e-ifc

Electronic International Fertilizer Correspondent *(e-ifc)*
Quarterly publication from IPI

No. 40 | March 2015

INTERNATIONAL POTASH INSTITUTE
60 ANNIVERSARY 1952-2012
Optimizing Crop Nutrition

Editorial

Dear readers,

In this issue of *e-ifc*, we present a mini review on the role of chloride (Cl) in plant nutrition. It is an unusual micronutrient for various reasons: its concentration in plants can vary enormously with some plants requiring very high levels whilst others are sensitive. Its supply is, in many cases, provided by proximity to the sea, and by the fact that, generally, it is supplied by applying KCl. The paper by Ren, Xu and Kirkby provides a number of useful insights in how to evaluate the Cl needs of plants.

Also, in this edition, we look at the economics of applying various fertilizer treatments to no-till maize in Bahia State, Brazil. Surely, farmers fertilize to maximize their profits. Wander, da Silva and Wiendl analyze the results from an IPI experiment in the region. Yet with price fluctuations of crop and inputs, this type of analysis must be considered every now and then to include recent changes and ensure the system's optimization.

I wish you a good read.

Hillel Magen
Director

Photo cover page:
Effect of potassium (K) application on yield and quality of apples. Application of potassium (K) at a rate of 2.5 kg per plant increased size and improved color of apples for farmer Ab. Ahad Shah in Aham Sharief village, Bandipora district, Jammu & Kashmir, India. Photo: Courtesy Potash for Life, January 2015.

Research Findings

Redwin winter wheat; photos taken after flowering at a field site near Fort Smith Montana. The entire field was seeded to this cultivar and leaf spot symptoms were apparent across the entire field. The soil test very low in Cl. Photo: Courtesy Dr. Richard Engel, Montana State University, USA.

The Value of KCl as a Fertilizer with Particular Reference to Chloride: A Mini Review

Ren, L.[1], Xu, G.[1], and E.A. Kirkby[2]

Abstract

Potassium chloride (KCl), muriate of potash, is the most commonly used K fertilizer in the world providing crops with two nutrients, K and Cl, essential for both plants and animals. On application to most soils, both these nutrients are readily available to crops. In arable cropping, KCl is applied with other N and P containing fertilizers frequently increasing the efficiency of their utilization. The physiological and biochemical roles played by K in crop plants are mostly well understood and have been extensively investigated. Potassium is known to activate more than 60 enzymes, has a direct function in the synthesis of protein, exerts a major influence on plant water relations, cell turgor and is essential in the process of growth and development of cells. Potassium also plays a key role in photosynthesis and the

[1]College of Resources and Environmental Sciences, Nanjing Agricultural University, Nanjing 210095, China
[2]Faculty of Biology, University of Leeds, Leeds LS2 9JT, UK
Corresponding author: eakirkby@yahoo.co.uk

transport of resulting sugars together with amino N compound to developing fruits and roots. During recent years it has become increasingly clear that K has a major function in crop production in mitigating effects of abiotic and biotic stresses including salinity, cold, frost, waterlogging, and drought as well as insects, pests and various diseases. The detailed molecular and biochemical controlling mechanisms involved still require further elucidation. Potassium and nitrogen are the two nutrients that are taken up in the largest amounts by crops. There is an extensive literature showing these two nutrients act in partnership to have an enormous impact in determining crop yield and quality. When K supply is inadequate (i.e. the ratio of K/N supplied to crops is too low), low molecular weight sugars and amino acids accumulate rather than the formation of high molecular weight compounds including proteins, starch, polysaccharides and cellulose present in high quality crops. Crop yields and quality are correspondingly affected. The role of chlorine as an essential nutrient in various aspects of crop nutrition is also becoming increasingly evident. The chlorine content of the lithosphere is about 500 mg kg^{-1} and occurs almost exclusively as the anion chloride (Cl^-). In general, irrigation water contains less than 150 Cl^- mg L^{-1}, which makes it suitable, for most crops providing that leaching can take place. Recommended amounts of KCl fertilizer applied to crops in field practice are in the range of 75-150 kg ha^{-1} for field crops and 300-500 kg ha^{-1} for horticultural crops. KCl is the only suitable form of Cl supply for irrigation and fertigation because of its high solubility. Chlorine is an unusual micronutrient in that Cl concentration in plants can vary enormously. It is required in the water splitting reaction of photosynthesis in the evolution of oxygen, charge compensation, and osmoregulation of the whole plant, as well as regulating movement of the stomatal guard cells of some crop species. Deficiency in crops usually only occurs in areas at great distance from the sea where the input from the atmosphere does not meet the demand, which for dryland wheat production is 4-8 kg ha^{-1}. It can also be a problem in crops such as kiwi fruit and palm trees that have a particularly high demand for Cl. Chloride toxicity occurs worldwide and is a general stress factor limiting crop growth in arid and semi arid areas. Crops differ markedly in sensitivity to Cl. Sensitive crops include: pepper, cabbage, lettuce, rape, tobacco, potato and sweet potato whereas a number of the major staple world crops are insensitive: rice, wheat, corn, sorghum, cotton, tomato, eggplant, banana and peach. It is well recognized that Cl can suppress a wide variety of plant pathogens in different crops. These include rust disease of barley (*Puccinia hordei*), stem blight disease of corn (*Aspergillus niger*), brown heart disease of potato (*Cephalotrichum stemonitis*), barley root rot (*Cochliobolus sativus, Fusarium culmorum*), and corn stalk rot (*Fusarium spp*). The soil borne fungus take-all in cereal crops (*Gaeumannomyces graminis*) is particularly sensitive to Cl. The reason for this appears to relate to its enhancing effect on Mn uptake and in increasing cellular osmotic pressure. In the context of human nutrition, the benefits of a balanced diet supplied with adequate amounts of K and Cl is discussed as well as the detrimental effects of excess NaCl.

Introduction

The fertilizer potassium chloride (KCl) (muriate of potash, MOP) provides two essential elements, the macronutrient potassium, as a cation (K^+) and the micronutrient chlorine, as an anion (Cl^-) and is the source of 90% of mineral K applied to crops throughout the world (IFA, 2013). Of all the mineral K fertilizers, KCl has the highest content of K (over 50%). It is readily soluble in water and on application to the soil, K^+ enters the soil solution and exchange complex and can then be rapidly taken up by plant roots. It also mixes well with N and P fertilizers and is rarely applied alone. Indeed KCl application offers an important means of raising the efficiency of utilization of these fertilizers. In the case of grassland, KCl is the only form of mineral K fertilizer applied. K removed in hay and silage in nutrient cycling is easily replaced by top dressing with KCl. Nearly all crops respond to KCl under conditions of K deficiency or inadequate supply. For only a very few crop plant species sensitive to Cl^- should application of KCl be restricted, as for example tobacco in which Cl at normal rates of application is detrimental to leaf quality and smoke flavour. The great overall advantage of KCl is that in comparison with other fertilizer forms (K_2SO_4 and KNO_3) it is relatively low in cost and easily accessible.

Most of the essential physiological functions of potassium in crop plants have been well researched. Potassium is taken up by the plant in similar very large quantities as nitrogen and plays a fundamental role in plant physiology and biochemistry especially in relation to N metabolism (see Marschner, 2012; Mengel and Kirkby, 2001; and Roemheld and Kirkby, 2010). It is known to activate more than 60 enzymes, have a direct function in the synthesis of protein, exert a major influence on plant water relations, cell turgor and be essential in the process of growth and development of cells. Potassium also plays a key role in photosynthesis in both the light and dark reactions culminating in the formation of sugar via the reduction of CO_2. Potassium is an exceptional macronutrient in that it is not to any extent incorporated into organic molecules so that it is present within the plant almost exclusively as a univalent cation. In this form it is highly mobile, is the dominant cation both in xylem and phloem pathways and is associated with the transport of inorganic anions and organic metabolites. In the xylem, K at concentrations in the range of 10-20 mmol L^{-1} are responsible for nutrient transport from root to shoot in many crop species whereas in the phloem much higher concentrations (100-200 mmol L^{-1}) occur. Here K controls loading of sucrose and amino acids produced during photosynthesis and their transport to developing fruits and roots. Within recent years it has become increasingly clear that K is the most important mineral nutrient acting to mitigate abiotic and biotic stresses affecting crop production including salinity, cold, frost, waterlogging, and drought as well as insects, pests and various diseases (Cakmak, 2005; Wang *et al*., 2013). In this area much research is still needed to elucidate underlying physiological and molecular interacting and controlling mechanisms but there is no doubt that K ions protect cells against reactive oxygen species (ROS) induced under stress conditions (Cakmak, 2005).

