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Optimizing Crop Nutrition

Editorial

Dear readers,

Climate change is high on the global agenda and, from 30 November to 12 December 2015, the world's focus was on Paris and the United Nations Climate Change Conference (COP21). Many ask what is the relationship between agriculture and climate change? Indeed, agriculture contributes to climate change. Of all greenhouse gases (GHG) caused by humans, agriculture from field-to-plate contributes approximately 30 percent. Since the 1960s, the quantity of agricultural-related GHG has doubled. Today, as a result of our increasing appetite for meat, enteric fermentation (by ruminants) and manure left on pastures accounts for more than 50 percent of GHG from crops and livestock. Fertilizers, paddy rice, manure management and burning of savannas account for the remaining 13, 10, 7 and 5 percent, respectively, according to FAO. Conversely, agriculture is also part of global efforts to reduce GHG emissions by improving how soil stores carbon.

We should not forget that demand for food production is expected to increase by at least 50 percent by 2050. Agricultural practices that mitigate and adapt to climate change are becoming known as 'climate-smart' (see http://www.fao.org/climate-smart-agriculture/en/). Climate smart agriculture strives to reduce emissions, whilst enhancing farmer resilience and improving their incomes. Yet there is no one-size-fits-all approach to reduce GHG emissions and increase food production. This provides 'food for thought' as we begin a new year in an increasingly warming world.

A happy and fertile 2016 to all.

Hillel Magen
Director

Editorial 2

Research Findings

Efficiency of Potassium Application in Relation to Nitrogen Fertilization Level in Winter Wheat, Grain Maize, and Sugar Beet Culivated in Western Ukraine 3
Polevoy, V.M., L.Y. Lukashchuk, and G. Peskovski

Potato Performance under Different Potassium Levels and Deficit Irrigation in Dry Sub-Humid Mediterranean Conditions 14
Darwish Talal, Fadel Ali, Baydoun Safaa, Jomaa Ihab, Awad Mohamad, Hammoud Zeina, Halablab Ousama, and Atallah Therese

Use of Polyhalite as a Source of Sulfur for Oilseed Rape and Winter Wheat in France 21
Dugast, P.

Events 27

Publications 30

Scientific Abstracts 31

Clipboard 32

Photo cover page:
Polyhalite is an evaporite mineral, a hydrated sulfate of potassium, calcium and magnesium with formula: $K_2Ca_2Mg(SO_4)_4 \cdot 2H_2O$. For decades it was mined in small quantities and tested in various crops in the USA and Europe. Some years ago, Cleveland Potash in the UK started commercial mining of the mineral. A new potash fertilizer is now available to farmers to choose from. Photo by ICL.

Research Findings

Photo by G. Peskovski.

Efficiency of Potassium Application in Relation to Nitrogen Fertilization Level in Winter Wheat, Grain Maize, and Sugar Beet Cultivated in Western Ukraine

Polevoy, V.M.[(1)], L.Y. Lukashchuk[(1)], and G. Peskovski[(2)]

Abstract

Agricultural production in the countries of the former USSR sharply declined during the end of the 20th century and has only started its recovery during the last 10-15 years. The destruction of the agricultural systems led to the abandonment of well-rooted practices, particularly those of mineral nutrition, the reconstitution of which is currently a major challenge. The objectives of the present study were to reassess, demonstrate, and discuss the efficiency of potassium (K) application in relation to nitrogen (N) fertilization level in winter wheat, maize, and sugar beet production in Western Ukraine. Here, the main results obtained for the three crops during a 3-year research project are reported briefly. Field trials were conducted over three growing seasons (2012-2014) on a shallow, slightly loamy Chernozem, low in organic matter (OM) content. Each trial consisted of

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nine treatments, the first of which was a non-fertilized control. The other eight treatments consisted of four rates of K application on top of two N levels (120 and 180 kg ha^{-1}), and an even phosphorus (P) application within a crop. The yields of the non-fertilized control of winter wheat and sugar beet corresponded with the mean annual yields obtained in recent years, highlighting the existing poor level of basic mineral nutrition in those two crops in Ukraine. On the other hand, the large difference between the non-fertilized control and the mean annual yields in maize demonstrates the significant progress made recently in the cultivation of this crop in Ukraine. Adequate N and P application is a prerequisite for achieving significant yields and improved quality in all three crops. On top of this, increased K application also brought about significant improvement in yield and quality parameters. Interactive relationships occurred between N and K uptake, where increased K application promoted N uptake, and vice versa. In all three crops, maximum yield, produce quality, and net income were obtained at the highest rates of K application tested. However, for winter wheat and sugar beet, the maximum has not yet been achieved, thus a further increase in the annual K dose should be examined from an economic viewpoint. In maize, on the other hand, additional K application is not expected to provide any higher yields. Nevertheless, annual K dose distribution during the season according to the progress of crop developmental stages, particularly in wheat and sugar beet, should be examined to achieve further improvements in yield and quality.

Map 1. Map of Ukraine, Western Polissya, the region where the experimental work took place, is indicated by a red circle. *Source*: https://www.studentnewsdaily.com/.

Introduction

Agricultural production in the countries of the former USSR sharply declined during the end of the 20th century and has only started its recovery during the last 10-15 years. In the context of the current economic and food-price crisis, Russia, Ukraine, and Kazakhstan might be presented with a window of opportunity to reemerge on the global agricultural market, if they succeed in increasing their productivity. However, the future of their agriculture is highly sensitive to a combination of internal and external factors, such as institutional changes, land-use changes, climate variability and change, and global economic trends. The future of this region's grain production is likely to have a significant impact on the global and regional food security over the next decades. (Lioubimtseva and Henebry, 2012).

Winter wheat (*Triticum aestivum*) is the leading crop in Ukraine, which has been historically known as the 'breadbasket of Europe'. Winter wheat is usually sown in the autumn to emerge and establish a vegetative crown before being covered by a thick protective layer of snow throughout the winter. In the spring, the crown evokes tillers that differentiate and elongate later on to carry ears with grains. Harvest takes place during late summer and the yields are determined by the number of reproductive heads, the number of grains per ear, and the grain weight. In spite of the relatively stable area of harvested winter wheat in Ukraine for the previous three decades (5-7 million ha), annual production has fluctuated considerably. On top of normal year-to-year variation, a clear decline can be noticed from 1990 to 2003, with a quite steady increase thereafter (Fig. 1). Linked to the vast political changes and the consequent economic collapse, this pattern is attributed to the dissociation of the previous agricultural systems, and the reorganization of new ones. The decline and the later rise of the mean annual yield may be a good indicator for the changing culture of mineral nutrition. Well-rooted practices were abandoned during the agro-economic crisis, and new concepts and methods are now being examined and adopted. Mineral fertilizer use has been increasing steadily for over 10 years, and the higher application rates have likely contributed to a concurrent increasing trend in wheat yield. Although in recent years, the government has not been providing direct subsidies to grain and oilseed producers, Ministry of Agriculture reports

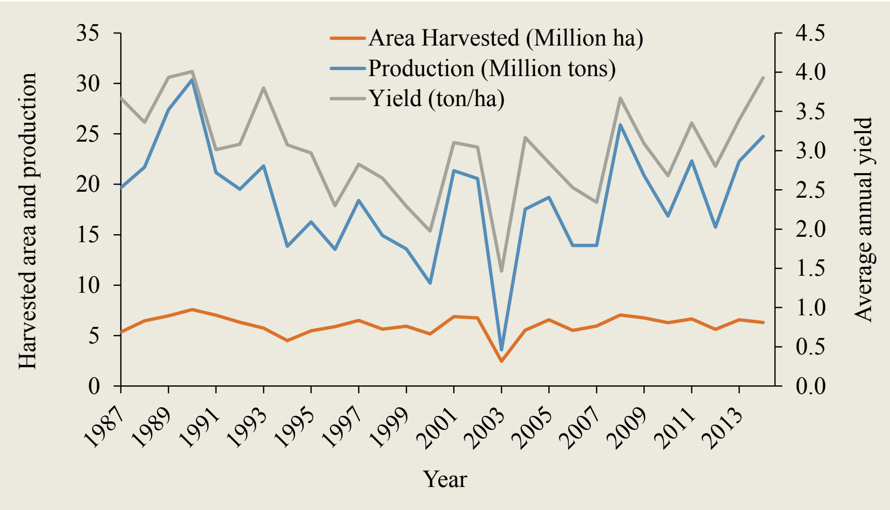

Fig. 1. Wheat production in Ukraine: Harvested area, production, and average wheat grain yields. *Data source:* http://www.indexmundi.com/agriculture/?country=ua&commodity=wheat.

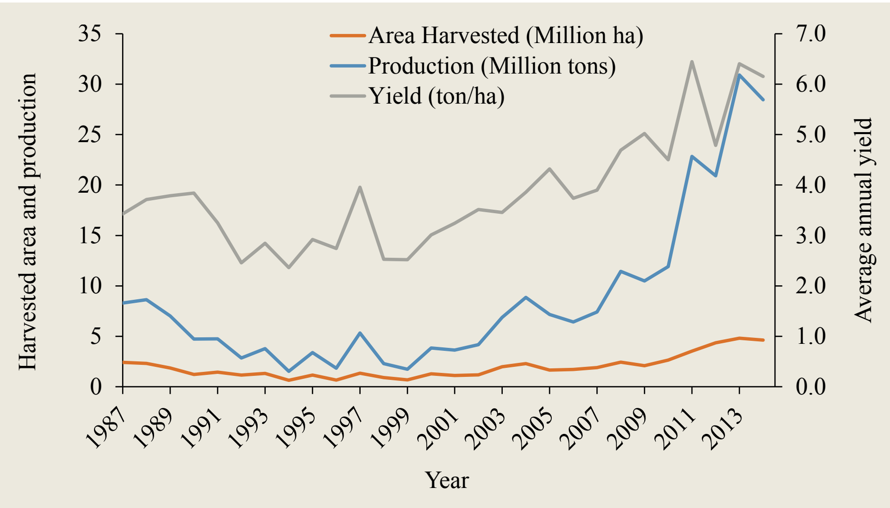

Fig. 2. Maize production in Ukraine: Harvested area, production, and average maize grain yields. *Data source:* http://www.indexmundi.com/agriculture/?country=ua&commodity=corn.

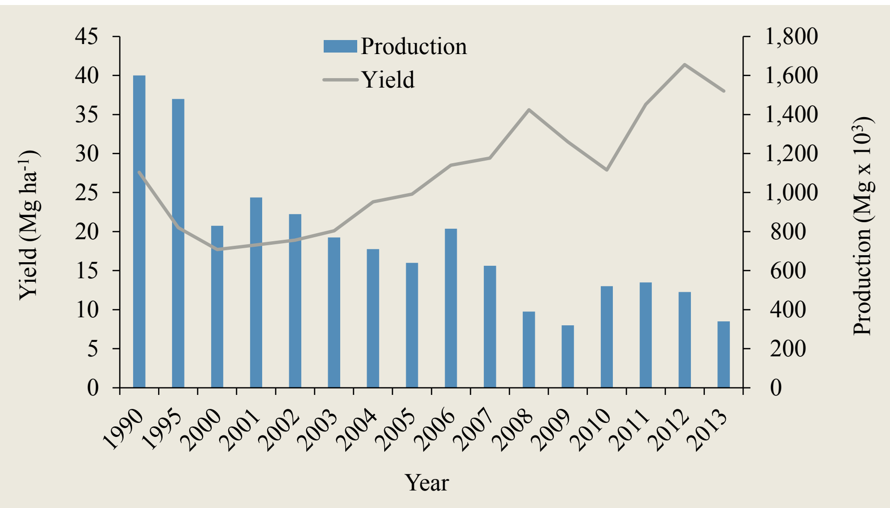

Fig. 3. Sugar beet production in Ukraine: Annual production and yield (Dubinyuk and Hager, 2013).

and private commodity analysts indicate that mineral-fertilizer application will increase again (Lindeman, 2013).

Maize (*Zea mays* subsp. mays) is a relatively new crop in Ukraine. Being cold-intolerant, maize must be planted in the spring in the temperate zones. As a C_4 plant, maize is considerably more water-efficient than C_3 plants like the small grains, alfalfa and soybeans. However, having a shallow root system, maize is very sensitive to drought, particularly at silk emergence, when the flowers are ready for pollination. Silage maize is harvested while the plant is green and the fruit immature. Field maize is left in the field very late in the autumn to thoroughly dry the grain. In the past, maize in Ukraine was grown mainly for animal feed. At present, Ukraine has experienced a remarkable boost in maize production; from 2000 to 2013 the harvested area grew four-fold, and the yield doubled from 3 to about 6 Mg ha^{-1} (Fig. 2). Producing more than 30 million Mg a year with an export rate of 60%, Ukraine was catapulted to the world's second maize exporter, after USA and alongside Argentina and Brazil (Olearchyk and Terazono, 2013).

Ukraine's geographic position, availability of favourable soil and good climatic conditions make it potentially attractive for growing sugar beet (*Beta vulgaris* L.). In recent years, however, sugar beet production has experienced deregulation in Ukraine. Thus, sugar beet production area has been declining over the last two decades (Fig. 3). The main factors stimulating this decline are lack of export markets for Ukrainian refined beet sugar, domestic sugar market oversupply, large stocks, and consequent decline in the domestic market price of sugar (Dubinyuk and Hager, 2013). As a result, producers have lost interest in this crop which is very important in crop rotation, sugar factories are working inefficiently, unemployment in rural areas has increased, and sugar has even been increasingly imported into Ukraine.

There are two issues that might shed more optimistic light on this gloomy situation. The first is associated with the steadily increasing demand of fuel and energy resources, the dependence of Ukraine on the import of natural gas, oil and its derivatives, and a complicated ecological situation, all of which have made biofuel production in Ukraine extremely important and promising. Experience of other countries, such as the US, Brazil, and European countries indicates the effectiveness of processing agricultural raw materials and organic waste into biofuels. Thus, the establishment of bioethanol production based on sugar beet seems an attractive solution to the above mentioned problems, a solution which may reconstruct the declining sugar beet industry in Ukraine (Pryshliak, 2014). The second issue is that in spite of declining production, mean annual yields have steadily increased (Fig. 3), providing evidence of significant improvements in agricultural practices and organization.

Despite the impressive increases in the mean annual yields of the three major crops, these are still related to the lower level of yields, when compared to achievements made in other countries sharing similar climate conditions (Chuan *et al.*, 2013). Further increasing yields and quality is the primary challenge of these crops in Ukraine. Realizing the potential yields is undoubtedly involved with significant improvement of mineral fertilization practices and concepts. While the nitrogen (N) and phosphorus (P) requirements are quite well disseminated to farmers, potassium (K) receives much less attention. The principal contribution of K application to most crops is well-documented (Pettigrew, 2008). Yet, the implementation of this principle always requires experimental work aimed to adapt practices to local conditions, and to demonstrate possible advantages at agricultural as well as economic levels.

