



Research Findings



Wheat plots in the vicinity of Debre Berhan, Semien Shewa zone, Amhara region, Ethiopia. Photo by E. Sokolowski.

Potash Fertilization of Teff and Wheat in the Highlands of Ethiopia

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Abstract

Arable lands in Ethiopia are seriously degraded as a result of natural and anthropogenic factors. DAP (di-ammonium phosphate) and urea have been the only fertilizers in use for the past four decades in Ethiopia, while potassium (K) fertilizers were considered unnecessary. However, recent studies have shown that Ethiopian soils undergo continuous K depletion, and that supplemented K may assist in elevating productivity of cereals. In the present study, on-farm experiments were conducted in 83 teff fields, and 150 wheat fields, in Tigray, Oromiya, and Amhara - three large states in Ethiopia. In each field, a pairwise test was carried out, comparing a common practice plot with a

‘+K treatment’ plot, which received an additional 50 kg KCl ha⁻¹. On average, the ‘+K treatment’ gave rise to significant yield increases of 289.4, 160.3, and 183.2 kg teff grains ha⁻¹, and 307.0, 448.5, and 170.0 kg wheat grains ha⁻¹, in Tigray, Oromiya, and Amhara, respectively. Nevertheless, an immense diversity

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occurred in the control yields of both crops, and also in the yield response to K application. Possible reasons for this yield diversity, as well as appropriate approaches aimed at raising cereals' yields while preserving the system's sustainability, are discussed.

Keywords: *Eragrostis tef*; potassium; soil degradation; *Triticum aestivum*; yield.

Introduction

Agriculture, characterized mainly by smallholder farming, is the dominant economic activity in Ethiopia. There are many constraints hampering Ethiopian agricultural productivity, among which the depletion of soil fertility is a key factor. Arable lands in Ethiopia are seriously degraded as a result of natural and anthropogenic factors. Along with the 'low input - low output' approach typifying the smallholder agricultural system, Ethiopian farmers still use lower fertilizer application rates compared with their counterparts in East Africa. In addition, the use of farmyard manure and crop residues is nil, or at minimum levels, subjecting soils to rapid nutrient removal. However, during recent years, the Ministry of Agriculture and Natural Resources, and the Regional Agriculture and Natural Resource Bureaus, have intensified the promotion of compost use among smallholder farmers in order to replenish soil fertility and to increase agricultural productivity.

In the framework of the 'Freedom from Hunger Campaign' during the 1960-70's (Bunch, 2007), FAO launched fertilizer demonstration trials that showed the importance of nitrogen (N) and phosphorus (P) - in this order - as the most crop-limiting nutrients in Ethiopian soils. These trials also showed that the response to potassium (K) was inconsistent or not significant enough to include it in the recommended fertilizer package. In addition, the exchangeable K content of most agricultural soils, particularly Vertisols, exceeded the

universally accepted threshold set according to the ammonium acetate extraction method. Thus, until recently, the notion that "K fertilizers are not necessary" was widely adopted. Even a recent survey on the impacts of land use changes on soil fertility did not include K in the list of essential soil macronutrients (Haile *et al.*, 2014). Subsequently, DAP (di-ammonium phosphate) and urea were the only fertilizers in use for the past four decades in Ethiopia. Indeed, K fertilizer was not imported for crop production in Ethiopia until 2014.

Thus, after decades of soil-K exhaustion, indications for the increasing need to restore the soil-K status are gradually emerging (Haileselassie *et al.*, 2005; Kraaijvanger and Veldkamp, 2015). There are reports indicating sharp increases in wheat (*Triticum*) grain and straw yields in response to application of 50 kg K_2SO_4 per ha on Vertisols (Astatke *et al.*, 2004). Similar results were reported by Berhe and Gebretsadik (2010) for teff (*Eragrostis tef*) crops grown on Vertisols. In addition, farmers in the

central highlands of Ethiopia often apply wood ash to their Vertisol fields, in fact enriching the soil with K (52%) and sulfur (S) (18%). It is strongly suspected that at a very low soil-K status, exchangeable K tends to undergo fixation to clay crystal lattices in Vertisols, resulting in reduced K availability. Other findings have shown that some Ethiopian acid soils are also K-deficient (Paulos, 1996; Abayneh and Birhanu, 2006).

