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Optimizing Crop Nutrition

Editorial

Dear readers,

In this issue, we return to the topic of teff [*Eragrostis tef* (Zucc.) Trotter], which is the most important staple crop in Ethiopia.

Teff is one of the 'K forgotten' crops, whose potassium (K) requirements and response to K application, have seldom been addressed. In a previous issue of *e-ifc* (*e-ifc* No. 48, March 2017), we published exciting results which showed that a humble application of 50 kg KCl ha^{-1} brought a significant increase in teff yields in the Tigray, Oromiya, and Amhara regions of Ethiopia. Also in 2017, IPI published the 'Teff Compendium', a booklet highlighting nutrient deficiency symptoms (including photos) in teff.

In this *e-ifc* edition, we are pleased to feature another important paper on teff, focusing on the response of the crop to K fertilizer application in four districts of the North Shewa region in Ethiopia. The results show that teff performance and yield parameters were enhanced with K fertilization. This paper closes the cycle on IPI publications on teff, which highlight the potential for increasing yields and farmers' profits when using a balanced fertilization scheme on their teff crops.

We take this opportunity to also remember one of the authors of this teff paper, Prof. Tekalign Mamo - a great champion of Ethiopian and African agriculture and soil health - who suddenly passed away in 2017. Let this paper be our humble tribute to his rich legacy in soil fertility, natural resources conservation, and community engagement that has benefited millions of small-scale farmers in Africa.

In this *e-ifc* edition, we also feature two papers on the response of onion to polyhalite fertilization in Turkey, and on the crop productivity and drought tolerance behavior of groundnut under various K application schedules in India. In addition, we report on a successful IPI fertigation training course that was held in China in conjunction with China Agricultural University at Quzhou, Hubei province.

I wish you an enjoyable read.

Dr. Patricia Imas
IPI Scientific and Communications Coordinator

Photo cover page: Potash application in rice crop in China. Photo by ICL.

Research Findings

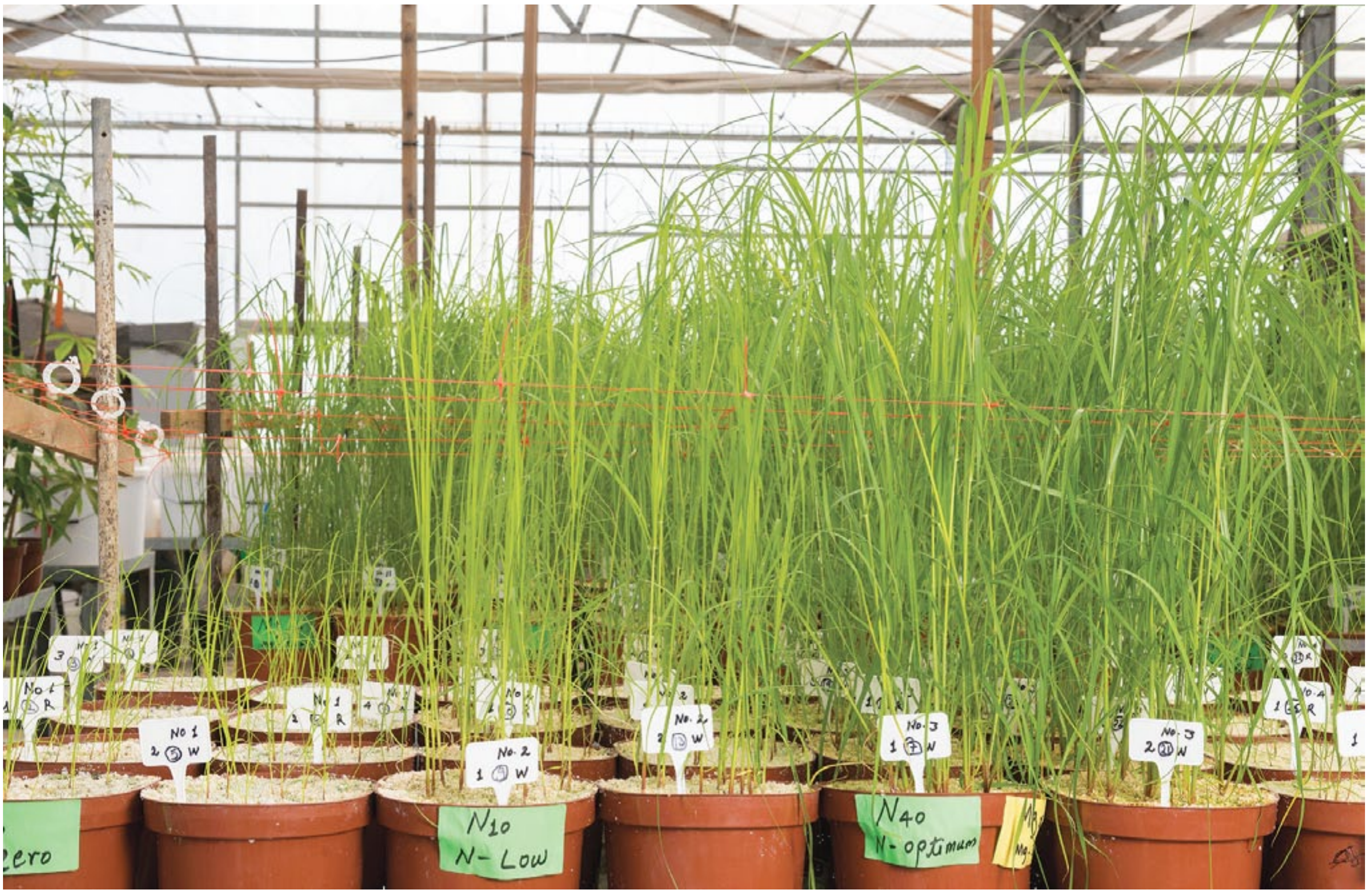

Photo 1. Teff pot experiment at the Center for Fertilization and Plant Nutrition (CFPN), Gilat, Israel. Photo by the authors.

Response of Teff [*Eragrostis tef* (Zucc.) Trotter] to Potassium Fertilizer Application in Four Districts of North Shewa, Ethiopia

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Abstract

Teff [*Eragrostis tef* (Zucc.) Trotter] is a cereal crop species unique to Ethiopia, where it is an important staple crop. It is grown on more than 3 million ha of land. In recent decades, soil fertility has significantly declined in Ethiopia. While nitrogen (N) and phosphorus (P) are traditionally applied by teff growers, potassium (K) has been ignored due to the perceived notion that soils in Ethiopia provide all K requirements. However, recent studies have led to opposite conclusions. Teff K requirements, and its response to K application, have seldom been addressed. The objectives of the present study were to examine teff response to rising K application rates on Vertisols in four regions in the Ethiopian Central Highlands: Sululta, Mulu, Bereh, and Moretena

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Jiru. Potassium was applied at rates of 0, 30, 60, 90, and 120 kg K_2O ha^{-1} along with urea + NPSZn blend applied at 64 kg N ha^{-1} and 20 kg P_2O_5 ha^{-1}.

Generally, crop performance and yield parameters displayed significant increases up to K application range of 60-90 kg K_2O ha^{-1}, with grain yield rising by 26-30% at Moretena Jiru; 21-50% at Bereh; 36-82% at Sululta; and 60-130% at Mulu. Crop yields were between 1-3 Mg ha^{-1}. The large differences between regions may be attributed to the teff genotype cv. Dega at Moretena Jiru and cv. Konchu at the other regions, and to soil fertility traits that require further exploration.

Economically, the incentive of local teff growers to choose an appropriate K application rate would emerge from the expected increment in the marginal profit although this differed considerably between regions, being positive up to 30, 60, 90, and 120 kg K_2O ha^{-1} at Moretena Jiru, Bereh, Mulu, and Sululta, respectively. Potassium application significantly increased N, P, and K concentrations in grains and straw, indicating that K was a principal limiting factor in teff crop development. Consequently, the uptake rates of these nutrients rose significantly, which indicates a possible need to increase their application rates when K is adequately supplied.

In conclusion, the potential of K supply to substantially enhance teff productivity is significant but largely depends on local soil traits that should be thoroughly examined in advance.

Keywords: Eragrostis tef (Zucc.) Trotter; nitrogen uptake; potassium; soil fertility; Vertisol.

Introduction

Teff [*Eragrostis tef* (Zucc.) Trotter], a self-pollinated, C-4 cereal crop belonging to the genus Eragrostis under the family Poaceae (Ketema, 1997; Assefa *et al.*, 2015; Paff and Asseng, 2017), originated in Ethiopia, where it is an important staple crop grown on more than 3 million ha of land. Among the cereals produced in Ethiopia, teff is first in area cultivated but second and last in production and productivity, respectively. Teff is grown by over 6.6 million households and constitutes the major staple food grain for over 50 million Ethiopians (CSA, 2016). The major teff producing areas are Amhara, Central Oromia and West Tigray, where productivity ranges from 1.3-1.5 Mg ha^{-1} (CSA, 2012). There are two groups of teff cultivars - improved and traditional. The national average yield of traditional varieties is 0.91 kg ha^{-1} and that of the improved varieties is estimated to be 1.7-2.2 Mg ha^{-1} on farmers' fields or 2.2-2.8 Mg ha^{-1} on large research-managed farms (Berhe, 2008). However, teff productivity potential is much higher, and can be realized through further practical improvements and enhanced soil nutritional status (Feyera *et al.*, 2014; Mebratu *et al.*, 2017; Tesfahun, 2018).

Teff has a number of particular features, which make it a preferred crop among farmers. As the most favored staple food in the country, the demand for the product is ever increasing; annual teff production increased from 3.0 to 4.8 million metric tons, from 2007 to 2013, respectively (CSA, 2014). Teff has an excellent resistance to drought, as well as to water logging stresses (Tefera and Ketema, 2001) and it is relatively invulnerable to weevils and other pests. It is also suitable for multiple cropping. In addition, teff straw provides a valuable animal feed during the dry season. Recently, teff has been recognized and is highly appreciated as a 'superfood' (Baye, 2015; Heuzé *et al.*, 2016; Shumoy and Raes, 2017). It is relatively rich in protein, ranging from 8.4-19.4% of dry matter, depending on the cultivar, location, and year (CGIAR, 2009), but is gluten-free, and therefore considered an excellent solution for the increasing gluten-sensitive population worldwide (Baye, 2015). Teff has a good amino acid composition, with lysine (3.7% protein) and sulfuric amino acids levels (methionine 4.1% protein) higher than in wheat or barley (Bekele and Lester, 1981). Teff grains are also richer in iron (Fe), calcium (Ca), and copper (Cu) than other common cereals (Mengesha, 1966). In spite of its importance in Ethiopia, and its worldwide appreciation, teff nutrient requirements and its response to modern fertilizer sources have not yet been fully studied.

Soil fertility is a primary constraint affecting agricultural production in sub-Saharan Africa (SSA) (Sanchez *et al.*, 1997; Bationo *et al.*, 2007; Vanlauwe *et al.*, 2010; Guta *et al.*, 2014; Tadele, 2017). The scenario with regards to soil fertility and productivity in Ethiopia is similar to other neighboring eastern and central African countries that have high annual rates of nutrient depletion (Esilaba *et al.*, 2000). Three primary biophysical limitations, among others, that decrease agricultural production in Ethiopia are poor soil health, low soil fertility, and crop nutrient imbalances (Gete *et al.*, 2010). Core constraints in Ethiopian soils include depletion of soil organic matter due to widespread use of biomass as fuel, depletion of macro- and micronutrients, removal of top soil by erosion, change of soil physical properties, and increased soil salinity with time (Gete *et al.*, 2010).

More than five decades ago, nitrogen (N) and phosphorus (P) were identified as being the most deficient nutrients in the majority of Ethiopian agricultural soils. As a result, application of fertilizers containing N and P (urea and DAP) began in the late 1960s, which produced dramatic increases in the yields of several crops. Consequently, the use of urea and DAP have been by far the most widely adopted inputs by farmers (Haile and Mamo, 2013). Due to this long-term unbalanced fertilization practice, deficiency of other nutrients, mainly potassium (K), sulfur (S), zinc (Zn) and boron (B) started to become apparent (Astatke *et al.*, 2004; Haile and Mamo, 2013; EthioSIS, 2014). Based on recent findings by EthioSIS, the Ethiopian Ministry of

Agriculture (MoA) has recommended the use of a new type of blended or compound fertilizers: NPS, NPSB, NPSZn, NPSZnB. However, in spite of their significant positive response, Ethiopian farmers still lag far behind those of other developing countries in fertilizer consumption. Currently, only 40% of Ethiopian smallholder farmers use fertilizers, at average rates of less than 40 kg ha^{-1}, significantly below recommended rates (Feyera *et al.*, 2014). Furthermore, this MoA reform in fertilization policy has not yet addressed crop K requirements.

Potassium is one of the essential elements required by plants for their healthy growth and development (Marschner, 2011; Zörb *et al.*, 2014). It plays a very important role in the activation of enzymes, photosynthesis, starch synthesis, nitrate reduction and sugar degradation (Askegaard *et al.*, 2004). Potassium is the only nutrient that is not a constituent of organic structures. Its function is mainly in osmoregulation, the maintenance of electrochemical equilibria in cells and its compartments, and the regulation of enzyme activities (Hsiao and Laüchli, 1986). It also has a crucial role in the energy status of the plant, translocation and storage of assimilates, and maintenance of tissue water relations (Imas *et al.*, 1999). Thus, soil K deficiency may result in high susceptibility of crops to diseases, pests, frost, and drought, leading to poor development and, subsequently, to serious reduction in produce yield and quality (Umar and Moinuddin, 2002). Potassium deficient plants, especially small grains and maize, are prone to lodging (Hodges, 2010).

In Ethiopia, so far, there has been a general understanding that soils are rich in K, and K fertilizers have not been part of the fertilizer extension program, mostly based on the reports of the Freedom From Hunger Campaign, in which inconsistent crop response to K fertilizers were found. Murphy (1968), as well as other fragmented reports on exchangeable K analysis, brought evidence for high soil K values. Similar to the case with other macro- and micronutrients, until 1998, little has been known about the exact K status in Ethiopian soils (Mamo and Haque, 1988). However, cumulative findings (Astatke *et al.*, 2004; Haile and Mamo, 2013; EthioSIS, 2014) have reported that K deficiency is becoming a common phenomenon in wide areas in the country. Possible causes for the occurrence of K deficiencies in some Ethiopian highland soils are soil erosion and K leaching, caused by torrential rainfalls, deforestation, and continuous K mining through crop uptake (Haile, 2009). Recent findings from the national soil fertility mapping work (EthioSIS, 2014) have also proved that, in Tigray region, 58% of the agricultural land required K fertilization, while in the case of the Amhara National Regional State more than 90% of the agricultural lands require K fertilization (EthioSIS, 2014).

One of the major reasons for lack of K fertilizer recommendation on clay soils (Vertisols) is the fact that their exchangeable K analyses were often higher than the established critical levels. These results were assessed by the commonly employed ammonium acetate extraction method, or the Mehlich III multi-extractant (Astatke *et al.*, 2002). Recently, these methods were shown to significantly overestimate the available soil K phase. Furthermore, more accurate methods revealed that many Vertisol soils in Ethiopia exhibit very poor K availability (Kassahun, 2017). In a countrywide experiment, the contribution of a modest K application, 50 kg KCl ha^{-1}, gave rise to significant yield increases of teff and wheat, but this varied with site and soil properties (Mulugeta *et al.*, 2017). Under controlled fertigation, K application brought about significant increases in grain yields in potted plants as well as in field experiments (Gashu, 2017). Nevertheless, there is a substantial knowledge gap regarding teff K requirements and response to K fertilization in situ on Ethiopian arable Vertisols.

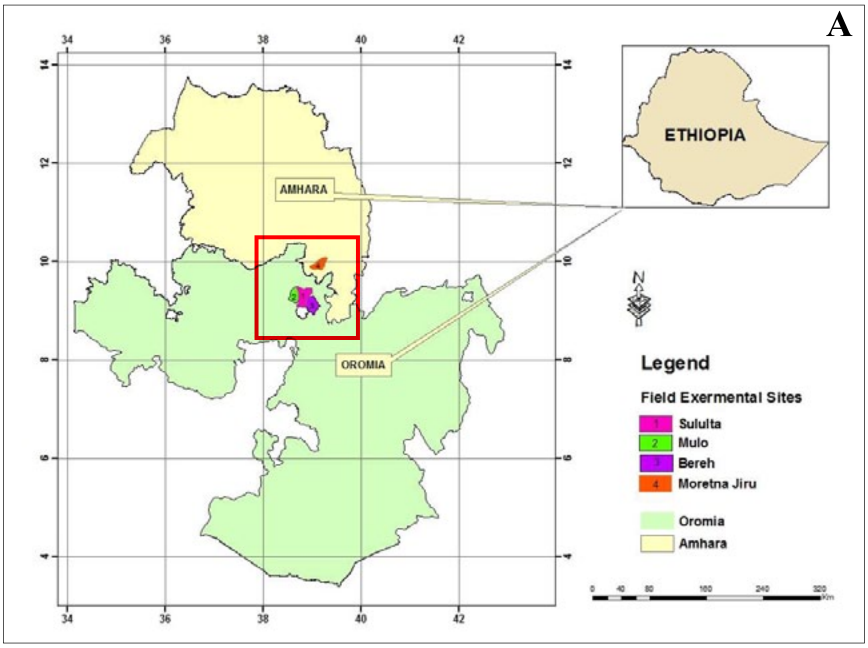
Photo 2. Soil surveying at the research site in Sululta woreda, Oromia region, Ethiopia, 50 km from Addis Ababa. Photo by the authors.

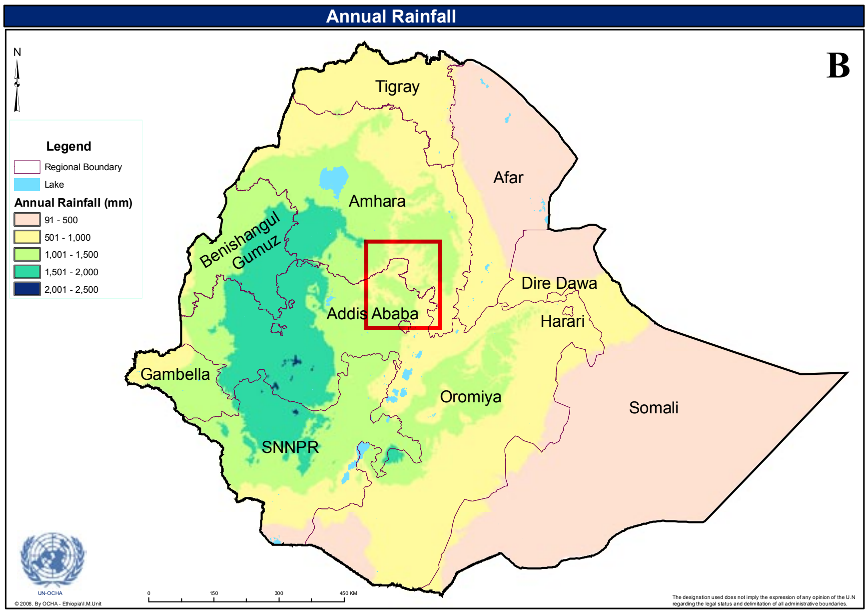
Photo 3. Threshing teff at the research site. Photo by the authors.

The specific objective of the present study was to characterize teff crop response to rising K application rates on Vertisols at field level, including crop performance, grain and straw yields, and macronutrient uptake. In general, the study is aimed to provide a basic K fertilization perception that will lead to practical recommendations for agricultural development officers and farmers, in order to enhance teff production in the Ethiopian Central Highlands, and to highlight future directions on aspects of soil K and nutrient stress research in Ethiopia.

Materials and methods

Field studies were conducted in three woredas of the central highlands of Oromia Regional State - namely Sululta, Mulo, Bereh - and in Moretena Jiru of Amhara Regional State, in Ethiopia. All four sites are located at close proximity to Addis Ababa or 195 km away (Moretena Jiru) (Map 1).





Map. 1. The experiment sites in Ethiopia (A); mean annual precipitation in Ethiopia (B). *Source:* UN Office for the Coordination of Humanitarian Affairs; https://reliefweb.int/map/ethiopia/ethiopia-annual-rainfall.

Altitude of all experiment sites is high, above 1,500 m a.s.l., with an average daily temperature range of 15-18°C and minimum temperature of 6-10°C with very rare frost events, and maximum temperature of 18-22°C. Annual precipitation ranges of 1,000-1,300 mm distributed between a relatively dry season from October to February, with 3-5 wet days and less than 40 mm per month; a rainy season during July-August, with 28 wet days and more than 250 mm a month; and intermediate seasons from March to June and in September, with 9-23 wet days and 50-100 mm a month, averagely (http://www.addis-ababa.climatemps.com/graph.php).

Soil was sampled at each site before fertilizer application. Surface soil (0-20 cm deep) was sampled in three replicates at each site and pooled together. The samples were air-dried, ground on a 2-mm sieve, thoroughly mixed and readied for physicochemical analysis. Soil pH was determined in H_2O using 1:2.5 soil to solution ratio; electrical conductivity was measured using a Hanna EC 215 conductivity meter. Soil available P and exchangeable basic cations (K, Na, Ca, and Mg) were extracted using the Mehlich-III procedure (Mehlich, 1984), after which an inductively coupled plasma (ICP) spectrometer was used to determine their concentrations. Soil N concentration was determined using the Kjeldahl method. Soils of all sites were characterized as Vertisol, Nitisol, and Cambisol with dominant clay texture (60-80%), slightly acidic (pH 6-6.7), and with very low to low nutrient availability (Table 1).

Table 1. Soil properties and climate conditions at the experimental sites.

Soil property	Units	Location			
		Sululta	Mulu	Bereh	Moretena Jiru
Sand	%	7.63	21.1	12.94	8.61
Silt	%	11.61	20.26	20.73	10.42
Clay	%	80.76	58.63	66.32	80.97
Textural class		Clay	Clay	Clay	Clay
pH (H_2O)		6.4	6.0	6.7	6.6
P	ppm	11.28	9.70	10.57	16.01
Total carbon	%	1.81	1.53	0.85	0.73
Total N	%	0.15	0.14	0.07	0.06
C:N ratio		11.9	11.2	12.9	12.8
EC_e	dS m^{-1}	0.13	0.11	0.11	0.2
Ca	$Cmol^{(+)}$ kg^{-1}	33.03	26.99	34.55	38.20
K	$Cmol^{(+)}$ kg^{-1}	0.76	1.22	1.02	0.70
Mg	$Cmol^{(+)}$ kg^{-1}	9.62	9.89	8.51	9.89
Na	$Cmol^{(+)}$ kg^{-1}	0.19	0.15	0.17	0.13
CEC	$Cmol^{(+)}$ kg^{-1}	54.93	51.94	55.00	61.36
K:Mg ratio		0.08	0.12	0.12	0.07
Region altitude	m a.s.l.	1,500-2,500	1,500-2,800	1,800-3,000	1,600-3,000
Mean annual rainfall	mm	1,000-1,200	1,200	1,300	1,200
Min/max temp.	ºC	10/18	8/20	6/20	9/22

Fertilizers used in all treatments were NPSZn [a granulated blend of N (12%), P_2O_5 (45%), sulfur (5%, sulphate origin), and zinc (1%)] and urea. Urea was used in a split application, 1/3 at sowing and 2/3 at the tillering stage. Nitrogen and P rates were 64 kg N ha^{-1} and 20 kg P_2O_5 ha^{-1}, according to MoA recommendations (Feyera *et al.*, 2014). Five K application rates (0, 30, 60, 90 and 120 kg K_2O ha^{-1}) were assigned to the plots. The experiment was laid out in a randomized complete block design (RCBD) with three replications. Teff cultivars used were Kuncho (at Sululta, Mulu, and Bereh) and Dega (at Moretena Jiru). Seeds were sown at a rate of 7 kg ha^{-1} in a plot size of 6 x 4 m with row spacing of 20 cm apart. The spacing between plots and blocks was 0.5 and 1 m, respectively. All cultural and agronomic practices were applied on each plot as per the recommendation for teff.