The present study objectives were to reassess, demonstrate and discuss the K (MOP) application efficiency in relation to N fertilization level in winter wheat, maize, and sugar beet production in Western Ukraine. Here, the main results obtained for the three crops during a 3-year research project are presented briefly.

Materials and methods

Experimental work was carried out during the growing seasons of 2012, 2013, and 2014 at the Institute of Agriculture of Western Polissya in Western Ukraine. The trials were conducted on a shallow, slightly loamy Chernozem, low in organic matter (OM) content. Over the three growing seasons, the following agrochemical properties were measured in the topsoil: soil pH, OM content, available P_2O_5 and exchangeable K_2O (DSTU, 2005), and hydrolysable N (Cornfield, 1960). Detailed description of the experimental setup is presented in Tables 1 and 2.

Each trial consisted of nine treatments, the first of which was a non-fertilized control. The other eight treatments consisted of four K application rates on top of two N levels and an even P application within a crop (Table 2). Each of the nine treatment was replicated four times. Fertilizer application rates shown in NPK

Table 1. Technical details and soil properties referring to the three experimental sites and crops.

Crop	Cultivar	Preceding crop	Sowing time	Sowing rate	Topsoil properties				
					pH	OM	Avail. P_2O_5	Exch. K_2O	Hydrol. N
				m^{-2}		%	--------mg kg^{-1} soil--------		
Wheat	Voloshkova	Winter rapeseed	30-09-2012	5×10^6	6.74	1.71	173	120	139
Maize	Mariin 190 SV	Winter wheat		6×10^5	6.15	1.83	220	107	106
Sugar beet	Shevchenkovsky	Winter wheat	04-2014		6.40	2.13	220	102	111

Table 2. Detailed NPK doses applied in each treatment.

Treatment		Control	N_1PK_1	N_1PK_2	N_1PK_3	N_1PK_4	N_2PK_1	N_2PK_2	N_2PK_3	N_2PK_4
			kg ha^{-1}							
Wheat	N	0	120	120	120	120	180	180	180	180
	P	0	70	70	70	70	70	70	70	70
	K	0	0	60	90	120	0	60	90	120
Maize	N	0	120	120	120	120	180	180	180	180
	P	0	90	90	90	90	90	90	90	90
	K	0	0	60	120	180	0	60	120	180
Sugar beet	N	0	120	120	120	120	180	180	180	180
	P	0	160	160	160	160	160	160	160	160
	K	0	0	80	160	240	0	80	160	240

terms refer to N, P_2O_5, and K_2O supply in kg ha^{-1}, respectively. Similarly, nutrient concentrations in plant biomass were recorded in terms of N, P_2O_5, and K_2O percent of dry weight. Plot size was 89 m^2, from which 50 m^2 were harvested. The fertilizers used were ammonium nitrate (AN), mono-ammonium phosphate (MAP), and muriate of potash (MOP), all of which were applied by hand.

In winter wheat, production analyses included mean grain yield, number of productive tillers per m^2, plant height, ear length, grains per ear, grain weight per ear, and the weight of a thousand grains. Nitrogen, P, and K concentrations were determined in the grain and straw. Grain quality was measured in terms of protein and gluten content. Production analyses of maize included the number of productive plants per m^2, plant height, number of cobs per plant, cob weight, number of grains per cob, weight of 1,000 grains, and overall grain yield. Nitrogen, P, and K concentrations were determined in the grain and straw. Protein content was determined in the grains. In sugar beet, N, P, and K contents were determined in the leaves and roots at harvest as well as root yield, root sugar content, and refined sugar yield. Economic efficiency of fertilizer application for each crop was established for the various treatments in terms of net income as UAH (Ukranian Hryvnia). This was calculated using the marginal yield addition obtained due to fertilizer treatment compared to no fertilizer, subtracting the additional expenses required.

Results

Very similar results were obtained each year for the crops studied. To simplify, we report on the findings of 2013 for winter wheat, and those of 2014 for the two other crops.

Winter wheat

Potassium fertilization significantly enhanced uptake of both N and K, as indicated by the increased concentrations of these elements in plant biomass. In comparison to both NP treatments (without K), the application of 60-90 kg K_2O per ha (with N and P) brought about an N increase of 0.7-1.2 mg g^{-1} grains. Nitrogen concentration in the straw was the highest at $N_{180}P_{70}K_{60}$ (4.9 mg N g^{-1}). Potassium concentrations in the grain ranged from 5.3-6.6 mg g^{-1}. Under K application, K concentration in the straw ranged from 9.4-13 mg g^{-1}, with the highest value obtained in the highest N K treatment ($N_{180}P_{70}K_{120}$).

Grain yield analysis (Fig. 4A) demonstrates that N application at rates of 120 and 180 kg ha^{-1} contributed 1.15 and 2 Mg ha^{-1}, respectively (together with P at a rate of 70 kg ha^{-1}), above the basal yield of 4 Mg ha^{-1} obtained with the unfertilized, control treatment. Yield response to K application levels was linear, preserving the primary advantage obtained by the higher N level. Thus, each kg of K application contributed 5.1-5.7 kg grains ha^{-1}, irrespective of the other fertilizers' application rates.

Photo by IPI.

Further analyses revealed the direct influence of fertilizer application on the yield components. It appears that the basal rate of N and P ($N_{120}P_{70}$) had a profound effect on the productive tillers, the number of which up surged from 489 to 569 per m^2 (16.4%). The marginal effect of a further increase in N rate ($N_{180}P_{70}$) was smaller, giving rise to an additional 4% only. Potassium application resulted in a linear effect, in which each kg of K fertilizer yielded an increase of about 2,500 productive tillers per ha (Fig. 4B). The number of grains per ear increased by 5-6% in response to NP fertilization. The effect of K application on this parameter was significant and positive, but it seemed to gradually decline with increasing K rate (Fig. 4C). Thus, while the linear component of the function indicated approximately 3% increase per kg K ha^{-1} applied, the marginal effect would be much smaller at the higher K doses. While NP application gave rise to 11-16% increase in the grain weight, K application did not have any significant influence on this yield component (Fig. 4D). Potassium fertilization did not affect plant height nor ear length.

Grain quality, in terms of protein and gluten content, reached its maximum at the $N_{180}P_{70}K_{60}$ treatment, with 13.2% protein, of which 25.8% was gluten; increasing K rates did not bring about any further improvement in quality. Nevertheless, due to K influence on grain yield, the highest net income was obtained at the highest K rate (treatment $N_{180}P_{70}K_{120}$) - 1067 UAH ha^{-1}.

Maize

Nitrogen uptake, as indicated by N concentration in plant biomass, was increased by K application and ranged from 8.5-11 mg g^{-1}, which was higher by up to 2.6 mg g^{-1} than in the control NPK_0 plants. Potassium uptake also increased, ranging from 13.1-15.7 mg g^{-1} plant biomass, and was higher by 0.8-2.8 mg g^{-1} than in NPK_0 plants. The K application effect was also pronounced in the grains at harvest, with increases of 0.8-1.3, 1.2, and 0.3-1.1 mg of N, P_2O_5, and K_2O, respectively, per g dry weight.

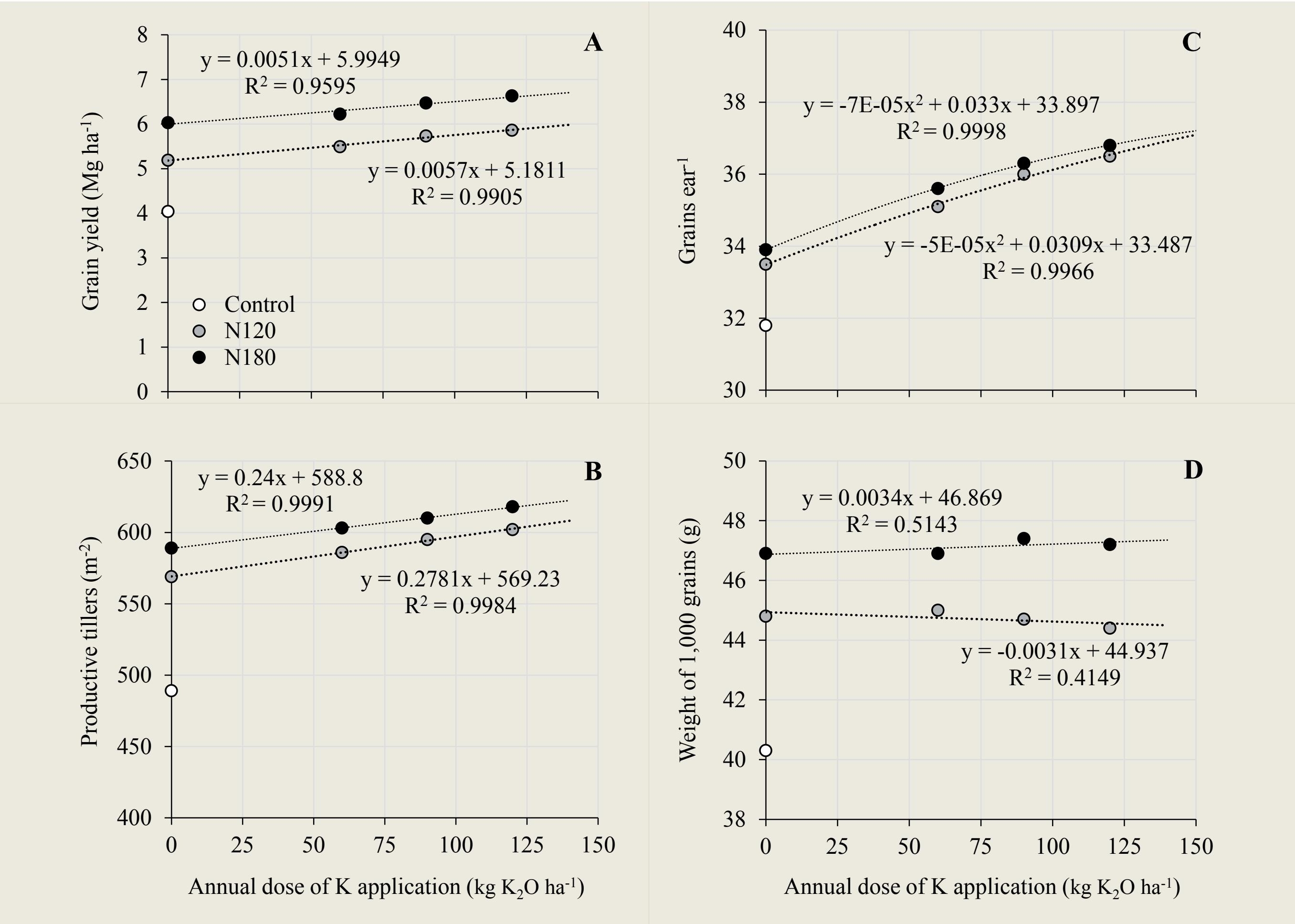

Fig. 4. Effects of fertilizer rates on winter wheat in 2013 with regard to: A) grain yield; B) number of productive tillers; C) number of grains per ear; and d) weight of 1,000 grains.

Nitrogen and P fertilizers had a dramatic effect on maize grain yield. Phosphorus at 90 kg P_2O_5, and at 120 and 180 kg N ha^{-1}, gave rise to grain yield increases of 61 and 84%, respectively, as compared to the non-fertilized control (Fig. 5A). Grain yield increased along with the rising rates of K application, but seemed to be saturated at the higher K rate (180 kg K_2O ha^{-1}). Thus, the highest yields were obtained at the $N_{180}P_{90}K_{180}$ treatment, 11.79 Mg ha^{-1}, 31% more than the $N_{180}P_{90}K_0$ treatment, and 141% more than the non-fertilized control.

Potassium application had a rather small, insignificant effect on the number of plants per m^2 and on plant height (data not shown). Also, no influence on the number of cobs per plant (~1.02) could be observed. However, the mean cob weight was significantly increased as a result of fertilization treatments (Fig. 5B). Whereas, mean cob weight of non-fertilized control plants was about 140 g, it was 187 g and 204 g in the NPK_0 treatments. Potassium application brought about a further increase in cob weight, up to 231 g under the $N_{180}P_{90}K_{180}$ treatment. Most of the increment in cob weight was attributed to a significant increase in the grains share in the cob. In response to the NPK_0 treatments alone, the grains share grew from 64 to 73-76%, and increased further, up to 81%, as a result of raising the K dose to 180 kg K_2O ha^{-1} (Fig. 5C).

The highest grain protein content (9.95%) was reached at $N_{180}P_{90}K_{120\text{-}180}$. Net income was highest (5048 UAH ha^{-1}) under the $N_{180}P_{90}K_{180}$ treatment.

Sugar beet

Nitrogen uptake by sugar beet was significantly increased by K application; N concentration in the above ground organs of the plant increased from 3.32% in the NPK_0 treatments up to 3.93% in the $N_{180}P_{160}K_{240}$ treatment. In the roots, N concentration ranged from 0.97-1.05%, with only a slight K application effect. On the other hand, K_2O concentration in the roots increased from 0.8-0.88% in the NPK_0 treatments up to 0.99% in the $N_{180}P_{160}K_{240}$ treatment.

Nitrogen and P fertilizers considerably affected sugar beet root yield. Phosphorus applied at 160 kg P_2O_5, and nitrogen at 120 and 180 kg ha^{-1}, brought about yield increases of 32 and 39%, respectively, compared to the non-fertilized control (Fig. 6A). Potassium application caused a further yield increase, which displayed a linear response up to 60.3 Mg ha^{-1} in the $N_{180}P_{160}K_{240}$ treatment, about 10% higher than in the respective K_0 treatment.

Sugar concentration in the beets ranged between 17.3-17.6% and did not differ significantly between treatments. Hence, the refined sugar yield corresponded with the fresh root yields, displaying similar responses to the various fertilization treatments (Fig. 6B). Thus, sugar yield increased from about 6.76 Mg ha^{-1} in the non-fertilized control, to 9-9.5 Mg ha^{-1} in the NPK_0 treatments, and rose further up to 10.55 Mg ha^{-1} at the highest applied NPK rates. Consequently, the highest net income of 9450 UAH ha^{-1} was obtained at the highest fertilization rates, $N_{180}P_{160}K_{240}$.

Discussion

The non-fertilized control of winter wheat (Fig. 4) and sugar beet (Fig. 6) yields corresponded with the mean annual yields obtained in recent years in Ukraine, about 4 (Fig. 1) and 38 Mg ha^{-1} (Fig. 3), respectively. These results are highlighting the existing poor level of basic mineral nutrition in those two crops in Ukraine. The large difference between the non-fertilized control and the mean annual yields in maize (Figs. 2 and 5) demonstrates the significant progress made recently in the cultivation of this crop in Ukraine.