Potassium chloride applied to the soil releases equal amounts of Cl and K ions into the soil solution. Chloride is very mobile in the soil and easily removed by leaching, whereas K entering the soil solution becomes relatively immobile and is held mainly in the soil solution and exchangeable K pools which are accessible for uptake by the roots (Roemheld and Kirkby, 2010). Although much less Cl is usually required for growth and development, chlorine, is an unusual micronutrient in that it is required for some essential functions in minute amounts but its uptake can vary greatly depending on the accessibility of Cl and plant species (Epstein and Bloom, 2004; Chen *et al*., 2010).

The purpose of this mini review is to consider KCl as a crop fertilizer particularly in its relationship to N fertilization to explain the important interaction between these nutrients and to update information on the chlorine component in relation to soil and irrigation, deficiency and toxicity, effects of fertilization on crop yields and environment, effects on crop diseases, and the role played by chloride and K in human health.

Uptake and assimilation of N in relation to KCl application to crops

In crops fertilized with KCl, K exerts a very strong influence on N uptake and metabolism. Nitrate is the principal form of N uptake in most arable soils during the growing season when nitrifying bacteria are active. In many crop plant species both K and nitrate ions are rapidly taken up by roots and transported together from root to the shoot and leaves which are often the main sites of nitrate reduction and assimilation. Both nutrients can be cycled and recycled between shoots and roots which serve several well defined functions. These include supplying the roots with nutrients assimilated in the shoots (nitrate and sulphate reduction), maintenance of cation/anion balance providing additional driving force for solute flow in the xylem and phloem and acting as a shoot signal to convey nutrient demand to the roots. Cycling of mineral nutrients like K is also required to cover the demand for growth of apical root zones and to smooth out fluctuations that occur spatially and with time in the external nutrient supply of soil grown plants (Marschner *et al*., 1997). These two nutrients K and N acting in partnership have an enormous impact on plant biochemistry and physiology including: induction of cell division and extension in shoots and roots i.e. growth; maintenance of cell turgor; control of plant water relations, enzyme activation; photosynthesis; and protein synthesis (Mengel and Kirkby, 2001). Additionally the ratio of K/N considerably affects metabolism. A low ratio induces the accumulation of low molecular weight compounds i.e. amides, amino acids and sugars, whereas a high K/N ratio favours the accumulation of high molecular weight compounds including proteins, starch, polysaccharides and cellulose (Marschner, 2012). An example illustrating the practical implication of this close interaction between K and N on crop yield is shown in Fig. 1 from an experiment on an Illinois soil, low in soil available K. Increasing rates of K fertilization to corn plants adequately supplied with N stimulated rates of nitrogen uptake, thereby increasing corn grain yield and efficiency of N utilization (Better Crops, 1998). A similar response of palm oil yield to the beneficial interactive effect between N and K in can be seen in Fig. 2 (Webb, 2009). There are many other similar examples in the agronomic literature showing the beneficial influence of KCl fertilization on N uptake and utilization increasing yield and quality in various crops as reported by Gething (1993) and Mengel and Kirkby (2001). This influence of K is also beneficial to the environment in restricting nitrate leaching and possible denitrification of nitrate unused by the crop.

In the older literature in particular, attention was given to the possible depressing effects of chloride on nitrate uptake by crops

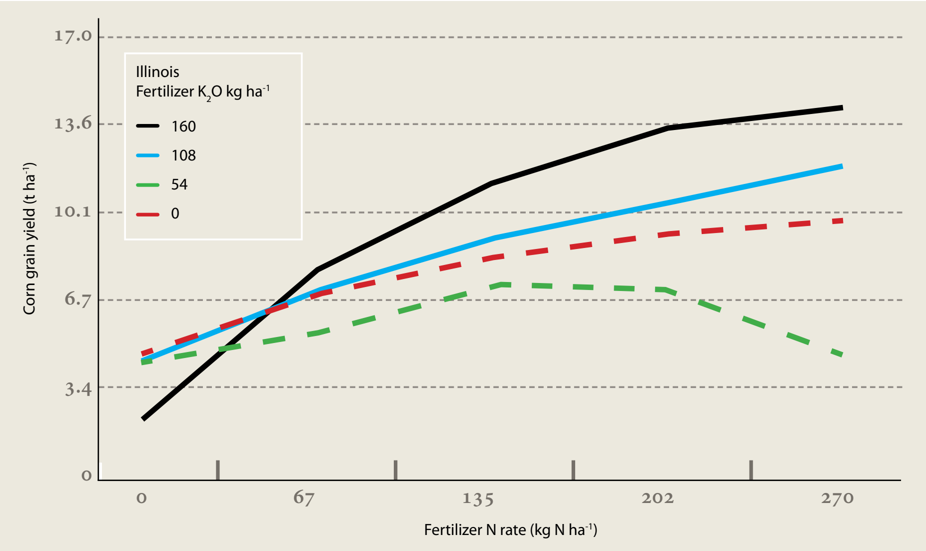


Fig. 1. Corn (*Zea mays* L.) yield in response to increasing rates of soil applied N and K. Adapted from Better Crops, 1998.

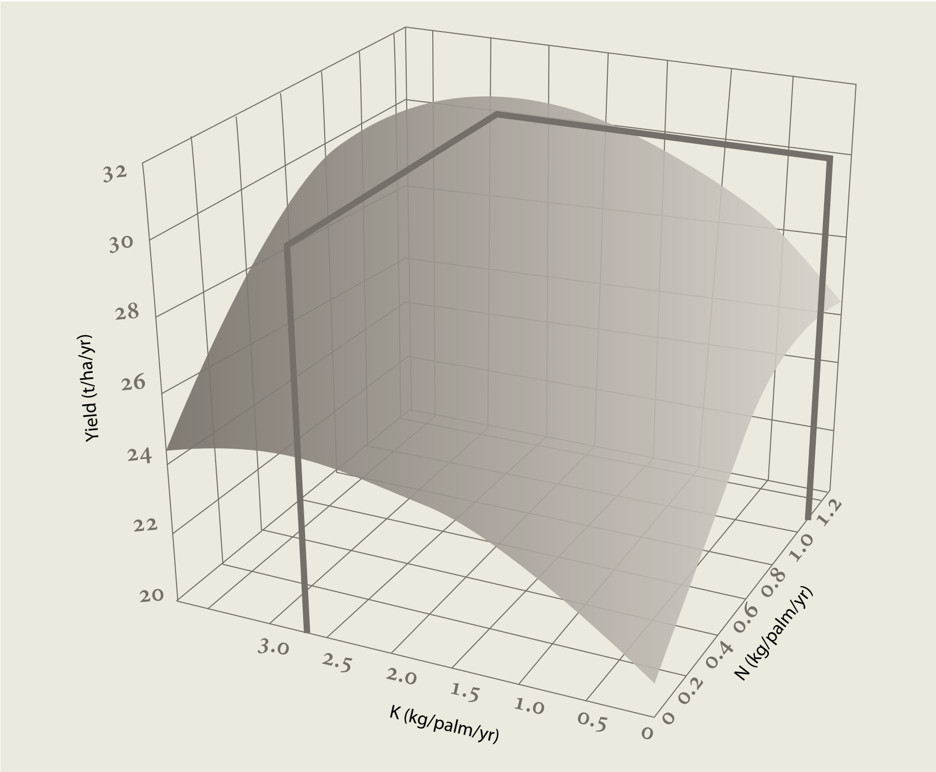


Fig. 2. Oil palm yield in response to increasing rates of soil applied N and K. Adapted from Webb, 2009.