The lack of a reliable countrywide soil fertility database is a key obstacle in realizing the government's recent plans to double agricultural production within a five-year period. In order to tackle this problem, the Ministry has designed a two-pronged approach: 1) to conduct a soil and plant nutrient survey in priority areas in order to determine key soil nutrient limitations; 2) to test different imported straight, blended or compound fertilizers against the commonly used fertilizers (DAP and urea) for their impact on crop yield in different areas and crops. In contributing to the second approach, the present study's objective was to evaluate



Comparison of adequate balanced fertilizer application (photo left) to half of the amount (photo right). Location: Southern Nations, Nationalities, and Peoples' Region (SNNPR), zone Wolaita, Woreda=Sodozuria, site=Kokate. Photo by E. Sokolowski.

K requirements and to demonstrate the contribution of adding this nutrient to the common fertilization practice on wheat and teff yields in Tigray, Oromiya and Amhara - three Ethiopian regions (Fig. 1) where these crops dominate agricultural production.

Materials and methods

Verification trials for K response in teff and wheat were conducted in the central highlands of Ethiopia in the three states of Tigray, Oromiya and Amhara. Amhara and Oromiya are high rainfall areas while Tigray is not (Fig. 1). The dominant soil types for all states are Vertisols and Nitisol. The trial was conducted in different farmers' fields throughout the states. Each farmer grew

one crop. There were two plots per farmer laying side by side: one for the control and the other for the additional K treatment, with a one meter wide path between them.

There were two treatments: 1) control, where the common fertilizer practice of urea and DAP was applied, and; 2) '+K treatment', where KCl was applied at 50 g ha⁻¹, in addition to the urea and DAP fertilizer (Table 1). No other fertilizers were applied. For each treatment, the plot size was 250 m² for teff, and 500 m² for wheat. The Kuncho variety was used for teff, while different improved varieties recommended for the areas were used for wheat. On Vertisols, wheat was planted on broad beds,