After planting, the fields were supervised weekly and parameters of crop performance were recorded at their optimum time. Plant height (cm) - from the ground level to the tip of the main panicle - and the main panicle length (cm) - from the base of the first panicle branch to the tip of the main panicle - were determined at physiological maturity as an average of 10 randomly selected mother plants within 1 m^2 of each plot. The number of fertile tillers was also counted and calculated in a similar way. At harvest, the aboveground biomass of 9 m^2 of each plot was weighed. After hand threshing, total grain and straw yields were determined and the harvest index calculated as the ratio between grain and total aboveground biomasses.

Grain and straw were then sampled, dried, ground to a fine powder, weighed and burnt to ash for 4 hours in an oven at 480ºC before chemical analyses of NPK. Phosphorus and K concentration in the biomass samples were analyzed using an ICP spectrometer and N concentration was determined using the Kjeldahl method. Total crop N, P and K uptakes were calculated from nutrient concentrations multiplied by the relevant grain or straw yield.

Crop performance and yield parameters, as well as nutrient concentrations, were subjected to ANOVA using SAS software (SAS, 2004) to detect variations among treatments. Where the ANOVA test was significant, further mean separation was carried out using least significant difference (LSD) method at 0.05 probability level.

Results

Crop performance and yield parameters

Potassium application had significant effects on most parameters of plant development and yield determinants, and was effective through the four regions (Table 2). Although small differences occurred in the mean plant height, it increased significantly under rising K application rates from 0-60 kg K_2O ha^{-1}, but remained stable under further increase in K rates. The mean number of fertile tillers produced by a plant rose steadily from 5.8-8.4 (45%) in response to the rising K rates from 0-90 kg K_2O ha^{-1}. Panicle length, another important yield determinant, was significantly responsive within a K rate range of 0-60 kg K_2O ha^{-1}, growing from 39.6-47.7 cm, while further K rate increases did not promote a response. Consequently, mean grain yield rose from 1.6-2.3 Mg ha^{-1} under K rates ranging from 0-90 kg K_2O ha^{-1}, with no further increases above this application rate. In contrast, straw yield response to K application rates was insignificant, although some tendency to increase could be noticed (Table 2). The mean harvest index rose substantially from 0.37 in the absence of K supply to 0.49 under K rates equal or higher than 60 kg K_2O ha^{-1}. The effect of K application on teff performance displayed significant differences between the experiment sites, as well as the different cultivar used at the Moretena Jiru (MJ) site (Table 2).

Specific and detailed information on the effects of K application rates on teff crop performance is given in Fig. 1. Differences in plant height between regions were insignificant, while its response pattern to the elevated K application rates was obvious, with significant increases up to 90 kg K_2O ha^{-1} and a tendency to slightly

Table 2. A two-way analysis of K fertilization experiments on teff crop in Ethiopia. The upper part demonstrate the effects of five K application rates, and the lower part shows the influence of the four experiment sites on mean plant height, fertile tiller production, panicle length, grain and straw yields, and harvest index.

	Plant height	Fertile tillers	Panicle length	Grain yield	Straw yield	Harvest index
	cm	*plant^{-1}*	*cm*	---------*kg ha^{-1}*----------		
K rates (kg K_2O ha^{-1})						
0	93.7c	5.8c	39.6c	1.6c	4.0	0.37c
30	95.4cb	5.9bc	42.5b	2.0b	4.4	0.45b
60	96.3ab	7.1b	47.7a	2.2ab	4.5	0.49a
90	99.8a	8.4a	48.1a	2.3a	4.7	0.49a
120	98.2a	8.3a	48.0a	2.4a	4.6	0.49a
CV (%)	14.9	4.8	3.6	5.2	2.34	0.3
LSD (5%)	2.5	0.79	1.9	0.21	0.7	0.02
Location						
SU	97.0ab	7.5a	39.1d	1.7b	4.4c	0.42b
MU	97.5a	6.1c	42.4c	1.9b	4.7bc	0.42b
BR	96.9ab	7.1a	45.2b	1.8b	5.0b	0.41b
MJ	95.4b	6.8b	51.2a	2.8a	6.0a	0.51a
CV (%)	13.2	5.5	5.1	6.3	1.6	1.3
LSD (5%)	1.9	0.41	2.3	1.0	0.5	0.06

Note: Similar letters within a column of each part indicate no significant differences at 5%. The different Ethiopian regions of the experiment sites: Sululta (SU); Mulu (MU); Bereh (BR); and Moretena Jiru (MJ). CV: Covariance; LSD: Least Significant Difference.

decline under the highest K rate. Plant height at Moretena Jiru fluctuated substantially compared to the other locations (Fig. 1A).

Similar to plant height, the production of fertile tillers did not differ between locations, while the effect of K rate was very significant and stable up to 90 kg K_2O ha^{-1}. Tiller production increased under a further rise in K rate only at Moretena Jiru (Fig. 1B). In contrast, panicle length differed significantly between locations (Fig. 1C). The shortest panicles and the weakest response to K rate was observed at Sululta. In the other three sites, panicle length was similar under no K application, about 43-44 cm. Potassium application resulted in different response patterns at the low rate of 30 kg K_2O ha^{-1}. However, as K rates rose, panicle length increased, being somewhat greater at Bereh than at Mulu, and significantly greater at Moretena Jiru, reaching a maximum of 53.3 cm already under 60 kg K_2O ha^{-1} (Fig. 1C).

Grain yield was remarkably higher at Moretena Jiru, while no significant differences occurred between the other regions (Fig. 1D). While steadily increasing with the rising K rates at Sululta and Mulu, grain yield at Bereh climbed to a maximum at 60 kg K_2O ha^{-1} and declined with further rises in K rates. At Moretena Jiru, however, grain yield peaked already at 30 kg K_2O ha^{-1} and remained stably high, at about 3 Mg ha^{-1}. The highest relative yield increase was obtained at Mulu at 120 kg K_2O ha^{-1} - 130% above control. At the other regions, the highest relative yield increases were 82, 50, and 30%, at Sululta, Bereh, and Moretena Jiru, respectively.

Straw yield was also much higher at Moretena Jiru, with no significant differences between the other sites (Fig. 1E). In spite of a tendency to increase in response to elevated K rates, this effect was rather weak, fluctuating, and insignificant. In contrast,

Photo 4. Inspecting teff deficiency symptoms at CFPN, Gilat, Israel. Photo by the authors.

Photo 5. International researchers and private sector delegates visiting the teff experiment at CFPN, Gilat, Israel. Photo by E. Sokolowski.

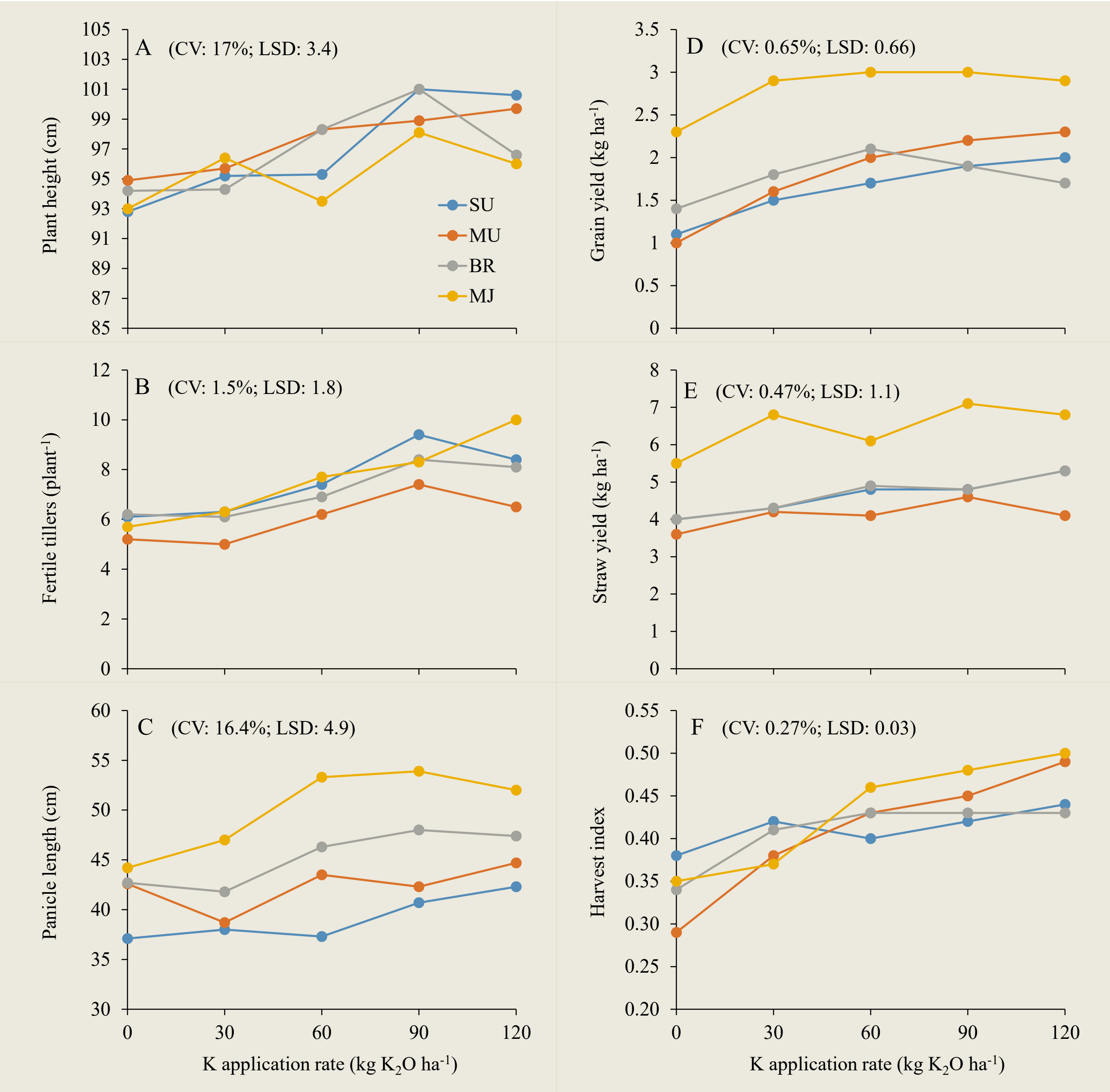


Fig. 1. Effects of K application rate on teff plant height (A), number of fertile tillers (B), panicle length (C), grain yield (D), straw yield (E), and harvest index (F). Significance of differences among treatments and locations are indicated by CV and LSD (5%) values. Experiment sites were Sululta (SU), Mulu (MU), Bereh (BR), and Moretena Jiru (MJ).

harvest index was extensively influenced by the K application rates, excluding Sululta, where it fluctuated within a narrow range (Fig. 1F). At Bereh, harvest index rose drastically from 0.34 under no K supply to 0.41 at 30 kg K_2O ha^{-1} and ranged from 0.41-0.43 with higher K rates. At Mulu, where harvest index was the lowest under no K supply (0.29), it up surged to 0.43 at 60 kg K_2O ha^{-1} and continued to increase up to 0.49 at 120 kg K_2O ha^{-1}. A significant harvest index climb was also obtained at Moretena Jiru, where it steadily rose from 0.35 in the absence of K fertilizer to 0.50 at the highest K rate (Fig. 1F).

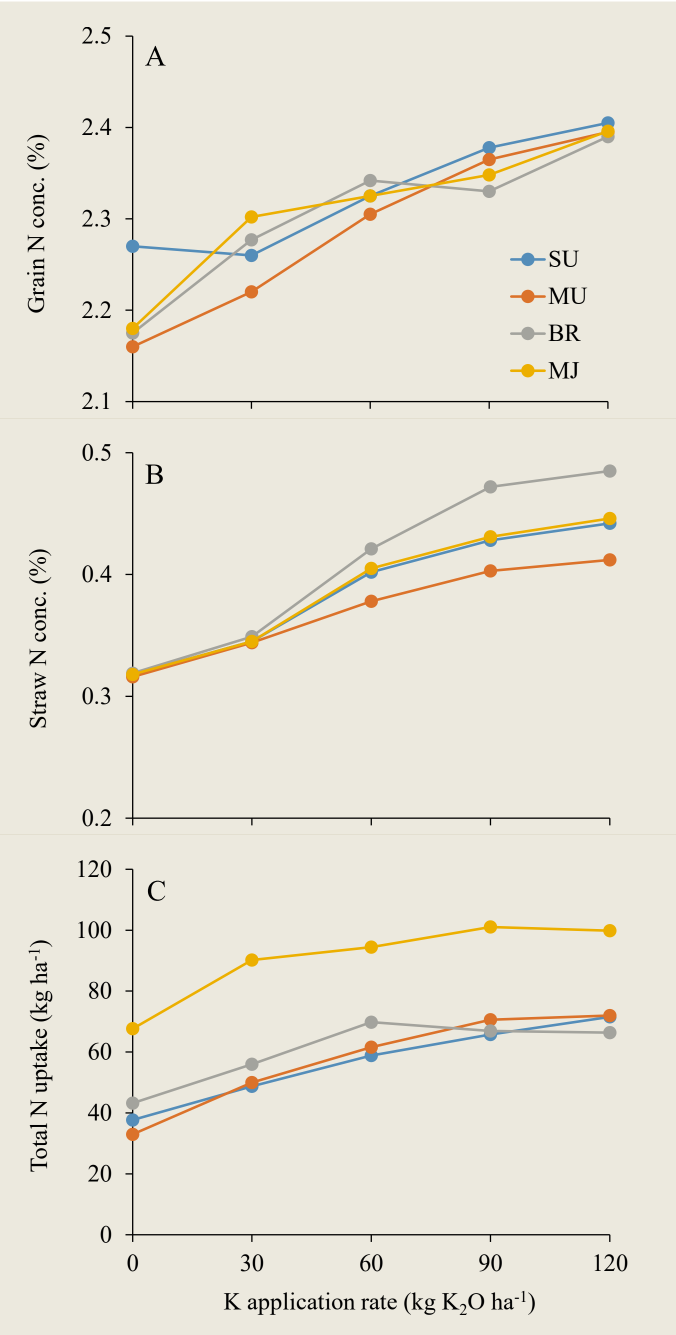


Fig. 2. Effects of K application rate on N concentration in teff grains (A), straw (B), and on total N uptake by teff crop (C). Experiment sites were Sululta (SU), Mulu (MU), Bereh (BR), and Moretena Jiru (MJ).

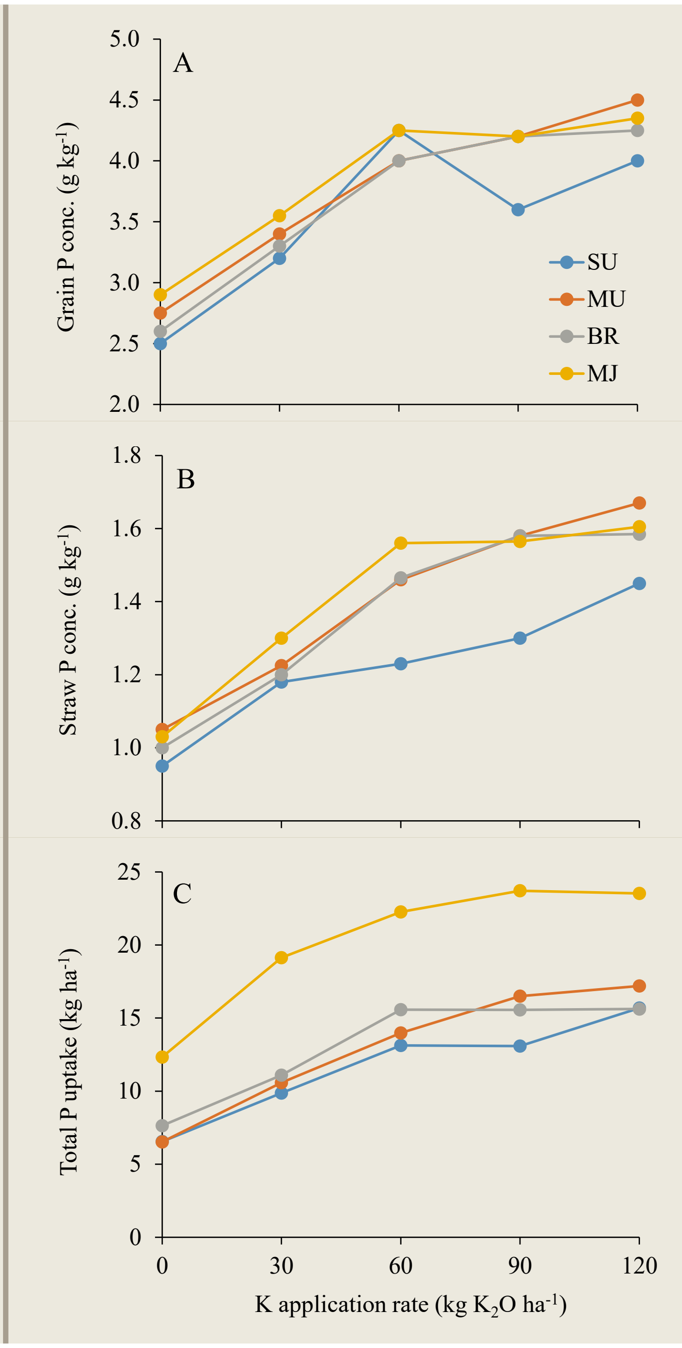


Fig. 3. Effects of K application rate on P concentration in teff grains (A), straw (B), and on total P uptake by teff crop (C). Experiment sites were Sululta (SU), Mulu (MU), Bereh (BR), and Moretena Jiru (MJ).

Effects of K application on plant N concentrations and uptake

The increasing K application rates brought about a significant rise in grain N concentration (Fig. 2A). This effect was quite similar in all experimental sites, where grain N concentration rose steadily from 2.17% in the absence of K supply up to 2.4% at the highest K rate. Straw N concentration was generally 5-fold lower than that of grain N concentration and this increased significantly in response to the elevated K application rate (Fig. 2B). However, the response of straw N concentration to K rates differed substantially between regions; Bereh had the

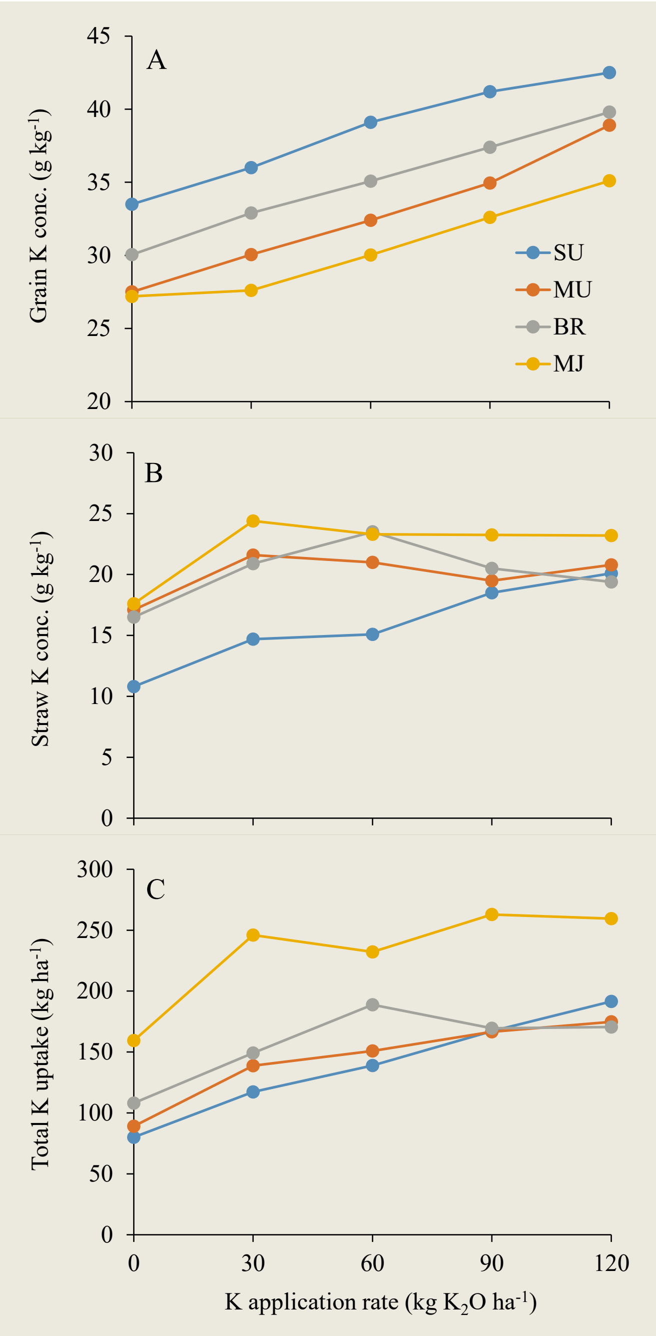


Fig. 4. Effects of K application rate on K concentration in teff grains (A), straw (B), and on total K uptake by teff crop (C). Experiment sites were Sululta (SU), Mulu (MU), Bereh (BR), and Moretena Jiru (MJ).

greatest, Mulu had the lowest, while intermediate responses were obtained at Moretena Jiru and Sululta. The consequent crop N uptake was significantly greater at Moretena Jiru, rising from 67 to 101 kg N ha^{-1} under K rates increasing from 0 to 90 kg K_2O ha^{-1}, respectively (Fig. 2C). Crop N uptake did not differ significantly between the other three regions. Nevertheless, it consistently increased with the rising K rates from about 35 to 72 kg N ha^{-1} at Mulu and Sululta, while at Bereh, crop N uptake peaked at 70 kg N ha^{-1} at 60 kg K_2O ha^{-1} but slightly decreased with further K rate increase.

Effects of K application on plant P concentrations and uptake

Potassium supply also had significant effects on crop P concentration and uptake (Fig. 3). Grain P concentration surged up from the range of 2.5-3 g kg^{-1} under no K supply to about 4-4.25 g kg^{-1} at 60 kg K_2O ha^{-1}, above which it declined (Sululta), remained stable (Moretena Jiru), or slightly rose (Bereh and Mulu) with further increases in K rates (Fig. 3A). Straw P concentrations under no K supply ranged from 0.95-1.05 g kg^{-1} and, excluding Sululta, significantly rose to 1.45-1.56 g kg^{-1} at 60 kg K_2O ha^{-1} (Fig. 3B). Straw P concentration continued to rise at Mulu as K rates increased, while remaining constant at Moretena Jiru, or continued to rise at 90 kg K_2O ha^{-1} at Bereh and then stabilized under the highest K rate. At Sululta, the rise in straw P concentration was significant but equal to that exhibited in the other regions between 0-30 kg K_2O ha^{-1}. However, above this rate and up to 90 kg K_2O ha^{-1} it rose much less, and then, at the highest K rate, it rose further than in the other regions (Fig. 3B).