equivalent to the application of about 500-1000 kg Cl ha^{-1} (Maas *et al.*, 1982). Recommended amounts of KCl fertilizer applied to crops in field practice are in the range of 75-150 kg ha^{-1} for field crops and 300-500 kg ha^{-1} for horticultural crops (Fan *et al.*, 2007; Shen *et al.*, 2011; Liu *et al.*, 2012), and are thus much lower than the amount of Cl supplied by irrigation. Moreover, the movement of Cl^- in soil solution is largely determined by water flow (White and Broadley, 2001) and thus Cl^- is easily leached through the soil profile. The addition of Cl^- by KCl fertilizer is therefore safe for most agricultural crops. Potassium chloride is the only suitable source of K that can be used in irrigation and fertigation systems; K_2SO_4 is unsuitable because of the low solubility of $CaSO_4$ while KNO_3 is not easy to handle and is much more expensive.

and hence N utilization. There is no doubt that Cl does compete with nitrate during uptake (Xu *et al.*, 2000; see also references in Khan *et al.*, 2014), but it has to be borne in mind that for most crops the demand for N is very much higher than that of Cl. Usually crop vegetative tissue has a concentration of between 2-5% N in the dry matter which is considerably greater than Cl which usually reaches only about 1% Cl and is often much lower (Heckman, 2006). Moreover, plants not only take up chloride but they release it back into the soil (White and Broadley, 2001). Additionally some plant species and cultivars can and do exclude Cl uptake (Abel, 1969 and Xu *et al.*, 2000). In comparison with the intense physiological and biochemical interactions between N and K any effect of Cl is thus normally of much lesser importance.

Cl^- in soil and irrigation

The chlorine content of the lithosphere is about 500 mg kg^{-1} and occurs almost exclusively as chloride. Hence, most of the water resources in the world contain significant amounts of Cl. In irrigated soils, the Cl^- concentration of topsoil depends closely on the amount and salt concentration of the irrigation water (Xu *et al.*, 2000). In the same review the authors reported that in general, irrigation water contains less than 150 Cl^- mg L^{-1}, which makes it suitable, for most crops providing that leaching can take place. For example, irrigation of 500 mm of water per growth season with a Cl^- concentration of 100-200 mg L^{-1} is

Cl^- in crops, deficiency and toxicity

Chloride is an essential nutrient for plants. It is required in the water splitting reaction of photosynthesis in the evolution of oxygen, charge compensation, and osmoregulation of the whole plant, as well as in the stomatal guard cells of some crop species (Xu *et al.*, 2000; Chen *et al.*, 2010; Marschner, 2012). Various reports of Cl deficiency symptoms have been published since those of Broyer *et al.* (1954) first established chloride as an essential plant nutrient. Whitehead (1985) reported that Cl deficient red clover grown in water culture showed symptoms of leaf wilt, shrivelling and necrosis and stem cracking. Heckman (2006), has drawn attention to a lack of data concerning critical concentrations for many crop species but in wheat at heading there are reports of values of about 1-1.5 mg Cl g^{-1} DM. Deficiency of Cl can occur in the field at sites at great distances from the sea as has been reported in the mid west US wheat belt (Fixen, 1993) where Cl content in the rainfall does not meet the demand of about 4-8 kg Cl ha^{-1} required for adequate crop yield as calculated from the Cl concentration value cited above. Deficiency symptoms in wheat occur as chlorotic and necrotic lesions in the leaves referred to as "Cl deficient leaf spot syndrome" and were reported by Engel *et al.* (1997), see Photo 1. From extensive work from chloride fertilization based on soil testing Mengel *et al.* (2009) report the high probability of beneficial effects of chloride fertilization in dryland wheat and sorghum production in central Kansas. Chloride deficiency can

Photo 1. Chloride deficiency in WB881 durum wheat plants grown in hydroponics in a controlled growth room. The plants were grown in the absence of chloride. Photo: Courtesy Dr. Richard Engel, Montana State University, USA.

also occur in crops with high Cl requirements such as kiwi fruit and palm trees (see Marschner, 2012).

Chlorine toxicity is much more common as a limiting factor in growth worldwide particularly in arid and semi arid environments. According to Marschner (2012) an external concentration of 20 mmol L^{-1} can lead to Cl toxicity in sensitive crop species whereas in tolerant species the value can be 4 to 5 times higher without reducing growth. In most arable soils, the concentration of Cl^- is much lower at about 2-3 mmol L^{-1} in soil solution which is not toxic to most crops (Xu *et al.*, 2000). Corn (*Zea mays* L.; cultivar of Trojan 114) for example tolerated an application of 728 mg Cl^- kg^{-1} in the greenhouse without showing any detrimental effects. The same was true for yield and growth at 340 kg ha^{-1} Cl^- in field experiments (Parker *et al.*, 1985). Cotton yield and quality were unaffected by Cl^- concentrations below 1,600 mg kg^{-1} (Tan and Shen, 1993). Sugar beet requires large amounts of chloride. Its yield increased with increasing Cl^- applications up to 1,600 mg kg^{-1} (Jing *et al.*, 1992). The same authors observed that yield of this crop was not reduced even with applications of Cl^- as high as 3,200 mg kg^{-1} in a clay soil.

Effect of Cl^- fertilization on crop yield and environment

The beneficial effect of Cl on crop yield and quality has been reported in experiments comparing forms of K application Parker *et al.* (1985) determined greater yields in corn (*Zea mays* L.) with equivalent rates of KCl fertilizer as compared to K_2SO_4 fertilizer. A similar beneficial effect of Cl^- fertilizer over sulphate on corn grain yield in field experiments was also reported by Heckman (1995). On a sandy loam soil, with chloride applications of up to 400 kg ha^{-1} over a three year period, yields of 500-1,500 kg ha^{-1} more grain were obtained over the control. Yields were positively correlated with increases in ear leaf Cl concentration. It was concluded that the reasons for enhanced levels of Cl nutrition included a favourable influence on corn production by enhancing retention of water in plant tissues and extending the period of grain fill as well as partitioning more photosynthate into the grain.

From the field experiments of Wen (2006) the rates of application of Cl^--containing fertilizers should be carefully managed in relation to crop species. Crops insensitive to Cl^- such as rice, wheat, corn, sorghum, cotton, tomato, eggplant, banana and peach can tolerate Cl^- fertilizer at rates of 1,350-1,800 kg ha^{-1} $season^{-1}$, whereas rates of application should be lower for moderate Cl^- tolerating crops such as soybean, pea, strawberry, peanut, apple, sugarcane where the range should lie between 675-1,350 kg ha^{-1} $season^{-1}$. For Cl^- sensitive crops such as pepper, cabbage, lettuce, rape, tobacco, potato and sweet potato the Cl^- application should not exceed 675 kg ha^{-1} $season^{-1}$.

Environmental effects of the continuous application of Cl^--containing chemical fertilizers to a paddy soil were studied over a 34 year period at a long-term field experiment site in Hunan Province, China. It was shown that the effect of this Cl treatment in comparison to the application of SO_4^{2-}-containing fertilizer was to enhance biodiversity as measured by an increasing number of weed species and higher biomass of water surface weeds and submerged weeds (Shen *et al.*, 2011). Compared with applied SO_4^{2-}-containing fertilizers, the authors reported that weed biomass was increased by 24.2% and 17.6% by managed Cl^--containing fertilizer in the late rice season and early rice season, respectively, indicating that Cl^- was not harmful to plant growth or development.

