy

During recent years, Ethiopia has significantly increased its food production. However, with reference to agricultural development policy, the following points were raised:

a) Implementation of additional improved practices (e.g. nutrient management, improved irrigation systems, seed quality) is necessary for further productivity increase.

b) Additional credit opportunities to farmers, beyond that provided by existing policy, would play a significant role in improving crop productivity in Ethiopia.

c) The livestock sector holds huge potential for growth and deserves to be prioritized in future agricultural productivity planning, both in Ethiopia and other parts of eastern Africa.

d) The need to revise outdated African fertilizer policy and legislation in order to address emerging issues.

e) The policy body needs to strengthen soil fertility research by establishing a soil research institute, as in other developing countries.

3. Collaboration

Productive partnerships and networking among stakeholders will be central to improving productivity in Ethiopia and in East Africa. In this context:

a) Supporting the capacity building efforts of young researchers engaged in soil fertility in general, and K research in particular.

b) Joint production of extension materials that show the beneficial roles of K fertilization from crop, human, and livestock perspectives.

c) Capacity building in the fertilizer value chain is urgently needed.

d) IPI and MoA Ethiopia will seek to implement a K-research network in the country.

e) IPI and MoA Ethiopia will organize an annual K workshop. The 2015 workshop will focus on supporting the recommendations of this symposium and providing guidelines for additional research and dissemination activities in sub-Saharan Africa.

SUB-SAHARAN AFRICA

1st IPI – Ministry of Agriculture-Ethiopian ATA joint Symposium

The role of potassium in cropping systems of sub-Saharan Africa: current status and potential for increasing productivity

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