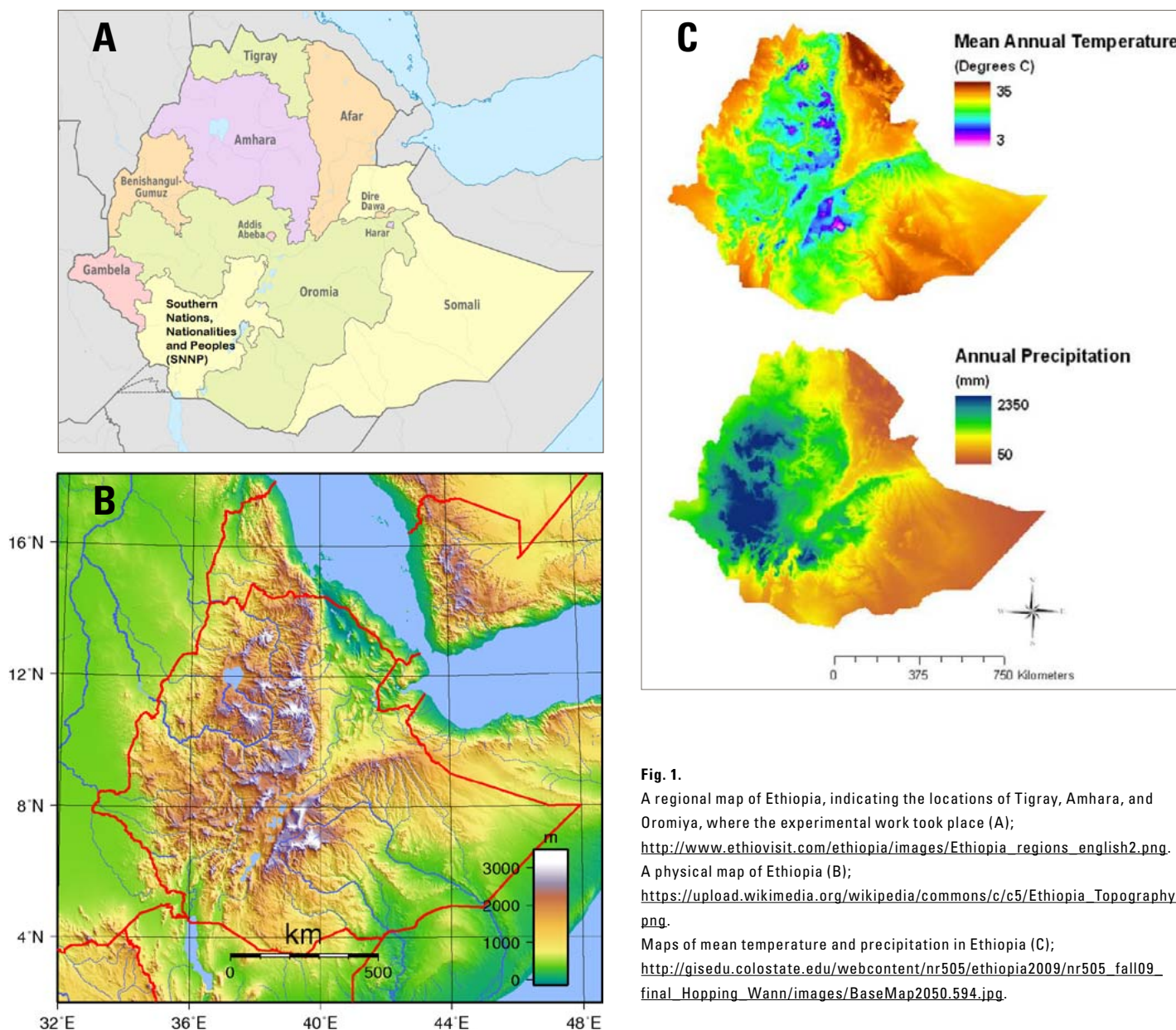


Fig. 1. A regional map of Ethiopia, indicating the locations of Tigray, Amhara, and Oromiya, where the experimental work took place (A); http://www.ethiovisit.com/ethiopia/images/Ethiopia_regions_english2.png. A physical map of Ethiopia (B); https://upload.wikimedia.org/wikipedia/commons/c/c5/Ethiopia_Topography.png. Maps of mean temperature and precipitation in Ethiopia (C); http://gisedu.colostate.edu/webcontent/nr505/ethiopia2009/nr505_fall09_final_Hopping_Wann/images/BaseMap2050.594.jpg.

Table 1. Fertilizer type and dose applied to the two treatments in the teff and wheat experiments in Ethiopia.

Fertilizer	Treatments	
	Control	+K treatment
	-----kg ha ⁻¹ -----	
Urea	100	100
DAP (di-ammonium phosphate)	100	100
KCl (potassium chloride)	0	50

constructed using a “broad bed maker” or other local tools, in order to facilitate drainage of excess water. All recommended cultural practices were followed.

The statistical analysis were performed using pairwise t-tests, with a confidence level of 0.95. Data analysis was conducted separately and independently for each region and crop, as well as for all plots regarded as a whole for each crops. Before statistical analysis, the data was trimmed in order to remove outliers.

Results

Teff

Application of 50 kg KCl ha⁻¹, added to the common fertilizer practice of urea and DAP, gave rise to average teff yield increase of 289, 160, and 183 kg ha⁻¹, in Tigray, Oromiya, and Amhara, respectively. However, the range of control teff yields and, furthermore, the response patterns to K application differed significantly between and within the regions. In Tigray, control teff yields ranged from 1,960 to 4,000 kg ha⁻¹, which were very high compared to Oromiya and Amhara, where in 78 and 68% of the plots, respectively, control yields were considerably lower than 2,000 kg ha⁻¹ (Fig. 2).

The pattern of the teff relative yield added in response to a standard KCl dose of 50 kg ha⁻¹ was largely affected by the control yield level. In Tigray and Oromiya, logarithmic-type functions could be roughly fitted, according to which the relative contribution of K application to yield was mostly higher at the lowest control yield levels and significantly declined as control yields increased (Fig. 3). The situation in Amhara was quite different; yield response was very low, even negative, where control yields were lower than 1,300 kg ha⁻¹. From that basic yield level, and up to about 2,500 kg ha⁻¹, teff response to K application scattered widely from 3 to 25% yield increase, with a few exceptions reaching even higher rates (Fig. 2). Nevertheless, above a control yield of 2,500 kg ha⁻¹, yield response to K application fluctuated between high and negative values. Consequently, teff response pattern to the single KCl dose in Amhara may be described roughly by a negative parabolic-type function of the control yield.