Effect of Cl^- fertilization on crop diseases

The Cl^- component in fertilizers has been reported to control a number of diseases in different crop species (Fixen, 1993). According to Elmer (2007) Cl^- application suppresses 23 pathogens on 12 crop species. These include rust disease of barley (*Puccinia hordei*), stem blight disease of corn (*Aspergillus niger*) and brown heart disease of potato (*Cephalotrichum stemonitis*) (Mao and Li, 1999; Zhang *et al.*, 2010). Barley root rot (*Cochliobolus sativus, Fusarium culmorum*) has also been shown to be suppressed by KCl fertilization (Timm *et al.*, 1986). Heckman (1998) demonstrated the beneficial effect of Cl^- fertilizer on corn stalk rot (*Fusarium spp*) in field experiments in which the concentration of Cl^- in the ear-leaf was inreased by raised levels of applied Cl^-. Zhe incidence of stalk rot (*Gibberella zeae*) was also found to be controlled to a greater extent with KCl than K_2SO_4 (Huber, slide 27 on http://brasil.ipni.net/ipniweb/region/brasil.nsf/e0f085ed5f091b1b852579000057902e/98de35edd4f507f483257afe005d60e6/$FILE/Palestra%20Don%20Huber.pdf). According to Huber, farmers in the USA have to face a cost as much as 8-10 billion dollars per year for corn stalk rot damage caused by *Gibberella zeae* and other fungi . The severity of stripe rust in wheat (*Puccinia striiformis* f. sp. *tritici*) was also shown to be significantly reduced in an experiment involving 381 cultivars spring top dressed with NH_4Cl as compared to $(NH_4)_2SO_4$ again indicating a specific effect of Cl^- (Christensen *et al.*, 1982).

The soil borne fungus take-all (*Gaeumannomyces graminis*) in wheat and barley seriously limits grain production in various regions in the world (Huber *et al.*, 2012). This fungal pathogen has a growth optimum at pH 7 and is highly sensitive to low pH as observed by Taylor *et al.* (1983). Both NH_4Cl and $(NH_4)_2$ SO_4 applications depress soil pH. However, the additional presence of Cl appears to be more effective in suppressing pathogen activity. Application of NH_4Cl supplying chloride at approximately 350 kg ha^{-1} to winter wheat, was shown to increase grain yield by 11 to 40% over that obtained with equivalent supply of $(NH_4)_2$ SO_4 in plots where the presence of take-all disease was confirmed (Christensen *et al.*, 1981), (see also Christensen *et al.*, 1993). This beneficial effect appears to relate specifically to the Cl and is not dependent on the accompanying fertilizer cation. The same authors reported similar benefits of Cl application supplied as KCl with N in the form of NH_4N in increasing yield of winter wheat and depressing the incidence of take-all in the roots (Table 1). The most effective treatment was to apply the KCl both in autumn and spring.

Table 1. Effect of chloride as KCl on the "Incidence of Take-All in Winter Wheat" in a field experiment supplied with NH_4N.

Chloride treatment		Infected roots	Grain yield
---------------*kg ha*$^{-1}$---------------		-------*%*-------	------*t ha*$^{-1}$------
Autumn	Spring		
0	0	45	5.3
56	0	34	5.7
56	185	11	6.5

Source: Christensen, N.J. *et al.* 1981. Agron. J. 73:1053-1058.

A most detailed and thought provoking account of chlorine and plant disease has been produced by Elmer (2007). He suggests that the major influence of chloride fertilization on plant disease appears to be a reduction of cell osmotic potential (increased turgor pressure) together with an increase in manganese uptake and an enhancement of beneficial microbes through changes in root exudation. Manganese increases host resistance by inducing deposition of ligneous defence barriers (Huber and Wilhelm, 1988). The increase in osmotic pressure can be accounted for as a result of the Cl uptake. There are both chemical and microbiological means to achieve a chloride-mediated Mn uptake in which soil pH has a controlling influence. In acid soils (pH lower than 6.6) adequately supplied with Mn, chloride suppresses nitrification and a chemical reduction occurs to produce Mn^{2+} whereas in neutral and alkaline soils, Cl may enhance Mn by altering the nutritional composition of the root exudates which in turn favours microbes that are able to induce Mn reduction. The beneficial effect of suppressing the incidence of take-all by use of a nitrification inhibitor is shown by Huber (slide 25 at http://brasil.ipni.net/ipniweb/region/brasil.nsf/e0f085ed5f091b1b852579000057902e/25dd770a7fa6689c83257b090060759d/$FILE/Palestra%20Don%20Huber.pdf). It also appears likely that Cl^- enhances the activity of relevant plant resistant enzymes. For example cucumber downy mildew (*Pseudoperonospora cubensis*) was suppressed by Cl^- application which was associated with an increase in β-1,3-glucanase activity (Jia *et al.*, 2004). A detailed account of the beneficial effect of Cl^- in restricting various plant diseases is given in Heckman (2006) and also referred to in Huber *et al.* (2012).

The effect of Cl^- and K^+ on human health

Chlorine is an essential mineral nutrient for humans (animals) as well as plants and similarly to plants is ingested as Cl^-. The body of an average adult human contains about 115g chloride making up about 0.15 % of the total body weight and the Cl anion represents about 70% of the total anion charge within the blood (Meletis, 2014). By far the greatest intake of Cl by humans is from table salt NaCl. The World Health Organization, 2012 recommends that human adult consumption should be limited to 5 g salt (NaCl) per day. This represents 3,035 mg Cl^-, an amount which is at least 5 fold greater than that which can be supplied in the diet by plant material assuming a daily intake of 30 g dry plant material (approx 300 g fresh plant material) with a Cl concentration in the range of 2-20 mg g^{-1} in the dry matter (Xu *et al.*, 2000). The 5 g NaCl figure for human intake is often greatly exceeded, as in the US, so that the contribution of Cl from plant material can be even lower than the value cited above. Excessive intake of NaCl is extremely damaging to health causing hypertension and is associated with cardiovascular disease. Indeed a current problem in the human diet is the low intake of K relative to the high Na intake (see Roemheld and Kirkby, 2010); this is one of the reasons for the benefit of a high intake of fruit and vegetables as a source of K in the human diet. Amongst the functions of K in human nutrition are its essential roles in protein synthesis, carbohydrate metabolism, electrical activity of the heart and the acid base balance together with its functions as an anti oxidant in both plants and animals. Chloride obtained from crops is thus not harmful to human health and KCl application to crops is without influence on the intake of Cl by humans, and is of benefit in providing a source of K.

Khan *et al.* (2014) suggest that KCl fertilization of crops can be detrimental to human health by depressing crop quality but convincing evidence of any direct effect on the human diet is lacking. What is certain is that worldwide, KCl is the predominant form of K fertilization for nearly all commercially produced nutritional crops and it has been extensively demonstrated that both the yield and quality of crops adequately supplied with KCl is far superior than when supply is inadequate or deficient (Kafkafi *et al.*, 2001). As an example of a supposedly harmful effect of KCl fertilization, Khan and his colleagues cite literature relating to potato production arguing that chloride fertilization lowers starch concentration which in turn reduces specific gravity "with adverse consequences for health such as obesity and cardiovascular diseases arising from greater oil retention in processed products such as potato chips and French fries". Here the authors appear to lose sight of the major causes of the increasing rates of obesity and cardiovascular diseases now established as: a high calorie poor diet increasingly being made up of sugar and junk foods low in fibre, an excess Na intake, and a lack of the macro and micronutrients and vitamins as a regular major components of the daily intake. In relation to the dangers of consuming French fries, heating these above 120° C gives rise to the potential carcinogen acrylamide. Tubers of potato varieties with high concentrations of reducing sugars and asparagine are particularly prone to acrylamide formation (Amrein *et al.*, 2003). In this respect the work of Gerandas *et al.*, 2007 provides clear evidence of the benefit of increasing K/N ratio of fertilizer treatment during tuber growth in depressing the accumulation of reducing sugars, asparagine as well as the levels of acrylamide in the French fries from the processed tubers.

References

Abel, G.H. 1969. Inheritance of the Capacity for Chloride Inclusion and Chloride Exclusion by Soybeans. Crop Sci. 9:697-698.

Amrein, T.M., S. Bachmann, A. Noti, M. Biedermann, M.F. Barbosa, S. Biedermann-Brem, K. Grob, A. Keiser, P. Realini, F. Escher, and R. Amado. 2003. Potential of Acrylamide Formation, Sugars, and Free Asparagine in Potatoes: A Comparison of Cultivars and Farming Systems. J. Agric. Food Chem. 51(18):5556-5560.

Better Crops, 1998. Potassium for Agriculture. 82(3). Potash and Phosphate Institute (PPI). ISSN:0006-0089.