The basal N and P fertilization (NPK_0) provided the most significant contribution to yields of all three crops examined in the present study. The first level of N application (N_{120}, 120 kg N ha^{-1}), with the constant basal application of P (70, 90, or 160 kg ha^{-1}, applied to winter wheat, maize, or sugar beet, respectively), gave rise to the highest increase in yield, 28, 61, and 33%, compared to yields of the non-fertilized control of winter wheat, maize, and sugar beet, respectively. When this basal N application level was raised by 50% to 180 kg ha^{-1}, winter wheat grain yield grew further by an additional 21%, displaying a high and stable marginal output. These results are supported by recent findings with winter wheat in China, showing that a rate of 180 kg N ha^{-1} can support no more than a median range of grain yield (about 6 Mg ha^{-1}) and that higher yields require significantly further N inputs (Chuan *et al*., 2013). Thus, under the circumstances of the present trial, N requirements were still far from being fulfilled. In maize and sugar beet, on the other hand, the marginal outputs provided by the higher N application level decreased, indicating that the crop N requirements were almost satisfied.

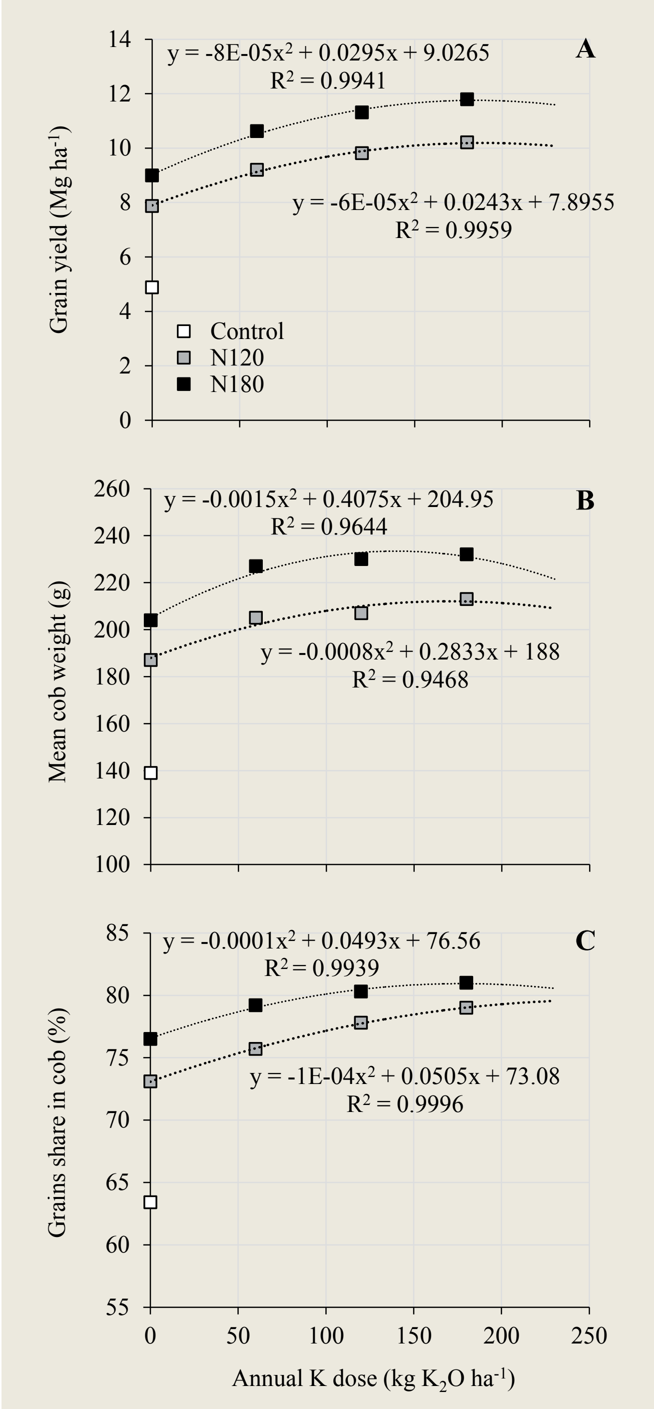

Fig. 5. Effects of fertilizer rates on maize in 2014 with regard to: A) grain yield; B) mean cob weight; and, C) on the grains share in the cob.

Potassium is one of the principle plant nutrients underpinning crop yield production and quality determination. While involved in many physiological processes, K's impact on water relations, photosynthesis, assimilate transport and enzyme activation can have direct consequences on crop productivity. Potassium deficiency can lead to a reduction in the number of leaves produced and the size of individual leaves. Coupling this reduced amount of photosynthetic source material with a reduction in the photosynthetic rate per unit leaf area, the result is an overall reduction in the amount of photosynthetic assimilates available for growth. The production of less photosynthetic assimilates and reduced assimilate transport out of the leaves to the developing fruit greatly contributes to the negative consequences that K deficiencies have on yield and quality production (Pettigrew, 2008). Indeed, amongst all crops examined in this study, K application brought about further increases in yield. In winter wheat, yield response was linear, with a maximum increase of 10 or 13%, depending on the basal N application level, which also indicates a tight dependence of K contribution on plant N status. According to He *et al.* (2012) and Chuan *et al.* (2013), a K application rate of 120 kg ha^{-1} would support much higher yields (about 7 Mg ha^{-1}), but only under elevated N inputs of more than 200 kg ha^{-1}. The greatest contribution of K fertilization to yield was obtained in maize, reaching a maximum of 30%, with no evident dependence on N level. In contrast to winter wheat and sugar beet, the influence of K seemed to be saturated at its highest application rate (180 kg ha^{-1}), hence any further increase of K rate would be ineffective. The maximum increase in sugar beet root and sugar yields ranged at 12%, displaying a linear relationship between K input and beet yield. It appears that further increasing K input might result in elevated yields, and should be considered economically.

Careful attention must be paid to the specific effects of K application on plant development and on the dominant yield components in each crop, trying to understand K role and elucidate practical conclusions (Grzebisz *et al.*, 2013). Among the three crops, winter wheat exhibits the most complex course from seed to yield (Haun, 1973; Zadoks *et al.*, 1974). It is sown in the autumn and the plants must survive the many stresses of winter; plants with well-developed crowns have the best chance of winter survival. Potassium has a primary role in the successful establishment of seedlings as it supports the development of an adequate root system (Weaver, 1926; Ma *et al.*, 2013). Grain yield can be expressed as the product of three variables (yield components) as follows:

Grain yield = (number of heads) x (kernels per head) x (kernel weight)

The impact of each yield component on final grain yield is determined at different stages during the growing season. Successful and timely establishment of seedlings is a pre-requisite to the number of productive tillers produced per plant, which sets the upper limit on the number of heads that can be produced by a wheat crop. In the spring, tiller production is favored by moist, warm weather, and good soil fertility. Tillers must survive to maturity to contribute to grain yield. The developing head and elongating stem generate large demands on the plants' resources, thus relatively weak, poorly developed tillers fail to compete and are often lost, particularly under unfavorable environmental conditions (Lopes *et al.*, 2014). The results of the present study demonstrate the pivotal role of K in supporting tiller development, thus increasing the number of productive tillers (Fig. 4B). Potassium, through its constructive effect on root growth and development, might have intensified the ability of the root system (Weaver, 1926) to explore the soil during drought periods. Also, being involved in the plant's water relations (Fischer, 1968; Haeder and Beringer, 1981), an adequate K status would strengthen plant drought tolerance (Grzebisz *et al.*, 2013).

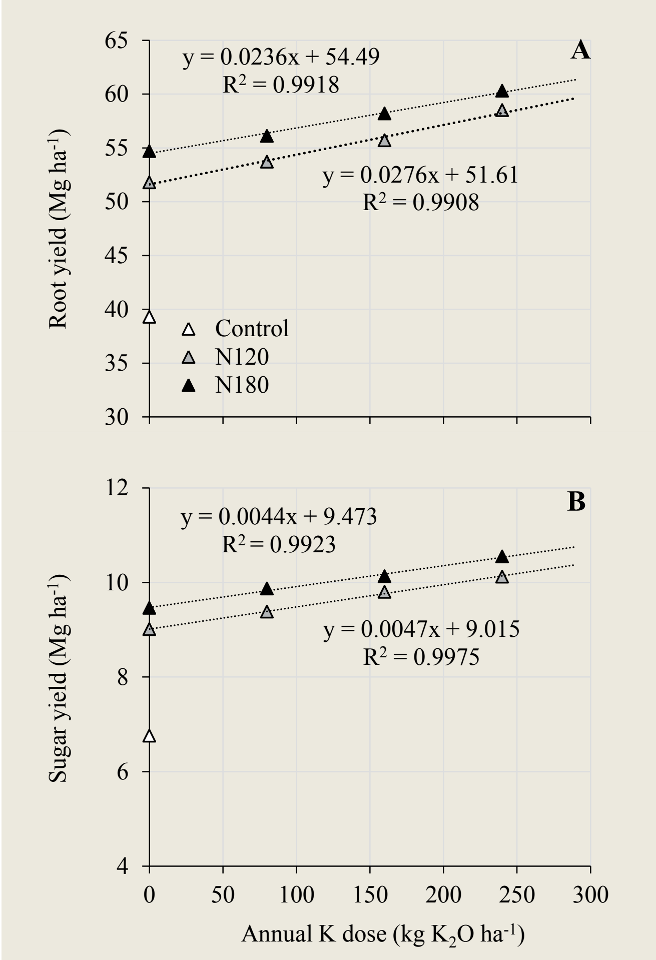

Fig. 6. Effects of fertilizer rates on sugar beet in 2014 with regard to: A) taproots yield; and B) refined sugar yield.

Increased levels of K application brought about a significant rise in the number of grains per ear (Fig. 4C), indicating its influence during the initiation and development of the primary reproductive stage. This effect may be attributed to an improved carbohydrate status of the plant, which allows and supports prolonged activity of basal developmental processes in the ear. Known to promote photosynthetic (Huber, 1985) and carbohydrate translocation (Conti and Geiger, 1982) processes, K impact is not surprising here. Nevertheless, at the later stage of grain filling, no significant effects of K input levels could be observed (Fig. 4D), possibly due to the depletion of this nutrient from the root zone along the season. The timing and distribution of mineral application along the growing season may be crucial, particularly when addressing K, with its combined influences on plant growth and development. In the present study, and according to common practices in the region, the annual K dose was applied basally, prior to sowing. Potassium is very mobile in the plant, but also in the soil; it might be easily leached away from the root zone. The grain yield potential of winter wheat is twice as high as obtained here, reaching about 12 Mg ha^{-1} (Chuan *et al.*, 2013; Dang *et al.*, 2013). Further improvement of winter wheat yields in Ukraine might be achieved by adjustment of K application practices to the dynamic requirements of the plant throughout the season (He *et al.*, 2012; Dang *et al.*, 2013; Ma *et al.*, 2013; Scanlan *et al.*, 2015). In other words, practices using slow-release fertilizers, split K application, or foliar application (Niu *et al.*, 2013; Lu *et al.*, 2014) should be considered well before the emergence of genetically-based solutions (Wang and Wu, 2015). Also, larger N and K doses will be required, as indicated by Chuan *et al.* (2013), as well as in the present study (Fig. 4A).

In contrast to the relatively long and complex pattern of winter wheat growth and development, that of maize for temperate climatic conditions is concentrated in the short summer. Cultivars are selected accordingly, with an ability to grow rapidly and boost the grain yield up as early as possible. Where the numbers of plants and cobs are predetermined at sowing, cob size and grain share are the most effective yield components. Pettigrew (2008) described a cascade of physiological impairments associated with K deficiency in maize (and other plant species). Insufficient K levels reduced leaf area expansion leading to reduced leaf size (Jordan-Meille and Pellerin, 2004). The combination of smaller leaf area and reduced photosynthetic rate under insufficient K levels (Basile *et al.*, 2003) leads to a reduction in the total carbohydrate pool produced in the source tissues (leaves). Coupling that with the restricted assimilate transport characteristic of K-deficient plants (Ashley and Goodson, 1972) results in a smaller total assimilate supply available for sink tissues (cobs), which will ultimately diminish yield and quality produced by those plants. Thus, the significant contribution of K application to maize yield, as found in the present study (Fig. 5A), should be attributed to the general positive effect of K on plant productivity. The majority of K accumulation occurs before silking (Hanway, 1962, Karlen *et al.*, 1988), suggesting an important role of K as the grains set and their further development. Indeed, high levels of K application were associated with larger cobs and greater grain share (Fig. 5), as also shown by Heckman and Kamprath (1992) and Qiu *et al.* (2014).

Potassium requirements of sugar beet are high and comparable to other plants having large storage organs. Also here, given optimum weather conditions, the larger the aboveground biomass (rosette of leaves) obtained the greater the taproot biomass and its sugar content (Kenter *et al.*, 2006). Sugar beet production requires especially fertile soils rich with mineral nutrients and organic matter. While at the early stages of plant development, N would be the major nutrient required for the foliar and taproot growth in terms of fresh weight, K is probably more essential during the later stage of sugar translocation from the leaves, filling the taproot (growth in terms of dry matter) (Giaquinta, 1979). Thus, the effect of elevated K application on sugar beet yields, as shown here, are not surprising. Furthermore, it appears that K requirements are even higher, as indicated by the linear function in Fig. 6. Alternatively, splitting the annual K dose, with more emphasis on the second half of the growing season, may increase the K nutrition efficiency of this crop.

Potassium is an essential mineral in human diet and in animal feed. Increased K application tended to increase the content of this nutrient in grains and stover of wheat and maize, as well as in the sugar beet taproot. Protein content also increased, a fairly well-known phenomenon attributed to K (Mengel *et al.*, 1981; Blevins, 1985), particularly that of gluten, a major quality parameter of wheat flour. Thus, increased K application had positive effects on the produce quality, and hence on the price and revenue of growers.

Interestingly, increased K doses promoted the rise of N uptake, as indicated by the increased N concentration in the biomass of all three crops studied here, and by previous published work (Mengel and Kirkby, 1987; Chuan *et al.*, 2013). From a plant nutrition viewpoint, it is very easy to justify the beneficial effect of K in raising nitrogen use efficiency thereby increasing crop yield and quality (Stromberger *et al.*, 1994). Potassium provides the main cation, and nitrate (NO_3^-) the main anion taken up from soil solution by crop plants in the well-aerated high pH soils at the trial sites. These ions play a dominant balancing role not only in uptake but also in transport within the plant from root to shoot. In most crop plants, the shoot provides the major site of NO_3^- reduction and the synthesis of amino acids and sugars. Potassium is also essential for their transport in supplying developing storage organs that include the grains of winter wheat, cobs of grain maize, and the roots of sugar beet studied in these trials.

Conclusions

Adequate N and P application is prerequisite for considerable performance and yields of three major field crops in Ukraine: winter wheat, maize, and sugar beet. On top of this, increased K application brought about significant improvement in yield and quality parameters. Interactive relationships occurred between N and K uptake, where increased K application seemed to promote N uptake, and vice versa. In all three crops maximum yield, produce quality, and net income were obtained at the highest rates of K application in the trial. However, for winter wheat and sugar beet, the maximum has not yet been achieved, thus further increase of the annual K dose should be examined from an economic viewpoint. In maize, on the other hand, additional K application is not expected to further increase yields. Nevertheless, distribution of the annual K dose during the season according to the progress of crop developmental stages, particularly in wheat and sugar beet, should be examined to achieve further improvements in yield and quality.