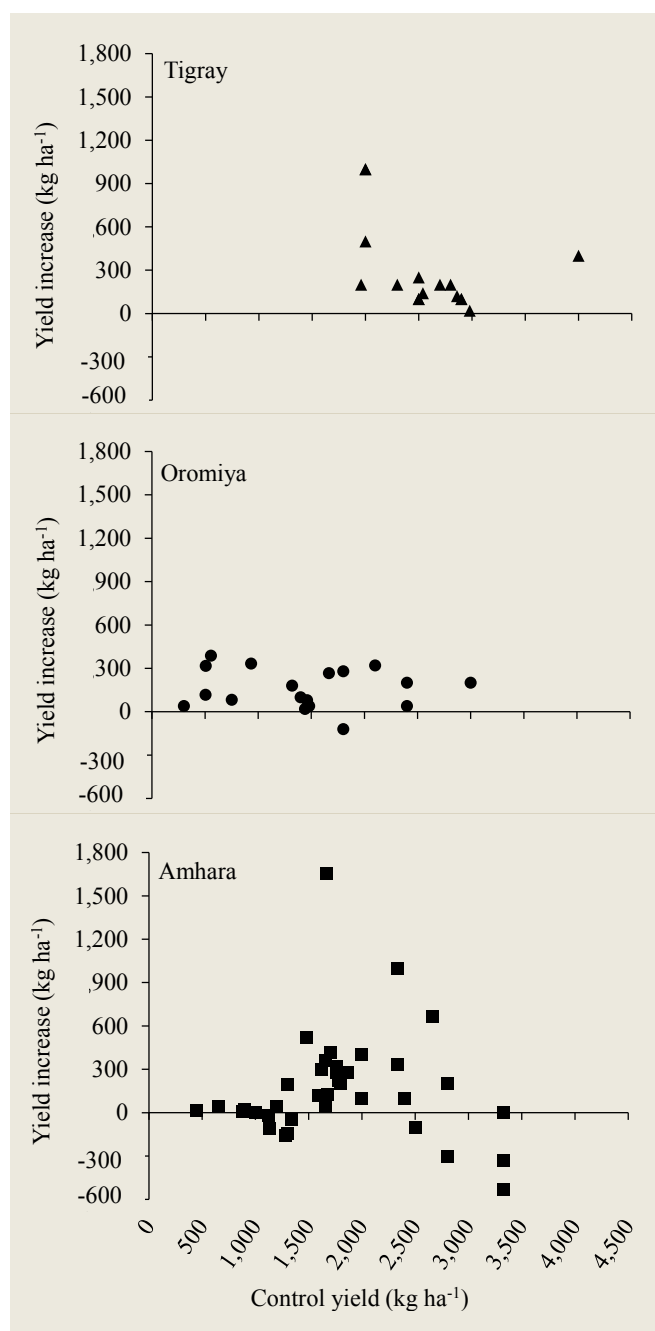


Fig. 2. Teff absolute yield increase in response to application of 50 kg KCl ha⁻¹, as a function of the control yield in three regions of Ethiopia.