Broyer, T.C., A.B. Carlton, A.M. Johnson, and P.R. Stout. 1954. Chlorine - A Micronutrient Element for Higher Plants. Plant Physiol. 19:925-936.

Chen, Wenrong, He, Zhenli L., Yang, Xiao E., Mishra, Suren and Stoffella Peter J. 2010. Chlorine Nutrition of Higher Plants: Progress and Perspectives. J. Plant Nutr. 33(7):943-952.

Cakmak, I. 2005. The Role of Potassium in Alleviating Detrimental Abiotic Stresses in Plants. J. Plant Nutr. Soil Sci. 168:521-530.

Christensen, N.J., R.G. Taylor, T.L. Jackson, and B.L. Mitchell. 1981. Chloride Effects of Water Potentials and Yield of Winter Wheat Infected with Take-All Root Rot. Agron. J. 73:1053-1058.

Christensen, N.W., Christensen, N.W., T. L. Jackson, and R. L. Powelson. 1982. Suppression of take-all root rot and stripe rust diseases of wheat with chloride fertilizer. *In:* Plant Nutrition 1982. Proceedings of 9th International Plant Nutrition Colloquium, Warwick, England. Scaife, A. (ed.), p. 111–116. Slough, England: Commonwealth Agricultural Bureau.

Christensen, N.W., R.G. Taylor, and P.E. Fixen. 1993. Crop Responses to Chloride. Adv. Agron. 50:107-150.

Elmer, W.H. 2007. Chlorine and Plant Disease. *In:* Mineral Nutrition and Plant Disease. Datnoff, L.E., W.H. Elmer, and D.M. Huber (eds.). American Phytopathological Society Press. p. 189-202.

Engel, R.E., P.L. Bruckner, D.E. Mathre, and S.K.Z. Brumfield. 1997. A Chloride-Deficient Leaf Spot Syndrome of Wheat. Soil Sci. Soc. Am. J. 61:176-184.

Epstein, E., and A.J. Bloom. 2004. Mineral Nutrition of Plants: Principles and Perspectives, second edition. Sinauer Associates.

Fan, G.G., L. Zhang, T.S. Li, and T.S. Wang. 2007. Effects of Application of N, P, K Fertilizer on Corn Yield and Efficiency. Guizhou Agricultural Sciences. 35(4):79-80. (In Chinese).

Fixen, P.E. 1993. Crop Responses to Chloride. Adv. Agron. 50:107-150.

Gething, P.A. 1993. Improving Returns from Nitrogen Fertilizer: The Potassium Nitrogen Partnership. IPI Research Topic No. 13 (2nd revised edition). 53 p.

Gerandas, J., F. Heuser, and B. Sattlemacher. 2007. Influence of Nitrogen and Potassium Supply on Contents of Acylamide Precursors in Potato Tubers and on Acrylamide Accumulation in French Fries. J. Plant Nutr. 30:1499-1516.

Heckman, J.R. 1995. Corn Responses to Chloride in Maximum Yield Research. Agron. J. 87(3):415-419.

Heckman, J.R. 1998. Corn Stalk Rot Suppression and Grain Yield Response to Chloride. J. Plant Nutr. 21(1):149-155.

Heckman, J.R. 2006. Chlorine. *In:* Handbook of Plant Nutrition Barker, A.V., and D.J. Pilbeam (eds.) CRC Taylor and Francis. p. 279-291.

Huber, D., V. Roemheld, and M. Weinmann. 2012. Relationship between Nutrition, Plant Diseases and Pests. *In:* Marschner`s Mineral Nutrition of Higher Plants, third edition. Marschner, P. (ed.). p. 283-298.

Huber, D., and N.S. Wilhelm. 1988. The Role of Manganese in Resistance to Plant Disease. *In:* Manganese in Soils and Plants. Graham, R.D., R.J. Hannam, and N.C. Uren (eds.) Kluwer Academic Publishers. Dordrecht, The Netherlands. p. 155-173.

IFA, 2013. Fertilizer Indicators. 3rd Edition. Paris, France.

Jia, J.Y., X.F. Yun, and G.L. Ma. 2004. Cell Wall Degrading Enzyme Activity Induced by Copolymer of Chloride and Potassium Ions in Cucumber Leaf. Journal of Inner Mongolia Agricultural University. 25(3):52-56.

Jing, A.S., B.C. Guo, and X.Y. Zhang. 1992. Chloride Tolerance and its Effects on Yield and Quality of Crops. Chin. J. Soil Sci. 33(6):257-259.

Kafkafi, U. G. Xu, P. Imas, H. Magen, and J. Tarchitsky. 2001. Potassium and Chloride in Crops and Soils: The Role of Potassium Chloride Fertilizer in Crop Nutrition. IPI Research Topic No. 22. 220 p.

Khan, S.A., R.L. Mulvaney, and T.R. Ellswouth. 2014. The Potassium Paradox: Implications for Soil Fertility, Crop Production and Human Health. Renewable Agriculture and Food Systems 29:(1)3-27.

Liu, K.H., X.O. Tan, W.J. Zhang, and K.H. Xie. 2012. The Quantity of Potassium Chloride Fertilizer on Tobacco. Ningxia Journal of Agriculture and Forestry Science and Technology. 53(2):35-37. (In Chinese).

Maas, E.V., S.R. Grattan, and G. Ogata. 1982. Foliage Salt Accumulation and Injury in Crops Sprinkled with Saline Water. Irrig. Sci. 3:157-168.

Mao, Z.Y., and J.K. Li. 1999. Containing Chloride Fertilizer in China. Beijing: China Agriculture Publishing House. p. 49-50.

Marschner, P. 2012. Marschner`s Mineral Nutrition of Higher Plants, third edition. Elsevier. p. 651.

Marschner, H., E.A. Kirkby, and C. Engels. 1997. Importance of Cycling and Recycling of Mineral Nutrients within Plants for Growth and Development. Bot. Acta 110:265-273.

Melatis, C. 2014. Chloride the Forgotten Essential Mineral. DrMeletis.com. Website.

Mengel, D., R. Lamond, V. Martin, S. Duncan, D. Whitney, and B. Gordon. 2009. Chloride Fertilization and Soil Testing-Update for Major Crops in Kansas. Better Crops 93(4):20-22.

Mengel, K., and E.A. Kirkby. 2001. Principles of Plant Nutrition 5th edition. Springer.

Parker, M.B., T.P. Gaines, and G.J. Gascho. 1985. Chloride Effects on Corn. Commun. Soil Sci. Plant Anal. 16(12):1319-1333.

Roemheld, V., and E.A. Kirkby. 2010. Research on Potassium in Agriculture: Needs and Prospects. Plant Soil 335:155-180.

Shen, P., J.S. Gao, M.G. Xu, D.C. Li, D.K. Niu, and D.Z. Qin. 2011. Effects of Long-Term Applying Sulfur- and Chloride-Containing Chemical Fertilizers on Weed Growth in Paddy Field. Chinese Journal of Applied Ecology. 22(4):992-998.

Tan, N.X., and J.X. Shen. 1993. A study on the Effect of Cl on the Growth and Development of Cotton. Soil Fertilizer 2:1-3. (In Chinese).

Taylor, R.G., T.L. Jackson, R.L. Powelson, and N.W. Christensen. 1981. Chloride, Nitrogen Form, Lime, and Planting Date Effects on Take-All Root Rot of Winter Wheat. Plant Disease. 67:1116-1120.

Timm, C.A., R.J. Goos, B.E. Johnson, F.J. Siobolik, and R.W. Stack. 1986. Effect of Potassium Fertilizers on Malting Barley Infected with Common Root Rot. Agron. J. 78:197-200.

Wang, M., Q. Zheng, Q. Shen, and S. Guo. 2013 The Critical Role of Potassium in Plant Stress Response. Int. J. Mol. Sci. 14:7370-7390.

Webb, M.J. 2009. A Conceptual Framework for Determining Economically Optimal Fertiliser Use in Oil Palm Plantations with Factorial Fertiliser Trials. Nutrient Cycling in Agroecosystems 83:163-178.