Subsequently, K application rates had very significant effects on crop P uptake (Fig. 3C). The most dramatic effect was observed at Moretena Jiru, where crop P uptake doubled, from 12 to 24 kg P_2O_5 ha^{-1} between 0 and 90 kg K_2O ha^{-1}, respectively. At the other sites, crop P uptake was about 7 kg P_2O_5 ha^{-1} under no K supply, rose consistently to 13-15.5 kg P_2O_5 ha^{-1} at 60 kg K_2O ha^{-1}, and slightly increased (Sululta and Mulu) or remained stable (Bereh) under higher K rates (Fig. 3C).

Effects of K application on plant K concentrations and uptake

Grain K concentration increased significantly at a similar rate in all sites in response to elevated application of the nutrient (Fig. 4A). However, the values differed considerably between sites, being highest at Sululta, and lowest at Moretena Jiru. In contrast, straw K concentration only responded to the first step in K application rate (30 kg K_2O ha^{-1}) at all sites apart from Sululta, (Fig. 4B). Under higher K application rates, straw K concentration remained stable or even slightly declined. At Sululta, where the initial straw K concentration was much lower than at the other sites, it increased consistently with the rising K application rates. Potassium uptake rates increased steadily at Sululta and Mulu, beginning at 80 and 90 kg ha^{-1} under no K application, and ending at 190 and 170 kg ha^{-1} at the highest K application rate, respectively (Fig. 4C). At Bereh, maximum K uptake (190 kg ha^{-1}) was reached at 60 kg K_2O ha^{-1}, above which it slightly declined. This pattern was also observed at Moretena Jiru but with significantly higher rates of K uptake, reaching up to 250 kg ha^{-1} (Fig. 4C).

Economic analysis

Economic analysis carried out in the four regions revealed that Moretena Jiru, with the cultivar Dega, was the most profitable teff production site, with net return ranging from 50,000-62,000 ETB ha^{-1} (Fig. 5A). At Sululta and Mulu, the net return was much lower, ranging between 23,000-28,000 and 45,000 ETB ha^{-1}, under no K application and 120 kg K_2O ha^{-1}, respectively. Interestingly, at Bereh, the net return climbed from 33,000 under no K application up to 47,000 ETB ha^{-1} under 60 kg K_2O ha^{-1}, but it clearly declined with further elevation of the K application rate (Fig. 5A). The marginal profit, a parameter which focuses on the contribution of each K rate increment to the net profit, clarifies the incentive for farmers at each site to choose the appropriate K input (Fig. 5B). It clearly shows that the economically appropriate K rate is significantly different for each site. While at Moretena Jiru, the K rate upper threshold appears quite low, 30 kg K_2O ha^{-1}, it rises to 60, 90, and even 120 K_2O ha^{-1}, at Bereh, Mulu, and Sululta, respectively. It also appears that supplying K to teff crops is most cost effective at Mulu, with a maximum marginal profit of 22,000 ETB ha^{-1}, compared to 18,000 at Sululta, and to about 14,000 ETB ha^{-1} at Moretena Jiru and Bereh (Fig. 5B).

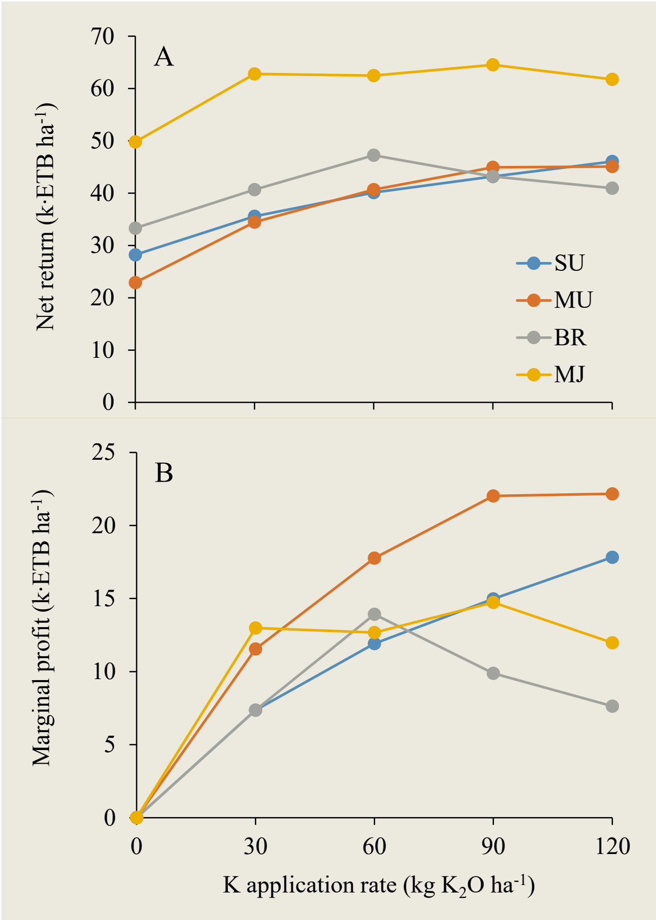


Fig. 5. Net return (A), and marginal net profit (B) calculated for teff response to K application rates on Vertisols in the Central Highlands of Ethiopia. Experiment sites were Sululta (SU), Mulu (MU), Bereh (BR), and Moretena Jiru (MJ).

Discussion

Overall, teff displayed significant positive responses to the rising K application rates, with an average optimum ranging from 60-90 kg K_2O ha^{-1} (Table 2). The response to K included general growth parameters such as plant height, but it was particularly significant in yield determinants - the number of fertile tillers and panicle length. These results are in agreement with earlier studies that described K significance to cereals' productivity (Fageria, 2007; Pettigrew, 2008; Verma and Ali, 2017) and particularly in teff (Fayera *et al.*, 2014; Gashu, 2017). Nevertheless, the most striking results are associated with the influence of K application dose on N and P concentration in the grain and the straw, which increased significantly (Figs. 2, 3, and 4). These results provide strong indications that soil K availability is a substantial limiting factor in teff development on Ethiopian Vertisols.

Beyond K's pivotal role in the maintenance of the plant water status, photosynthesis and carbon allocation, and in general crop performance, it has a significant positive effect on the development of the root system (Pettigrew, 2008). Potassium deficiency impairs both lateral root initiation and development (Armengaud *et al.*, 2004; Shin and Schachtman, 2004). It also seems to have a depressive effect on primary root growth (Gruber *et al.*, 2013; Kim *et al.*, 2010; Rengel and Damon, 2008). In rice, K deficiency decreased root growth and root-to-shoot ratio by reducing soluble sugar content in the roots (Cai *et al.*, 2012). Evidence for improved root establishment in response to elevated K rate was recently brought in a potted teff experiment under fertigation (Gashu, 2017). If an adequate K supply indeed supports a significantly larger root system, it can explain the higher concentrations and uptake of other macronutrients. Moreover, higher N and P uptake promotes further plant growth and development, which in turn demands more K, and so on. This feed-forward process would come to an end once a new limiting factor occurs. In the present study, the annual N application dose of 64 kg ha^{-1} seems to limit teff production at Sululta, Mulu, and Bereh under K doses greater than 60 kg K_2O ha^{-1}, while at Moretena Jiru, the sources of N are unclear, as N uptake exceeded 100 kg ha^{-1} (Fig. 2C).

While P limitation may be of some concern at Moretena Jiru only (Fig. 3C), K uptake unconditionally and by far exceeded K application doses at all sites (Fig. 4C). This result may suggest that teff plants can acquire considerable amounts from the exchangeable and non-exchangeable K phases in the clay minerals. However, these K resources are not endless and must be replenished through adequate fertilization. The exact dose for sustainable cropping management should be determined according to an in-depth analysis of the clay minerals at each site to determine the K distribution along the availability chain:

available (soluble); exchangeable; non-exchangeable; and, mineral phases, and to crop requirements (Askegraad *et al.*, 2004; Firmano *et al.*, 2017).

In spite of the clear and straightforward effects of K application rates on teff productivity, there were significant differences between the experiment sites (Table 2). Crop performance and yields were much higher at Moretena Jiru, compared to those obtained at Sululta, Mulu, or Bereh. This difference may be primarily attributed to the teff cultivar, Dega, which was employed at Moretena Jiru, in contrast to 'Konchu', the cultivar used at the other sites. While no additional information is available on specific differences between these two cultivars, the genetic diversity in teff is huge (Assefa *et al.*, 2015), hence significant differences in productivity, as well as in other traits, would be largely expected (Tefera and Ketema, 1990; Mebratu *et al.*, 2017; Paff and Asseng, 2018).

Having no information regarding exceptional weather events during the cropping season and given that climate conditions are quite similar at Sululta, Mulu, and Bereh, the differences between these three sites that occurred in teff performance and its response to K application (Table 2) can be attributed mainly to some dissimilarities in their soil properties (Table 1). However, it would be difficult to point to specific soil traits. Teff crops at Sululta and Mulu were highly responsive to the rising K rates, and further K rate increase could have resulted in even higher yields (Fig. 1). This was despite of the significant difference between the two sites in their soil texture: 58 and 80% clay, at Mulu and Sululta, respectively. On the other hand, at Bereh, with an intermediate clay proportion (66%), K application rates greater than 60 kg K_2O ha^{-1} did not bring about any further yield increases (Fig. 1). While no momentous differences between the other determined soil properties were observed (Table 1), these results suggest that an answer might rest in the mineral composition of the local clay and its interaction with K ions. Also, the K application regime, which was not addressed in the present study, may require a special assessment in order to provide optimum nutrient availability during crop development.

The different response patterns between sites were strongly reflected in the economic analyses carried out to elucidate a site-suitable K rate for teff production (Fig. 5). Thus, under the circumstances of the present study (weather conditions, cultivars, current fertilizer costs and local produce prices), Mulu appears the most cost effective site for K inputs. Second best would be Sululta, where a clear upper threshold of K application rates has not been reached. In contrast, the upper K rate that is still profitable at Moretena Jiru was 30 kg K_2O ha^{-1}, and 60 K_2O ha^{-1} at Bereh, where further increases in K rates significantly reduced the profit.

It can be unequivocally concluded, that K supply is necessary to obtain reasonable teff yields on Vertisols of the Ethiopian Central Highland, as it improves all crop performance parameters. In these soils, soil K availability is definitely a limiting factor, the removal of which brings about new horizons for teff productivity. Under the higher levels of K application rate, the recommended N and P rates might become restrictive, requiring some reassessment. However, due to significant divergence in soil properties and other environmental conditions among and within regions, site specific recommendations of fertilizer practices, for teff, or other crop species, must be founded on thorough local soil tests.

Acknowledgements

This article is dedicated to the memory of Prof. Tekalign Mamo, who was the author's MSc. chief-advisor and unfortunately passed away before the study was completed. The authors thank Dr. Kidmanu and Mr. Sokolowski for their important advice, and MoANR staff for their assistance. The study was financially supported by ATA Ethiopia, IPI Switzerland, CASCAPE Ethiopia and OCP Morocco.

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Regional activities/sub-Saharan Africa/Ethiopia

Research Findings

Photo by the authors.

Effect of Different Potassium and Sulfur Fertilizers on Onion (*Allium cepa* L.) Yield and Quality

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Abstract

Onion (*Allium cepa* L.) is the most widely cultivated species of the genus Allium. It is rich in many essential nutrients and sulfur (S)-containing compounds considered important for human health. While potassium's (K) role in plant nutrition is well established, K fertilization practices still suffer from low agronomic efficiency. Recently, crop S requirements have gained special attention, particularly in Allium species. Polyhalite is a sedimentary marine mineral, consisting of a hydrated sulfate of K, calcium (Ca) and magnesium (Mg) at rates of 14, 48, 6, and 17% of K_2O, SO_3, MgO, and CaO, respectively. The objective of this study was to compare the effects of polyhalite, potassium sulphate (SOP), and potassium chloride (MOP) fertilizers on onion bulb yield, nutrient uptake, and on bulb quality properties. An equal dose of 270 kg K_2O ha^{-1} was applied as MOP, SOP, polyhalite, and a mixture of polyhalite and SOP, and these were compared against a control which applied nitrogen (N) and phosphorus (P) fertilizers.

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While MOP increased bulb size and yield by 28%, S fertilizers contributed additional yield increases ranging from 12 to 22% compared to the control. The major effect of all of the fertilizers was that they improved K availability during the onion crop cycle. Polyhalite application resulted in the highest yield, probably due to its slow-release character, providing constant soil K availability throughout the crop cycle. High rates of S application did not correlate with high yield or quality. While polyhalite's advantageous agronomic efficiency was obvious, suitable rates of application remain subject to economic considerations.

Keywords: Allium cepa L.; bioactive compounds; MOP; nutrient uptake; organosulfur compounds; polyhalite; SOP.

Introduction

Onion (*Allium cepa* L.), the most widely cultivated vegetable species of the genus Allium, is pivotal to many cuisines worldwide. About 170 countries cultivate onions for domestic use or trade. In 2016, the global area cultivated with onion was about 5 million ha, which produced 93 million Mg, with a calculated average yield of 18 Mg ha^{-1} (FAOSTAT, 2016). Among the world's greatest onion producers, China, India, and the US are the leading countries, while Turkey is the sixth with production of 2.1 million Mg and an average yield of 32 Mg ha^{-1}.

Onion is often consumed raw, but it is predominantly used to add a unique and highly appreciated flavor to cooked food, as well as its closely related species – garlic and leek (Block, 1995). Onion bulbs contain 89% water but are rich in many essential nutrients and compounds like biotin, vitamin C, quercetin, and antioxidants (Koca *et al.*, 2015; Insani *et al.*, 2016; Lisanti *et al.*, 2016). Nevertheless, sulfur (S)-containing compounds found in the Allium family have been the focus of much research interest during the last few decades (Randle *et al.*, 1995; Ramirez *et al.*, 2017). Recently, more attention has been given to the health attributes associated with onion consumption, which include diabetes prevention, skin health, an improved immune system, lowering of blood pressure and cholesterols, anti-inflammatory disease activity, stress relief, and anti-cancer properties (Nicastro *et al.*, 2015; Suleria *et al.*, 2015; Fujiwara *et al.*, 2016; Insani *et al.*, 2016; Chu *et al.*, 2017).

While the pivotal role of potassium (K) in plant nutrition and crop development and yield is well-established (Marschner, 1995), the agronomic efficiency of K fertilizer application is very low in many crops and countries (Zörb *et al.*, 2014). To resolve this problem, the ability of farmers to accurately select the appropriate fertilizer and deliver the required K dose at the proper time during the crop cycle, must be improved. Excess K application at an early crop developmental stage followed by K deficiency at later stages is a recurrent problem worldwide, due to the common practice of full-dose pre-planting application.

Plant sulfur requirements have gained special attention in the last few decades due to the dramatic reduction in atmospheric S-pollutants that caused S deficiency symptoms in many crop species (Haneklaus *et al.*, 2006). Sulfur is essential to protein production in all plant species (Brosnan and Brosnan, 2006). In crop species producing appreciated secondary metabolites containing S, such as Brassicaceae and Allium, achieving optimal S application is particularly important (McGrath and Zhao, 1996; Lancaster *et al.*, 2001; Al-Fraihat, 2009; Garg *et al.*, 2018). Sulfur is available to plants only as sulfate (Haneklaus *et al.*, 2006), hence most S fertilizers consist of sulfate salts, such as gypsum ($CaSO_4{\cdot}2H_2O$), sulfate of potassium (SOP, K_2SO_4), ammonium sulfate, or various phosphor-sulfates.

Polysulphate™ (produced by Cleveland Potash Ltd., UK) is the trade mark of the natural mineral 'polyhalite', which occurs in sedimentary marine evaporates, consisting of a hydrated sulfate of K, calcium (Ca) and magnesium (Mg) with the formula: $K_2Ca_2Mg(SO_4)_4{\cdot}2(H_2O)$. The deposits found in Yorkshire, in the UK, typically consist of K_2O: 14%, SO_3: 48%, MgO: 6%, CaO: 17%. As a fertilizer providing four key plant nutrients – S, K, Mg, and Ca – polyhalite may offer attractive solutions to crop nutrition. In addition, polyhalite releases the nutrients considerably slower than other S-containing fertilizers, which may also be significant for soil K availability.

The objective of this study was to compare the effects of polyhalite, potassium sulphate (SOP), and potassium chloride (KCl, MOP) fertilizers on onion bulb yield, nutrient uptake, and on bulb quality properties.

Materials and methods

The experiment was carried out in the Antalya region of Turkey (Map 1) on slightly alkaline, K-poor sandy-loam soil (Table 1).

Photo 2. Experimental onion field under preparation. Photo by the authors.

Map. 1. The experiment site in Antalya, Turkey. *Source:* Google Maps.

Onion was sown in a nursery early in September 2016, transplanted on 1 November, and harvested as bulbs on 24 May 2017. Irrigation was practiced when necessary and all the other agricultural practices were carried out on time. Nitrogen (N)-phosphorus (P)-K fertilization was carried out pre-planting according to soil nutrient status (Table 1) and onion crop requirements for a target yield, as follows: 200 kg N ha^{-1}, 170 kg P_2O_5 ha^{-1}, and 270 kg K_2O ha^{-1}. Di ammonium phosphate (DAP) and urea were supplied as N and P fertilizers, while MOP (KCl), SOP (K_2SO_4), or polyhalite were examined as the K donors. Sulfur was provided through SOP or polyhalite, in accordance with the treatments. A detailed description of the five treatments included in the experiment is given in Table 2.

The experiment layout was a randomized block design with four replications. Just prior to bulb initiation, the recommended leaf sampling time for onion, leaf macronutrients (N, P, K, Ca, Mg and S [%]) and essential micronutrients (iron [Fe], zinc [Zn], manganese [Mn], and copper [Cu] [mg kg^{-1}]) were determined. At harvest, measurements including bulb yield (kg ha^{-1}), bulb weight (g), and economic evaluation were taken. Total soluble solids (TSS, %), total phenol (mg kg^{-1}), vitamin C (mg 100 g^{-1}), and antioxidant activity (%) were determined as onion quality indicators.

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

Soil property		
pH (1:2.5)	8.2	Slightly alkaline
$CaCO_3$ (%)	19.9	High
EC (micromhos cm^{-1}) (25°C)	89	No salinity
Sand (%)	61	
Clay (%)	11	Sandy loam
Silt (%)	28	
Organic matter (%)	2.1	Medium
Phosphorus (mg kg^{-1})	5	Poor
Potassium (mg kg^{-1})	58	Poor
Calcium (mg kg^{-1})	2,631	Medium
Magnesium (mg kg^{-1})	102	Medium
Iron (mg kg^{-1})	7.6	High
Manganese (mg kg^{-1})	5.8	Sufficient
Zinc (mg kg^{-1})	0.2	Insufficient
Copper (mg kg^{-1})	0.8	Sufficient

Following harvest, plant macro- and essential micronutrient concentrations were determined according to Mills and Jones (1996) and crop nutrient uptake was calculated. The effects of different fertilizers on the above given parameters were statistically analyzed using ANOVA. The correlations between essential plant nutrients at bulb initiation and quality parameters were determined.

Results

Fertilizer treatments significantly affected bulb size (Fig. 1A). Polyhalite, when applied as the only K donor, brought about the largest mean bulb size, 359 g. Bulb weight under SOP was insignificantly smaller, and declined further under the mixed SOP + polyhalite treatment. KCl (MOP) treatment gave rise to a considerably smaller average bulb size, 309 g, which was still significantly larger than that of the control. Since planting density was similar in all treatments, bulb size had a clear consequent effect on the yield (Fig. 1B) with the same order: polyhalite > SOP + polyhalite > KCl > Control, while under SOP yield did not differ significantly from that of polyhalite or the combined fertilizers treatment.

Table 2. A detailed description of the five fertilization treatments employed.

Treatment	N	P_2O_5	K_2O	S	Notes
	--------------	*kg ha^{-1}*	--------------		
Control	200	170	0	0	
KCl (MOP)	200	170	270	0	443 kg MOP ha^{-1}
K_2SO_4 (SOP)	200	170	270	97	540 kg SOP ha^{-1}
Polyhalite	200	170	270	370	1,928 kg polyhalite ha^{-1}
K_2SO_4 + polyhalite (1:1)	200	170	270	234	270 + 964, kg ha^{-1} of SOP + polyhalite, respectively

Bulb quality properties were also significantly influenced by the fertilizer treatments (Fig. 2). SOP and polyhalite - each fertilizer applied on its own - had the highest TSS values, 7.80-7.95%, and

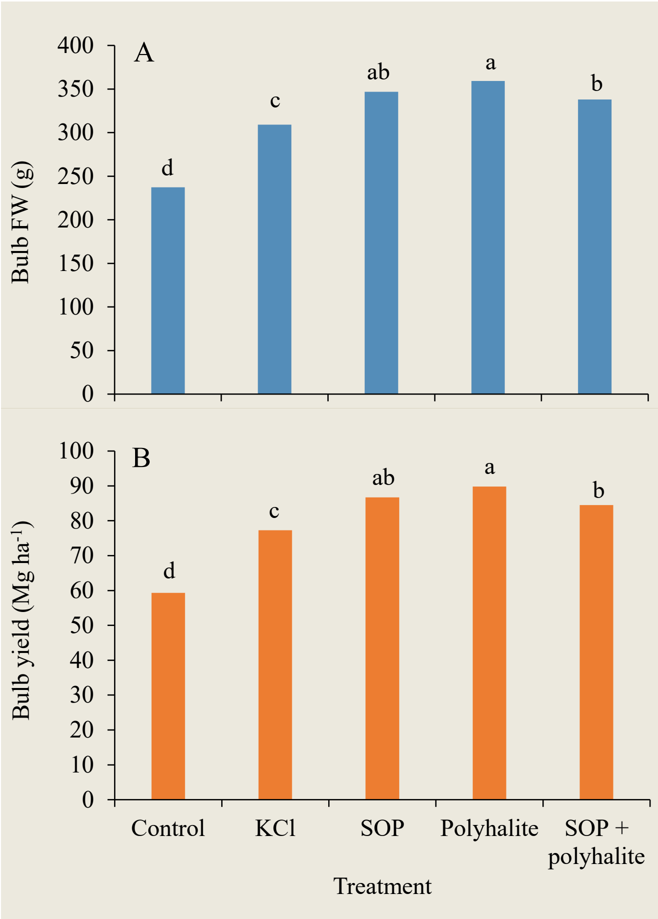

Fig. 1. Effects of different K and S fertilizers on onion bulb fresh weight (A) and on onion yield (B). Similar letters indicate no significant differences at $P < 0.01$.

Photo 3. Effect of different potassium fertilizers on onion plants. Photo by the authors.