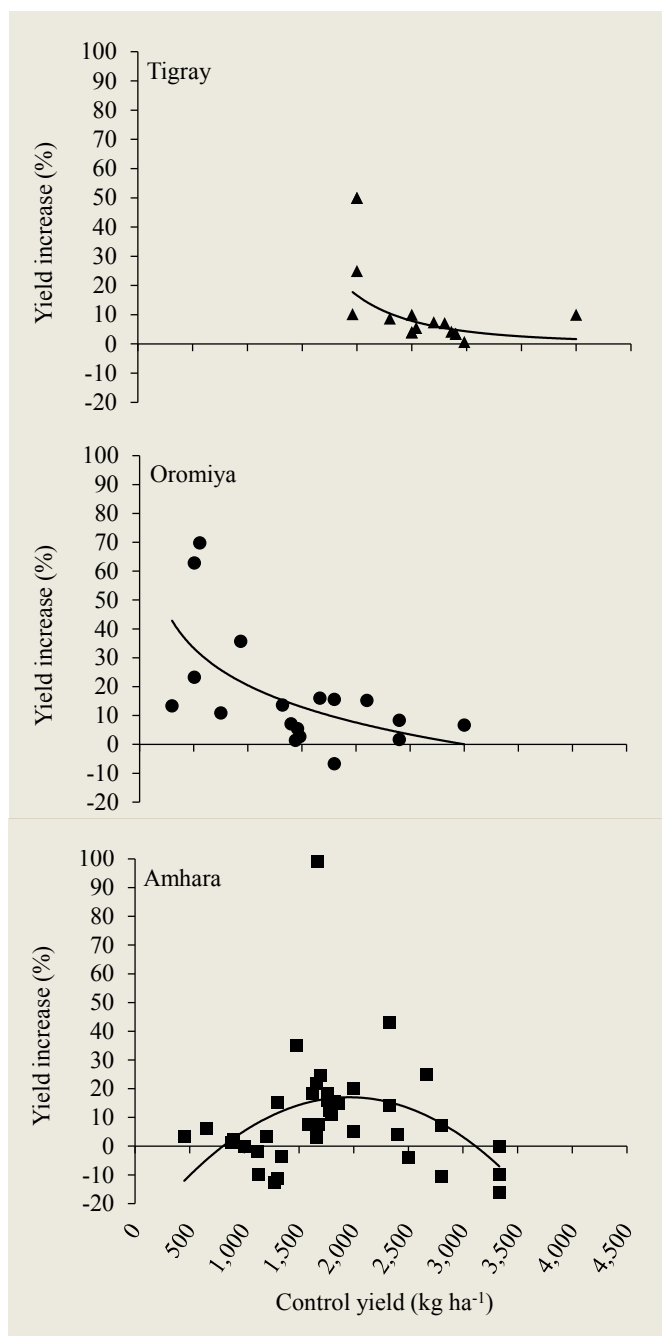


Fig. 3. Teff relative yield increase in response to application of 50 kg KCl ha⁻¹, as a function of the control yield in three regions of Ethiopia.

Wheat

Control wheat yields in Tigray were bound to a relatively narrow range, from 2,300 to 5,500 kg ha⁻¹ (Fig. 4). Excluding two plots, K application resulted in yield increases ranging from a few to 1,000 kg ha⁻¹, averaging at 307 kg ha⁻¹. In Oromiya, control yields displayed very high variability, ranging from 400 to 8,400 kg ha⁻¹. Also here, with the exception of three plots, the majority of the