Wen, N. 2006. Effect of Cl^- in Fertilizer on Crops. Xinjiang Chemical Industry 1:47-52. (In Chinese).

White, P.J., and M.R. Broadley. 2001. Chloride in Soils and its Uptake and Movement within the Plant: A review. Ann. Bot. 88:967-988.

Whitehead, D.C. 1985. Chlorine Deficiency in Red Clover Grown in Solution Culture. J. Plant Nutr. 8:193-198.

World Health Organization. 2012. Guideline: Sodium Intake for Adults and Children. ISBN: 978 92 4 150483 6. Geneva, Switzerland.

Xu, G.H., H. Magen, J. Tarchitzky, and U. Kafkafi. 2000. Advances in Chloride Nutrition of Plants. Advances in Agronomy 68:92-150.

Zhang, Z.H., L.P. Wang, and L.Y. Chen. 2010. Research Progress of Chlorine on the Vegetable Crops. North Horticulture 8:225-229. (In Chinese).

The paper "The Value of KCl as a Fertilizer with Particular Reference to Chloride: A Mini Review" also appears on the IPI website at:

IPI K Centre/Basic Facts about Chloride

Research Findings

Field day in LEM experimental area. Photo by T. Wiendl.

Economic Viability of Potassium Fertilization in Corn Production on Tropical Soils under No-Tillage System

Wander, A.E.[1], O.F. da Silva[1], and T. Wiendl[2]

Introduction

Improving nutrient efficiency is a worthy goal and a fundamental challenge facing the fertilizer industry, and agriculture in general. The opportunities are there and tools are available to accomplish the task of improving the efficiency of utilizing applied nutrients. However, caution is needed to ensure that improvements in efficiency do not come at the expense of farmers' economic viability or the environment. Judicious application of fertilizer best management practices, which include the slogan 'right rate, right time, right place' targeting both high yields and nutrient efficiency will benefit farmers, society, and the environment alike (Roberts, 2008).

This paper is therefore aimed at assessing the economic viability of different potassium (K) fertilizing practices in corn (maize) production under a no-tillage system.

[1]Embrapa Rice and Beans, P.O.Box 179, 75375-000 Santo Antonio de Goias, GO, Brazil. alcido.wander@embrapa.br; osmira.silva@embrapa.br
[2]International Potash Institute (IPI), Latin America Coordination, São Paulo, SP, Brazil. toni.wiendl@ipipotash.org

Methodology

Polidoro and Teixeira (2013) are carrying out a long-term field experiment in Luís Eduardo Magalhães (Bahia State, Brazil) on corn (maize) cultivation under no-tillage. We have therefore used corn yields obtained for the 2011/2012 season of this work for the eight treatments (Table 1).

Table 1. Treatments analyzed for economic viability.

Treatment		N	P_2O_5	K_2O	S	Applied as	Time of application
		-------------*kg ha*$^{-1}$-------------					
T_1	Farm practice	8.3	83	62	0	415 kg ha^{-1} of 2-20-15	Basal
T_2	SSP only	0	86	0	58	480 kg ha^{-1} of SSP	Basal
T_3	SSP+K90$_{TD}$	0	86	90	58	480 kg ha^{-1} of SSP 150 kg ha^{-1} KCl	Basal Top
T_4	SSP+K90$_{BD/TD}$	0	86	90	58	480 kg ha^{-1} of SSP 150 kg ha^{-1} KCl	Basal 50% basal 50% top
T_5	SSP+K45	0	86	45	58	480 kg ha^{-1} of SSP 75 kg ha^{-1} KCl	Basal Basal
T_6	SSP+K90$_{BD}$	0	86	90	58	480 kg ha^{-1} of SSP 150 kg ha^{-1} KCl	Basal Basal
T_7	Control	0	0	0	0		
T_8	Farm practice + K45$_{TD}$	8.3	83	107	0	415 kg ha^{-1} of 2-20-15 75 kg ha^{-1} KCl	Basal Top

Note: SSP: Single super phosphate; KCl: Potassium chloride; TD: Top dressing; BD: Basal dressing.

For economic analysis, partial budgeting (PB) analysis was used. This form of analysis is best adapted to small changes that may be considered in the business depending on the analysis of two or more alternative practices. This analysis does not determine whether these two practices are the most desirable for the farm, it only indicates the change that will occur in farm income (increase, decrease or no change). The positive and negative effects have to then be separated and listed in different sections of the PB as developed by Lessley *et al.* (1991).

The PB measures the positive and negative effects of changes of a farm practice. The left side of PB shows the positive effects on net income, including additional income and reduced costs. To counterbalance this positive effect, the right side includes reduced income and additional costs or the negative effects of the proposed change (Table 2).

PB has four categorical parts: additional income, reduced costs, reduced income and additional costs (Lessley *et al.*, 1991).

We compared each treatment T_2 to T_8 (new treatments) against farm level practice (T_1).

The costs of the fertilizers were as follows: SSP (18% P_2O_5, 19% Ca and 12% S) at Brazilian dollars (R$) 1,112.58 and KCl (60% K_2O) at R$ 1,792.78 per ton (IEA, 2013). Corn price refers to average prices in November 2013: R$ 20.86 per 60 kg bag of corn (IEA, 2013).

Left T_3, right T_2. Photo by T. Wiendl.

Positive effects of changing farm practice

Additional income: Represents the value of the incremental corn yield after the adoption of a new fertilizing practice.

Reduced costs: In the case of new farm practices replacing another practice in use by farmer, the expenses associated with the replaced fertilizing practice are reduced costs. These are either variable or fixed. If a variable input is no longer used, or less of it is used (such as fertilizer), costs are reduced. In the case where the change results in reduced labor time and there is a productive use for this released labor force, the value of released labor should also be recorded. It may be possible to reduce the fixed costs of depreciation, taxes and insurance, as well as interest on average value of some repairs if there is a reduction or elimination of investments in land, buildings, equipment or machinery. Total additional income and reduced costs have the same positive effect on net income.

Negative effects of changing farm practice

Reduced income: A proposed change in the farm practice may reduce farm income because of decreased yield.

Additional costs: This portion of PB includes any new costs associated with a proposed change. These costs can be fixed or variable. Additional variable costs can be involved where the change includes increased machinery operations, labor, fertilizers amounts, etc. If the proposed change requires new investments, e.g. machinery and equipment, the costs related to depreciation, interest, repairs and taxes fall into this category. If an asset has a useful life of more than one year, this investment should be distributed over its useful life. When change does not require any additional investments, there is no additional cost.

Total reduced income and total additional costs have the same negative effect on net income.

Net income after changing farm practice

The effect of the proposed change in net income was carried out by comparing the sum of additional income and the reduced costs with the sum of reduced income and reduced costs. In the case where the additional income and reduced costs are greater than the reduced income and reduced costs, an increase in net income will result. Yet once the increase in net income is positive, there is still a need to evaluate it with the additional labor, investment and risk associated with the proposed change.

Table 2 illustrates the partial budget approach used in this study.

Results

Table 3 describes the yields and the economic results due to changes in income and costs.

Our findings showed a strong correlation (R2=0.9853) between farm net income change and obtained corn yields.

Conclusions

1. K_2O fertilization is economically important and greatly raises farmers' net income.
2. All tested options using K_2O fertilization improved farm net income compared to farmer standard K_2O fertilizing practices.
3. The best economic option (T_6) was using 480 kg ha^{-1} of SSP and 90 kg ha^{-1} of K_2O as basal dressing.
4. The second best option (T_4) was using 480 kg ha^{-1} of SSP plus 90 kg ha^{-1} of K_2O divided into 50% as basal dressing and 50% as top dressing.
5. Adding N through NPK brought no additional economic benefit. Replacement of 2-20-15 by SSP and KCl resulted in higher income even for less K applied per ha.
6. Changes in farm net income are directly linked to the yield changes.

Table 2. PB structure for a corn-producing farm to analyze alternative fertilizing practices.