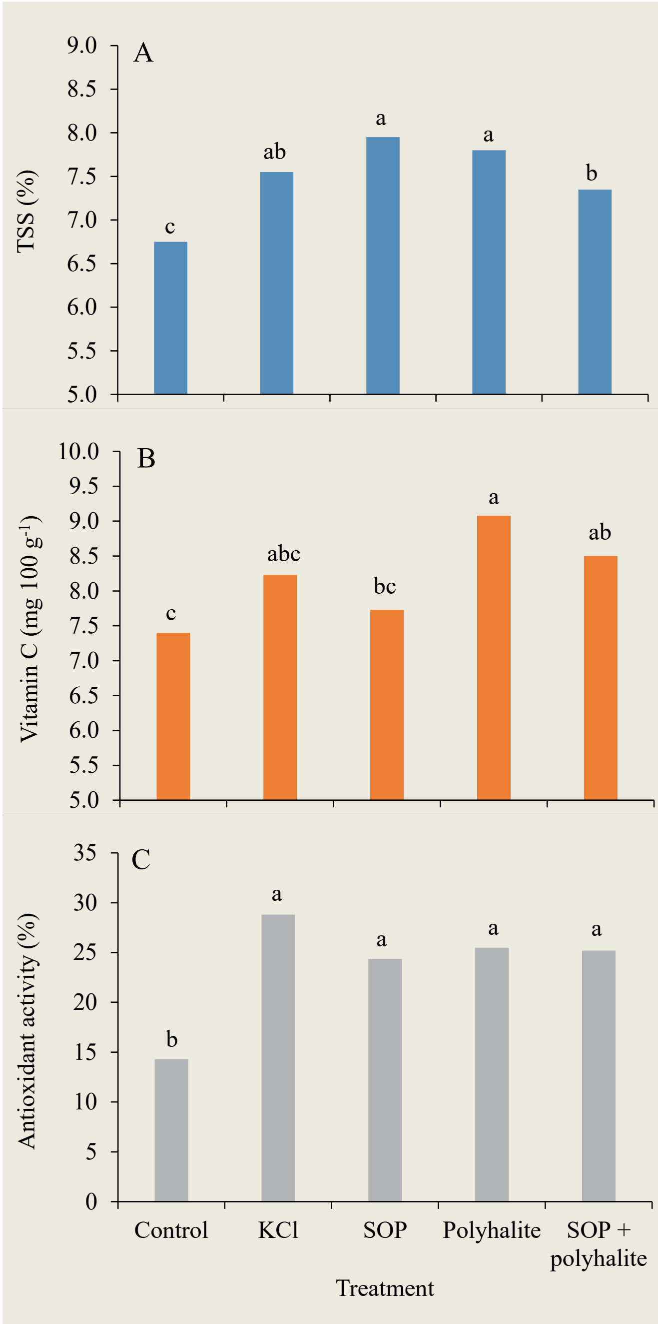

Fig. 2. Effects of different K and S fertilizers on onion bulb TSS (A), vitamin C content (B), and antioxidant activity (C). Similar letters indicate no significant differences at $P < 0.01$ for TSS and antioxidant activity, and at $P < 0.05$ for vitamin C content.

were significantly higher than in the combined treatment and far better than that of the control. KCl had an intermediate TSS, significantly higher than the control, but statistically it could not be distinguished from the other treatments (Fig. 2A). Total phenols content ranged from 160 to 190 mg kg^{-1} bulbs and was unaffected by the fertilizers. Vitamin C, on the contrary, displayed the highest content in bulbs grown under polyhalite, 9.08 mg 100 g^{-1}, significantly higher than SOP and the control, but was not significantly different from the bulb vitamin C contents under KCl or mixed SOP + polyhalite (Fig. 2B).

Antioxidant activity in the bulbs was significantly lower in the control, 14.3%, and ranged from 24 to 29% among the other treatments, displaying no significant differences (Fig. 2C).

Leaf K content prior to bulb initiation was significantly higher in the four treatments supplied with K fertilizers, compared to the control (Table 3). Among these treatments, leaf K content in the mixed SOP and polyhalite applications was significantly higher than in KCl-supplied plants, while those of SOP or polyhalite alone had intermediate values. Leaf S content just prior to bulb initiation was significantly higher in plants supplied with S fertilizers, compared to KCl-supplied plants or the control. Interestingly, the latter treatments also differed significantly in leaf S content, although both were not supplied with S fertilizers (Table 3). Leaf content of the other macro- and micronutrients were unaffected by the fertilizer treatments. Phosphorus and Ca among the macronutrients, and Zn, Mn, and Cu among the micronutrients were above the values recommended by Maynard and Hochmuth (1996).

At harvest, bulb macronutrient concentrations, excluding Ca and Mg, differed significantly between treatments (Table 4). Bulb N concentrations were higher under MOP or SOP and declined in the other treatments, but although being significant, these differences were limited to a narrow range, 2-2.3%. Bulb P concentrations were considerably higher, ranging from 0.6 to 0.7%, with slight yet significant differences between treatments. Bulb K concentration at harvest was strongly influenced by the fertilizer treatments, being significantly higher in all K-applied plants compared to the control (Table 4). Among these treatments, polyhalite had the highest bulb K concentration, SOP had slightly lower values, while bulb K concentrations of the KCl and the mixed fertilizer treatments were significantly smaller. Polyhalite treatment also exhibited the highest bulb S concentration, which significantly differed from those of SOP and the mixed fertilizer treatments. Bulb S concentration of KCl applied plants was significantly lower than all of the other treatments, except the control which displayed the lowest S levels (Table 4). Bulb Fe concentration at harvest did not differ among treatments, however, values were considerably higher than in the leaves at bulb initiation (Tables 3 and 4). Also, bulb Mn and Cu did not differ among treatments and did not change from bulb initiation to harvest. Bulb Zn, on the other hand, was significantly lower in S-applied plants (Table 4).

Table 3. Macro- and micronutrients in onion leaves just prior to bulb initiation.

Treatment	Macronutrient						Micronutrient			
	N	P	K	Ca	Mg	S	Fe	Zn	Mn	Cu
	%						*mg kg⁻¹*			
Control	3.02	0.56	1.36c	1.48	0.25	0.47c	73	24	50	12
KCl	2.94	0.58	1.92b	1.54	0.25	0.54b	71	23	47	11
K_2SO_4	3.04	0.56	2.46ab	1.68	0.29	0.67a	82	25	50	11
Polyhalite	2.92	0.55	2.41ab	1.64	0.25	0.63a	84	25	47	11
K_2SO_4 + polyhalite	3.02	0.54	2.55a	1.69	0.27	0.64a	74	25	47	10
Significance level	ns	ns	*	ns	ns	*	ns	ns	ns	ns
References values	2.0-3.0(1)	0.2-0.5(1)	1.5-3.0(1)	0.6-0.8(1)	0.15-0.30(1)	0.20-0.60(1)	60-300(2)	15-20(1)	10-20(1)	5-10(1)

*: $p \leq 0.001$; ns: non-significant; similar letters within a column indicate no significant differences.
Reference values were taken from: Maynard and Hochmuth, 2007(1); Mills and Jones, 1996(2).

Table 4. Bulb macro- and micronutrient concentrations at harvest.

Treatment	Macronutrient						Micronutrient			
	N	P	K	Ca	Mg	S	Fe	Zn	Mn	Cu
	%						*mg kg⁻¹*			
Control	2.07cd	0.64b	1.62c	1.57	0.29	0.63d	253	44a	50	15
KCl	2.22ab	069a	2.09b	1.46	0.30	0.76c	257	45a	45	15
K_2SO_4	2.29a	0.60c	2.30ab	1.35	0.27	0.92b	226	35c	41	13
Polyhalite	2.15bc	0.68a	2.56a	1.64	0.32	1.03a	272	39bc	41	14
K_2SO_4 + polyhalite	2.03d	0.64b	2.27b	1.60	0.30	0.90b	255	39b	45	13
Significance level	*	*	**	ns	ns	**	ns	**	ns	ns

*: $p \leq 0.01$; **: $p \leq 0.001$; ns: non-significant; similar letters within a column indicate no significant differences.

Crop N uptake ranged from 194 to 290 kg ha^{-1}, thus exceeding, in the K-applied treatments, the annual N rate applied (Table 5). Among these treatments, K uptake was significantly higher under SOP and polyhalite fertilizers alone, and moderate (though significantly higher than the control) under KCl and the mixed fertilizer treatments. Phosphorus uptake was far below the applied rate, ranging from 45 to 70 kg ha^{-1}. Under polyhalite, P uptake was significantly higher than in all other treatments, while the control had the lowest values. Potassium uptake under S-applied treatments was equal or slightly higher than the applied K dose (270 kg K_2O ha^{-1}), considerably lower under KCl, and very low under the control. Polyhalite also gave rise to a significantly higher K uptake rate, while descending levels were recorded under SOP and the mixed fertilizers. Uptake rates were lower in the KCl application and the control, which had the lowest value (Table 5). This response pattern repeated with small differences for Ca, Mg and the micronutrients. Sulfur uptake by control plants was minimal, 50 kg ha^{-1}, and it increased considerably (50%) under KCl application, although these two treatments were not supplied with S. Among the other treatments, S uptake varied significantly, being highest under polyhalite and lowest under the mixed fertilizers. Nevertheless, no correlation occurred between S application (Table 2) and uptake rates (Table 5).

Discussion

Results clearly demonstrate the significance of fulfilling onion K requirements with adequate fertilizer supply. KCl application gave rise to significant increase in bulb weight, thus directly enhancing onion yield (Fig. 1). These results are in agreement with recent studies which showed that onion yield and quality were dependent on a considerable K supply (Behairy *et al.*, 2015; Díaz-Pérez *et al.*, 2016; Garg *et al.*, 2018). However, under a similar K application rate (270 kg K_2O ha^{-1}), additional S supply brought about significant further yield increases of 10-20%, depending on fertilizer type. This may suggest that the agronomic K efficiency differs among the tested fertilizers. Also, it may indicate positive interactions between S and other macronutrients.

Nitrogen was similarly supplied in all treatments at a rate of 200 kg N ha^{-1}, which was pretty close to the N uptake of the control (Table 5; Fig. 3). KCl application (270 kg K_2O ha^{-1}) caused a 27% N uptake increase, from 194 to 250 kg N ha^{-1}, indicating that K

Table 5. Macro- and micronutrient uptake rates as a function of fertilizer treatments.

Treatment	Macronutrient						Micronutrient			
	N	P	K	Ca	Mg	S	Fe	Zn	Mn	Cu
	------------	------------	------------	------------	*kg ha^{-1}*	------------	------------	------------	------------	------------
Control	194.3c	44.4c	133.1d	150.6d	28.0d	50.3e	2.24d	0.29c	0.50b	0.102c
KCl	252.5b	60.5b	223.0c	190.6c	35.2c	76.5d	2.81c	0.39ab	0.58ab	0.131b
K_2SO_4	288.3a	61.5b	283.2b	202.4bc	38.5b	103.8b	3.04b	0.36b	0.62a	0.129b
Polyhalite	282.3a	68.7a	312.4a	248.5a	43.2a	114.7a	3.54a	0.40a	0.63a	0.143a
K_2SO_4 + polyhalite	251.8b	58.6b	265.5b	218.2b	38.8b	94.6c	3.03b	0.39ab	0.62a	0.126b
Significance level	**	**	**	**	**	**	**	**	*	*

*: $p \leq 0.05$; **: $p \leq .001$; similar letters within a column indicate no significant differences.

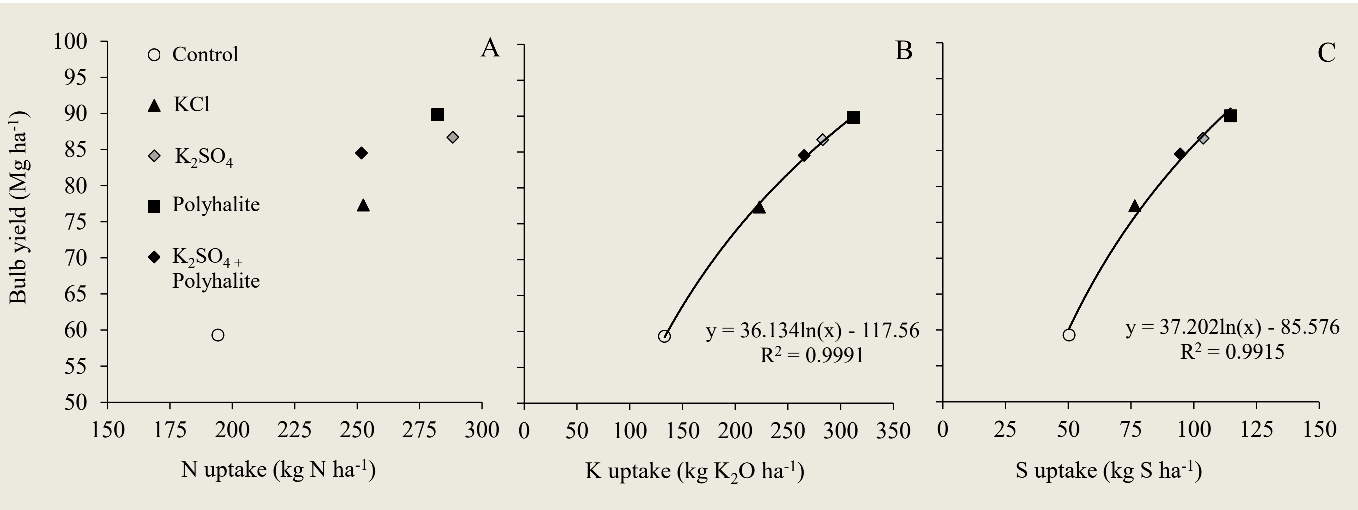

Fig. 3. Onion bulb yield as a function of N (A), K_2O (B), and S (C) uptake under different fertilizers. For further details see Table 2.

was a major limiting factor in the control, and that N requirements have been underestimated in the present study. Additionally, when the same K rate was applied through SOP (K_2SO_4), polyhalite, or as a mixture of the two fertilizers, bulb yields were significantly higher, and furthermore, N uptake substantially increased further under polyhalite or SOP alone (Fig. 3A).

While N is elementary to protein synthesis, S is a constituent of the amino acid methionine, which is essential for the initiation of protein synthesis (Brosnan and Brosnan, 2006). Therefore, positive interactions between N and S are expected and, indeed, have been reported, mainly in Brassicaceae (McGrath and Zhao, 1996), but also in onion (Al-Fraihat, 2009). Kopriva *et al.* (2002) determined regulatory interactions between N and S assimilation in plants, according to which S availability regulates N utilization efficiency in plants, and thus affects photosynthesis, growth, and dry mass accumulation by crops. Thus, S limitation might lower the use of other nutrients, particularly N, and vice versa, when supplied.

The relationships between K and S might seem even stronger (Fig. 3B). In the present study, K uptake by onion crop under no K supply (control) was considerably higher, 133 kg K_2O ha^{-1}. Naturally, K uptake increased significantly under KCl application, but remained below the supplied dose (223 vs. 270 kg K_2O ha^{-1}, respectively). Potassium uptake climbed further (as did bulb yields) when S was supplied in addition to the same K dose. Three explanations may be suggested for this result: positive interactions between K and S; salinity effects by KCl; or differences between fertilizers in K availability/uptake efficiency. The interaction between K and S is not fully understood. Garg *et al.* (2018) claimed a clear interaction and determined the necessary K:S ratio, and similar conclusions were published regarding garlic (Magray *et al.*, 2017). However, in both cases, data regarding the fertilizer compositions used in their experiments were not given, and thus no further interpretation of the results could be made. On the other hand, Díaz-Pérez *et al.* (2016) found no interactions to occur in a wide range of K:S ratios, probably due to the very fertile soil.

Onion is relatively sensitive to salt stress (Shannon and Grieve, 1998), the osmotic component of which might cause root shrinkage, while the toxic component might lead to inhibited plant development (Kiełkowska, 2017). Although the soil of the present study was not saline, a single application of the seasonal KCl dose often causes a transient salt stress, which may negatively affect early plant development. Naher *et al.* (2017) has recently demonstrated the advantage of SOP over MOP in this respect, which may provide some explanation to improved onion performance under SOP.

Nevertheless, the most tempting explanation to the apparently synergistic relationship between K and S found in the present study is rather simple - soil K availability throughout the crop cycle. Excluding the control, the K application dose was similar in the other four treatments. A single KCl application provides surplus K nutrition, accompanied by salt stress, at the early stages of crop development, however, due to the high mobility of K^+ in the soil, the availability of this ion steeply declines, and thus may limit optimum bulb growth and development. Foliar K applications were shown to amend such situations in onion (Behairy *et al.*, 2015). Still, the improved K status at the early stages enhanced N as well as S uptake, yielding significantly better crop performance. These effects may be very similar under SOP, without the transient salt stress. Therefore, plant establishment was probably improved, enabling a better crop

Photo 4. Experimental onion field, Antalya, Turkey. Photo by the authors.

Photo 5. Effect of different potassium fertilizers on onion bulbs. Photo by the authors.

performance later on. In contrast to the two former fertilizers, polyhalite releases the nutrients at a much slower rate. When applied as a single K donor at the sufficient dose, polyhalite supplies all K requirements throughout the crop cycle, providing opportunities for interactions with N, S, and other nutrients along plant development. This may explain the greater N and S uptake rates and crop performance under polyhalite application. Under the mixed SOP + polyhalite treatment, soil K availability might have slightly declined, probably because the half strength SOP or polyhalite did not meet the maximum crop K requirements at certain developmental stages, with negative consequences on crop performance.

The pattern of S uptake was especially interesting (Fig. 3C), particularly in relation to S application rates (Table 2). Similar to the case of K, the onion crop took up about 50 and 75 kg S ha^{-1} under the control and KCl treatments, respectively, where no exogenous S application had occurred. In the other three treatments, S uptake rates increased but hardly correlated to the application rates. In fact, an increase in S application rates from 97 (SOP) to 370 (polyhalite) kg S ha^{-1} gave rise to uptake rates ranging from 95 to 115 kg S ha^{-1} - a very low marginal response - with subsequently poor increases in yield. It appears that S is essential to onion crop development at a minimum threshold required for a given crop status, which is primarily determined by the other macronutrients. From this basic threshold, S uptake increased only when K or N limitations were released, and was strongly correlated with crop development and yield (Tables 3 and 5) and not with S availability. As indicated by the huge gap between S application and uptake rates, surplus S application alone would not promote plant growth.

Onion quality parameters also responded significantly to the basic improvement of soil K rather than to S availability (Fig. 2). Previous studies that examined S application on onion quality had equivocal results. In general, the type of S source and soil properties, mainly soil pH, had significant influences on bulb quality (Brown and LeClaire-Conway, 2014). Under hydroponic conditions, which eliminated soil influences, S application increased bulb firmness through dry matter allocation to the cell wall, whereas no effects occurred on other quality parameters (Lancaster *et al.*, 2001). Often, S application tended to increase the levels of S-containing secondary metabolites, while its effects on TSS or antioxidant contents were much weaker (Bloem *et al.*, 2006; Forney *et al.*, 2010). In many cases, including in the present study, S effects on bulb quality parameters could not be elucidated under strong interactions with the application of other macronutrients such as N and K (Bloem *et al.*, 2005; Al-Fraihat, 2009; Forney *et al.*, 2010; Díaz-Pérez *et al.*, 2016; Shankar *et al.*, 2017; Garg *et al.*, 2018).

In conclusion, the findings of the present study demonstrate the significance of K supply in obtaining high onion yield and quality. Interactions between K, N, and S, when adequately supplied, further increase onion yields. Polyhalite application brought about the highest yields, probably due to its slow-release character, providing constant soil K availability throughout the crop cycle. High rates of S application did not correlate with high yield. While polyhalite's advantageous agronomic efficiency is obvious, suitable rates of application remain subject to economic considerations.

Acknowledgements

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The paper "Effect of Different Potassium and Sulfur Fertilizers on Onion (*Allium cepa* L.) Yield and Quality" also appears on the IPI website at:

Regional activities/Europe

Research Findings

Photo 1. Crop growth at 30 DAS at the experimental plot; activities of rabi-summer 2014-2015. Photo by H.K. Patro.

Effects of Potassium Application Regime on Productivity and Drought Tolerance Parameters of Groundnut (*Arachis hypogaea* L.) in Odisha, India

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Abstract

Groundnut (*Arachis hypogaea* L.) is an important oilseed crop in India but its productivity is poor due to factors such as high soil acidity, low fertilizer use, imbalanced fertilizer practices, and frequent crop failures due to recurrent low soil moisture. Groundnut farmers in India, and Odisha in particular, often ignore the high potassium (K) requirements of this crop, which results in low yield and quality, as well as declining soil fertility. Appropriate K application management, therefore, needs to be addressed in order to meet groundnut K demands throughout the season.

The objectives of the present study were: to determine an appropriate K dose for rabi groundnut crops to suit the growing conditions in Odisha; to compare between basal and split K application; and to establish a well-founded fertilization

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recommendation for Odisha groundnut farmers. Three K doses (40, 60, and 80 kg K_2O ha^{-1}) were examined through basal and split application (basal and at bloom) versus unfertilized control and farmers' practice (18; 48; 36 kg ha^{-1} of N; P_2O_5; K_2O, respectively) altogether comprising eight treatments. Physiological indicators of water stress, drought resistance, and yield components were determined during crop development over two growing seasons in 2014 and 2015.

In most parameters studied, there was a significant advantage to the split K application at the highest dose tested. Due to an increased number of fertile pods per plant, pod yield was 30% higher than under control conditions, in addition to greater kernel weight and higher shelling rates. It may be concluded that split K application is far better for groundnut crops. Nevertheless, further research is required to determine K uptake rates, K agronomic efficiency, and consequently, the appropriate K dose under the conditions characterizing the groundnut production system in Odisha.

Keywords: *Arachis hypogaea* L.; K rate; nitrate reductase (NR) activity; relative water deficit (RWD); split K application; stem water potential (SWP).

Introduction

Among the nine important oilseed crops grown in India, groundnut (*Arachis hypogaea* L.) is of most importance, as it contains 43-55% oil and 25-28% protein. In 2012, groundnut consumption was about 3.28 and 4.52 kg capita^{-1} yr^{-1} in rural and urban areas, respectively (NSSO, 2012). However, the productivity is low in India due to rain dependency (85%), monoculture (60%) and cultivation on marginal land (Jat *et al*., 2011). Yields fluctuated among years from 554 to 1,163 kg ha^{-1} and consequently, groundnut total production in India varied from 3.48 to 9.67 million Mg, during the period from 1950-51 to 2013-14, from an area of about 5 million ha (India Ministry of Agriculture, 2014).

In India, Gujurat was ranked first in area under cultivation (1.84 million ha), production (4.92 million Mg), and productivity (2,670 kg ha^{-1}), in 2013-14. At the same time, in Odisha, where the present study took place, the groundnut growing area was 0.07 million ha with production of 0.08 million Mg, and productivity of 1,231 kg ha^{-1} (India Ministry of Agriculture, 2014). Here, winter (rabi) groundnut crops are concentrated in river beds and banks, relying on residual soil moisture, while spring (rabi-summer) groundnut crops usually follow rice crops, also relying on residual soil moisture, but with partial irrigation. The current groundnut productivity in Odisha is low, mainly due to high soil acidity, low fertilizer application, imbalanced fertilizer use, and frequent crop failures due to recurrent low soil moisture and incidences of disease.