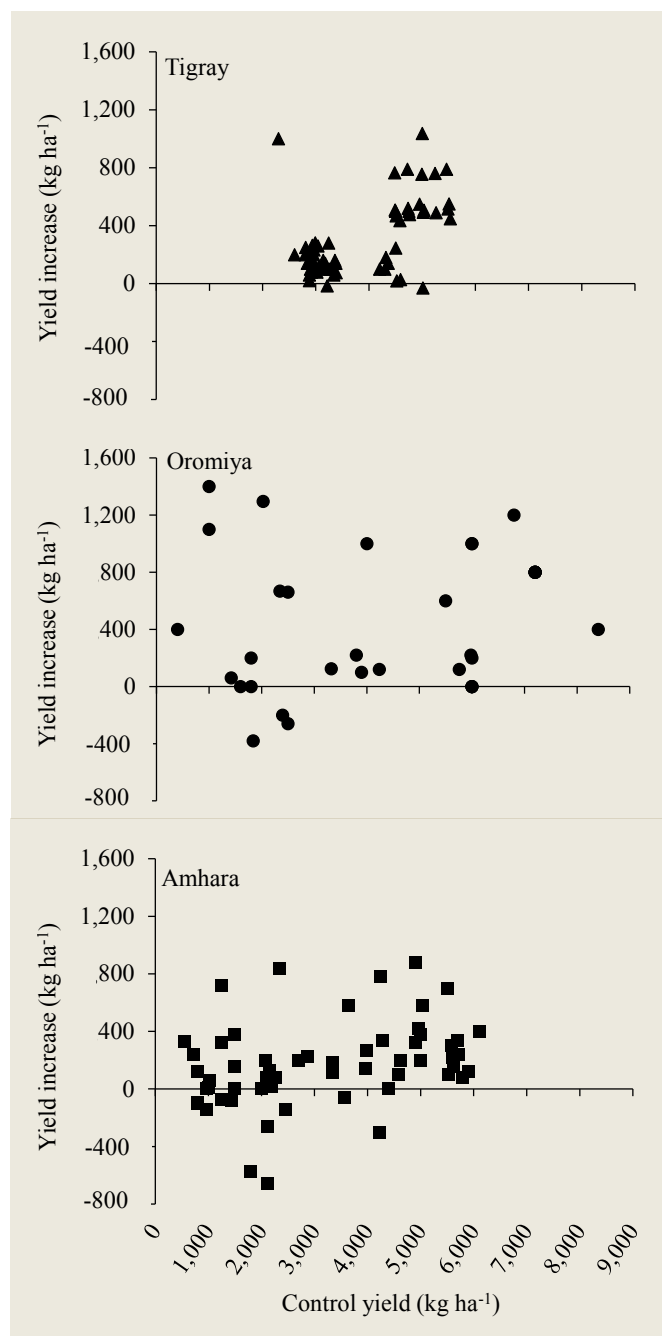


Fig. 4. Wheat absolute yield increase in response to application of 50 kg KCl ha⁻¹, as a function of the control yield in three regions of Ethiopia.

plots displayed yield increases from a few to 1,400 kg ha⁻¹, with an average of 448 kg ha⁻¹. In Amhara, control wheat yields ranged from 540 to 6,100 kg ha⁻¹. Potassium application brought about the lowest average yield increase, only 170 kg ha⁻¹. However, it included a number of negatively responding plots (17%), while the additional yield among the majority of the plots ranged from a few to 880 kg ha⁻¹ (Fig. 4).

The highest relative yield responses to K application seemed to occur where control yields were below 2,000 kg ha⁻¹, as was particularly noticed in Amhara and Oromiya (Fig. 5). The added yield was, in some cases, as high as 100-140% in Oromiya, and about 40-60% in Amhara. Nevertheless, most cases of a negative response also occurred at this range of control yield, making it difficult to illustrate any solid relationships between the control yield and the rate of yield response to K application. Above a control yield of 2,000 kg ha⁻¹, the relative yield increase varied up to a threshold of 20%, which was very seldom crossed.

Discussion

On average, the supplemented dose of 50 kg KCl ha⁻¹ brought about significant increases in both teff and wheat yields in all three Ethiopian regions (Table 2). These preliminary results indicate that, generally, soils in most experimental locations have undergone some nutrient depletion and lack available K. Consequently, the idea to disseminate K fertilization practices seems to have considerable potential to increase cereals productivity in Ethiopia.

Nevertheless, there was an immense diversity in the control yields, where no K fertilizer was added. Teff yields ranged from as low as 300 up to 3,000 kg ha⁻¹ in Oromiya, and from 450 to 3,300 kg ha⁻¹ in Amhara (Figs. 2 and 3). In a similar way, wheat yields ranged from 400 up to 6,100 or 8,400 kg ha⁻¹, in Oromiya and Amhara, respectively (Figs. 4 and 5). Tigray, on the other hand, displayed narrower yield ranges, from 2,000 to 4,000 kg ha⁻¹ for teff, and from 2,300 to 5,500 kg ha⁻¹ for wheat. This diversity in yields, within as well as between regions, calls for careful dissection before any recommendations are disseminated.

A major reason for yield variability is the particular topography and climate of the Ethiopian highlands, where the survey took place. The altitude of teff and wheat production areas, which may vary from 1,800 to 2,800 m, plays an important role in the distribution of wheat production through its influence on rainfall, temperature, and disease presence. Since teff and wheat are often grown to meet farmers' basic self-nutritional requirements, with no alternatives, yield levels are seldom considered. This, along with the unpredictable precipitation regime and distribution characterizing many regions in Ethiopia, may provide possible explanations for the unusually wide range of yields within the same region.