Proposed change: Should the farmer replace his current K_2O fertilizing practice (A) with a new one (B)?	
Positive effects	*Negative effects*
Additional income (yield increases)	Reduced income (yield decreases)
Reduced costs (saved fertilizer, machinery and labor)	Additional costs (additional fertilizer, machinery and labor)

Table 3. Yields and the changes in net income (R$ ha^{-1}) of each treatment related to farm level standard in Luís Eduardo Magalhães (Bahia State, Brazil).

Treatment (K_2O fertilization practice)		Corn yield	Yield change over control	Change in net income over control	PB comments
		Number of 60 kg bags ha^{-1}		*R$ ha^{-1}*	
T_1	Farm practice	93	0	-	
T_2	SSP only	75	-18	-472.53	Yields decreased more than the saved costs
T_3	SSP+$K90_{TD}$	136	43	496.43	Significant yield increase
T_4	SSP+$K90_{BD/TD}$	150	57	788.47	Significant yield increase
T_5	SSP+K45	136	43	665.68	Significant yield increase. Yield level was the same as T_3, but with lower costs
T_6	SSP+$K90_{BD}$	156	63	948.63	Highest yield increase observed in all treatments
T_7	Control	39	-54	-690.69	Significant yield reduction
T_8	Farm practice + $K45_{TD}$	130	37	602.57	Yield increases, but also higher costs

Note: TD: Top dressing; BD: Basal dressing.

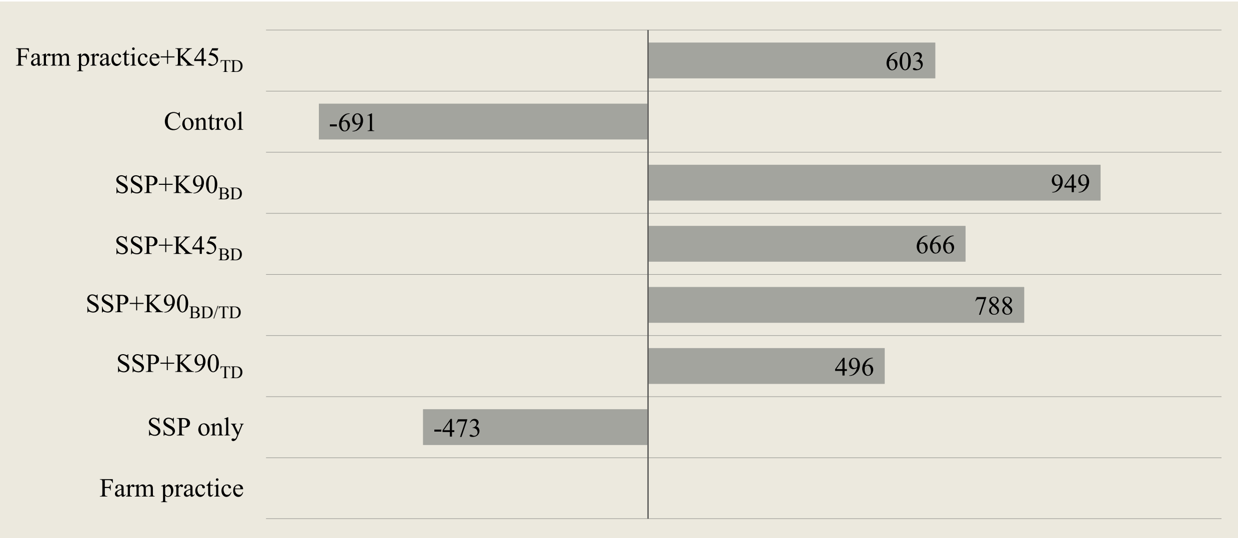


Fig. 1. Economic effect of each fertilizing practice in corn production on farmer's net income (BRL) in Luís Eduardo Magalhães (BA, Brazil), 2011/2012.

References

Bernardi, A.C.C., M.C.S. Carvalho, J.C. Polidoro, and V.M. Benites. 2013. Potassium Fertilization in Tropical Soils under No-Tillage System. *e-ifc* 34:8-12.

Instituto de Economia Agricola (IEA). 2013. Prices for Corn and Fertilizer. Nov. 2013.

Lessley, B.V., D.M. Johnson, and J.C. Hanson. 1991. Using the Partial Budget to Analyze Farm Change, 1990-1991 edition, University of Maryland System. 7 p.

Polidoro, J.C., and P.C. Teixeira. 2013. Adubação Potássica em Solos Leves. Presentation at Workshop on Support of Balanced Potash Use in Brazilian Agriculture - 10 Years of Collaboration between IPI and Embrapa, Piracicaba, SP, Brazil, October 10, 2013.

Roberts, T.L. 2008. Improving Nutrient Use Efficiency. Turkish Journal of Agriculture and Forestry 32(3):177-182.

The paper "Economic Viability of Potassium Fertilization in Corn Production on Tropical Soils under No-Tillage System" also appears on the IPI website at:

Regional activities/Latin America

Research Findings

Photo by A.C.C. Bernardi.

Soil Fertility Management and Weed Occurrence in Alfalfa Pasture

Bernardi, A.C.C.[1]

Introduction

Grazed pastures in Brazil provide the major source of food for beef and dairy cattle. For this reason, well established, properly managed pastures of high productivity are essential in order to support adequate gains in animal weight. Soil fertility is one of the most important controllable factors for determining forage yield and quality. Alfalfa (*Medicago sativa* L.), which is highly important for forage production in Brazil, is extremely demanding in soil nutrients, so that the provision of an adequate supply of nutrients is essential to maintain high forage quality and profitable yields (Moreira *et al*., 2008; Bernardi *et al*., 2013a,b). Interestingly, this crop requires higher levels of soil fertility than other tropical pastures (Bernardi *et al*., 2012).

The most common nutrient inputs for alfalfa are lime, phosphorus (P) and potash (K) fertilizers in the high weathered, low-fertile and acids soils of tropical regions (Moreira *et al*., 2008; Bernardi *et al*., 2013a,b). No nitrogen (N) fertilizer sources are used in the alfalfa production system in Brazil since all N is supplied by biological fixation by *Sinorhizobium meliloti*. Liming is essential for growing alfalfa in order to increase soil pH because of the sensitivity of the crop to soil acidity; the recommended

[1]Embrapa Pecuária Sudeste, C.P.339, CEP 13560-970, São Carlos, SP, Brazil,
alberto.bernardi@embrapa.br

pH range being between 6.5 and 7.5 (Honda and Honda, 1990). In addition, liming has other beneficial effects including raising the base saturation of the soil to 80% (Moreira *et al.*, 2008), reducing the aluminum (Al) and manganese (Mn) toxicity as a consequence of increased soil pH, and thereby also increasing the availability of the macronutrients calcium (Ca), magnesium (Mg), K and P. Liming also favors organic matter mineralization, increasing the efficiency of symbiotic N fixation, fertilizer use efficiency and microbiological activity in the soil. Phosphate and micronutrient fertilizers are usually applied once a year. In tropical soils, P can be immobilized as precipitated phosphates of iron (Fe) or Al, or adsorbed phosphate on soil particles. This adsorption is reversible and phosphate is released into the soil solution with increasing soil pH from acid conditions by liming (Bernardi *et al.*, 2012; Berg *et al.*, 2005; Sarmento *et al.*, 2001). Three forms of K (unavailable, fixed and exchangeable) are present in soils. Potassium considered readily available to plants is that in soil solution, which is in rapid equilibrium with K held on exchangeable cation sites of the soil complex. Potassium fertilizer, as muriate of potash (KCl), is usually applied after each grazing or cut, thereby avoiding loss of K to the crop as a result of K leaching through the soil profile, which can be a problem on these tropical soils of low cation exchange capacity (CEC) (Bernardi *et al.*, 2012, 2013a., 2013b).