Potassium (K) is an essential nutrient involved in most of the biochemical and physiological processes that influence plant growth and metabolism (Zörb *et al*., 2014). It also contributes to the survival of plants exposed to various biotic and abiotic stresses, such as diseases, pests, drought, salinity, cold, frost and waterlogging (Wang *et al*., 2013). Potassium availability significantly affects plant growth, anatomy, morphology, and metabolism, and is involved in many physiological and molecular mechanisms related to its stress resistance. Potassium is the "plant-preferred" ion for maintaining its water status (Reddy *et al*., 2003). It facilitates root expansion, thus increasing root-to-shoot ratio and hence, water and nutrient uptake (Cakmak *et al*., 1994; Rengel and Damon, 2008). Potassium governs plant turgor and is involved in stomatal conductance (Marschner, 2012),

Photos 2. From left to right: Layout preparation; groundnut seeds; groundnut germinating at 6 DAS; view of the field at 35 DAS. Photos by H.K. Patro.

occupying a central role in plant growth and carbon exchange rate. Consequently, K availability must be maintained in order to obtain reasonable crop yields.

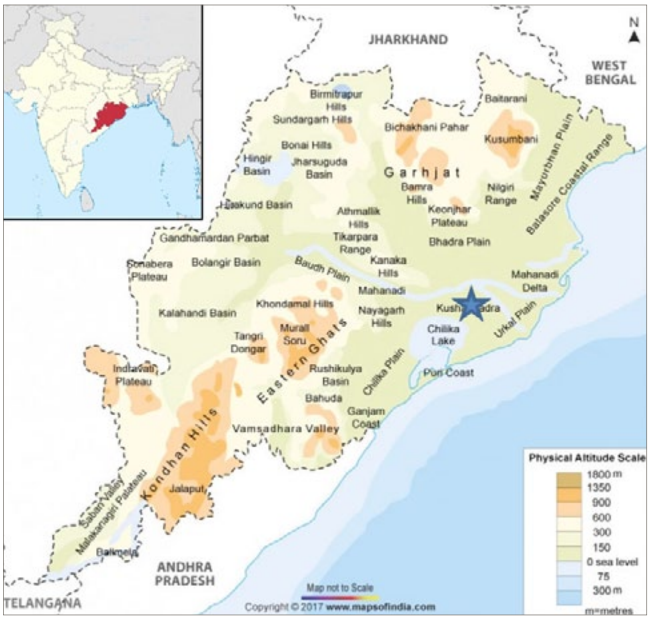
Optimization of mineral nutrition is key to successful groundnut production, as the nutrient demand of this species is very high. Modern high-yielding groundnut varieties remove more nutrients from the soil than traditional varieties. Unfortunately, groundnut growers in Odisha use very low quantities of fertilizer, and when they do, K application is often ignored. This has brought about an exhaustion of the native soil K, leading to a severe reduction in soil fertility. Soil K availability, in the short and long term, is an outcome of complex dynamics between four distinct K phases: soluble, exchangeable, non-exchangeable, and mineral. The dynamics are mainly determined by the bedrock type, but are also substantially affected by temperature and soil moisture fluctuations, the nature of the crop species, and by the farming practice. Under monsoon climates, heavy rainfall often causes rapid nutrient leaching from the soluble and exchangeable phases. On the other hand, certain clay minerals tend to exhibit strong K fixation (Zörb *et al*., 2014). Therefore, recommendations of appropriate fertilizer application must be founded on recent soil testing. Moreover, beyond the establishment of total crop K requirement per season, the timing of application must be considered.

Many studies have been carried out on groundnut fertilization in India. Mandal *et al*. (2002) reported that on average, groundnut requires yearly 160-180 kg nitrogen (N), 20-25 kg of phosphorus (P) and 80-100 kg of K to produce 2.0 to 2.5 Mg ha^{-1} of economic yield. Other studies focused also on the appropriate timing of fertilizer application (Rao *et al*., 2000; Ghosh *et al*., 2003; Chitdeshwari *et al*., 2007). These studies demonstrated that during the intensive growth period of groundnut from 30 to 70 days after sowing (DAS), which also includes the initiation of the reproductive phase, namely bloom, pegging, and pod set, nutrient requirements upsurge. To ensure sufficient nutrient availability during this critical period, fertilizer application at the required quantity seems essential. In particular, split K application has been addressed by several studies (such as CSM, 1990; Chinnasamy, 1993; Ponnuswamy *et al*., 1996), all of which reported significantly higher yields compared to a single, basal application. Nevertheless, the doses and splitting modes were considerably different from each other, leaving just the principal lesson, split K application, to be adopted and quantitatively adjusted according to local conditions.

The objectives of the present study were, therefore, to determine an appropriate K dose for rabi groundnut crops under Odisha's environmental conditions; to compare between basal and split K application; and to establish a well-founded fertilization recommendation for Odisha groundnut farmers.

Materials and methods

The experiment was conducted at the main agronomy research farm of the College of Agriculture at the Orissa University of Agriculture and Technology, Bhubaneswar, Odisha, India. The location has a latitude and longitude of 20°15'N and 85°52'E, an altitude of 25.9 m above sea level, and is situated about 64 km away from the Bay of Bengal (Map 1). The soil is sandy loam, slightly acidic, medium in organic carbon, low in available N, high in available P_2O_5 and low in available K_2O content.



Map. 1. The location of the experiment site in Odisha district (marked with a star). *Source:* Maps were downloaded from: https://store.mapsofindia.com/digital-maps/country-maps-1-2-3/india/state-maps-1-2-3-4/odisha-physical-map (Odisha), and https://simple.wikipedia.org/wiki/Odisha (India).

Odisha is characterized by a sub-tropical climate with a hot and humid summer (March-June), hot and wet monsoon season (late June-mid October), and a mild and dry winter (November-February). Broadly, the climate falls in the group of moist hot type (Lenka, 1976). The mean annual rainfall is 1,527 mm, which is received over 99 days, 74% of which occur from June to September. May is the warmest month (37.7°C) and January is the coldest (15.0°C). The highest evaporation occurs in May and the lowest in September, with 8.0 and 3.3 mm day^{-1}, respectively. These climate conditions restrict the groundnut growing season to the period between December and June, about 180-210 days (Svoboda and Fuchs, 2016). The 2015 season was much warmer than 2014, excluding April (Fig. 1). Also, 2015 was generally wetter, excluding May, when compared to 2014.

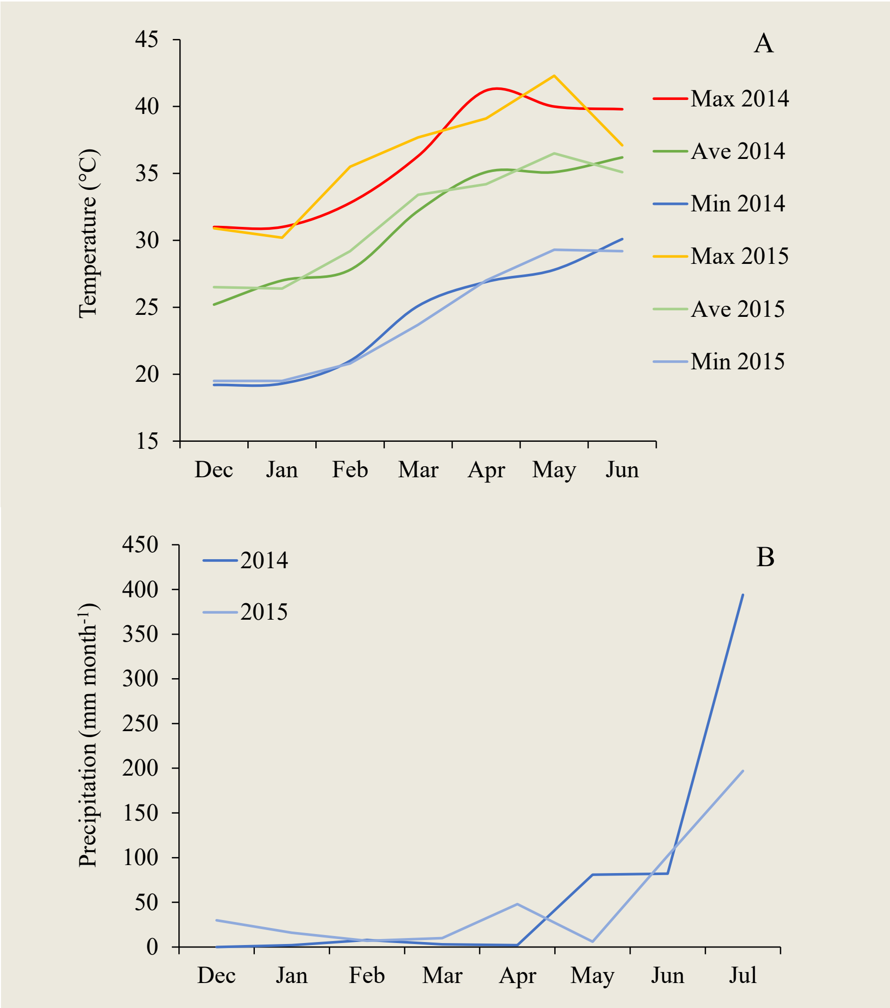


Fig. 1. Monthly maximum, average, and minimum temperatures (A), and monthly precipitation (B) during the 2014 and 2015 groundnut seasons in Odisha, India. *Source:* https://www.worldweatheronline.com/bhubaneswar-weather-averages/orissa/in.aspx.

The field of the experiment site was ploughed three times, laddered, and leveled. Nitrogen, P, and K were applied as per treatment specifications in the forms of urea, single super phosphate (SSP), and muriate of potash (MOP), respectively (Table 1). Gypsum and Chlorodust®, at 250 and 25 kg ha^{-1}, respectively, were uniformly applied. The farmers' practice (FP) included a dose of N-P_2O_5-K_2O at a ratio of 18:46:30 kg ha^{-1} and farm yard manure (FYM) at 5 Mg ha^{-1}, applied 15 days before sowing. Sowing took place on 23 and 14 January in 2014 and 2015, respectively. Seed rate was 175 kg pods ha^{-1}, with 30 cm between plant rows, and 10 cm between plants within a row. Surface irrigation was provided during the crop season whenever required. Prophylactic measures were undertaken to protect the crop from diseases and pests.

One day before harvest, soil surface was softened with light irrigation. All border plants were removed before the harvest of each experimental plot. The pods were plucked by hand and cleaned. The pod and haulm were sundried and their weights were recorded separately for each experimental plot.

The experiment comprised eight treatments in three replications, in a randomized block design (RBD). Details of the treatments and the corresponding symbols used for the experiment are given in Table 1. Treatments T3-T8 were basally applied with the full recommended N dose of 20 kg ha^{-1}. The basal dose of fertilizers was placed in furrows at the time of sowing as per treatment specifications and the subsequent splits of K were placed beside the rows.

A groundnut variety known as Devi (originally, ICGV 91114) was used in the experiment. ICGV 91114 is a Spanish variety and has an erect growth habit with sequential flowering and medium elliptic, green to light-green leaves. It is a high-yielding variety, which matures within 110-120 days in the dry winter (rabi) season and is tolerant of mid-season and end-of-season droughts. Due to its early and uniform maturity, attractive pod and seed shape and high shelling turnover, ICGV 91114 is a very popular variety in many parts of India, including Odisha.

During crop development, several indicators of plant drought damage or tolerance were measured, including SPAD, chlorophyll stability index (CSI), membrane stability index (MSI), proline content, nitrate reductase (NR) activity, relative water deficit (RWD), and stem water potential (SWP). SPAD values, commonly used to estimate chlorophyll content, N, and the general physiological status of the plant (Rodriguez and Miller, 2000), were determined in the field at 30, 45, 60, and 75 DAS using a SPAD 502 Plus Chlorophyll Meter (Spectrum Technologies Inc.). To determine CSI, fresh leaves were collected from each treatment plot at 45 and 60 DAS. In two glass test tubes, 0.25 g of representative leaf sample and 10 ml of distilled water were added. One tube was then subjected to heat in a water bath at 56^{0}C for 30 minutes, while the other served as control. Total chlorophyll in the two samples was extracted with 80% acetone and determined using a colorimeter at 652 nm (Lichtenthaler, 1987). CSI, which is directly proportional to drought stress (Blum and Ebercon, 1981; Rahbarian *et al*., 2011), was calculated as the percentage of the total chlorophyll content of the thermally treated as related to the control sample. MSI was determined by the ion leakage method (Deshmuukh *et al*., 1991). Proline content, as a measure of plant resistance to stress, was determined after Bates *et al*. (1973) on leaves collected from each treatment at 45 and 60 DAS. NR activity was determined in leaves collected from each treatment at 45 and 60 DAS, following methods described by Nair and Abrol (1977).

Water stress parameters were determined with fresh leaves which were collected and brought to the lab at 45 and 60 DAS. After leaf fresh weight (FW) was determined, the leaves were immersed in water for an hour. Excess water was then gently removed from the leaves' surface and they were weighed again to determine turgid weight (TW). The leaves were dried in a hot air oven at 80°C for 48-72 h, following which their dry weight (DW) was determined. RWD was calculated as the ratio between the current leaf water content and the maximum leaf water content under full turgidity, as follows: RWD=[(FW-DW)/(TW-DW)]·100. For the determination of SWP, a fully expanded young leaf was wrapped in a damp paper towel and aluminum foil for an hour to allow equilibrium with the plant water potential, and then detached and measured using a Scholander pressure bomb (Model 1000, PMS Instrument Co., Albany, OR, USA) (Tyree and Hammel, 1972).

Five plants were randomly sampled from the middle of each plot to determine the number of pods per plant. At harvest, the pods of each plot were sundried for 3-4 days, weighed, and pod yield was calculated in kg ha^{-1}. A sample of about 1 kg pods was taken from each plot, decorticated, and the shells and kernels were weighed

Table 1. A detailed description of the fertilization treatments.

Symbols	Treatment details	Abbreviation used in text
T_1	Control (no NPK)	T_1; Control
T_2	Farmers' practice (18:46:30 kg NPK ha^{-1}).	T_2; FP
T_3	Full (100%) recommended PK dose: 40 kg P_2O_5 ha^{-1}; 40 kg K_2O ha^{-1}, all at sowing (basal).	T_3; RDF, K_b
T_4	Full (100%) recommended P dose+150% RD of K: 60 kg K_2O ha^{-1}, basal.	T_4; RDF+50% K, K_b
T_5	150% P: 60 kg P_2O_5 ha^{-1}+200% K: 80 kg K_2O ha^{-1}, basal.	T_5; RDF+50% P+100% K, K_b
T_6	Full (100%) recommended PK dose: 40 kg P_2O_5 ha^{-1}; 40 kg K_2O ha^{-1}. K dose split between basal and bloom (30 DAS) applications, 20 kg K_2O ha^{-1} each, respectively.	T_6; RDF, K_s
T_7	100% P: 40 kg P_2O_5 ha^{-1}+150% K: 60 kg K_2O ha^{-1}. K dose split between basal and bloom (30 DAS) applications, 30 kg K_2O ha^{-1} each, respectively.	T_7; RDF+50% P+50% K, K_s
T_8	150% P: 60 kg P_2O_5 ha^{-1}+200% K: 80 kg K_2O ha^{-1}. K dose split between basal and bloom (30 DAS) applications, 40 kg K_2O ha^{-1} each, respectively.	T_8: RDF+50% P+100% K, K_s

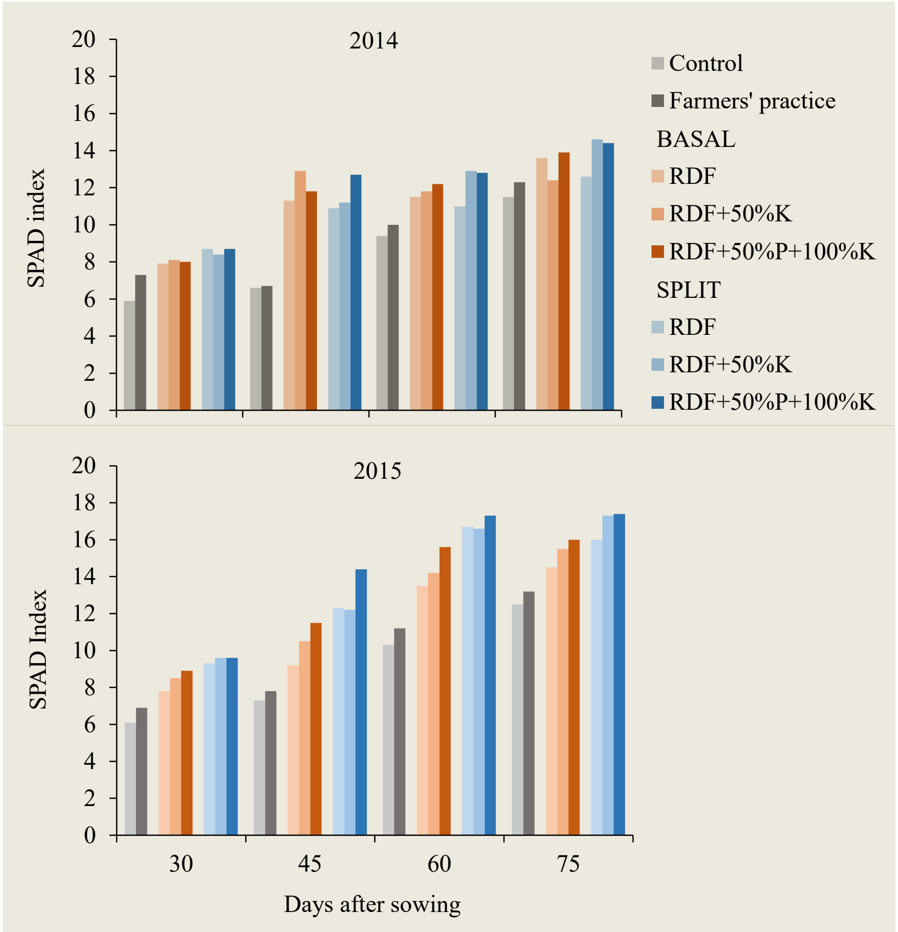


Fig. 2. Effects of elevated K rates, and of basal versus split K application on SPAD values of groundnut crop measured in the two experimental years at 30, 45, 60, and 75 DAS. A detailed explanation of treatments is given in Table 1.

separately to determine the shelling percentage, as follows: shelling (%)=[(kernels wt./(kernels+shells wt.)]·100. The weight of 100 kernels was determined by a random sampling and weighing of 100 kernels of each plot.

All data were subjected to statistical analyses suitable to the experimental design, following Panse and Sukhatme (1985). The treatment variations were tested for significance using an F test and the critical difference (CD) was calculated at P=0.05 and presented.

SPAD values increased with plant age from 45 to 75 DAS (Fig. 2). While K application rate had slight and inconsistent effects on SPAD in 2014, SPAD values displayed a much clearer response in 2015, increasing with the rise in K application rate in most cases. SPAD response to split K dose was also stronger in 2015, being significantly higher than at the basal application.

In 2014, RWD was extremely high in the control plants compared to other treatments, but no significant difference occurred between the measurements taken at 45 and 60 DAS (Fig. 3). In the other treatments, RWD was significantly higher at 60 than at 45 DAS. While no significant influence occurred for K dose at 45 DAS, a clear trend of decreasing RWD in response to K rate was observed at 60 DAS. Furthermore, this trend was much stronger under the split, compared to the basal K application (Fig. 3).

In 2015, RWD was significantly high at control and FP treatments, slightly less at the basal treatments, and further declined to significantly lower levels under the split K application (Fig. 3). The effect of K rate on RWD was obvious only at the split K group, decreasing with the elevated K rate at both measurement days. The control plants SWP was significantly lower than in the other treatments in both years. SWP steadily increased with the rising K rate at the basal applications (Fig. 3). Under split K application, SWP was generally at the highest range, however, it responded to the rising K rate only in 2015. Noteworthy was the significantly lower SWP at 60, compared to 45 DAS in 2014, but not in 2015.

Since the values and response patterns for CSI, MSI, NR activity and proline concentration were similar in both experimental years in the groundnut leaves, they were pooled and averaged (Fig. 4). No significant effects of K rate, application mode or the timing of measurement on CSI were found, although slight trends

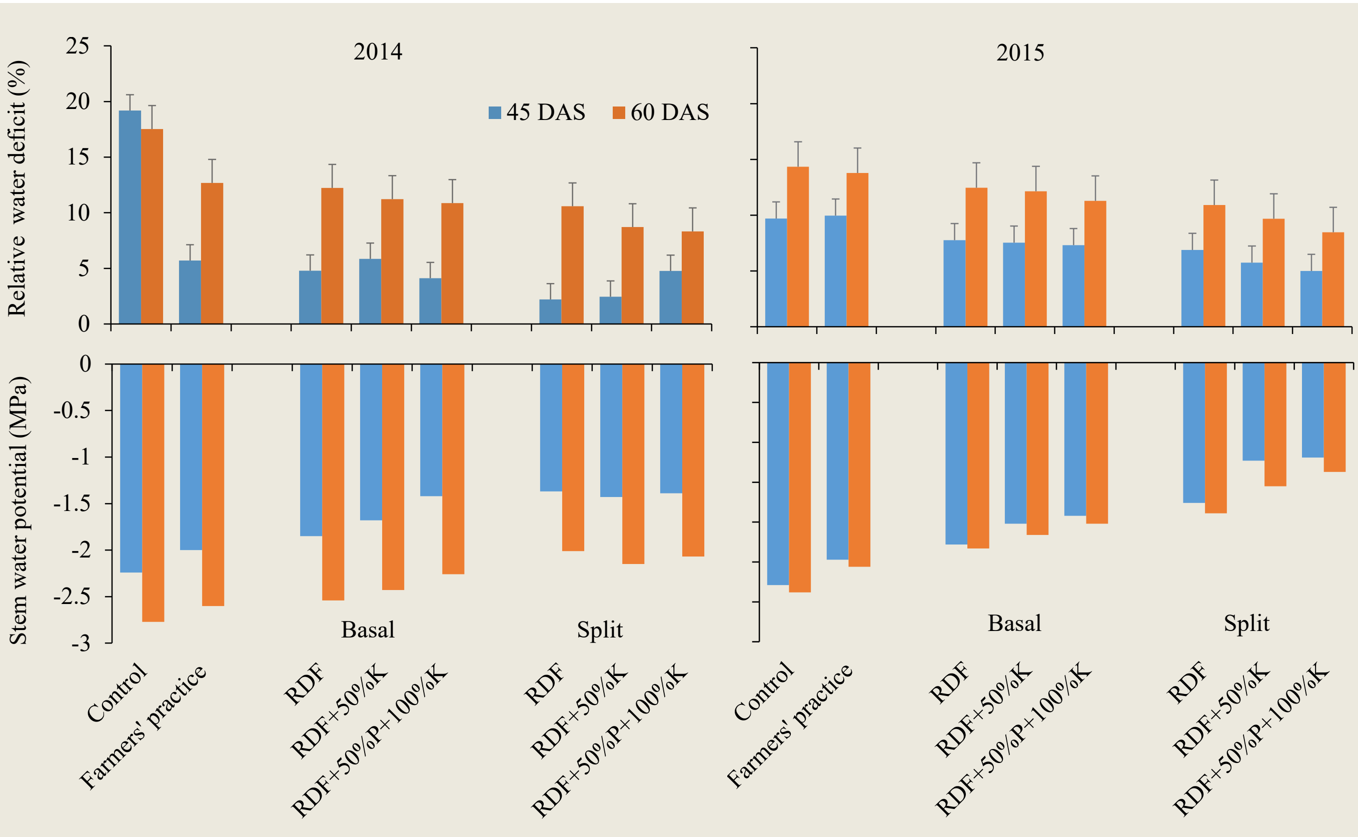


Fig. 3. Effects of elevated K rates and of basal versus split K application on RWD and SWP values of groundnut crop measured in the two experimental years at 45 and 60 DAS. A detailed explanation of treatments is given in Table 1.

of increasing CSI could be observed in response to K rate and split application (Fig. 4A). MSI was significantly lower at 60, compared to 45 DAS (Fig. 4B). MSI response to K treatments was rather weak, particularly at 45 DAS, nevertheless, it gradually increased from the control to the highest K rate under split application, where it was significantly higher (Fig. 4B). In contrast, NR activity exhibited a substantial response to the fertilizer treatments (Fig. 4C). It rose consistently from about 10 to 36 µL NO_2 gFW^{-1} h^{-1}, in control (T_1) and in the higher and split K dose (T_8), respectively. Generally, NR activity was higher at 45 than at 60 DAS. These patterns were similar but much weaker with the response of proline concentration to K fertilization regime (Fig. 4D).