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The paper "Efficiency of Potassium Application in Relation to Nitrogen Fertilization Level in Winter Wheat, Grain Maize, and Sugar Beet Cultivated in Western Ukraine" also appears on the IPI website at:

Regional activities/Eastern Europe
Nitrogen and Potassium Interactions

Research Findings

Photo 1. A view of the potato field trial during spring 2015. Photo by authors.

Potato Performance under Different Potassium Levels and Deficit Irrigation in Dry Sub-Humid Mediterranean Conditions

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Abstract

A trial on potato (*Solanum tuberosum* L.) response to three doses of potassium (K) under deficit irrigation was conducted under dry sub-humid conditions in Bekaa plain, Lebanon, between 8 April 2015 and 31 July 2015. Grown on clay, neutral pH, Eutric Fluvisol, table potato crop (cv. Spunta) was fertilized at three levels of K: 120 (K_1), 240 (K_2) and 360 kg K_2O ha^{-1} (K_3), tested against a zero-K treatment (K_0). All treatments received equal amounts of nitrogen (150 kg N ha^{-1}) and phosphorus (150 kg P_2O_5 ha^{-1}). The crop, subjected to mild deficit irrigation (85% of evapotranspiration) starting from the shoot development stage, was irrigated with a drip system. Soil moisture was monitored

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throughout the season by moisture sensors inserted at 25 cm and 50 cm soil depth to schedule the irrigation. The crop performance was assessed by measuring canopy temperature and chlorophyll content as a function of the different K applications. The K_3, treatment exhibited higher chlorophyll contents during flowering, tuber initiation and bulking stages. At midday, the K_3 canopy temperature was the lowest (29.6 °C), compared to K_0 (31.0 °C), indicating facilitated stomatal aperture, and consequent carbon exchange rate. These results demonstrate the important role of K in establishing and maintaining carbon translocation from source leaves to sink organs, thus enhancing potato productivity. The final tuber yield increased significantly from 2.3 in K_0 to 3.3 kg m^{-2}, in K_3. The average tuber weight and commercial tuber weight were significantly greater in the K_3 treatment while the tuber dry matter content was unaffected by the application of potassium. Further increase in potato tuber yields should be sought through the distribution of K applications during the season, particularly during the crucial stage of tuber bulking, when K requirements rise. Potassium role in regulating plant water relations in potato should be further examined in order to cope with extreme weather conditions that often occur in semiarid and dry sub-humid regions.

Introduction

Water use in agriculture represents around 70% of water consumption in Lebanon (Darwish *et al.*, 1999). In the near future, the competition between domestic and agricultural water use will become more significant. Therefore, it will be necessary to produce as much, and even more, with greater water use efficiency (WUE). Potato is a major cash crop in the Bekaa plain with an area exceeding 19,000 ha (MoA, 2012). Potato is grown in the Bekaa plain in two seasons: spring and summer. However, the average potato yield in Lebanon (23 Mg ha^{-1}) is far below the crop's potential productivity. Such a low yield is attributed to the imbalanced applications of nutrients for intensive potato crop production (Karam *et al.*, 2011). Grown during spring or summer, the crop is highly dependent on irrigation. Potato is considered sensitive to water stress, as an optimum yield could not be attained with 30 to 50% soil moisture depletion (Panigrahi *et al.*, 2001; Onder *et al.*, 2005). The absence of irrigation for two weeks during the tuber ripening stage caused 40% yield loss (Karam *et al.*, 2014). Irrigation management could be combined with optimized fertilizer applications to increase potato yields. An application of potassium (K) fertilizers (120 kg K ha^{-1}) under controlled deficit irrigation (80% of soil field capacity) improved the quantity and quality of potato yield, together with elevated WUE (Abd El-Latif *et al.*, 2011). In Lebanon, both WUE and nitrogen use efficiency (NUE) in table potato were improved by the adjustment of the inputs to estimated crop nutrient demands and available pools (Darwish *et al.*, 2003). Employing an appropriate irrigation schedule and a balanced fertilization by fertigation improved both WUE and NUE (Darwish *et al.*, 2006). Potato has a high K demand (Haeder *et al.*, 1973; Jansson, 1980; Panique *et al.*, 1997). In addition to facilitating starch accumulation in tubers, K^+ regulates the amount of water in the plant and plays a role in maintaining turgidity of plant cells. In the absence of sufficient K, crops do not use water efficiently and become less able to withstand water stress during drought periods. Addition of K fertilizer improved water relations of different crops under water stress conditions (Islam *et al.*, 2004). Potassium is also a major player in various metabolic processes such as protein biosynthesis (Belvins, 1985) and osmotic adjustment (Fischer, 1968). Thus, K application enhances N and phosphorous (P) uptake irrespective of soil moisture levels (Baque *et al.*, 2006). Maintaining higher cytoplasmic K levels increased plant drought tolerance (Chow *et al.*, 1990; Cakmak and Engels, 1999). Potassium is also required as a regulator for photosynthetic CO_2 fixation, especially in environmentally stressed conditions. Even in heavy textured soils, known for their high water retention capacity, adequate amounts of K and N fertilization under moderate deficit irrigation (80% of crop evapotranspiration (ETc)) showed positive effects on potato crop performance, productivity and N recovery (Darwish *et al.*, 2006). In poor sandy soils in Poland, with high risks of nitrate leaching, K addition to a rain-fed potato crop positively affected NUE (Grzebisz *et al.*, 2015).

The objectives of the present study were to promote sustainable land management in the largest Lebanese agricultural area in the Bekaa plain through the improvement of potato performance and yields under drought conditions. Different K application rates were tested under a mild deficit irrigation (85% of crop water demand). Fertilizers were applied directly to the soil, while water was applied via drip irrigation. The performance of table potato crop was followed during the spring and summer of 2015, in addition to assessing indicators like canopy temperature and chlorophyll contents.

Materials and methods

A trial on potato response to fertilization and irrigation was conducted in the central Bekaa plain, Lebanon, at the Research Center for Environment and Development, Beirut Arab University (33°47'58.6" N; 35°51'40.8" E), from 8 April 2015 to 31 July 2015 (Photo 1). Soil analysis prior to the experimental work indicated moderate fertilization levels in recent years. The levels of plant available phosphorus (Olsen P) and exchangeable K (ammonium acetate extraction) were indicative of the moderate fertilization of the site (Table 1).

Potato seeds (Spunta variety, Class A seeds) were mechanically sown on 8 April 2015, at a density of 57,000 plants ha^{-1}. The total planted area was 700 m^2 divided into four blocks, each one divided into four plots in a complete randomized block design.

Table 1. Initial soil properties analyzed in April 2015 at two soil depths.

Soil depth	Textural class	pH	Organic matter	$CaCO_3$	Olsen P	Exchangeable K
cm			-------*g kg*$^{-1}$ *soil*-------		-------*mg kg*$^{-1}$ *soil*-------	
0-20	clay	7.1	21	190	9.1	250
20-40	clay	7.3	20	170	5.5	150
Levels recommended by the Lebanese Agricultural Research Institute (LARI)					40	300

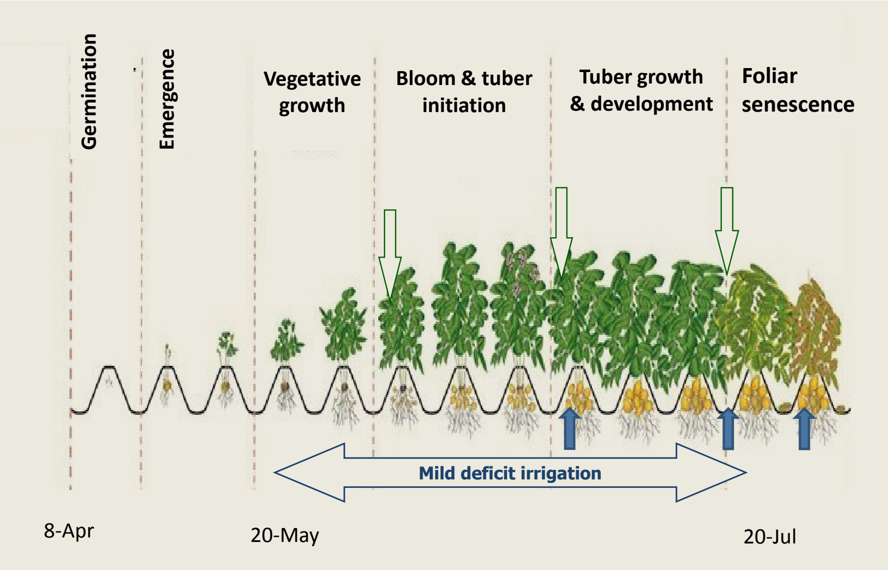

Fig. 1. Representation of the potato sampling in relation to the main stages of the crop. Transparent vertical arrows refer to the sampling dates of shoots (8-Jun, 22-Jun, and 9-Jul), bold arrows to those of tubers (22-Jun, 9-Jul, and 30-July), and the blue horizontal arrow indicates the duration of the mild deficit irrigation.

Treatments consisted of different K rates, as follows: K_0 - zero-K control; and K_1, K_2, and K_3, applied with 120, 240, and 360 kg K_2O ha^{-1}, respectively. Potassium, in the form of potassium sulfate (K_2SO_4) was applied directly to the rows before planting. All treatments received similar N (150 kg N ha^{-1}) and P (150 kg P_2O_5 ha^{-1}) rates (the soil was poor in P), in a split application before sowing and at the time of shoot development (Fig. 1). The crop performance was evaluated at different stages: mid-flowering, full flowering and physiological maturity by sampling four individual plants per plot (Fig. 1). At full maturity (July 30th), six plants were sampled from each plot by digging out the tubers, which were graded (below or above 3.5 cm in diameter), weighed immediately, then a subsample was dried for the dry matter content. ANOVA analysis was performed to check the effect of different levels of K application.

A drip irrigation system was employed (Photo 2). The amount of irrigation water was based on crop demand as determined by the grass evapotranspiration (ET_0) obtained from an agroclimatic station located in central Bekaa as well (33°51'30.5" N; 35°59'12.7" E). The crop coefficient (Kc), varied between 0.4 and 0.9 (FAO, 1969; Papadopoulos, 1988; 1996). Mild deficit irrigation (85% of ETc) was started at the vegetative development stage and lasted till foliar senescence (Fig. 1). Irrigation scheduling was based on soil water potential measurements read every morning at a depth of 25 cm. Irrigation was launched whenever the soil water potential was close to an average value of 300 mbar. Soil water potential recorded 24 hours after irrigation showed an average value of 100 mbar. Canopy temperature was measured using an infrared thermometer (Raytek: Ray R 3i LT DL2), while chlorophyll content was determined in-situ using a portable chlorophyll meter (Konika Minolta: SPAD 502DL Plus).

Photo 2. Drip irrigation systems are still not commonly used by farmers (less than 10%) in Lebanon, despite their advantages and contribution to water saving. Photo by authors.

Results and discussion

At mid-flowering and tuber initiation (8-Jun), the average vegetative dry weight was 0.175 kg m^{-2}, and did not differ significantly between treatments despite decreased aboveground matter in K_2 and K_3 treatment plants (Fig. 2). Two weeks later (22-Jun), growth of the aboveground biomass was almost halted. On the other hand, the developing tubers gained about 0.25 kg m^{-2}, during the same period (Fig. 2). Tuber biomass was slightly, but significantly, larger among K-fertilized plants.

The application of 360 kg K_2O ha^{-1} (K_3) gave rise to significantly higher fresh tuber yield, 42% greater than the yield of the K_0 treatment (Table 2). The intermediate K doses applied to K_1 and K_2 were insufficient to increase tuber yields significantly above K_0. These results may indicate that the exchangeable K present in the soil pool (Table 1) is too small to obtain considerable tuber yields. Moreover, with a demanding crop such as potato, increasing K application dose further may result in even larger tuber yields.

While the number of tubers varied from 26-34 tubers m^{-2}, with no significant influence of K application rates, the latter had an obvious effect on tuber size, though at the highest K dose only (Table 2). Tuber size increased by 67%, from 75 to 126 g, which also had considerable positive consequences on the commercial value of the produce.

In spring potato, the number of shoots emerging from the tuber-seeds and the aboveground biomass developing until tuber initiation, together set the primary potential of the number of initiating tubers. This is the reason why, in potato, sufficient N nutrition is essential at the beginning of the cropping season (Papadopoulos, 1988; Mustonen *et al.*, 2010). The prevalence of inductive environmental factors, such as low temperature and short day-length, determines to what extent this primary tubering potential is realized (Moorby and Milthorpe, 1975; Ewingand Struik, 1992). Potassium does not seem to have any influence on tuber initiation, however, it has a central role in strengthening sink organs and in the regulation of carbohydrate translocation (Haeder *et al.*, 1973). Tuber dry matter content increased slightly with rising K dose, but this was statistically insignificant indicating that the genotypic limits of the cultivar (18-20%) overrule nutritional factors.

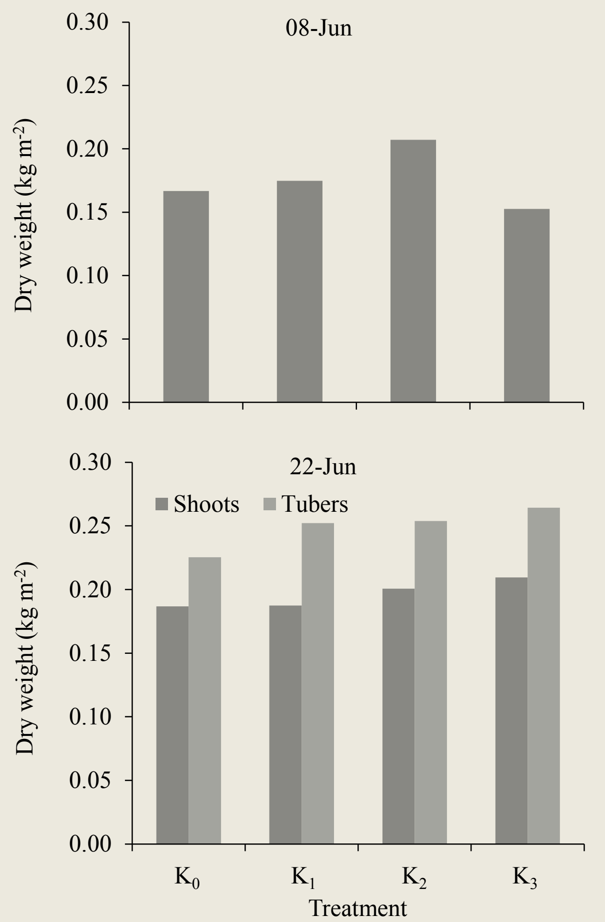

Fig. 2. Effect of K application rates (K_1: 120, K_2: 240 and K_3: 360 kg of K_2O ha^{-1}) on aboveground and tuber growth (kg DW m^{-2}) at tuber initiation (8-Jun), and two weeks later (22-Jun).