Teff is an allotetraploid cereal crop indigenous to Ethiopia (Ingram and Doyle, 2003). It comprises about 25% of the local cereal consumption, and has recently gained significant worldwide attention as a 'super food' (Gebremariam *et al.*, 2014). During centuries of local trade and cultivation, teff has developed significant internal diversity, including several recognized varieties and numerous landraces (Belay *et al.*, 2006). Wheat diversity in Ethiopia is much more complex (Gebre-Mariam *et al.*,

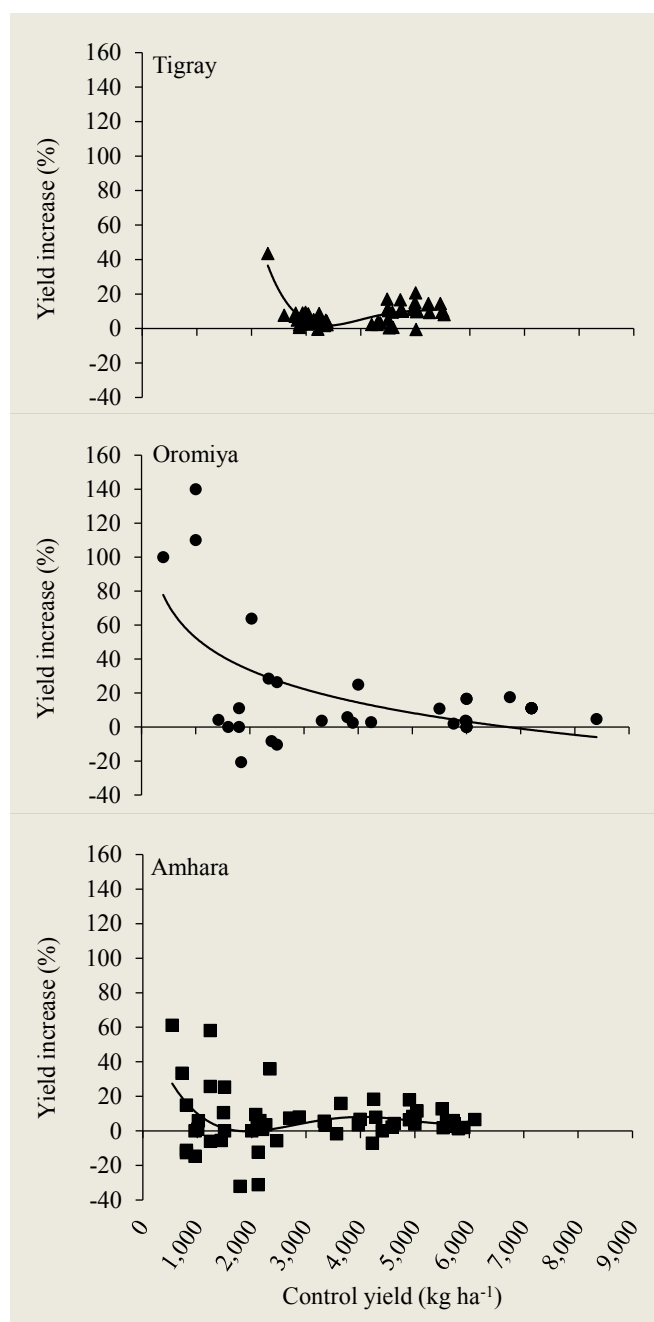


Fig. 5. Wheat relative yield increase in response to application of 50 kg KCl ha⁻¹, as a function of the control yield in three regions of Ethiopia.

1991). While bread wheat (*T. aestivum*) cultivars were gradually introduced into Ethiopia during recent centuries, durum wheat (*T. durum*) is indigenous to Ethiopia where it has been cultivated since ancient times (Mengistu and Pé, 2015; Mengistu *et al.*, 2016). Tradition, personal experience, soil fertility, and altitude are among the major considerations made by the local smallholder when they choose a variety, a landrace, or often a mixture from the considerable genetic range of wheat available (Dea and Scoons,

Table 2. Mean yield contribution of K application (50 kg KCl ha⁻¹) above control, measured for teff and wheat crops in a countrywide experiment at farmers' fields in Tigray, Oromiya, and Amhara, Ethiopia.