All yield parameters were improved by all fertilization treatments compared to the unfertilized control (Fig. 5). FP displayed a general advantage over control, particularly in 2014, the yield parameters of which were basically lower than those of 2015. Compared to FP, the basal K application had no significant influence on the yield parameters in 2014, including no differences that occurred between K rates. The split K application, however, resulted in significant increases in most yield parameters in 2014, with substantial rises in pod number and pod yield in response to elevated K rates (Fig. 5). In 2015, shelling percentage and kernel weight were significantly higher than in 2014. Also, the basal K application seemed more effective than FP, with a slight but consistent advantage to the higher K rates. As in 2014, the split K application gave rise to further increases in yield parameters, with a similar response pattern to the elevated K rates (Fig. 5). Hence, the higher K rates, split between basal and upon bloom applications resulted in the highest groundnut yields in both years.

Discussion

In Odisha, India, groundnut is grown during the dry season, relying on residual soil moisture remaining in river banks after the wet monsoon season or following rice crops. In the absence of sufficient supplement irrigation, rabi crops are often subjected to drought stress. The early reproductive stages, usually occurring between 35 and 75 DAS, are highly susceptible to drought stress (Reddy *et al.*, 2003). A minimum level of soil moisture is required to allow K uptake by the roots, as well as for successful pegging and early pod development (Smith, 1951; Reddy *et al.*, 2003). The 2014 groundnut season was significantly drier than 2015 during

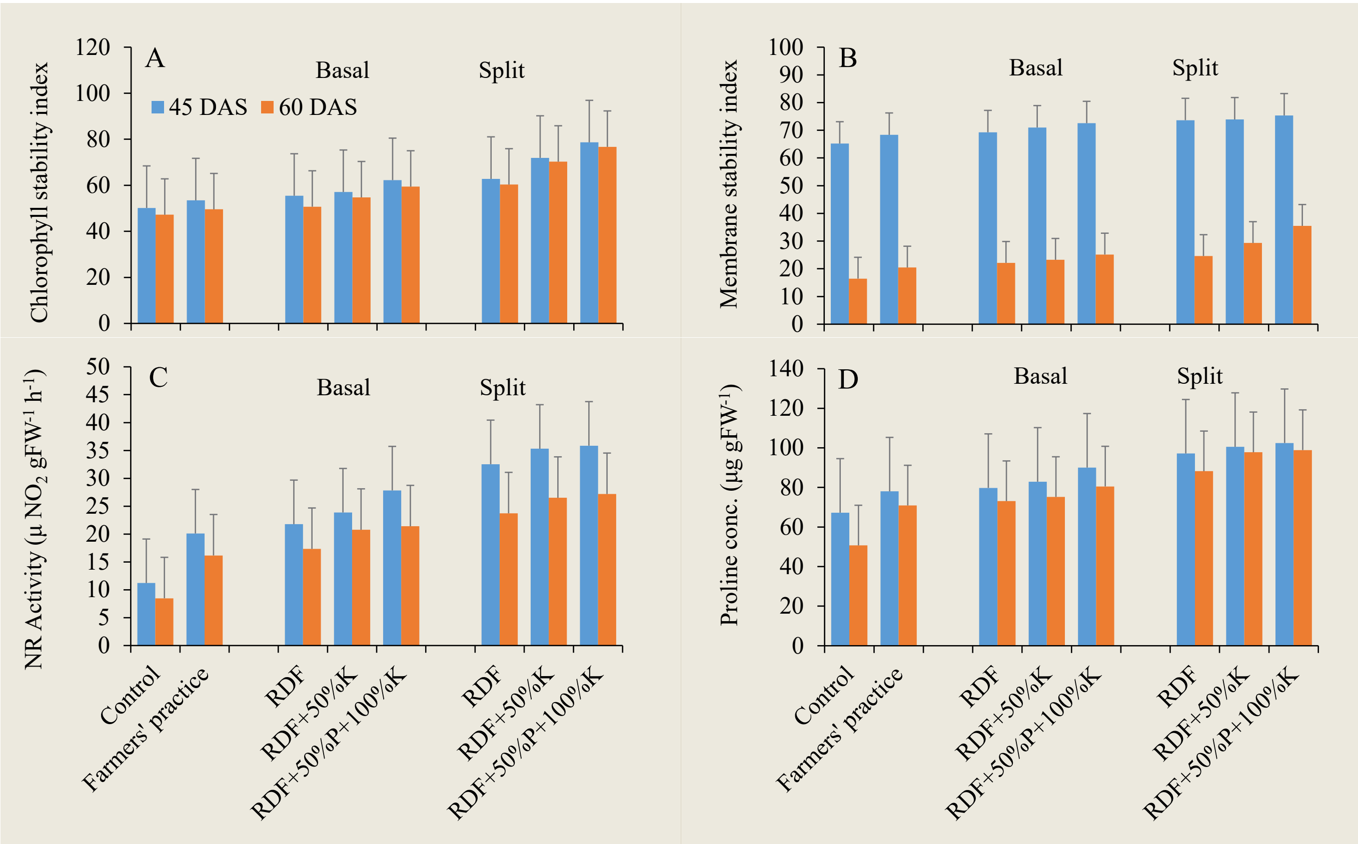


Fig. 4. Effects of elevated K rates, and of basal versus split K application on CSI (A), MSI (B), NR activity (C), and proline concentration in groundnut leaves measured at 45 and 60 DAS. Data for the two years were pooled and averaged. A detailed explanation of treatments is given in Table 1.

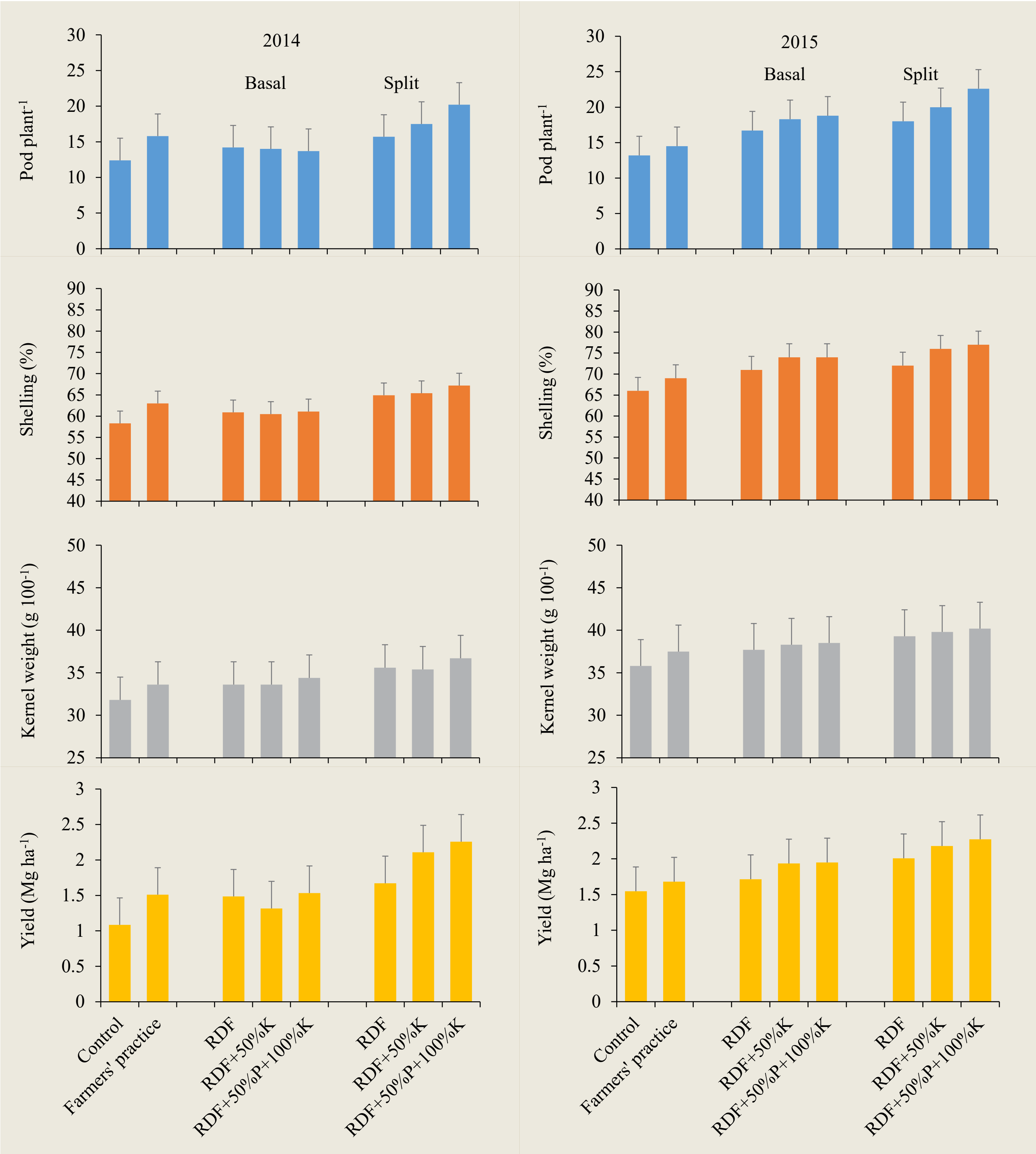


Fig. 5. Effects of elevated K rates, and of basal versus split K application on groundnut yield parameters in 2014 and 2015. A detailed explanation of treatments is given in Table 1.

this critical period (Fig. 1), which might have been the reason for many differences between the two years that occurred in physiological indicators (Figs. 2, 3, and 4), and consequently, in yield parameters (Fig. 5).

SPAD, a general indicator of crop vigor, N content, and chlorophyll status (Srinivasarao *et al*., 2016), demonstrates the differences between the two years (Fig. 2). In 2014, a clear positive effect of K application on SPAD values was observed, but any further influence of K dose or application management was rather poor and inconsistent. In contrast, SPAD responses to these parameters were clear and significant in the wetter groundnut season of 2015. These differences may indicate that the limiting factor in 2014 was insufficient K uptake by the crop due to the dry soil, in spite of adequately supplied fertilizers.

Potassium regulates plant water relations, facilitates water uptake, as well as growth and development. Among other mechanisms and factors, K plays a crucial role governing the osmotic regulation required to draw water into plant roots. Potassium deficient plants have difficulties in withstanding drought because of their failure to adjust the root osmotic potential necessary to absorb water from a drying soil. In the present study, K application reduced leaf RWD and increased SWP under normal and stress conditions (Fig. 3). These two parameters consistently responded to both elevated and split K dose, demonstrating the central role of sufficiently available K in plant water status, as previously discussed by Umar and Moinuddin (2002). Proline accumulation, another osmo-regulator, also facilitates plant drought resistance. Interestingly, proline concentration increased steadily with the rising K dose; moreover, it was higher under the split K management (Fig. 4D). Altogether, it appears that improved K management can significantly raise the drought resistance of groundnut crops, thus improving water uptake and supporting productivity.

CSI and MSI are good measures of plant cell integrity. Low values may indicate stress (Rahbarian *et al*., 2011) but also aging of the sampled leaves. The increasing CSI and MSI values with the rising K availability, through higher dose or under split application (Fig. 4A-B), demonstrate the indirect contribution of better K nutrition to facilitated performance of a groundnut crop. Beyond this general influence of K, the straightforward increasing values of NR activity in response to elevated K readiness (Fig. 4C) help to demonstrate the pivotal role of this nutrient in N uptake and metabolism, which is fundamental to plant growth and development (Hasanuzzaman *et al*., 2018).

Basal K application is necessary for groundnut as it complements N and P uptake at the early stages of crop development. Also, it promotes root proliferation, thus extending plant water acquirement from the soil. Nevertheless, the capacity of the young crop to take up the whole seasonal K dose is very limited. Therefore, most of the K dose, if basally applied, may be lost through leaching or fixation, and will not be available to the crop at later developmental stages, when K demands surge.

Splitting K dose into two applications, basal and upon bloom, provides the groundnut crop with more appropriate K quantities throughout the season, precisely when required. The advantages of split K application, which was demonstrated in several previous studies (CSM, 1990; Mondal and Goswami, 1991; Chinnasamy 1993; Ponnuswamy *et al*., 1996; Rao *et al*., 2000; Ghosh *et al*., 2003; Chitdeshwari *et al*., 2007), has therefore also been confirmed in the present experiment; in both years, the split K application gave rise to greater pod numbers and yields, and to higher kernel weight (Fig. 5). More recent studies on groundnut crops in India (Borah *et al*., 2017; Sanadi *et al*., 2018) also support these results.

A significant increase of the recommended K dose, from 40 to 80 kg K_2O ha^{-1}, and particularly under split K application, brought about a significant increase in yield of 30% (Fig. 5). These results are supported by previous studies that also showed remarkable groundnut yield increases in response to elevated K doses (Jain *et al*., 1990; Jana *et al*., 1990; Mitra and Sahoo, 1998; Truong *et al*., 2017). However, the upper threshold, above which further increase of K dose is not expected to contribute to yield or quality, is still unclear. In addition, the efficiency of K application in the present study is undetermined. Further research into the groundnut cropping systems in Odisha is hence required to quantify K uptake rates and K agronomic efficiency, and to evaluate the economic feasibility of a split K application regime at higher K doses.

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The paper "Effects of Potassium Application Regime on Productivity and Drought Tolerance Parameters of Groundnut (*Arachis hypogaea* L.) in Odisha, India" also appears on the IPI website at:

Regional activities/India

Events

IPI events

May 2018

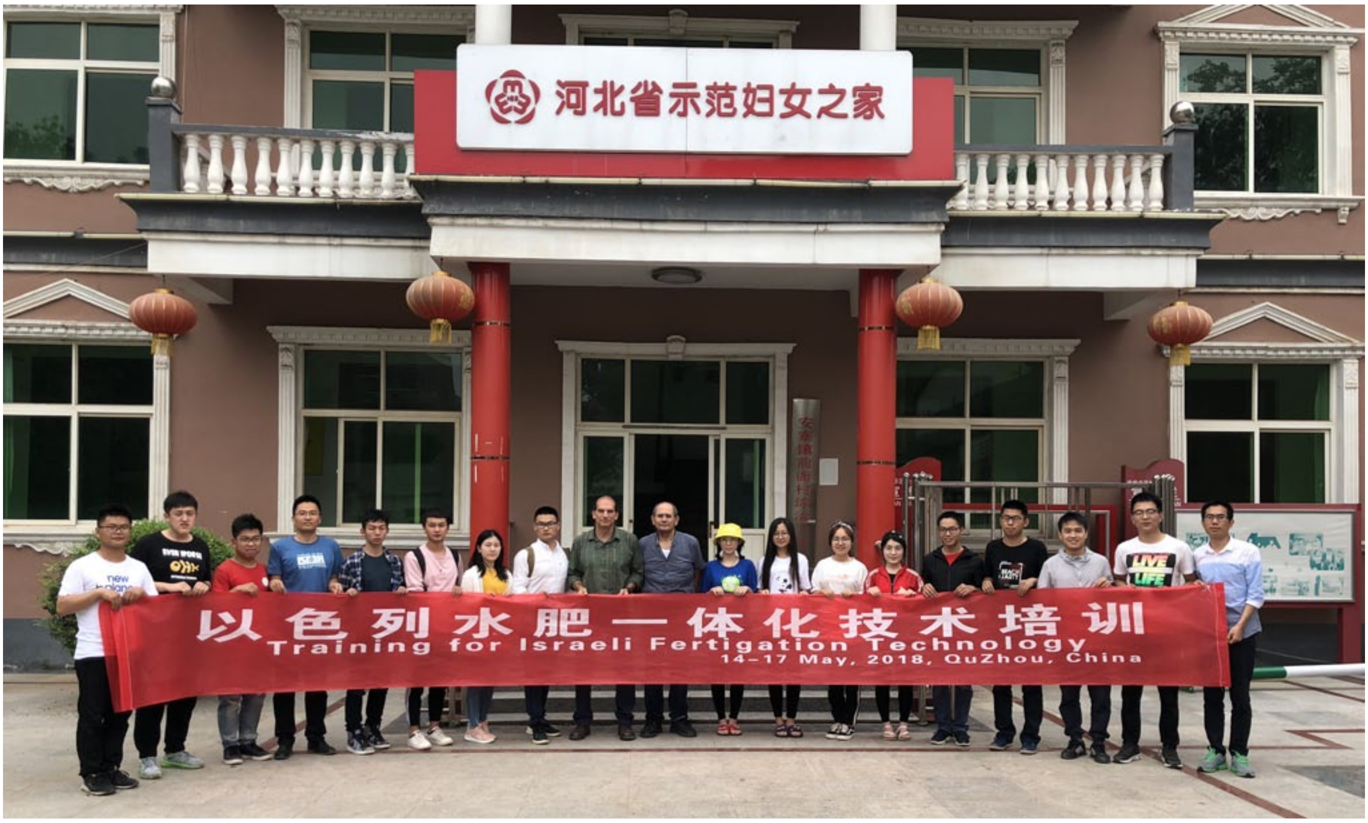

Photo 1. Participants and trainers at training location Quzhou, Hubai Province, China. Photo by G. Li.

Fertigation Technology in Practice

Report of the first phase of a two-part training program for undergraduates and post graduates, which took place from 14-17 May 2018 in Quzhou, Hubai Province, China. The program was developed by the International Potash Institute (IPI) in conjunction with China Agricultural University (CAU), to enhance understanding and practical knowledge of fertigation. The goal is that the participants will become valued agri-professionals providing accurate fertilizer advice to farmers for a range of crops.

Context for the course

In China, demand from farmers for quality advice on fertigation is increasing. On a visit to Israel to see advisory systems, prominent CAU academic Professor Zhang Fusuo saw how Israeli agricultural extension officers worked in the field to help farmers make best use of fertigation technology. Professor Zhang wanted to devise a training program to help students of agriculture in China become better-equipped to advise farmers.

The main purpose of the course, developed by CAU in collaboration with IPI, was to strengthen the capacity of Chinese agri-professionals to be able to calculate and recommend appropriate fertilizer programs for fertigation in a range of crops. Another desired outcome of this initiative is a stronger relationship between university and the private sector, particularly fertilizer companies, in order to collaborate and share information with each other.

The 'Fertigation technology in Practice' course aims included the following:

- to broaden the knowledge of professionals advising farmers and instruct them on methods to disseminate knowledge to farmers;
- to enable participants to deliver their knowledge in a clear manner;
- to bridge the gap between theoretical and practical farm management to share best practice;
- to expand participants' understanding of state-of-the-art technological advances in soil science and irrigation, sensor-based irrigation, information management, precision agriculture and remote sensing technologies.

It was decided that a phased program of initial training followed by private study and then a second phase of training was the best option.

If this 'Fertigation Technology in Practice' pilot training program is successful it is hoped it will provide a model for future training in China.

Photo 2. Training in the classroom. Photo by E. Sokolowski.

Photo 3. Mr. Asher Azenkot answering questions in the field. Photo by E. Sokolowski.

Course participants

Seventeen students from CAU, representing several different regions of China, were selected for the training. They are a mix of undergraduates, post graduates and PhD students. All of these students had already taken part in the CAU "Back Yard Centre" program through which a student spends six months living and working on farms in different locations in China in order to gain real life experience of the practicalities and problems of crop production.

Joining them on the CAU-IPI Fertigation in Practice training program are representatives from Wuzhoufeng, one of China's most important fertilizer companies.

About the training

The course comprises three elements. The first phase is the four days of training and practical tasks. This was held in May 2018 at the CAU experimental station in Quzhou in the Hubei province of China. Content included: crop water requirements; fertilizer calculation; leaf nutrient diagnosis; irrigation technology and layout; drip irrigation; design for dripper pressure compensation; irrigation scheduling; and principles and practicalities of fertigation. Extension expert Asher Azenkot from the Israeli Ministry of Agriculture, and Eldad Sokolowski, IPI Coordinator for China, led the sessions with translation into Chinese by Dr. Guohua Li, ICL Agronomist China.

Their sessions, as summarized by CAU training coordinator Dr. Chendong, combined theory of irrigation with a lot of field work in order that the participants could apply the principles in practical situations and make accurate calculations for fertilizer use through fertigation. Field visits, for example, to see drip fertigation in vineyards, were an important component. They gave the students the opportunity to see how a system had been designed and installed and understand the choice of row spacing, the number of drippers and the fertilizer dose. Also, field visits enabled the group to see and discuss factors affecting fertilizer choice, such as water hardness, solubility, as well as issues that arise during fertigation including how to prevent soil salinization.

The second phase of the training is through individual study. Each of the participants is undertaking a study connected with fertigation in a crop of their choice in different provinces of China. Crops chosen by the participants include greenhouse tomatoes

(Hebei), lettuce (Hebei), apples (Zhjiang), citrus (Sichuan) and grapes in Qianya. Their studies include crops in pots, in protected environments as well as fields, and they are measuring crop yield and quality as well as labor requirement, farmer practice and problem-solving.

During the training it was discovered that simultaneous translation into Chinese was essential as the participants understanding of English was not adequate for technical information. It was also noted that they need to be helped with key elements of planning fertigation such as how to calculate the amount of irrigation required using pivot tables and also how to take into account the principle of pressure allocation in a fertigation system.