Table 2. Fresh tuber yield, number of tubers, average tuber size, average size of commercial tubers (ø >3.5 cm), and tuber dry matter content at full maturity on 30-Jul.

Treatment	Tuber yield	Number of tubers	Average tuber weight	Average commercial tuber weight	Tuber dry matter content
	kg m^{-1}	*Tubers m^{-2}*	----------------g----------------		%
K_0	2.331^{a}	30.9	75.4^{a}	119.0^{ab}	19.28
K_1	2.741^{ab}	34.2	80.1^{a}	110.4^{a}	19.39
K_2	2.664^{ab}	33.0	80.7^{a}	122.0^{ab}	19.49
K_3	3.305^{b}	26.2	126.3^{b}	162.5^{b}	19.57

Note: Different letters indicate significant differences *($p<0.05$)* within a column.

A dose of 360 kg K_2O ha^{-1} is quite similar to that recommended commercially, however, higher tuber yields are expected (Jansson, 1980). The reason for the discrepency may lie in the timing of K application during the cropping season. Nutrients should be applied when required and as accurately as possible to the uptake zone. The highest K requirement is during the tuber bulking stage, the onset of which is indicated by flowering. The daily N, P, and K requirements of potato tubers during this critical stage are 4.5, 0.3, and 6.0 kg ha^{-1}, respectively. Under optimum conditions, daily yield increase during tuber bulking may exceed 1.0 Mg ha^{-1} day^{-1} (Ewing and Struik, 1992). Therefore, an adequate supply of the required nutrients at the right N-P-K ratio during the tuber bulking stage would be crucial for further increasing potato yields.

Canopy temperatures were measured on 15-Jun (mid-bloom), 24-Jun (full bloom and tuber initiation) and 9-Jul (tuber growth).

The daily pattern of the canopy temperature had a peak at 13:00 hour (Fig. 3A). The four K treatments followed similar trends.

Midday canopy temperatures were higher on 9-Jul than on 15-Jun. Whereas, on 15-Jun, at tuber initiation, midday temperature was similar among all K treatments. Significant differences occurred later on during the period of intensive tuber growth (Fig. 3B); the higher the K application dose, the cooler the canopy. Plants' leaves are cooled through evapotranspiration; large amounts of water evaporate through stomata carrying the excess heat energy into the atmosphere. Potassium is involved in mechanisms governing stomata aperture (Fischer, 1968) aiming to maintain an appropriate balance between water loss and carbon assimilation. The role of K in the present study could be indirect; as it supports carbohydrate uploading in leaves and its translocation and unloading in tubers, thus enhancing the overall carbon demand in the plant (Lalonde *et al.*, 2004). The maintenance of high carbon demand puts significant pressure on the carbon assimilation processes, thus promoting prolonged stomatal aperture that in turn leads to extensive transpiration and lowered foliar temperature.

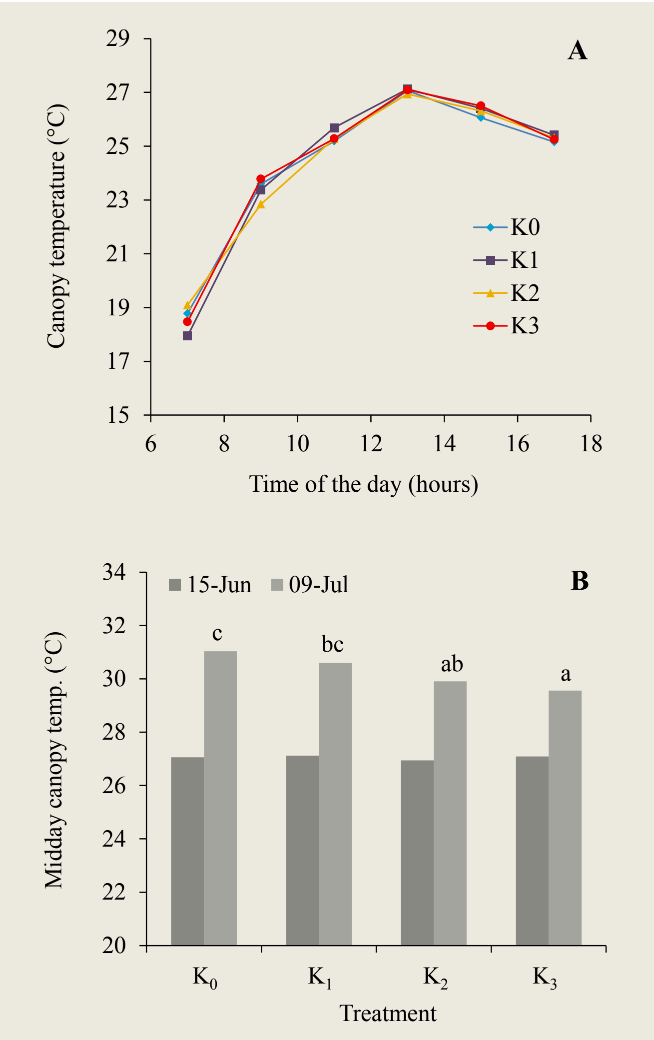

Fig. 3. The effect of the potassium level (K_1: 120, K_2: 240 and K_3: 360 kg of K_2O ha^{-1}) on the daily pattern of potato canopy temperature on 15-Jun (A) and on the midday canopy temperature on 15-Jun and 9-Jul (B). Different letters indicate significant differences ($p<0.05$) on 9-Jul.

High K application dose was associated with increased chlorophyll content in leaves already at full bloom and tuber initiation (Fig. 4). This difference between K treatments also lasted until tuber maturation (data not shown). The retention of high chlorophyll content in leaves quite close to foliar senescence is another indicator of the sustained carbon sink demand by the growing tubers under sufficient K availability. Thus, high K dose preserves intensive physiological activity, delays plant senescence, and contributes to significant yield increases.

Monitoring soil moisture content using sensors at 25 and 50 cm depths allowed thorough adjustment of the fertilizer doses and timing of irrigation. Drip irrigation conveys the water to the exact site of consumption. Continuous deficit (0.85 ETc) drip irrigation allowed the maintenance of relatively steady and spatially homogeneous moisture content throughout the season, varying from 0.34-0.45 m^3 water m^{-3} soil, before and after irrigation. These technologies can enable significant water savings and increased WUE. Indeed, an overall amount of 270 mm was applied to the experimental plot, compared with 345 mm water applied by farmers during the same season, using sprinklers. In the present study, WUE varied from 0.009-0.012 kg tubers kg^{-1}

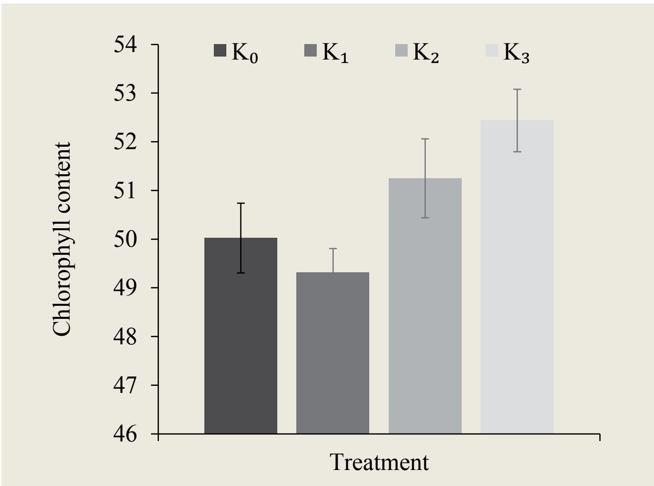

Fig. 4. Chlorophyll content (relative arbitrary units) in potato leaves under different K application doses, measured on 24-Jun, at full bloom and tuber initiation. Bars indicate mean of 32 measurements (4 plants, 8 leaves per plant) ±SE.

water applied, in K_0 and K_3 treatments, respectively. Nevertheless, the actual role of K regarding water saving and WUE in the present study remains unclear. On the heavy textured soil, and with the irrigation regime and technique employed, the mild deficit irrigation was probably not enough to cause significant water stress. Thus, the improved WUE was achieved due to K-promoted increase in productivity rather than by reduced water requirements.

The direct role of K in potato plants coping with water stress is of special importance in the dry sub-humid and semi-arid Mediterranean region. Heat waves, known also as Khamseen, coming from the neighboring Sahara desert or Arabian Gulf often occur during April to June. The sharp increase in temperature, accompanied by a drastic decline in air humidity, challenges the fragile water status of potato plants, particularly during tuber initiation and growth (Bustan *et al.*, 2004). Elucidating K significance in this respect would require direct measurements of plant water potential, stomatal conductance, and transpiration.

Conclusions

Potassium application dose of 360 kg K_2O ha^{-1} promoted a significant increase, 67%, in potato tuber yield, compared to K doses of 0, 120, and 240 kg K_2O ha^{-1}. While showing no influence on the vegetative growth, K had remarkable effects on tuber size, hence on yield. The highest K dose gave rise to higher chlorophyll content and to delayed foliar senescence. Midday leaf temperature was reduced at the higher K dose, indicating extensive and prolonged stomatal conductance. These results demonstrate the important role of K in establishing and maintaining carbon translocation from source leaves to sink organs, thus enhancing potato productivity. Further increase in potato tuber yields should be sought through the increase of the highest K dose to 480 kg K_2O ha^{-1} and/or distribution of K application along the season, particularly during the crucial stage of tuber bulking, when K requirements rise. Potassium's role in regulating plant water relations in potato should be further examined in order to cope with extreme weather conditions that often occur in semi-arid and dry sub-humid regions.

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Regional activities/WANA
Potassium in Stress and Plant Disease

Research Findings

Rapeseed fields in France. Photo by P. Dugast.

Use of Polyhalite as a Source of Sulfur for Oilseed Rape and Winter Wheat in France

Dugast, P.[1]

Abstract

Polysulphate™ (Cleveland Potash Ltd., UK) is the trade mark of the natural mineral 'polyhalite', which occurs in sedimentary marine evaporates, consisting of K_2O: 14%, SO_3: 48%, MgO: 6%, CaO: 17%. Sulfur (S) deficiency has been recognized as a limiting factor for crop production in many regions in the world, particularly in Brassica and cereal crops. The objective of the present study was to assess the performance of common arable crops - oilseed rape (*Brassica napus* L.) and winter wheat (*Triticum aestivum*) under polyhalite fertilizer in comparison with commonly-used S fertilizers. Experiments were carried out in 2013 and 2014, in two locations in north-east France, typified by silty-loam and shallow calcareous soils, respectively. Supplemental S gave rise to a significant yield increase in oilseed rape, particularly on shallow calcareous soils. However, S impact on winter wheat yields in the present study was negligible, probably due to adequate S

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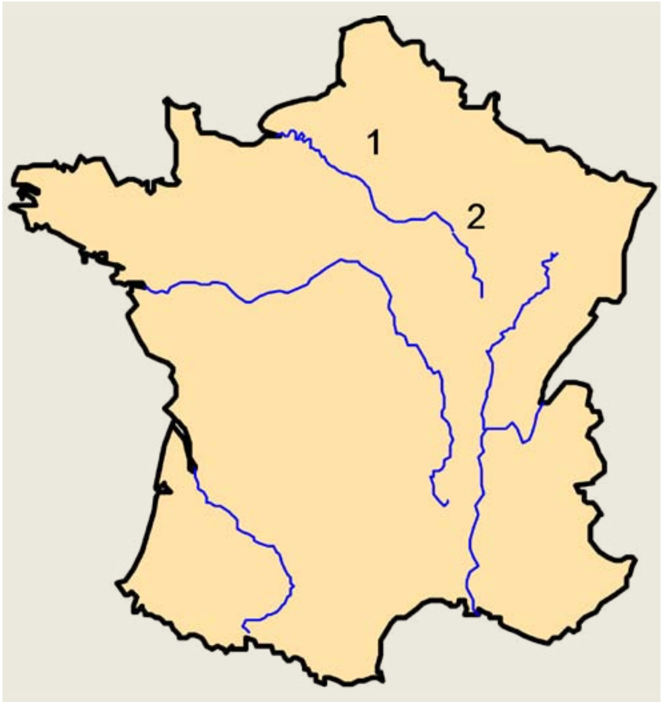
availability in the soil. Polyhalite performance was equivalent to those of well-established S fertilizers; further economic evaluations are therefore necessary.

Introduction

Sulfur (S) is increasingly being recognized as the fourth major plant nutrient after nitrogen (N), phosphorus (P), and potassium (K) (Khan *et al.*, 2005). Sulfur deficiency has also been recognized as a limiting factor for crop production in many regions worldwide. In particular, S deficiency incidence has increasingly been reported in Brassica and cereal crops in Western Europe during the 1990s, mainly as a consequence of a massive decrease in atmospheric S inputs as industrial pollution (which resulted in S inputs to the soil as acid rain) reduced under tighter regulations (Zhao *et al.*, 1999). Sulfur is a constituent of amino acids cysteine and methionine, which act as a precursor for the synthesis of proteins and other compounds containing reduced S (Marschner, 1995). Several studies have established regulatory interactions between N and S assimilation in plants (Kopriva *et al.*, 2002). Sulfur availability regulates N utilization efficiency in plants, and thus affects photosynthesis, growth, and dry mass accumulation in crops.

Winter wheat (*Triticum aestivum*) is a major arable crop, for which application of available sulfur is beneficial to achieve high yields (Randall *et al.*, 1981; Zhao *et al.*, 1999; Hoel, 2011; Järvan *et al.*, 2012; Kulhánek *et al.*, 2014), even if visual deficiencies are not even detected. Wheat's S requirement is about 15–20 kg ha^{-1} for optimum growth (Zhao *et al.*, 1999). Reproductive growth of wheat appears to be more sensitive to S deficiency than vegetative growth (Steinfurth *et al.*, 2012), resulting in decreased grain size under S-limiting conditions (Zhao *et al.*, 1999). In addition to impact on yields, the S status of wheat grain is an important parameter for the quality of wheat products (Moss *et al.*, 1981). Limiting S availability has been shown to favor the synthesis and accumulation of S-poor or low-S storage proteins, such as ω-gliadin and high molecular weight subunits of glutenin at the expense of S-rich proteins (Steinfurth *et al.*, 2012; Dai *et al.*, 2015). Sulfur deficiency also decreases the proportion of polymeric proteins in total proteins, but shifts the distribution of polymeric proteins toward lower molecular weight (Wrigley *et al.*, 1984). These changes in the protein composition results in alterations in dough physical properties, which impact on bread-making quality. A significant link between bread-making quality and the addition of S fertilizers has been established under field conditions (MacRitchie and Gupta, 1993; Zhao *et al.*, 1999).