Crop/region	Plots	Mean yield difference	±SE
-----kg ha ⁻¹ -----			
Teff			
Tigray	16	289.4	75.5
Oromiya	18	160.3	32.4
Amhara	49	183.2	52.3
Wheat			
Tigray	58	307.0	34.6
Oromiya	34	448.5	82.8
Amhara	58	170.0	38.9

2003). Besides the great potential of this genetic diversity for the improvement of wheat productivity (Mengistu *et al.*, 2016), tremendous variability is obviously introduced into any broad-scale on-farm experiment. The inordinate genetic variation, in both teff and wheat, offers additional perspectives to the yield diversity presented here.

Yield response to the added K dose, illustrated against the control yield at each location, also displayed significant variation (Figs. 3 and 5). It would be reasonable to expect relatively high response rates to additional K at the lower range of control yields, assuming that K availability was a limiting factor. Indeed, that kind of response was quite often observed. However, in too many cases, the response was weak or even negative (Figs. 3 and 5). A weak response at the lower yield range may be associated with other limiting factors, prior to the assumed K shortage. A transient water scarcity at early developmental stages may disturb tillering and significantly reduce the reproductive potential of cereal crops. Insufficient precipitation over the whole growing season would also result in significant yield reduction. In both situations, K application is expected to have only a minor influence in boosting yields. High crop density has been recently found to limit teff yield. Consequently, it was suggested to reduce crop density to 25 plants m⁻², thus providing more space for tillering (Berhe and Gebretsadik, 2010). Lack of micronutrients is another possible constraint reducing crop yields on a local basis; Haileselassie *et al.* (2011) found that zinc application could significantly increase teff yields.

Cases of significant negative response to K application, observed mainly in Amhara but also in Oromiya, are difficult to explain at the physiological level. However, they might indicate substantial local variation in soil features, which may even affect the yields of close neighboring plots in a farm, a situation reported by Dea and Scoons (2003).

Considerable variation in response to K application may arise from interaction between free K⁺ and clay crystals, particularly in long term K-depleted Vertisols. A single small K dose applied

to such soils might be rapidly fixed into the clay particles, before any uptake by the crop occurs. Significantly larger K quantities would therefore be required before any effect on the crop is observed.

Acid soils, which frequently occur in the tropical areas of south Ethiopia (Paulos, 1996; Abayneh and Birhanu, 2006), including Oromiya and Amhara, may provide an opposite reason for insufficient response to K application. In such soils, the free K⁺ ions hardly adhere to the positively charged surface of the clay

crystals and are leached from the rhizosphere by the frequent rains, with little chance to be taken up by the crop. Possible solutions for such cases would be liming, in order to increase soil pH, and frequent K applications to widen the opportunity window for root-K⁺ interaction.

When K uptake by the crop does occur, its effect on yield largely depends on interactions with other nutrients, such as N, P, and S, as well as micronutrients. Nitrogen deficiency, which might often occur when fertilizer is improperly applied, inhibits plant growth and development and, subsequently, strongly restricts the response to K application.

There is no way to predict crop response to K application at a given location other than by conducting a comprehensive soil test. A relevant approach can then be tailored accordingly and include a whole package of solutions. On the other hand, Haileselassie *et al.* (2005) concluded that closing nutrient balances at field scale to achieve sustainability would be too costly and difficult. Examining three perspectives of the Tigray grain production system, Kraaijvanger and Veldkamp (2015) suggest that gradually strengthening the existing mixed farming system by using fertilizers, organic manure and legume fallows would support crop productivity while maintaining other aspects of sustainability, such as food security and profitability.

Conclusions

After decades of K-free fertilization policy, several recent surveys have indicated a considerable degradation in soil fertility under the current soil uses in the Ethiopian highlands, including severe K depletion (Haileselassie *et al.*, 2005; Duguma *et al.*, 2010). The results of the present broad scale study show that supplementing with an application of 50 kg KCl ha⁻¹ brought about, on average, a significant increase in teff and wheat yields in the Tigray, Oromiya, and Amhara regions. However, the immense variation in yields, and furthermore, in the response to K application, indicate that practical prescriptions for elevating cereal productivity in Ethiopia should include a revised attitude to K fertilizers, but would also require careful locally-based analyses

and amenable approaches aimed at preserving the sustainability of the Ethiopian agricultural system.

Acknowledgements

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