Testimonials

"The course has so far been very helpful. We have gained a lot. Our company would like to send more representatives next time." *Yonggang Wang (Agronomist) and Xiaopeng Wang (Marketing Manager) with fertilizer company Wuzoufeng*

"The group is gaining a lot from the course. The training is proving very effective in taking the participants, particularly the students, from a theoretical level to being able practically to work with farmers and give good advice." *Eldad Sokolowski, IPI Coordinator for China*

"Since I saw the extension officers in Israel at work giving good advice to farmers I wanted to develop that expertise and approach in China. With the development of this course in China with IPI we are developing a model that could be scaled up to improve use of fertilizer and fertigation" *Professor Zhang Fusuo, Chinese Agricultural University*

Next phase

Later in 2018 the group will gather again; the venue is likely to be near Beijing. This final phase of the training program will pick up on the issues and challenges of fertigation revealed by the participants' completed assignments and further deepen the group's understanding of good fertilizer use and strengthen their skills to deliver good advice to Chinese farmers.

Consulting with the participants on what they want to cover in the next phase has helped the training coordinators and tutors to prepare a mix of theory and practical sessions to include:

- design of flow rate in fertigation according to topography, rainfall, etc.;
- working principles of reducing valve, air valve and other important units in fertigation system;
- how to better use fertigation system in low temperature conditions;
- comparison of application of fertigation in Israel, USA, and other countries;
- a case study (Israel) from the beginning of fertigation design to final harvest.

If the training is considered a success, then it could be rolled out on a much wider scale in China. The intention is that it could become an important part of an agriculturalist's professional development, and something students and fertilizer company professionals would pay for, in order to be fully equipped to provide fertigation guidance and advice to Chinese farm businesses on planning and using fertilizer through irrigation for better crop yields, quality and profitability.

The report "Fertigation Technology in Practice" also appears on the IPI website at:

Regional activities/China

Scientific Abstracts

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Yield and Nutritional Requirements of Cassava in Response to Potassium Fertilizer in the Second Cycle

Fernandes, A.M., B. Gazola, J.G. da Silva Nunes, E.L. Garcia, and M. Leonel. 2017. J. Plant Nutr. 40(20):2785-2796. DOI: https://doi.org/10.1080/01904167.2017.1382520.

Abstract: Potassium (K) is one of the most absorbed nutrients by cassava because it acts on the synthesis and starch accumulation in the storage roots. Here, we show that K application at the beginning of the second vegetative cycle of cassava submitted to shoot pruning increased the yield of roots and starch, and the nutrient demand of plants. Application of 45-89 kg ha^{-1} dipotassium oxide (K_2O) in the second cycle increased the yield of storage roots and starch from 36-49% and K applied at this time had a greater effect on the synthesis and allocation of starch in the storage roots. K supply increased the accumulation of N and S by 2.0- to 3.0-fold and the accumulation of other nutrients by 1.4- to 1.7-fold. The removal of phosphorus (P), manganese (Mn), and zinc (Zn) by storage roots was not affected by K application, whereas the removal of other nutrients increased by 1.3- to 4.3-fold.

Impact of Low Potassium Fertilization on Potassium Transformation under Different Crop Management Systems in Western Plain of Arid India

Sunil Kumar, I.J. Gulati, S.R. Yadav, R.S. Yadav, P.C. Moharana, R.L. Meena, B.L. Tailor, and R.S. Singh. 2018. J. Plant Nutr. 41(4):411-424. DOI: https://doi.org/10.1080/01904167.2017.1381121.

Abstract: Acquaintance of potassium (K) transformation in soil is crucial for K management in management system of arid India. Present study revealed that the extractable K like ammonium acetate-potassium (NH_4OAc–K), nitric acid (HNO_3)-K, and hydrochloric acid (HCl)–K under different systems were followed the order: irrigated low input > rainfed low input > irrigated high input > no input. The pearl millet systems in irrigated low input practice maintained a higher NH_4OAc-K than irrigated high input practice. The exchangeable-K (Exch-K), non-exchangeable-K (Non-exch K) and lattice-K were observed highest in irrigated low input system and lowest in no input system. It is noticed that Exch-K contributed 2.3-2.6% over total-K, which readily available to plants. The Exch-K was highly significant correlated with K pools and soil properties, indicating that rapid establishment of equilibrium between the pools. Thus, knowing K reserve and distribution of K forms can help in understanding K replenishment capacity of arid soil under long-term intensive cultivation.

Amelioration of Cadmium Stress in Gladiolus (*Gladiolus grandiflora* L.) by Application of Potassium and Silicon

Malik Muhammad Zaheer, Nasim Ahmad Yasin, Sajid Rashid Ahmad, Waheed Ullah Khan, Aqeel Ahmad Aamir Ali, and Shafiq Ur Rehman. 2018. J. Plant Nutr. 41(4):461-476. DOI: https://doi.org/10.1080/01904167.2017.1385808.

Abstract: Gladiolus corms were grown in media contaminated with cadmium (Cd) (50 mg kg^{-1}) and supplemented with silicon (Si) and potassium (K). The role of Si and K for mitigation of Cd toxicity was evaluated. Cd-induced stress generated significantly increased level of oxidative stress markers including hydrogen peroxide (H_2O_2), and malondialdehyde (MDA) in gladiolus. The application of K and Si improved the production of protein and proline in the treated plants. Moreover, K and Si supplemented plants exhibited an improvement in the activity of antioxidant enzymes and a reduction in the level of MDA, H_2O_2 and Cd uptake under Cd stress. Application of K and Si also enhanced the uptake of mineral nutrients including calcium (Ca), magnesium (Mg), manganese (Mn), sulfur (S) and K. The plants supplemented with K and Si exhibited a higher amount of total phenolics and flavonoids. The combined effect of Si and K was more pronounced regarding beneficial effects on gladiolus plants compared to individual effect of these elements under Cd stress. The current research reveals that Si and K may improve gladiolus growth by decreasing the oxidative stress and Cd uptake and by increasing the activity of antioxidant defense enzymes, the quantity of secondary metabolites and plant nutrition.

Influence of Mycorrhizal Fungi on Growth, Chlorophyll Content, and Potassium and Magnesium Uptake in Maize

Hassan Zare-Maivan, Narges Khanpour-Ardestani, and Faezeh Ghanati. 2017. J. Plant Nutr. 40(14):2026-2032. DOI: https://doi.org/10.1080/01904167.2017.1346119.

Abstract: Mycorrhizal fungi affect growth and nutrition of host plants positively. In this research, influence of vesicular-arbuscular mycorrhiza (VAM) on growth, chlorophyll content, and potassium (K) and magnesium (Mg) uptake in maize seedlings in pot culture was studied. This experiment was performed using natural soil containing a mixture of spores of *Glomus* spp. Mycorrhizal spores were exposed to four concentrations of K solution, i.e. 0.61 (soil K content), 0.92, and 1.23 meq/L and three concentrations of Mg, i.e. 4.8 (soil Mg content), 7.2, and 9.6 meq/L concurrently. Plants were watered every 4 days for

16 days with 50 mL distilled water. A pot with sterilized soil was used as negative control. For study of mycorrhizal colonization, very thin manually prepared longitudinal sections of plant roots (>1 mm in diameter) were stained with lactophenol-cottonblue and examined microscopically. Percentage of mycorrhizal colonization was determined using the grid-line intersect method. Samples from root and shoot of maize were collected for further analysis. Results showed mycorrhizal plants had significantly higher dry and fresh weight and chlorophyll content than plants grown in sterilized soil ($p \leq 0.05$). Treatments with concentrations of 7.2 meq/L of magnesium alone and in combination with 0.92 meq/L of potassium with7.2 meq/L of Mg had better effect on morphological characters (dry and fresh weight of root and shoot). Mycorrhizal colonization increased Mg uptake but decreased K uptake.

Effect of Gypsum on Potassium and Iron Release from Phlogopite to Alfalfa

Fatemeh Sheikhi Shahrivar, and Hossein Khademi. 2018. J. Plant Nutr. 41(4):509-519. DOI: https://doi.org/10.1080/01904167.2017.1385812.

Abstract: This study evaluated the effects of gypsum on the release rate of potassium (K) and iron (Fe) from phlogopite to alfalfa under greenhouse conditions. The medium was a mixture of quartz sand as filling material, K- and Fe-bearing micaceous mineral (phlogopite) and different levels of gypsum (0%, 2%, 5%, 12% and 25%). During the 6-month cultivation period, the pots were irrigated and/or fed with distilled water and four different nutrient solutions. The results showed statistically significant effects of different levels of gypsum on dry weight and K and Fe concentration of shoots and roots. It seems that an increase in calcium (Ca) concentration, due to the addition of gypsum, changes the equilibrium of K and Fe in the root zone and plant tissues. The results of this study show that the rate of K and Fe release from micaceous minerals is extremely reduced in the presence of gypsum.

Melatonin-Stimulated Triacylglycerol Breakdown and Energy Turnover under Salinity Stress Contributes to the Maintenance of Plasma Membrane H^+-ATPase Activity and K^+/Na^+ Homeostasis in Sweet Potato

Yu, Y., A. Wang, X. Li, M. Kou, W. Wang, X. Chen, T. Xu, M. Zhu, D. Ma, Z. Li, and J. Sun. 2018. Front. Plant Sci. 9:256. DOI: https://doi.org/10.3389/fpls.2018.00256.

Abstract: Melatonin (MT) is a multifunctional molecule in animals and plants and is involved in defense against salinity stress in various plant species. In this study, MT pretreatment was simultaneously applied to the roots and leaves of sweet potato seedlings [*Ipomoea batatas* (L.) Lam.], which is an important food and industry crop worldwide, followed by treatment of 150 mM NaCl. The roles of MT in mediating K^+/Na^+ homeostasis and lipid metabolism in salinized sweet potato were investigated. Exogenous MT enhanced the resistance to NaCl and improved K^+/Na^+ homeostasis in sweet potato seedlings as indicated by the low reduced K^+ content in tissues and low accumulation of Na^+ content in the shoot. Electrophysiological experiments revealed that exogenous MT significantly suppressed NaCl-induced K^+ efflux in sweet potato roots and mesophyll tissues. Further experiments showed that MT enhanced the plasma membrane (PM) H^+-ATPase activity and intracellular adenosine triphosphate (ATP) level in the roots and leaves of salinized sweet potato. Lipidomic profiling revealed that exogenous MT completely prevented salt-induced triacylglycerol (TAG) accumulation in the leaves. In addition, MT upregulated the expression of genes related to TAG breakdown, fatty acid (FA) β-oxidation, and energy turnover. Chemical inhibition of the β-oxidation pathway led to drastic accumulation of lipid droplets in the vegetative tissues of NaCl-stressed sweet potato and simultaneously disrupted the MT-stimulated energy state, PM H^+-ATPase activity, and K^+/Na^+ homeostasis. Results revealed that exogenous MT stimulated TAG breakdown, FA β-oxidation, and energy turnover under salinity conditions, thereby contributing to the maintenance of PM H^+-ATPase activity and K^+/Na^+ homeostasis in sweet potato.

Phosphorus and Potassium Effects on Taproot C and N Reserve Pools and Long-Term Persistence of Alfalfa (*Medicago sativa* L.)

Berg, W.K., S. Lissbrant, S.M. Cunningham, S.M. Brouder, and J.J. Volenec. 2018. Plant Sci. 272:301-308. DOI: https://doi.org/10.1016/j.plantsci.2018.02.026.

Abstract: Improved P and K nutrition can enhance yield and persistence of alfalfa (*Medicago sativa* L.) grown on low fertility soils, but it is unknown if the improved agronomic performance is associated with greater taproot N and C reserves. Our objective was to use cluster analysis to determine how alfalfa plant persistence is altered by P and K fertilization, and determine if changes in specific taproot C and/or N reserves were associated with alfalfa plant death. Taproots were dug and plants counted in May and December of each year and taproots analyzed for P, K, starch, sugar, amino-N, and soluble protein. K-means clustering was used to create six clusters that were subsequently compared using two-sample *t*-tests. Low K in herbage and taproots was associated with low yield and poor persistence of the Low and Very Low clusters and taproots of these plants generally had low starch, protein, and amino-N concentrations. Plants died primarily between May and December. Plant persistence of the low yielding, P-deficient Medium cluster was high and associated with high starch concentrations. Low amino-N concentrations in taproots may provide an early indication of potential plant death

because these were evident in poor-persisting Low and Very Low clusters early in the study.

Nitrogen, Phosphorus, and Potassium Effects on the Physiology and Biomass Yield of Baby Spinach (*Spinacia oleracea* L.)

Lufuno Ethel Nemadodzi, Hintsa Araya, Mpumelelo Nkomo, Wonder Ngezimana, and Nixwell Fhatuwani Mudau. 2017. J. Plant Nutr. 40(14):2033-2044. DOI: https://doi.org/10.1080/01904167.2017.1346121.

Abstract: Baby spinach is a relatively new crop of commercial significance in South Africa with considerable health attributes. Three parallel trials to investigate its response to nitrogen (N), phosphorus (P), and potassium (K) were conducted. N and P (0, 45, 75, 105, and 120 kg·ha^{-1}) and K (0, 63, 85, 127, and 148 kg·ha^{-1}) treatments were applied to baby spinach in a randomized block design with four replications. After the parallel trial, NPK combination trial was also done. The biomass yield, chlorophyll content, and leaf area index increased significantly with increase in N and P rates; K had no effect on the yield, chlorophyll content, stomatal conductance, and leaf area index. Yield and chlorophyll content peaked at 75 kg·ha^{-1} of N/P but growth was best optimized at the NPK combination of 45:45:60 kg·ha^{-1}.

Effects of Nitrogen, Phosphorus and Potassium Addition on the Productivity of a Karst Grassland: Plant Functional Group and Community Perspectives

Liu, C., Y. Liu, K. Guo, X. Qiao, H. Zhao, S. Wang, L. Zhang, and X. Cai. 2018. Ecological Engineering 117:84-95. DOI: https://doi.org/10.1016/j.ecoleng.2018.04.008.

Abstract: Rocky desertification is currently the most serious ecological and environmental problem in karst region of southwestern China. Its negative consequences for both natural ecosystems and the human inhabitants of the karst region have created a need for effective ecosystem restoration strategies, but success in these efforts has been limited. We hypothesized that scarcity of mineral nutrients could be a crucial factor in vegetation recovery, but relatively little information is available about the limiting roles of various mineral elements. We investigated responses of aboveground biomass and nutrient concentrations of a degraded karst grassland to nitrogen (N), Phosphorus (P) and Potassium (K) additions over a period of three years. Nutrient additions significantly increased aboveground biomass and nutrient concentrations for both the plant community and individual plant functional groups. Total aboveground biomass was significantly increased by N (by 35.6%), P (by 35.3%) and K (by 11.7%) fertilization over three years of nutrient additions. The interaction effects of year × N and year × P on total biomass were significant. Additions of N and P increased the biomass of grasses by 39.2% and 15.0%, respectively, and additions of P increased the biomass of forbs by 69.3%. The biomass of shrubs was significantly increased by P (by 111.3%), K (by 45.3%) and N (by 38.5%), and there were strong interaction effects of N, P and K on shrub biomass. P and K additions significantly increased the relative biomass of shrubs but decreased that of grasses, especially under the NPK treatment. Our results suggest that the productivity of degraded grassland in the karst region of China is co-limited by N, P and K, with N and P being the primary limiting factors. Among functional groups, grasses are mainly limited by N and P, forbs by P, and shrubs by all 3 elements, with P being the most limiting factor overall. Mineral fertilization stimulates plant growth and may be a useful tool in efforts to restore woody vegetation in degraded grasslands, thus counteracting the process of rock desertification in the karst region of southwestern China.

Interactions Between Potassium, Calcium and Magnesium in Sugarcane Grown on Two Contrasting Soils in South Africa

Rhodes, R., N. Miles, and J.C, Hughes. 2018. Field Crops Research 223:1-11. DOI: https://doi.org/10.1016/j.fcr.2018.01.001.

Abstract: The correction of soil fertility constraints is necessary for the successful production of sugarcane. Inhibition of potassium (K) uptake by sugarcane plants in the presence of high concentrations of calcium (Ca) and magnesium (Mg) has been reported, with some sugarcane-growing countries adjusting K fertiliser recommendations accordingly. Although the depressive effect of K on Ca and Mg uptake is well documented for other crops, this phenomenon has not been widely recognised in sugarcane, and is not taken into account when making Ca and Mg recommendations. The interactions between K, Ca and Mg were therefore investigated on two contrasting soil types (Oxisol and Inceptisol) on the east coast of KwaZulu-Natal, South Africa, in factorial-designed field trials. Trials at each site included the plant crop (first crop after planting) and two ratoon crops (crops which regrow following harvest). This paper deals with the impact of the treatments on leaf nutrient levels and crop yields. Potassium treatments (0, 100, 200 and 300 kg K ha^{-1}, as KCl) resulted in significant ($P < .001$) increases in leaf K concentrations, along with relatively consistent increases in sugarcane and sucrose yields with increasing leaf K. Increased leaf K concentrations led to decreases in leaf calcium (Ca) and magnesium (Mg). Calcium silicate products Calmasil® (a calcium silicate slag) and blast furnace cement, applied at rates to supply 0 and 300 kg Si ha^{-1}, also supplied large amounts of Ca and Mg. Application of these products resulted, at times, in increased leaf Ca and Mg. Silicate application increased sugarcane and sucrose yields in three out of the four ratoon crops under study. Despite recorded increases in leaf Ca and Mg, leaf K was not decreased by silicate application on the Oxisol, and seldom so on the Inceptisol. It is proposed that the inhibitory effect of Ca and Mg on K uptake

has historically been overestimated in sugarcane, and that the reverse effect - K suppression on Ca and Mg uptake - may have been underestimated.

Potassium Relative Ratio to Nitrogen Considerably Favors Carbon Metabolism in Late-Planted Cotton at High Planting Density

Saif Ali, Abdul Hafeez, Xiaolei Ma, Shahbaz AttaTung, Anda Liu, Adnan Noor Shah, Muhammad Sohaib Chattha, Zhao Zhang, Guozheng Yang. 2018. Field Crops Research 223:48-56. DOI: https://doi.org/10.1016/j.fcr.2018.04.005.

Abstract: A new planting model characterized with late sowing, high planting density, low N and single fertilizer application is much competitive to combat the present high cost cotton production. However, what is the optimal relative ratio of K to N under this model? As we understand it certainly plays a critical role in cotton production through a series of physiological processes. A two year (2016-2017) field experiment was conducted in a randomized complete block design with three K ratios relative to N [0.8 (K_1), 1.0 (K_2), and 1.2 (K_3)] with four replications. Results showed that relative increase in K ratio had significant effect on functional leaf biomass, specific leaf weight, carbon metabolism as well as cotton yield in both growing seasons. K_3 and K_2 produced the similar seed cotton yield but higher than K_1 in both years. Similarly, K_3 and K_2 prominently up-regulated the activity of ribulose 1, 5-bisphosphate carboxylase oxygenase (Rubisco), sucrose phosphate synthase (SPS) and sucrose synthase (SS) but down-regulated the activity of soluble acid invertase (SAI), glucose-6-phosphate dehydrogenase (G6PDH) and 6-phosphogluconate dehydrogenase (6PGDH). Moreover, the balance of carbohydrates (sucrose, starch, glucose and fructose) and ATP was more efficient under higher K ratio (K_3 and K_2) as compared with K_1. These findings might suggest that K rate should be equal to N as for promising yield and profitable return are concerned under newly proposed cotton planting model in the Yangtze River Valley of China.

Effect of Potassium Chloride-Induced Stress on Germination Potential of *Artemisia annua* L. Varieties

Prasad, P., J. Mehdi, R. Mohan, N. Goyal, S. Luqman, P. Khare, and B. Kumar. 2018. Journal of Applied Research on Medicinal and Aromatic Plants 9:110-116. DOI: https://doi.org/10.1016/j.jarmap.2018.03.005.

Abstract: *Artemisia annua* L. is a well-known antimalarial plant cultivated across the globe. In this study we are reporting the effect of potassium chloride-induced stress on germination potential of two *A. annua* varieties ('CIM-Arogya' and 'Jeevan Raksha') under *in vitro* conditions. The percentage of germination, seedling vigour index I & II, enzymatic and non-enzymatic, biochemical changes were observed by varying the salt concentration in the range of 0 mM (control) to 200 mM at 15 °C coupled with 16 h light and 8 h dark photoperiod. The results revealed a non-significant decrease in the germination percentage and significant decrease in seedling vigor index while proline and lipid peroxidation increased with a rise in the potassium chloride concentration irrespective to varieties. Comparatively, 'CIM-Arogya' variety showed higher germination percentage, seedling vigor index, carbohydrate, protein, catalase, proline and lipid peroxidation except total phenolic content which was superior in 'Jeevan Raksha' at 150 mM KCl. Furthermore, 'CIM-Arogya' showed a better adaptation and tolerance potential (up to 150 mM) to potassium chloride-induced stress than 'Jeevan Raksha' (up to 100 mM).

Nutrient Responses of Wheat and Rapeseed under Different Crop Establishment and Fertilization Methods in Contrasting Agro-Ecological Conditions in Nepal

Devkota, K.P., M. Devkota, L. Khadka, A. Khadka, G. Paudel, S. Acharya, and A.J. McDonald. 2018. Soil and Tillage Research 181:46-62. DOI: https://doi.org/10.1016/j.still.2018.04.001.

Abstract: In Nepal, low fertilizer application rate is the primary factor contributing to poor yields of wheat (*Triticum aestivum* L.) and rapeseed (*Brassica campestris* var. Toria) crops. Cash constraints among the smallholders who commonly cultivate these crops necessitate economically-efficient approaches for improving yield. To that end, research was conducted to document current production practices and to assess indigenous soil fertility and responses to nitrogen (N) fertilizer applied at different rates. Fifty-five on-farm experiments (31 in wheat and 24 in rapeseed) were conducted in 2012 and 2013 in two contrasting production agro-ecologies (rainfed Hill ecology- Palpa District and irrigated plain Terai ecology- Nawalparasi District), with nutrient responses in two crop establishment methods, i.e., conventional tillage (CVT), broadcast seeding, and no residue retention on soil surface contrasted to those under 'low soil disturbance' conservation (strip) tillage (CST), line seeding, and loose residue on soil surface. Household surveys ($N = 71$ wheat, $N = 49$ rapeseed) indicated that 73% of farmers did not apply farm yard manure (FYM) at any time during the year. In Nawalparasi, over 33% of wheat farmers did not apply N, phosphorous (P), and potassium (K) fertilizers. Similar use patterns were documented for rapeseed. In Palpa, a higher percentage of farmers did not apply fertilizer and, among those that did, the mean application rates were lower than in Nawalparasi. CST and CVT crop establishment methods did not influence response to N or estimates of indigenous soil fertility in either crop or ecology. On average, yield responses to full rates of N, P, and K fertilizer were 2.2, 1.1, and 0.5 t ha^{-1} in wheat, respectively, and 0.3, 0.2, and

0.1 t ha^{-1} in rapeseed. Except for K in wheat, the yield responses to full rates of all three nutrients were higher in Palpa than in Nawalparasi, which could be due to higher yield potential or higher efficiency of use in Hill. Due to insufficient fertilizer use among farmers, the attainable yield gap that can be attributed to nutrient limitations was 2.6 and 0.34 t ha^{-1} in Palpa (Hill) and 1.9 and 0.18 t ha^{-1} in Nawalparasi (plain Terai) for wheat and rapeseed, respectively. Despite short term, this yield gap analysis showed wheat yield could be increased by 144-336% in Hill and by 95-184% in Terai and rapeseed yield over 100% in Hill and over 47% in Terai through the balanced nutrients and best-crop management practices (BMP). The comparatively low partial factor productivity (PFP) and agronomic efficiency (AE) suggests that gains in efficiency also help to close the fertility-related yield gap. This study supports findings from many other long-term and more ecologically diverse studies and provides additional justification for prioritizing increased fertilizer use coupled with management approaches that increase use efficiencies in order to close yield gaps for both crops in both agro-ecological conditions in Nepal.