Sulfur is often associated with crops belonging to the Brassicaceae family. The Brassicaceae include several oilseed crops, among which canola (rapeseed or oilseed rape, *Brassica napus* L.) has become very important, economically. Sulfur and N fertilization, and the balance between them, have a prominent effect on glucosinolate concentration in brassicaceous plants and an increased S supply has been shown to result in higher levels of total glucosinolates (Li *et al.*, 2007). Sulfur deficiency was shown to increase the disease susceptibility of canola to various fungal pathogens (Dubuis *et al.*, 2005) and this loss of anti-fungal activity was strongly correlated with the reduction of various glucosinolates, suggesting that they could have antimicrobial potential. An increase in S fertilization has also been shown to affect polyphenol content e.g. flavonoids and phenolic acids (De Pascale *et al.*, 2007). Zhao *et al.* (1993) showed that supplemental S had brought about considerable increase in oilseed rape yield.



Map 1. Map of France, with the two experimental sites: 1. Deep silty-loam soil. 2. Shallow calcareous soil.

Sulfur is readily available to plants only in its inorganic form as sulfate (SO_4^{2-}). Organic and elemental S must be converted into the inorganic form through microbial activity, a process depending on the soil C:S ratio, temperature, and moisture (Boswell and Friesen, 1993). Sulfate, as a negatively charged ion, is extremely mobile in the soil and is often leached from the root zone. Therefore, significant efforts are made to slow the sulfate release rate to the soil (e.g. using granulation, which increases energy inputs and production costs).

Polysulphate™ (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%; and CaO: 17%. As a fertilizer comprising four key plant nutrients - S, K, Mg, and Ca - polyhalite may provide new approaches for crop nutrition. In polyhalite, S is progressively available; 50% is immediately available, and the rest is slowly released later on. Thus, the objective of the present study was to assess the performance of common arable crops - oilseed rape and winter wheat - under polyhalite fertilizer in comparison with commonly used S fertilizers.

Materials and methods

Trials were carried out for wheat and rapeseed at two experimental sites in north-east France, significantly differing in their soil properties (Map 1): 1. Catenoy, Oise, Picardie, typified by deep silty-loam soil (2013); and, 2. Rochetaillée (rapeseed) and Mouchy-le-Châtel (wheat), Haute Marne, Champagne-Ardenne (2014), with shallow calcareous soils.

Oilseed rape

In both experiments, polyhalite was compared to the soluble S reference magnesium sulphate (Mag25™: $MgSO_4$, 9.8% Mg, 12.3% S). Both sulfur fertilizers were applied to provide 30 or 28 g S ha^{-1}, in site 1 or 2, respectively. In 2013, polyhalite was applied at the C_1 stage of development (Joosen *et al.*, 2007), whereas the reference $MgSO_4$ was applied 15 days later, at the C_2 stage. In 2014, S application was tested at each of the evelopmental stages (Table 1). Nitrogen, P, K, and Mg were applied to provide non-limiting, balanced conditions. Trials were executed under a 3-replicate protocol. Yields (Mg ha^{-1}) are presented as grain dry matter at 9% standard humidity.

Winter wheat

In 2013, granulated ammonium nitrate (AN) containing sulphate (NS: 26% N; 13% S) was employed as the S reference fertilizer (20 kg S ha^{-1}). Polysulphate™ (20 kg S ha^{-1}) was applied at tillering simultaneously with N, using ammonium nitrate at a complementary level.

In 2014, S was provided at 25 kg ha^{-1} in both polyhalite and the S reference fertilizer, the latter consisting of magnesium sulphate. Nitrogen fertilization was based on urea ammonium nitrate (UAN), applied simultaneously with S at the five tiller stage. Phosphorus, K, and Mg were applied to provide non-limiting, balanced conditions. A detailed description is given in Table 2.

Table 1. Detailed description of the oilseed rape trials.

	Treatment	Code	N	SO_3	Date of S
			-------*kg ha^{-1}*-------		
			(UAN)		
2013 (Silty-loam soil)	Non-fertilized control	NFC	0	0	
	Nitrogen	NS_0	210	0	
	Nitrogen+Polysulphate™	NPS	210	72	27/02
	Nitrogen+Mag25™	Ref. S	210	72	20/03
2014 (Shallow calcareous soil)	Nitrogen	NS_0		0	
	Nitrogen+Polysulphate™ C_1	NPS C_1	180	70	24/02
	Nitrogen+Mag25™ C_1	Ref. S C_1	180	70	24/02
	Nitrogen+Polysulphate™ C_2	NPS C_2	180	70	17/03
	Nitrogen+Mag25™ C_2	Ref. S C_2	180	70	17/03

Note: UAN = Urea Ammonium Nitrate

Table 2. Detailed description of the winter wheat trials.

	Treatment	Code	N	SO_3	Date of S
			-------*kg ha^{-1}*-------		
			(AN)		
2013 (Silty-loam soils)	Nitrogen	NS_0	210	0	
	Nitrogen+Polysulphate™	NPS	210	50	28/02
	Nitrogen+S	Ref. S	210	50	28/02
			(UAN)		
2014 (Shallow calcareous soils)	Non-fertilized control	NFC	0	0	
	Nitrogen	NS_0	180	0	
	Nitrogen+Polysulphate™	NPS	180	62	04/03
	Nitrogen+Mag25™	Ref. S	180	62	04/03

Note: AN = Ammonium Nitrate; UAN = Urea Ammonium Nitrate

Yields (Mg ha^{-1}) are presented as grain dry matter at 15.5% standard humidity. Protein content is expressed as the percentage of grain weight at the 15.5% standard humidity.

Results and discussion

Oilseed rape

Large yield differences occurred between the fertile silty-loam soil (2013), where very high yields (2.9 Mg ha^{-1}) were obtained without any nitrogen supplements, and the poor, shallow calcareous soil (2014), where the highest yield levels did not reach 2.6 Mg ha^{-1}, even under the full fertilization regime (Fig. 1). Excluding differences in weather conditions between the two years or sites, the principal differences occurred in yield levels can be attributed to a certain inability of the shallow soils of Haute Marne region to withhold and provide adequate water for the crop (Fismes *et al.*, 2000). Oilseed rape yield is very sensitive to water deficiency, particularly at the stages of floral development, fruit set, and seed filling (Bouchereau *et al.*, 1996; Champolivier and Merrien, 1996; Wright *et al.*, 1996).

Nitrogen, when applied solely (NFC) to the rich soil of Catenoy, brought about a significant increase of almost 50% in yield. Oilseed rape is an N-inefficient crop, which always, though gradually, responds to additional N supply (Fismes *et al*., 2000; Rathke *et al*., 2006). In both experiments, S supplements tended to increase yield (Fig. 1), however, the response was much more significant in the shallow calcareous soil at Rochetaillée, Haute Marne. Whereas only 0.45 Mg ha^{-1} (about 10%) was added to the yield at the rich soil of Catenoy, the yield was almost doubled in response to S fertilization at Rochetaillée.

These results demonstrate again the significance of S fertilization to Brassicaceae crops and the synergistic relationships between N and S, whenever available in the soil (Zhao *et al*., 1993; McGrath and Zhao, 1996; Fismes *et al*., 2000; Li *et al*., 2007). The dramatic effect obtained in the shallow soils at Haute Marne may be explained by the fact that S is often leached out of the soil top layer, thus S application might significantly raise its availability to the crop.

The differences in yield between the two S sources did not provide any statistical significance, nor did their application at different stages of plant development. Other studies also show that when optimizing application date, polyhalite efficiency is perfectly similar to that of magnesium sulfate (unpublished data).

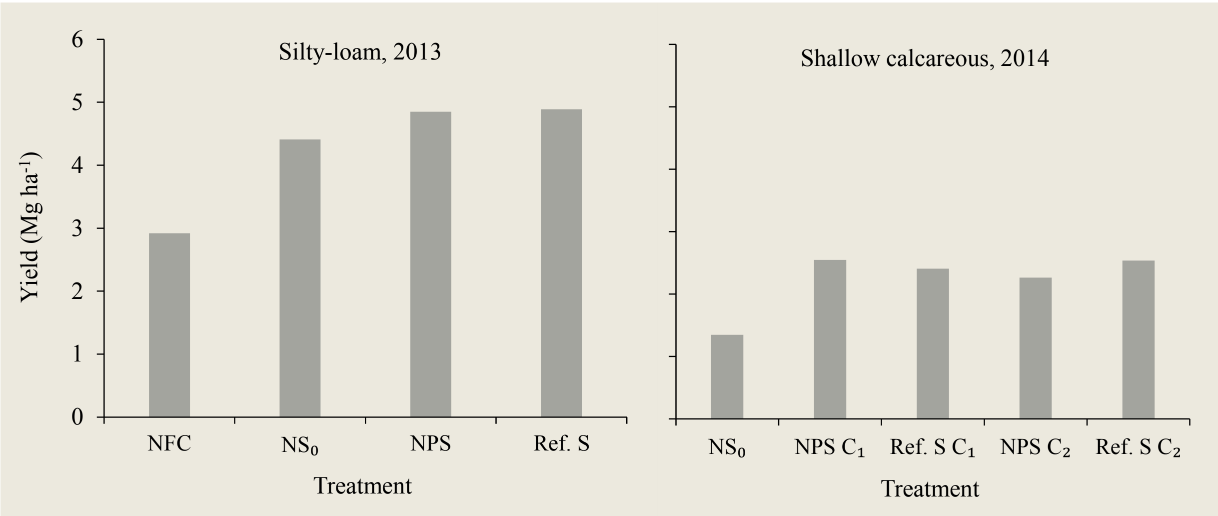


Fig. 1. Oilseed rape yields, expressed in standard terms of dry tonne per hectare (Mg ha^{-1}), as affected by two sulfur sources, Polyhalite or $MgSO_4$. NFC: non-fertilized control; NS_0: fertilized with N alone; NPS: N + polyhalite. Nitrogen and/or S were applied during stages C_1 and C_2 of rapeseed development. In 2013, CV (covariance) and MSE (mean standard error) were 4.6% and 0.2 Mg ha^{-1}, respectively; in 2014, CV was 10%.

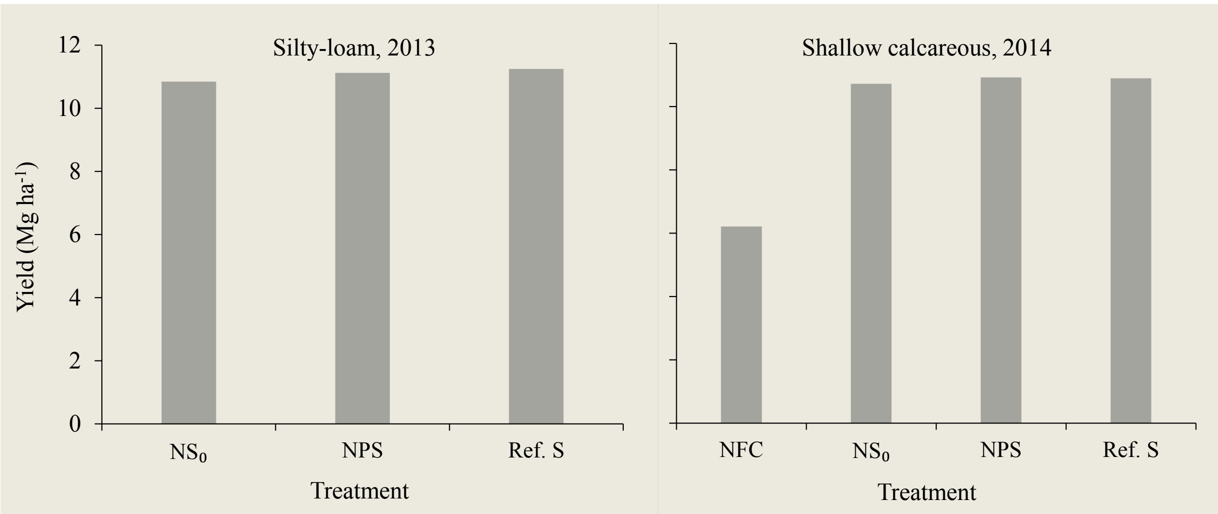


Fig. 2. Winter wheat yields, expressed in standard terms of dry tonne per hectare (Mg ha^{-1}), as affected by two sulfur sources, polyhalite vs. S reference fertilizer (NS in 2013 or $MgSO_4$ in 2014). NFC: non-fertilized control; NS_0: fertilized with N alone; NPS: N + Polyhalite. CV was 2.9% and 2%, in 2013 and 2014, respectively.

Winter wheat

On the fertile silty-loam soil (2013), and with a background of regular N application, the supplemental S slightly increased winter wheat yield by 0.3-0.4 Mg ha^{-1}, which was statistically insignificant (at a significance level of 5%) (Fig. 2). Grain protein content did not respond to the S supplement, remaining constant at 11.3-11.5%. On the shallow calcareous soil (2014), the contribution of N fertilizer alone was responsible for about 89% rise in grain yield, and to an upsurge in protein content from 9.3 to 10.6%. Nevertheless, the S supplement had negligible influences on yield and grain protein content. In both winter wheat experiments, no differences occurred between polyhalite and the S reference fertilizers, magnesium sulphate or AN containing sulphate, in regard to their effects on yield (Fig. 2).

The absence of a significant influence of S application on winter wheat yields in the present study is not surprising. In spite of the general proven effects of S fertilizers on wheat yield, it has been clearly stated that these might be strongly dependent on local or temporal, edaphic or climatic conditions, respectively (Hoel, 2011; Järvan *et al*., 2012; Kulhánek *et al*., 2014). In all these studies, S effects on winter wheat yields were inconsistent, occurring in certain years or locations but absent in others. Considering the high yields obtained, it may well be that the initial S status in the soil, in both sites, was enough to provide all crop requirements of winter wheat, so S supplement in these cases was ineffective. Unfortunately, some impacts that S fertilizers might have had on the grain and flour quality were beyond the scope of the present study and, therefore, were not examined.

Conclusions

The significance of S application to oilseed rape yield is demonstrated, particularly on shallow calcareous soils. Unfortunately, similar influences were not shown in this study for winter wheat, probably due to adequate S availability in the soil. Polyhalite performance was equivalent to those of well-established S fertilizers, and therefore, remains to be further evaluated at the economical level.

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The paper "Use of Polyhalite as a Source of Sulfur for Oilseed Rape and Winter Wheat in France" also appears on the IPI website at:

Regional activities/Europe

Events

IPI Events

November 2015

Report of the 2nd IPI-Ministry of Agriculture and Natural Resources-Hawassa University-Ethiopian ATA Joint Symposium entitled "The Role of Potassium in Balanced Fertilization", 24-26 November 2015, Hawassa, Ethiopia

About the symposium

The 2nd IPI Symposium on "The Role of Potassium in Balanced Fertilization" took place on 24-25 November 2015 at Hawassa University in the Southern Nations, Nationalities, and Peoples' Regional State, Ethiopia. Fifty experts and students in soil research from Ethiopia, Israel, Kenya, South Africa, Tanzania and Vietnam gathered to share knowledge, ideas and expertise to inspire agricultural development in sub-Saharan Africa (SSA). IPI symposium partners were: The Ethiopian Agricultural Transformation Agency (ATA); the Federal Democratic Republic of Ethiopia's Ministry of Agriculture; and Hawassa University.

Symposium participants at Hawassa University. Photo by IPI.

Sessions included: The Role of Fertilizer and its Value Chain in SSA; The Role of Potassium in Soil and Plant Systems in Eastern Africa; Evaluation of Soil Potassium Fertility; and, Balanced Nutrition for Increased Productivity. As part of the event, international participants were also shown the fruits of Ethiopian farmers' use of potassium fertilizer during two field visits in Meki and Bushofti, Oromia Region, Ethiopia.

Context

The role of potassium in balanced fertilization and its impact on crop productivity and quality is gaining increasing attention from agronomists and plant nutritionists. This is particularly relevant in SSA where soils are nutrient depleted, and fertilizer use and agricultural productivity remains the lowest in the world. Ethiopia is currently implementing its second five-year Growth and Transformation Plan (2016-2020) in which agricultural productivity is expected to increase to 40.6 million tonnes from the current level of 27 million tonnes. The Ethiopian Ministry of Agriculture is now distributing potash fertilizers to needy farmers and is developing its domestic custom-made fertilizer blending capabilities. This is based on extensive digital soil fertility mapping being carried out as part of the Ethiopian Soil Information Service (EthioSIS).

Testimonials

"The symposium brought together international expertise, which encouraged participants to rethink and redesign their research and develop approaches for balanced fertilization including potassium. It has built momentum in Ethiopia and Eastern Africa - it's no longer business as usual."

Professor Tekalign Mamo, Programme Leader, EthioSIS
(Former State Adviser to the Minister of Agriculture, Ethiopia for 12 years)

"The use of potassium in soil is such a crucial topic. It is an honour for our university - the top in Ethiopia - to host such an important meeting and put the spotlight rightly on potassium."

Professor Yosef Mamo, President, Hawassa University

"Science is the fundamental building block for agricultural productivity. Agriculture is knowledge-intensive. It requires that we look at issues and validate research again, again and again. We have to take this knowledge and share it. At the end of the day, farmers, and improving their valuable work, is our goal."

Hillel Magen, Director, IPI

"It is a privilege to be here and see successes in Ethiopia. Seeing is believing. This is the case for farmers using potash when they see improvements in what they grow. It's the same for us too, and our global industry; improving human health and people's quality of life is at the heart of everything we do."

Dani Chen, Executive Vice President, ICL

Prof. Yosef Mamo, President, Hawassa University. Photo by IPI.


Final panel at the symposium. Photo by IPI.

"It is clear that crops need potassium. Especially in light of erratic rainfall and moisture stress, potash is effective for farmers. Without potassium, maize yields for example can be 70% lower - completely uneconomical for farmers."

Dr. Mart Farina, Adviser, Omnia Fertilizer, South Africa

"If you have information about characteristics of soil you can tailor your fertilizer needs specifically to grow more, and better quality produce."

Dr. Tran Minh Tien, Deputy Director General, Soils and Fertilizers Research Institute (SFRI), Vietnam

Declaration

The **Declaration of the sub-Saharan Africa, 2nd IPI Symposium on 'The Role of Potassium in Balanced Fertilization'** is a result of the 2nd International Potash Institute (IPI), Ministry of Agriculture and Natural Resources of the Federal Republic of Ethiopia, Ethiopian Agricultural Transformation Agency and Hawassa University joint symposium held on 24-25 November 2015 in Hawassa, Ethiopia. The declaration is directed to sub-Saharan Africa's policy makers, academics, legislators, research institutions, NGOs, public and private sectors and relevant ministries.

The participants of this joint sub-Saharan Africa symposium include representatives from Kenya, Tanzania and Ethiopia cutting across private, research and higher learning institutions, and distinguished scientists in soil fertility management, agricultural and natural resources disciplines. Together, we recognize that:

- Nutrient depletion is severe in Ethiopia, Kenya, Tanzania and across the sub-Saharan Africa (SSA) region.
- Balanced crop nutrition is key to attaining potential yields and sustainable crop productivity in Ethiopia, Kenya, Tanzania and SSA.
- Fertilizer usage in SSA is the lowest in the world and, unlike the rest of the world, SSA countries have concentrated on N and P fertilization and neglected other key nutrients including K.
- Most SSA countries rely on blanket fertilizer recommendations that do not reflect varying soil fertility characteristics, specific conditions on the ground, or the actual nutrient requirements of crops.
- Potassium has been misconstrued to be sufficient in Ethiopia, Kenya, and Tanzania.
- Soil mapping (including soil fertility mapping) is key in delineating nutrient needs for different soil types and crops across SSA countries.
- The current generation is obliged to maintain soil fertility for both current and future generations.
- Caring for and protecting soils against degradation and nutrient depletion is cheaper than rehabilitation after serious land degradation.
- In most SSA countries, soil as a resource has not been given enough emphasis by policy bodies and relevant stakeholders.
- A shared soil database on soil research and information is non-existent in the SSA region.
- Soil salinity is becoming a challenge to sustainable agricultural production. This is a result of emphasis on development and intensification of irrigation schemes without parallel emphasis on reclamations measures in smallholder farming systems.
- Soil acidity is increasingly a challenge in some SSA countries limiting nutrient availability, crop response to fertilizers and fertilizer use efficiency, including potash fertilizers.
- Continuously monitoring soil fertility and implementing balanced fertilizer advisory systems are key components for improved crop production and productivity.

- Agricultural research is pertinent for developing balanced fertilizer recommendations, soil fertility improvements, rehabilitation of degraded lands and eventually, quality and yield improvements.
- Balanced fertilizer use has a direct relationship with and impact on sustainable environment, food security, human and livestock health.
- Educational institutions have a key role in creating awareness and imparting knowledge on soil fertility; ensuring that the curriculum is relevant to current needs.

As a result of the symposium discussions we, the participants, declare that:

1. Policy, research, education, capacity building and extension services should focus on balanced fertilization and integrated soil and water management for sustainable agricultural production and productivity.
2. We believe that integrated soil fertility management (ISFM) is the approach that SSA countries should follow to improve soil fertility and attain sustainable food self-sufficiency.
3. There is a need to reconsider fertilizer recommendations in the region that reflect the varying soil fertility status and crop needs towards balanced nutrient management.
4. Fertilizer recommendations should be based on soil tests, crop response data and economic analysis.
5. Soil fertility and fertilizer research should be conducted on representative locations and on a long-term basis.
6. Liming, used to address soil acidity, is a first step to soil fertility management in reclaiming acidic soils.
7. Knowledge management, synergy and coordination between Ethiopia, Kenya and Tanzania must be initiated to share and assign responsibilities to work on holistic soil fertility and management research.
8. The Soil Science Society of East Africa (SSSEA), the Ethiopian Soil Science Society (ESSS) and others, should work closely together as platforms to generate shared soil fertility and nutrient management research for exchanging knowledge and experiences.
9. Like Ethiopia, other countries in the region should develop their own soil fertility atlas of agricultural lands for balanced nutrient recommendations.
10. We believe that developing a soil information database and system in the region is critically important for knowledge storage, sharing and maintaining sustainable soil fertility information to contribute to better decision and/or policy formulation, recommendations and guideline development.
11. Equally, we believe that SSA governments and international collaborators should think about establishing an apex or umbrella body that backstops soil issues in individual countries.
12. Transforming soil fertility management requires support from soil testing services. Hence, service delivery by various institutions/organizations needs coordination, testing exchange programs for quality control, guidance and capacity building.
13. We recommend that educational institutions at all levels should revise their curriculum to include current soil fertility needs to reflect the importance of balanced fertilization to shape and guide the current and next generation towards maintaining good soil fertility to nourish the global population.
14. We recommend the development of country-based critical soil levels for potassium.
15. Citizens of SSA should have access to relevant and timely soil resource information, as well as soil and water testing facilities.
16. We recommend that SSA countries without specialized soil research or soil resource institutions should establish them to ensure sustainable management systems in their countries.
17. International institutions engaged in fertilizer production and trade should allocate funds to support local fertilizer initiatives, such as that being done by IPI.
18. SSA countries should promote custom-made fertilizers that will satisfy soil and crop needs.
19. The initiative taken by the 68th UN General Assembly to declare 2015 as International Year of Soils and December 5th as World Soil Day should be adopted by all stakeholders and include the need for balanced fertilization, including potassium.
20. Regional bodies such as the AU, EAC, COMESA and NEPAD should prioritize soil fertility and balanced fertilization in their programs aimed at enhancing agricultural growth in SSA.
21. IPI's initiative to bring together soil fertility experts, researchers, development experts and international institutions to discuss potassium should be adopted by other similar scientific institutions and panels.

Please see the presented papers on the IPI website at: Papers and Presentations.

This report also appears on the IPI website at:

Regional activities/SSA/Ethiopia

Events (cont.)

International Symposia and Conferences

March 2016

2nd Cassava World Africa, 1-2 March 2016, Accra, Ghana. The summit will focus on the "Roadmap to Raise Cassava Production and Investments of Higher Value-added Products".
The key highlights are "Progress and market prospects for cassava production of Starch, HQCF, Beer, Feed, Ethanol; Financing solutions and cassava investment projects across the continent; Cassava breeding and agronomy research to increase yields and quality including diseases management; Cost effective post-harvest logistics and processing technologies to increase cassava utilization; Mechanization of cassava production". For further information go to the event website.

CropWorld Global, 2-3 March 2016, Amsterdam RAI, Netherlands.
CropWorld Global is Europe's leading event dedicated to the latest developments & innovations on crop production, protection and agricultural technology. The event's new format connects a Congress and Expo. Leading global suppliers, buyers, scientists, regulators and key policy makers from the agriculture and crop industry will benefit from two days of first-rate networking and exposure to new business opportunities. See more details on the congress website.

April 2016

4th IFA/New AG International Conference on Slow- and Controlled-Release and Stabilized Fertilizers, 4-6 April 2016, Beijing, China.
The aim of the conference is to deliver the most up to date information in the fields of research and development; agronomic and environmental benefits; economics of use; policy and regulatory framework; current market and outlook for these products.

The conference programme will feature presentations by scientists, crop advisors, regulators and industry representatives, and a poster session will allow the presentation of commercial products.

Please see the Advanced Programme. For more information visit the New AG International Conference website.

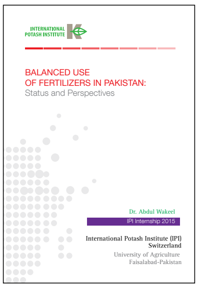
August 2016

5th Sustainable Phosphorus Summit 2016 (SPS 2016), 16-20 August 2016, Kunming, Yunnan, China.
SPS 2016 is the fifth in a successful series of Sustainable Phosphorus Summits that was launched in Linköping (Sweden) in 2010, and then went to Tempe (USA) in 2011, Sydney (Australia) in 2012 and Montpellier (France) in 2014, related to the Global Phosphorus Research Initiative. It is a global multidisciplinary event to discuss phosphorus production and utilization, management and sustainability. The conference will be hosted by China Agricultural University and Yuntianhua Group. See First Circular on the IPI website/Events.

December 2016

7th International Nitrogen Conference (INI 2016) "Solutions to Improve Nitrogen Use Efficiency for the World", 4-8 December 2016, Melbourne Cricket Ground, Victoria, Australia.
More information on this triennial event, which is supported by both IPNI and IFA, is available online on the conference website.

Publications



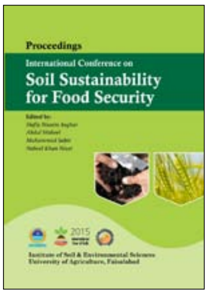
Balanced Use of Fertilizers in Pakistan: Status and Perspectives

IPI Internship Report prepared by Dr. Abdul Wakeel, IPI Consultant Pakistan. 36 p. October 2015.

An ever increasing population is significant on the use of chemical fertilizers for food security, because high yielding varieties and intensive use of soils deteriorates the natural resources especially soils in developing countries. Reduced soil fertility is one of many factors degrading soil quality and productivity.

This internship report is based on the data collected by interns to present the facts and figures of the use of fertilizers in Pakistan to signify the perspectives of balanced use of fertilizers with special reference to the use of potash. This report provides a view of Pakistani agriculture regarding balanced use of fertilizers to researchers, extension workers, progressive farmers and policy makers.

To download the full report go to the IPI website/Publications/Reports. For more information contact Dr. Abdul Wakeel, IPI Consultant Pakistan.



Soil Sustainability for Food Security

Proceedings of the International Conference on "Soil Sustainability for Food Security", held on 15-17 November 2015 at the Institute of Soil and Environmental Sciences, University of Agriculture, Faisalabad, Pakistan.

2015. Edited by Hafiz Naeem Asghar, Abdul Wakeel, Muhammad Sabir, and Nabeel Khan Niazi.

For more information or copies contact Dr. Abdul Wakeel, IPI Consultant Pakistan.

Fertilizers and Climate Change - Media Backgrounder

Published by IFA. 1 December 2015. With a growing world population and ever increasing global demand for food, it is more important than ever to maximize crop yields, and fertilizer will play a critical role in achieving that goal. Accordingly, the focus of greenhouse gas (GHG) reduction efforts must be on improving the relative carbon intensity of agricultural crops grown with the assistance of fertilizers, rather than on reducing absolute emissions. In other words, efforts should be placed on increasing nutrient use efficiency without jeopardizing productivity.

Please see the Media Backgrounder on the IPI website. For more information contact IFA at ifa@fertilizer.org or go to: www.fertilizer.org/NutrientStewardship; www.fertilizer.org/fertilizerfacts; twitter.com/fertilizernews.

Scientific Abstracts

K in the Literature

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Soil Fertility Status and Wheat Nutrient Content in Vertisol Cropping Systems of Central Highlands of Ethiopia

Hillette Hailu, Tekalign Mamo, Riikka Keskinen, Erik Karltun, Heluf Gebrekidan, and Taye Bekele. 2015. Agriculture & Food Security 4:19. DOI: 10.1186/s40066-015-0038-0.