Optimization of Nitrogen, Phosphorus, and Potassium Fertilization Rates for Overseeded Perennial Ryegrass Turf on Dormant Bermudagrass in a Transitional Climate

Ihtisham, M., S. Fahad, T. Luo, R.M. Larkin, S. Yin, and L. Chen. 2018. Front. Plant Sci. DOI: https://doi.org/10.3389/fpls.2018.00487.

Abstract: Bermudagrass [*Cynodon dactylon* (L.) Pers.] turf loss due to severe cold in transitional climates is a major concern. To overcome this problem, warm-season grass is often overseeded with a cool-season turfgrass. In this study, modeling and efficient nutrient management were used to evaluate this problem. A three-factor and five-level central composite rotatable design (CCRD) with a simulation of a regression model was used to optimize fertilization rates. The study investigated the combined effects of fertilization with nitrogen (N), phosphorus (P), and potassium (K) on both the morphological and physiological attributes and on the integrated turf performance (ITP) of overseeded perennial ryegrass (*Lolium perenne*). Fertilization with N and P significantly increased turf height, density, color, fresh and dry weights, while N, P, and K significantly affected turf cover, quality and winter-kill. The Spring transition was delayed by fertilization with N and P, and accelerated by fertilization with K. Photosynthesis (*Pn*), transpiration (*Tr*), and stomatal conductance (*Gs*) were considerably enhanced by fertilization with N, P, and K. Protein levels and total chlorophyll levels were substantially increased by fertilization with N and P and with N, P, and K, respectively, during a 2-year period. During two separate experiments conducted during 2 consecutive years, the optimal combinations of N, P, and K were N: 30, P: 24, K: 9, and N: 30, P: 27, K: 6 g m^{-2}. The major conclusion of this study is that a balanced nutrient application utilizing N, P, and K is key to enhancing the winter performance of perennial ryegrass.

Recycling of P and K in Circular Horticulture through Compost Application in Sustainable Growing Media for Fertigated Strawberry Cultivation

Vandecasteele, B., J. Debode, K. Willekens, and T. Van Delm. 2018. European J. Agron. 96:131-145. DOI: https://doi.org/10.1016/j.eja.2017.12.002.

Abstract: Peat replacement by compost in growing media can increase the sustainability of soilless cultivation. Compost, when mixed into growing media, is a source of fiber, i.e., a rooting medium, as well as an important source of nitrogen (N), phosphorus (P) and potassium (K). Physical properties as well as nutrient levels in growing media are known to affect plant growth and health. Therefore we monitored the evolution of nutrient release in compost-amended growing media for strawberry in greenhouse culture with drip fertigation for a double cropping system of cv. Elsanta, i.e., autumn culture with continued culture in spring. Compost amended and other alternative growing media for strawberry production were tested during four years of trials at full-scale level in a professional greenhouse growing system, in order to optimize the new cropping system with alternative substrates. Compost amended substrates contained 20-100% (v/v) compost, with different compost types tested. We assessed effects on yield and nutrients, i.e. nutrient availability in the substrate, uptake in the plants, and losses with the drainage water, as well as effect on diseases and pests (infection by powdery mildew (*Podosphaera aphanis*), aphids (*Chaetosiphon fragefolii*), and the anthracnose pathogen (*Colletotrichum acutatum*)). Adding compost to growing media has potential to increase the sustainability of soilless strawberry culture. Results show that growing strawberries on alternative substrates is feasible, but the substrate mixtures containing compost required adjusted fertigation due to nutrients supplied by the compost. This study revealed that strawberry plants made highly efficient use of the P and K in the compost when P and K input by fertigation was reduced, and that compost addition results in reduced export and potential losses of nutrients with the drain water and spent growing media. In general, the compost-amended substrates with lower N fertigation performed well as a growing medium during the autumn culture, but in the continued spring culture, these substrates needed an adapted fertigation regime for N, P and K. The N supply by the tested composts during the autumn culture allowed for significant reductions in N supplied by fertigation, i.e., 50% reduction when 100% (v/v) compost was used, and 10% reduction when 20% (v/v) compost was used. Degree of infection with powdery mildew and aphids was strongly positively correlated with the N status of the crop, pointing at the risks of

high N supply for the crop. At the end of the autumn culture, no significant positive or negative effect of the compost treatments on the latent survival of *C. acutatum* on the strawberry leaves was found.

Continuous Application of Inorganic and Organic Fertilizers over 47 Years in Paddy Soil Alters the Bacterial Community Structure and its Influence on Rice Production

Upendra Kumar, Amaresh Kumar Nayak, Mohammad Shahid, Vadakattu V.S.R. Gupta, P. Panneerselvam, Sangita Mohanty, Megha Kaviraj, Anjani Kumar, Dibyendu Chatterjee, B. Lal, P. Gautam, Rahul Tripathi, and B.B. Panda. 2018. Agriculture, Ecosystems and Environment 262:65-75. DOI: https://doi.org/10.1016/j.agee.2018.04.016.

Abstract: Soil bacterial communities are considered as an essential member of the microbial community, contributing to soil health. Continuous application of chemical fertilizers alters the bacterial community structure (BCS) thereby disturbing the soil biogeochemical cycling. The present study highlights the 16S rRNA amplicon sequencing-based variation of BCS through Illumina-MiSeq® in a 47 years old long-term fertilized paddy soil and its relation with grain yield (GY), straw biomass (SB) and various soil properties. The experiment comprising six treatments: control (no fertilizers), nitrogen (N), nitrogen + phosphorus (P) + potassium (K), farmyard manure (FYM), FYM + N and FYM + NPK. Data on rice crop performance indicated that GY and SB significantly ($p \leq 0.05$) enhanced by 45.1%-49.3% and 36.9-39.4% in FYM + NPK compared to control. Relative abundance of bacterial phyla varied across inorganic and organic fertilizer treatments. Dominant phyla across all treatments were Proteobacteria, Acidobacteria, Actinobacteria, Chloroflexi, and Firmicutes, accounting for about 80-85% of total operational taxonomic units (OTUs). N application alone over 47 years encouraged certain bacterial phyla (Firmicutes, Actinobacteria, and Nitrospira) while major (Proteobacteria, Acidobacteria and Cyanobacteria) and minor (Fibrobacteres, Spirochaetes, TM7 and GNO4) bacterial phyla were found to be suppressed compared to other treatments. Moreover, continuous use of chemical N in paddy soil, considerably suppressed some diazotrophs taxa Burkholderiales, Enterobacteriaceae, and other taxa *Kaistobacter*, *Anaeromyxobacter*, *Bdellovibrio*, and MND1. Redundancy analysis coupled with principal component analysis revealed that BCS was significantly influenced by soil pH and presence of higher nitrogen content. Interestingly, the highest proportion of bacterial OTUs was recorded in balanced fertilizer (NPK) (without FYM) and therefore, this result suggested for the first time that continuous application of NPK encouraged the beneficial bacterial community without compromising of GY and SB. Overall, the present study indicated that continuous application of N and NPK with or without FYM for more than four decades in paddy soil, encouraged certain BCS whereas, N application alone suppressed certain beneficial bacterial phyla, resulting in the alteration of soil biodiversity and rice productivity.

Effect of Tillage and Crop Establishment, Residue Management and K Fertilization on Yield, K Use Efficiency and Apparent K Balance under Rice-Maize System in North-Western India

Singh, V.K., B.S. Dwivedi, Yadvinder-Singh, S.K. Singh, R.P. Mishra, A.K. Shukla, S.S. Rathore, K. Shekhawat, K. Majumdar, and M.L. Jat. 2018. Field Crops Research 224:1-12. DOI: https://doi.org/10.1016/j.fcr.2018.04.012.

Abstract: The rice-maize cropping system (RMS) is an emerging option for diversification of the prevalent rice-wheat system (RWS) in South Asia. Studies underlined the significance of adequate potassium (K) nutrition for sustainable intensification of the RMS. Although studies on combined effects of tillage, residue retention, and nutrient management on crop yields and nutrient use efficiency for the RWS are plenty, such studies are scarce for the RMS. We, therefore, conducted a 5-year field study on sandy loam (Typic Ustochrept) soil at Modipuram, India to evaluate the effects of tillage and crop establishment, residue management and K fertilization on crop productivity, K use efficiencies, changes in soil K status, and apparent K balance under irrigated RMS in north-western India. Three combinations of tillage and crop establishment methods i.e., puddled transplanted rice (TPR) followed by conventional-till maize (TPR/CTM); conventional-till dry direct-seeded rice (CTDSR) followed by CTM (CTDSR/CTM); and zero-till DSR followed by zero-till maize (ZTDSR/ZTM) were considered as main plots. Sub-plot treatments consisted of two residue management options i.e., removal of residues (-R) of both crops, and partial residue retention (5 Mg ha^{-1}) for rice and maize, either at soil surface in zero till (ZT) plots or incorporated into the soil in conventionally-till (CT) plots (+R). The sub-sub plot treatments were no-K application (-K) and 62 kg K ha^{-1} application (+K) to both rice and maize. Data summed-up for 5 years revealed that rice grain yield and K uptake under TPR were significantly higher ($p < 0.05$) compared with CT/ZT DSR, irrespective of residue and K management options. The maize yield and K uptake were highest under the ZTDSR/ZTM treatment. Both rice and maize yields were significantly ($p < 0.05$) higher with 62 kg ha^{-1} K application under -R plots, but such effects were not significant under +R plots. Similarly the effect of residue management on yield and K uptake of rice and maize was significant only in the absence of fertilizer K application. Recycling of rice residue in maize had more pronounced effect on K uptake compared with that of maize residue in rice. Agronomic and recovery efficiencies of applied K were lower under +R plots, and agronomic efficiency was further decreased when both rice and maize were grown under ZT conditions (ZTDSR/ZTM). Soil exchangeable K content at 0-0.05 m and 0.05-0.15 m depths was

significantly higher ($p < 0.05$) under ZTDSR/ZTM compared with that under CTDSR/CTM and TPR/CTM treatments, and the values were greater under +R+K compared with -R-K treatments. Soil exchangeable K under -K-R plots dropped to 102 and 90 mg kg^{-1} at 0-0.05 m and 0.05-0.15 m depth, respectively vis-a-vis the initial K content (122 and 114 mg kg^{-1}, respectively). The apparent K balance, computed as K addition less K off-take by rice and maize during the study period of 5 years, was invariably negative in the absence of K fertilizer i.e., -307 kg ha^{-1} in TPR/CTM (+R-K) to -1483 kg ha^{-1} in ZTDSR/ZTM (-R-K) treatments. On contrary, the apparent K balance was positive in +R+K plots under different tillage and crop establishment methods. Positive correlation between soil exchangeable K and K input indicated that soil K mining in the RMS could be mitigated to a great extent with adequate supply of K through residue retention and K fertilization.

Effect of Applied Potassium Concentration on Clay Dispersion, Hydraulic Conductivity, Pore Structure and Mineralogy of Two Contrasting Australian Soils

Marchuk, S., and A. Marchuk. 2018. Soil and Tillage Research 182:35-44. DOI: https://doi.org/10.1016/j.still.2018.04.016

Abstract: Re-use of industrial and agricultural wastewater for irrigation can increase the concentration of potassium ions in soil solution and affect soil structural stability. However, investigations of clay dispersion have traditionally focused on soils with high exchangeable sodium. The objective of this study was to quantify the effects of potassium application on physical, chemical and mineralogical properties of two contrasting soils from South Australia. This work combines traditional soil and clay analysis methods with a range of additional techniques, including, scanning electron microscopy, transmission electron microscopy, X-ray diffraction and modeling for characterizing and quantifying the movement of different forms of potassium in soil. In laboratory studies, soils were treated with varying amounts of potassium and the measurements were made on the range of soil/clay properties before and after treatments. The results show that applied potassium can cause dispersion of soil but to a lesser extent than sodium. Potassium cations also could increase soil hydraulic conductivity (HC) to some extent when applied to a soil with high sodium content by substituting the Na^+ on exchange sites. Potassium could be fixed by clay minerals, changing their composition, decreasing cation exchange capacity and increasing mineral potassium content. This increase was confirmed by the decomposition of XRD diagrams and chemical analysis, consistently showing the increases in amount of mica/illite clay minerals in soils treated with potassium rich solutions. The dynamic of "illitisation" can be monitored by XRD analysis both qualitatively and quantitatively. X-ray computed tomography (CT) scanning of the soil columns has allowed visualization and quantification of the changes in pore system occurred due to the application of potassium.

Yield of and Nutrient-Water Use by Maize Exposed to Moisture Stress and K Fertilizers in an Inceptisol of West Bengal, India

Bhattacharyya, K., T. Das, K. Ray, S. Dutta, K. Majumdar, A. Pari, and H. Banerjee. 2018. Agricultural Water Management 206:31-41. DOI: https://doi.org/10.1016/j.agwat.2018.04.038.

Abstract: Potassium (K) is important for both qualitative and quantitative traits of maize. However, role of this macronutrient is often being ignored, and is often applied as an optional nutrient, with no proper fertilizer recommendation. Present experiment focused on the role of K fertilization in determining soil K fractions, maize yield, K and water use by maize under different irrigation regimes. Result revealed that K-fertilization significantly improved available soil K, fractions of K (especially non-exchangeable, mineral and total fractions), maize yield, K uptake and water use efficiency. Imposition of moisture stress up to 50% available soil moisture deficit (ASMD) significantly increased all the aforementioned parameters over the no stress situation, while irrigation available at 75% ASMD reduced them significantly. Soil K fractions, under different K fertilizations and irrigation schedules, decreased with the increase in soil depth upto 90 cm. Only exception was non-exchangeable soil K which remained stable across soil depths. The relationship among different K fractions and available soil K was estimated. Available K was observed to have strongest correlation with water soluble and exchangeable K in all possible irrigation regimes. Path analysis studies revealed that water soluble K exerted highest direct effect on changes in maize grain yield and K uptake followed by exchangeable, non-exchangeable and mineral K under irrigation availability at 25 and 50% ASMD. However, exchangeable K exerted highest direct effect on maize grain yield at 75% ASMD.

Potash Use in Aerobic Production System for Basmati Rice May Expand its Adaptability as an Alternative to Flooded Rice Production System

Wakeel, Abdul, Hafeez Ur Rehman, Muhammad Umair Mubarak, Abid Ilyas Dar, and Muhammad Farooq. 2017. J. Soil Sci. Plant Nutr. 17(2):398-409. DOI: http://dx.doi.org/10.4067/S0718-95162017005000029.

Abstract: Direct seeded aerobic rice system has been developed and adopted as an alternative for medium-grain rice in many parts of the world, whereas efforts for aerobic basmati rice types are still in infancy. Among two major constraints for aerobic rice, weeds are progressively being eliminated to great extent through introduction of new herbicides; however, the issue of unfilled

grains is still elusive. As potassium (K) deficiency produce sterile pollens in different crops, therefore possible K deficiency in aerobic rice production system may increase unfilled grains in rice. Therefore, it was hypothesized that K application may yield better by improving grain filling of basmati rice, especially, under aerobic conditions. Pot and field experiments were comprised of no K as control, K fertilization using 90 and 180 kg ha^{-1} keeping recommended N, P and Zn fertilization at the rate of 180, 125 and 25 kg ha^{-1}. Two fine grain rice cultivars Basmati-515 and Super basmati were used due to their differential response to K fertilization. Results indicated that application of 180 kg K_2O ha^{-1} significantly increased the K concentration in shoot, which increased the paddy yield. Highest chlorophyll contents were observed for Basmati-515 in aerobic rice and for Super basmati under flooded condition at 180 kg K_2O ha^{-1}. Decrease in number of un-filled grains may a contributory to paddy yield improvement in K fertilized treatments. The improvement in yield was more pronounced in Basmati-515 than Super basmati. Economic analysis showed higher benefit cost ratio for Basmati-515 with 90 kg K_2O_5 ha^{-1} under aerobic conditions. Net benefit of K fertilization was increased for both fertilizer rates and both cultivars except 180 kg K ha^{-1} in Super basmati. As K fertilization increased the number of filled grains and improved the rice yield, therefore it is suggested to apply K fertilizers for better yield and expanded adaptability of aerobic rice production system for basmati rice. Availability of indigenous soil K under aerobic and flooded conditions should be quantified to develop precise K recommendations for both production systems of basmati rice.

The Variability of Cottonseed Yield under Different Potassium Levels is Associated with the Changed Oil Metabolism in Embryo

Wei Hu, Zhen Dai, Jiashuo Yang, John L. Snider, Shanshan Wang, Binglin Chen, Zhiguo Zhou. 2018. Field Crops Research 224:80-90. DOI: https://doi.org/10.1016/j.fcr.2018.05.007.

Abstract: Although the effects of potassium (K) fertilizer on cottonseed yield have been explored, reports on cottonseed yield components and related oil metabolism in genotypes differing in sensitivity to low K are limited. To this end, the cultivars Simian 3 (low K-tolerant) and Siza 3 (low K-sensitive) were grown in 2012 and 2013 under three K_2O rates (0, 150 and 300 kg ha^{-1}). Results indicated that K application treatments (150 and 300 kg K_2O ha^{-1}) increased seedcotton yield, oil yield, protein yield, seed weight boll^{-1} and individual seed weight. Higher individual seed weight as the most basic cottonseed yield component was attributed to the enhanced oil weight seed^{-1} rather than protein weight seed^{-1} at higher K application rates. Higher oil weight seed^{-1} in the K application treatments than the 0 kg K_2O ha^{-1} treatment was a consequence of differences in oil accumulation dynamics. Additionally, higher rates of oil accumulation in the K application treatments were closely associated with phosphatidic acid phosphatase and glucose-6-phosphate dehydrogenase activities. Fatty acid composition was also altered by K treatment, where the percentage of palmitic and tetradecanoic acids decreased and linoleic acid percentage increased with K application, leading to a higher ratio of total unsaturated fatty acids to total saturated fatty acids. Furthermore, the magnitudes of increases in seedcotton yield and individual seed weight with K application were greater in the low-K sensitive cultivar than the low-K tolerant one. K application influenced oil accumulation dynamics and fatty acid saturation levels to a greater extent in the low-K sensitive cultivar than the low-K tolerant cultivar. In conclusion, K application could positively influence cottonseed yield by increasing oil accumulation in individual seed and positively improve the unsaturated fatty acid percentage of cottonseed oil.

OsHAK1 Controls the Vegetative Growth and Panicle Fertility of Rice by its Effect on Potassium-Mediated Sugar Metabolism

Guang Chen, Yu Zhang, Banpu Ruan, Longbiao Guo, Dali Zeng, Zhenyu Gao, Li Zhu, Jiang Hu, Deyong Ren, Ling Yu, Guohua Xu, Qian Qian. 2018. Plant Science 274:261-270. DOI: https://doi.org/10.1016/j.plantsci.2018.05.034.

Abstract: Plant growth and reproduction are both energy-requiring processes; the necessary energy is supplied by the products of photosynthesis. Both the vegetative growth and reproductive success of rice are compromised by the absence of a functional copy of the gene *OsHAK1*. Here, a comparison between wild type rice and *OsHAK1* knockout mutants not only confirmed the known detrimental effect of the absence of OsHAK1 on root growth, pollen viability and fertility, but also showed that sucrose phosphate synthase activity was lowered, and the sucrose content of the leaves was markedly increased, due to a partial block on the up-loading of sucrose into the phloem. The impaired allocation of sugar to the roots and spikelets caused by the knocking out of *OsHAK1* was accompanied by a down-regulation in the leaf sheaths and panicle axes of genes encoding sucrose transporters (*SUT* genes), which are active in the phloem, as well as in the roots and spikelets of those encoding monosaccharide transporters (*MST* genes), which transport hexose sugars across the plant plasma membrane. The activity of sucrose synthase, acid invertase and neutral invertase in the roots of mutant plants assayed at the tillering stage, and in their spikelets, assayed during grain-filling, was significantly lower than in the equivalent organs of wild type plants. As a result, the supply of total soluble sugar, glucose and fructose to sink organs was reduced, consistent with the effect of the mutation on root growth and panicle fertility. Compared to wild type plants, the mutants accumulated less potassium (K) throughout the plant. The conclusion was that the failure to fully supply the demand of the mutant's sink organs for assimilate was responsible for its compromised phenotype, and that the deficiency in K uptake

induced by the loss of OsHAK1 functionality was responsible for the disruption of sugar metabolism.

The Arabidopsis AtUNC-93 Acts as a Positive Regulator of Abiotic Stress Tolerance and Plant Growth via Modulation of ABA Signaling and K^+ Homeostasis

Xiang, J., X. Zhou, X. Zhang, A. Liu, Y. Xiang, M. Yan, Y. Peng, and X. Chen. 2018. Front. Plant Sci. 9:718. DOI: https://doi.org/10.3389/fpls.2018.00718.

Abstract: Potassium (K^+) is one of the essential macronutrients required for plant growth and development, and the maintenance of cellular K^+ homeostasis is important for plants to adapt to abiotic stresses and growth. However, the mechanism involved has not been understood clearly. In this study, we demonstrated that AtUNC-93 plays a crucial role in this process under the control of abscisic acid (ABA). AtUNC-93 was localized to the plasma membrane and mainly expressed in the vascular tissues in *Arabidopsis thaliana*. The *atunc-93* mutants showed typical K^+-deficient symptoms under low-K^+ conditions. The K^+ contents of *atunc-93* mutants were significantly reduced in shoots but not in roots under either low-K^+ or normal conditions compared with wild type plants, whereas the *AtUNC-93*-overexpressing lines still maintained relatively higher K^+ contents in shoots under low-K^+ conditions, suggesting that AtUNC-93 positively regulates K^+ translocation from roots to shoots. The *atunc-93* plants exhibited dwarf phenotypes due to reduced cell expansion, while *AtUNC-93*-overexpressing plants had larger bodies because of increased cell expansion. After abiotic stress and ABA treatments, the *atunc-93* mutants was more sensitive to salt, drought, osmotic, heat stress and ABA than wild type plants, while the *AtUNC-93*-overexpressing lines showed enhanced tolerance to these stresses and insensitive phenotype to ABA. Furthermore, alterations in the *AtUNC-93* expression changed expression of many ABA-responsive and stress-related genes. Our findings reveal that AtUNC-93 functions as a positive regulator of abiotic stress tolerance and plant growth by maintaining K^+ homeostasis through ABA signaling pathway in Arabidopsis.

Read On

Quality: Potassium Management is Critical for Horticultural Crops

Mikkelsen, R. 2018. Better Crops 2:24-26.

Pursuing Sustainable Productivity with Millions of Smallholder Farmers

Zhenling Cui *et al.* 15 March 2018. Nature 555:363-366.

Can Dirt Save the Earth?

Agriculture could pull carbon out of the air and into the soil - but it would mean a whole new way of thinking about how to tend the land.

Velasquez-Manoff, M. 18 April 2018. The New York Times Magazine.

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