Abstract: *Background:* Land degradation reduces agricultural productivity and poses a serious threat on food security status of households. In Ethiopia, farmers have been using only urea and di-ammonium phosphate for more than 15 years. Several reports that indicate lack of response to these fertilizers, which could be due to limitation of nutrients other than nitrogen and phosphorus. Therefore, the present study was initiated to evaluate the soil fertility status of ten sites in central highlands Vertisols of Ethiopia and wheat nutrient content. *Results:* The physico-chemical properties of soils showed that the soils were clayey in texture, neutral to slightly alkaline (pH 7.2-7.9) and low to medium in their organic matter (1.6-3.2 %) content. Total N content was low in 100 % of the samples while 80 % of the soil samples showed P deficiency (<10 mg kg^{-1}). Exchangeable K, Ca and Mg in all soil samples were high, while available sulfur was low. On the other hand, K to Mg ratio varied from 0.13:1 to 0.44:1, indicating Mg induced K deficiency. All soil samples were adequate when analyzed by ammonium bicarbonate di-ethylene tri-amine penta-acetic acid extractable Cu (>0.5 mg kg^{-1}), Fe (>5 mg kg^{-1}), and Mn (>1 mg kg^{-1}) contents. However, 70 % of the samples were deficient in Zn (<1.5 mg kg^{-1}) content. Mehlich 3 extractable B (<0.5 mg kg^{-1}) and acid ammonium oxalate extractable Mo (<0.1 mg kg^{-1}) were found to be low in all soil samples. The plant analysis data showed that all samples were low in N, P and K, while high in Ca and Mg concentrations. The deficiency of tissue K content was not predicted by the soil exchangeable K test. Plant micronutrient analysis showed that Cu, Fe, Mn and Cl concentrations were within the sufficiency range while Zn was deficient in all of the samples. *Conclusions:* Soil and/or tissue test results are indicative of deficiency of N, P, K, S, Zn, B and Mo that could be amended by fertilizer application, although more data are needed to thoroughly support this conclusion. The highest correlation (r >0.90) between soil and plant nutrient content was observed for P, K, Mg, Cu, Fe, Mn and Zn, implying that flag leaves at flowering stage can be used to calibrate soil and plant contents for the deficient nutrients.

Effect of Long-Term Fertilization on Soil Productivity on the North China Plain

Wang, J.Y., X.Y. Yan, and W. Gong. 2015. Pedosphere 25(3)3:450-458. DOI 10.1016/S1002-0160(15)30012-6.

Abstract: Soil productivity is the ability of a soil, in its normal environment, to support plant growth and can be evaluated with respect to crop production in unfertilized soil within the agricultural ecosystem. Both soil productivity and fertilizer applications affect crop yields. A long-term experiment with a winter wheat-summer maize rotation was established in 1989 in a field of the Fengqiu State Key Agro-Ecological Experimental Station, a region typical of the North China Plain, including seven treatments: 1) a balanced application of NPK chemical fertilizers (NPK); 2) application of organic fertilizer (OM); 3) application of 50% organic fertilizer and 50% NPK chemical fertilizers (1/2OMN); 4) application of NP chemical fertilizers (NP); 5) application of PK chemical fertilizer (PK); 6) application of NK chemical fertilizers (NK); and 7) unfertilized control (CK). To investigate the effects of fertilization practices on soil productivity, further pot tests were conducted in 2007–2008 using soil samples from the different fertilization treatments of the long-term field experiment. The soil sample of each treatment of the long-term experiment was divided into three pots to grow wheat: with no fertilization (Pot_{unf}), with balanced NPK fertilization (Pot_{NPK}), and with the same fertilizer(s) of the long-term field experiment (Pot_{ori}). The fertilized soils of the field experiment used in all the pot tests showed a higher wheat grain yield and higher nutrient uptake levels than the unfertilized soil. Soil productivity of the treatments of the field experiment after 18 years of continuous fertilizer applications were ranked in the order of OM > 1/2OMN > NPK > NP > PK > NK > CK. The contribution of soil productivity of the different treatments of the field experiment to the wheat grain yield of Pot_{ori} was 36.0%-76.7%, with the PK and

NK treatments being higher than the OM, 1/2OMN, NPK, and NP treatments since the soil in this area was deficient in N and P and rich in K. Wheat grain yields of Pot_{NPK} were higher than those of Pot_{ori} and Pot_{unf}. The N, P, and K use efficiencies were higher in Pot_{NPK} than Pot_{ori} and significantly positively correlated with wheat grain yield. Soil organic matter could be a better predictor of soil productivity because it correlated more strongly than other nutrients with the wheat grain yield of Pot_{unf}. Wheat yields of Pot_{NPK} showed a similar trend to those of Pot_{unf}, indicating that soil productivity improvement was essential for a further increase in crop yield. The long-term applications of both organic and chemical fertilizers were capable of increasing soil productivity on the North China Plain, but the former was more effective than the latter. The balanced application of NPK chemical fertilizers not only increased soil productivity, but also largely increased crop yields, especially in soils with lower productivity. Thus, such an approach should be a feasible practice for the sustainable use of agricultural soils on the North China Plain, particularly when taking into account crop yields, labor costs, and the limited availability of organic fertilizers.

The Impact of Climate Change on Maize Cultivation in Switzerland

Holzkämper, A., and J. Fuhrer. 2015. Recherche Agronomique Suisse 6(10):440-447.

Abstract: The premise that global warming changes the conditions for crop production was investigated throughout Switzerland on the basis of a climate suitability for grain maize cultivation. Gridded projections of temperature changes for three time periods (2020-49, 2045-74, 2070-99) available from twenty climate-model chains for the A2 emissions scenario (i.e. the «business as usual» scenario) were used. It was found that with climate warming, the suitable production area increases at higher altitudes but decreases at lower altitudes in the longer term. In a second part of the study, we investigated the influence of individual climatic factors on climate suitability using combined temperature and precipitation scenarios from ten model chains for the Zurich-Reckenholz and Changins sites. Results suggest that heat stress and accelerated plant development are increasingly limiting climate suitability at both sites, whilst water shortage during maturation is only increasing significantly at the Changins site in western Switzerland. The shortening of growth phases also plays a role here, since the temporal shift in crop development can reduce the risk of drought stress if droughtsensitive phenological periods are shifted away from periods of most intense stress. Despite uncertainties with regard to long-term climate change, the results of this study can provide advice for the planning of possible climate change adaptation measures (i.e. future cultivar choice, shifts in production areas).

Fertilizer Management for Sustenance of Soil Health

Singh, B. 2015. Indian J. Fert. 11(10):63-72.

Abstract: Soil is a dynamic and multifunctional system, which can ensure production of enough food and fibre for humans and feed for animals, provided it remains healthy. In the past half century, fertilisers have played a major role in achieving food security for the burgeoning human population. But to keep soil healthy for future generations, awareness is increasing towards understanding how fertiliser use affects the soil other than its effects on crop yields. Where removal of nutrients like P and K exceeds inputs via fertilisers, nutrient mining of soils occurs. Contrary to popular notions, regular and adequate fertiliser use is associated with small but consistent increases in soil organic matter as a result of increased root biomass. Fertiliser use can result in reduction of some soil organisms, but these effects are relatively short-lived and occur only at the site of the fertiliser band. Significant increases in microbial biomass are observed by long-term application of fertilisers in non-acid soils. Application of ammonium-based fertilisers can adversely affect soil health by inducing soil acidity, but the effect is governed by buffering capacity of the soil. The key to ensuring positive effects on soil lies in science-based fertiliser best management practices. In terms of effects on soil health or crop production, there is no conflict between mineral fertilisers and organic nutrient sources; quite the contrary, their use is complimentary.

Effect of Some Cations, Anions, and Organic Residues on Potassium Leaching and Fractionation in Calcareous Sandy Loam Soil

Heidari, S., and M. Jalali. 2015. Archives of Agronomy and Soil Science. 62(1):19-35. DOI 10.1080/03650340.2015.1040397.

Abstract: Potassium (K) is one of the essential elements for plants. There has been enough research to determine pollution of nitrogen (N), phosphorus (P), and heavy metals in soil. However, by comparison research on the storage and transport of K has been neglected. Chemical fertilizer usage leads to serious environmental problems in Iran. Leaching of K can be affected by type of anions and cations present in the chemical fertilizers. Potassium leaching experiments were performed using 10 mM NH_4Cl, $(NH_4)_2HPO_4$, $NH_4H_2PO_4$, NH_4NO_3, NH_4OAC, $CaCl_2$, $Ca(NO_3)_2$, $NaNO_3$, and $CO(NH_3)_2$. The leaching experiment lasted for 20 days (15 pore volumes). In addition, a set of experiments were conducted, where potato and wheat residues and poultry manure and sheep manure were added to soil at the rate of 5% and distilled water was used as the leaching solution to investigate impacts of organic residues on K leaching. In general, maximum K release was observed using NH_4Cl (566 kg ha^{-1}). Potato and wheat residues had maximum and minimum impacts on K

leaching, respectively. Potassium fractionation was carried out after the end of the leaching experiment. The results indicated that leaching of soil in the presence of soluble salts and organic residues altered K distribution in different parts of soil.

Sweet Basil (*Ocimum basilicum* L.) and Potassium Fertilization

Bihter Çolak Esetlilia, Bintuğ Öztürkb, Özgür Çobanoğlua, and Dilek Anaça. 2015. J. Plant Nutr. 39(1):35-44. 2016. DOI 10.1080/01904167.2015.1088022.

Abstract: The objective of the present study was to examine the effect of potassium (K) fertilization and soil texture on total yield (1st and 2nd cuttings) and yield components of sweet basil (*Ocimum basilicum* L.). A greenhouse pot experiment was conducted in a completely randomized statistical design. Basil growth was examined in two different textured soils under three different doses of K fertilization. Generally, for the basil grown under clay soil conditions, moderate amounts of K fertilization is proposed to be sufficient if higher linalool contents are wanted. However, if the growing conditions are sandy loam in texture, it is suggested that higher doses of K be used. Results also highlighted the contribution of second cut as an important cultural practice in the cultivation of an annual basil.

Read on

Nitrogen Use Efficiency (NUE) - An Indicator for the Utilization of Nitrogen in Agriculture and Food Systems

Prepared by the EU Nitrogen Expert Panel. 2015. See Press Release and full report on the IPI website/Other publications.

Wrapping up the International Year of Soils

FAO. 2015.

Common Agricultural Policy: Tackling Soil Loss Across Europe

Panagos, P., P. Borelli, and D.A. Robinson. 2015. Nature 526:195. DOI 10.1038/526195d.

Clipboard

The Brian Chambers International Award For Young Researchers in Crop Nutrition

Congratulations to Admassu Markos, Ethiopia

Admassu Markos, from Hawassa University in Ethiopia, who is studying the response of maize to potassium in southern Ethiopia, was a runner up at "The Brian Chambers International Award For Young Researchers in Crop Nutrition" at the International Fertilizer Society 2015 Agronomic Conference on "Adapting Crop Nutrition Practices to Current Challenges and Constraints" held on 10-11 December 2015 in United Kingdom.

The competition was based on poster presentation, and Admassu Markos submitted a poster entitled "Response of Maize to Potassium Fertilizer at Hadero, Southern Ethiopia".

To download the poster go to IPI website.

New IPI Coordinator for Eastern Africa: Dr. Lilian Wanjiru Mbuthia

Dr. Lilian Wanjiru Mbuthia is the IPI Coordinator for IPI activities in Eastern Africa. As ICL's senior agronomist based in Nairobi, she is responsible for promoting potash market development in Eastern Africa and providing support for specialty fertilizers. After many years abroad for her studies, including an MSc in plant pathology and entomology from Hanover University and a PhD in environmental soil science from University of Tennessee, Dr. Mbuthia returned to Kenya. Her MSc focused on the combination of biocontrol organisms in the control of soil-borne pathogens, specifically the combination of mycorrhiza and *Trichoderma harzianum* in the control of Fusarium wilt (*Fusarium oxysporum* f.sp. *lycopersici*) in tomatoes. Dr. Mbuthia's PhD focused on the dynamics of microbial community and nutrient cycling under different conservation agriculture practices (no-till, cover crops and fertilizations regimes) using both biochemical and molecular techniques.

Dr. Mbuthia's expertise will be invaluable in the coordination of IPI's projects and extension programs in Eastern Africa.

Dr. Lilian Wanjiru Mbuthia can be contacted at:
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New IPI Coordinator for Europe and Turkey: Dr. Menachem Assaraf

Dr. Menachem Assaraf re-joined the IPI team in 2015 as the IPI Coordinator for Europe and Turkey. Previously, from 2008 until 2010, he was IPI's coordinator in China and India. Dr. Assaraf works for ICLF as regional agronomist, Europe and Turkey and is also the ICL coordinator for CFPN, where he is in charge of developing potash and polysulphate demand within his regions of responsibility. He has been with ICL Bromine group since 2000; before this, he was business development manager at ICL Industrial Products. Dr. Assaraf completed a BSc in agronomy at Hebrew University of Jerusalem (HUJI) with an emphasis on plant protection, in particular soil-borne fungal diseases, and soil-borne nematodes. His MSc and PhD were carried out in collaboration with researchers in different departments at the Volcani Center, Beit Dagan, Israel. Dr. Assaraf's MSc focused on the characterization of the accelerated microbial degradation of fungicides (especially Benomyl/Benlate) in various soils and water and his PhD on the mechanisms (at genetic, molecular, and physiological levels), of heat-tolerant and heat-sensitive biotypes of the soil fungal disease *Fusarium oxysporum* f.sp. *niveum* (watermelon wilt) to heat and other abiotic stress agents.

Dr. Assaraf's expertise will be invaluable in the coordination of IPI's projects and extension programs in Europe.

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New IPI Coordinator for Latin America: Dr. Fabio Vale

Dr. Fabio Vale is Coordinator for IPI activities in Latin America. Dr. Vale is based in Brazil and is a consultant in fertilizer markets. He is also an agronomist with experience in product and technology development, and fertilizer recommendations and applications for several crops, including coffee, cotton, maize, soybean and sugarcane. In 2001, Dr. Vale completed a PhD in Soil and Plant Nutrition from São Paulo University, College of Agriculture (ESALQ), Piracicaba, Brazil, where his studies focused on "Assessment of the Availability of Micronutrients in Fertilizers". The end result of his research was the submission of suggestions to modify methods of fertilizer micronutrient analysis; in 2007, his recommendations were adopted by the Brazilian Ministry of Agriculture. Dr. Vale also received an MBA in Agribusiness from Sao Paulo University in 2012.

Over his career, Dr. Vale has built excellent relationships with leading researchers at universities and research institutions involved in soil fertility and plant nutrition. Dr. Vale has also published over 30 scientific papers in journals, congresses and symposia focused on soil fertility, plant nutrition and fertilizer use.

Dr. Vale's expertise will be invaluable in the coordination of IPI's projects and extension programs in Latin America.

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New IPI Coordinator for Southeast Asia: Mr. Gershon Kalyan

Mr. Gershon Kalyan is the Coordinator for IPI activities in Southeast Asia. As chief agronomist at ICL Haifa since 2001, he manages the agriculture department team of 12 agronomists. The team are responsible for agronomic and extension services and activities with farmers, and research services for sales, promotion and know-how in Israel and worldwide. Before the year 2000, he was a regional agronomist for many years in the northern part of Israel for ICL Haifa. Mr. Kalyan started his career as an extension service officer for the Ministry of Agriculture in the northern part of Israel after graduating from the Rehovot Faculty of Agriculture at the Hebrew University of Jerusalem (HUJI). Although Mr. Kalyan's expertise is in soil, water and fertilization, he has also studied marketing and management during his career.

Mr. Kalyan's expertise will be invaluable in the coordination of IPI's projects and extension programs in Southeast Asia.

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