In addition to soil fertility, the main limiting factors for cultivation of alfalfa in tropical regions are weed management, cultural practices and grazing management (Honda and Honda, 1990, Vilela *et al.*, 2008). Adequate soil fertility in established alfalfa pasture allows the forage to compete more effectively with weeds (Peters and Linscott, 1988; Lillak *et al.*, 2005). Weed interference may be responsible for 30-40% reduction in agricultural production in the tropics (Vilela, 1992). Weeds may lead to a decrease in alfalfa biomass production due to allelopathic effects and competition for water, light, nutrients and space (Peters and Linscott, 1988; Moyer, 1992). In addition to competing with alfalfa forage, weeds may also serve as hosts for pests and disease, and, moreover, may complicate grazing or mechanical harvesting causing losses of both pasture productivity and quality. Little is known in Brazil concerning alfalfa used in the dairy cattle system and the interaction between soil fertility and weed occurrence. Both crop and weed species are affected by changing levels of soil fertility. According to Liebman and Davis (2000), the differences among species involving root and shoot responses to nutrient enrichment, supply of fertilizer, or lack of supply, could shift the balance in competitive relationships between crops and weeds. During the establishment of the alfalfa crop, if soil fertility is adequate and the crop is managed well, high vigor seedling growth should occur. However, the problem of weeds may worsen during the maintenance phase of the alfalfa pasture. Previous investigations have shown that weeds may invade established alfalfa stands if they become thin (Peters and Linscott, 1988).

In the present paper, the effect of soil amendment with lime and gypsum and K fertilizer on a typical low fertile, highly weathered, acid tropical soil is evaluated in relation to alfalfa pasture yield and the occurrence of weeds.

Materials and methods

The study was conducted at Embrapa Pecuaria Sudeste, in Sao Carlos-SP, Brazil (22°01' S and 47°54' W; 856 m above sea level). The soil is a typical Haplurtox on which an irrigated alfalfa (*Medicago sativa* cv. Crioula) pasture had been intensively grown for two years. The forage was managed under a rotational system with a one day-grazing period and 30 days between the cycles throughout the year. The experimental plots were set up inside the paddocks (Photos 1). Lime was added to the soil to give a

Photos 1. Plots inside the paddocks (left) and dairy cows grazing alfalfa pasture (right). Photos by A.C.C. Bernardi.

base saturation of 80% in half the plots, and 60% in the other half. Gypsum was applied at 3 t ha^{-1} or not applied. Potassium fertilizer as KCl was applied to all plots at four rates increasing from 0 to 1.667 kg K_2O ha^{-1} (0, 833, 1,250 and 1,667 kg K_2O ha^{-1}). There were 16 treatments in total. Effects were evaluated during 10 alfalfa growth cycles. With soil fertility decline, an increase in occurrence of weeds was observed and assessed between the 7th and 10th growth cycle. At harvest, weeds and alfalfa biomass were separated and weighed. Alfalfa shoot dry matter yield was evaluated when 10% of the crop was flowering, one day before dairy cattle grazing.

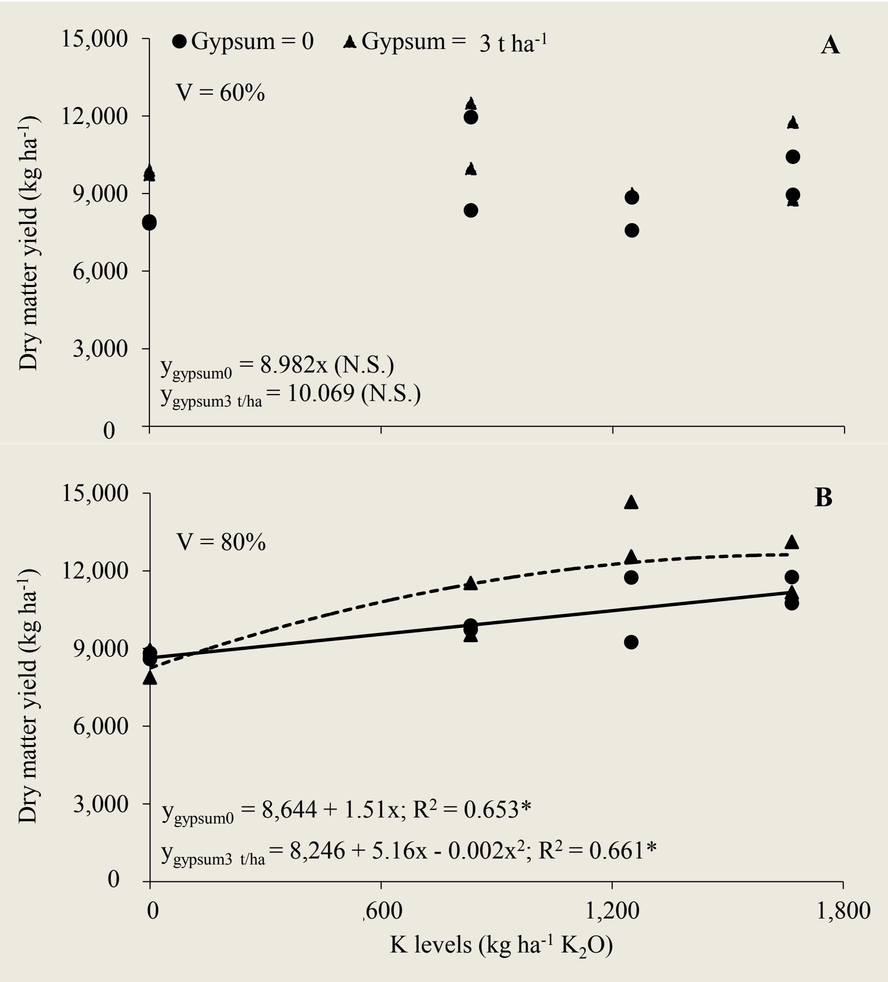


Fig. 1. Alfalfa dry matter yield due to K fertilization, gypsum and at base saturation of soil of 60% (A) and 80% (B); N.S. = not significant.

Results and discussion

The results indicated that alfalfa responded positively and significantly to K fertilization (Fig. 1) at higher base saturation (80%). The highest yield (11,574 kg ha^{-1}) was obtained with 1,290 kg ha^{-1} of K and using 3,000 kg ha^{-1} of gypsum. In the absence of gypsum, for the same amount of K, the maximum production was about 4% lower (11,162 kg ha^{-1}). At the lower base saturation (60%), no response to K fertilization was observed. These results confirm the beneficial effect of liming on increasing the efficiency of K fertilizer use in these acid tropical soils (Moreira *et al.*, 2008). The findings are also in accord with previous results of Syed-Omar and Sumner (1991), who observed increases in production of alfalfa up to a rate of 2,000 kg ha^{-1} of gypsum.

Alfalfa dry matter yield increased from 29 to 40%, which was directly related to K fertilization and confirmed previous findings of Smith (1975), Kafkafi *et al.* (1977), Rando and Silveira (1995), Rassini Freitas (1998), and Bernardi *et al.* (2013b). The positive effect of lime was the same as already described by Honda and Honda (1990) and Moreira *et al.*, (2008). A decrease in alfalfa productivity due to low soil fertility levels resulted in an increase in weed invasion into the forage stand (Photos 2). Fig. 2 shows the linear decrease in the occurrence of weeds with increasing K fertilizer doses. Considering the two levels of base saturation of 60% and 80% (supplied with 3,000 kg ha^{-1} of gypsum), resulting decreases in weed occurrence were from 30 to 22%, and from 21 to 9%, respectively. At both levels of base saturation (60% and 80%), in the absence of gypsum, K fertilization promoted a quadratic effect on the occurrence of weeds, indicating that the initial K levels favored the growth of weeds, probably because of their more efficient use of nutrients. These differences in nutrient use efficiency were pointed out by Liebman and Davis (2000). The results in this study also indicate that soil amendment, gypsum and K supply in adequate doses can contribute to the longevity of the alfalfa stand, as has been shown by Smith (1975), Berg *et al.* (2005), and Bernardi *et al.* (2013).

Conclusions

Soil fertility management has an impact on alfalfa yield and the potential for weed competition. Low soil fertility leads to loss of alfalfa pasture vigor and an increasing occurrence of weeds. Lime, gypsum and K fertilization can contribute substantially to the increased longevity of alfalfa. The major responses of alfalfa to K fertilization occurred at the higher soil base saturation (80%).

Photos 2. High fertility plot of alfalfa (left) free of weeds, and (photo right) low fertility plot with high weed occurrence. Photos by A.C.C. Bernardi.

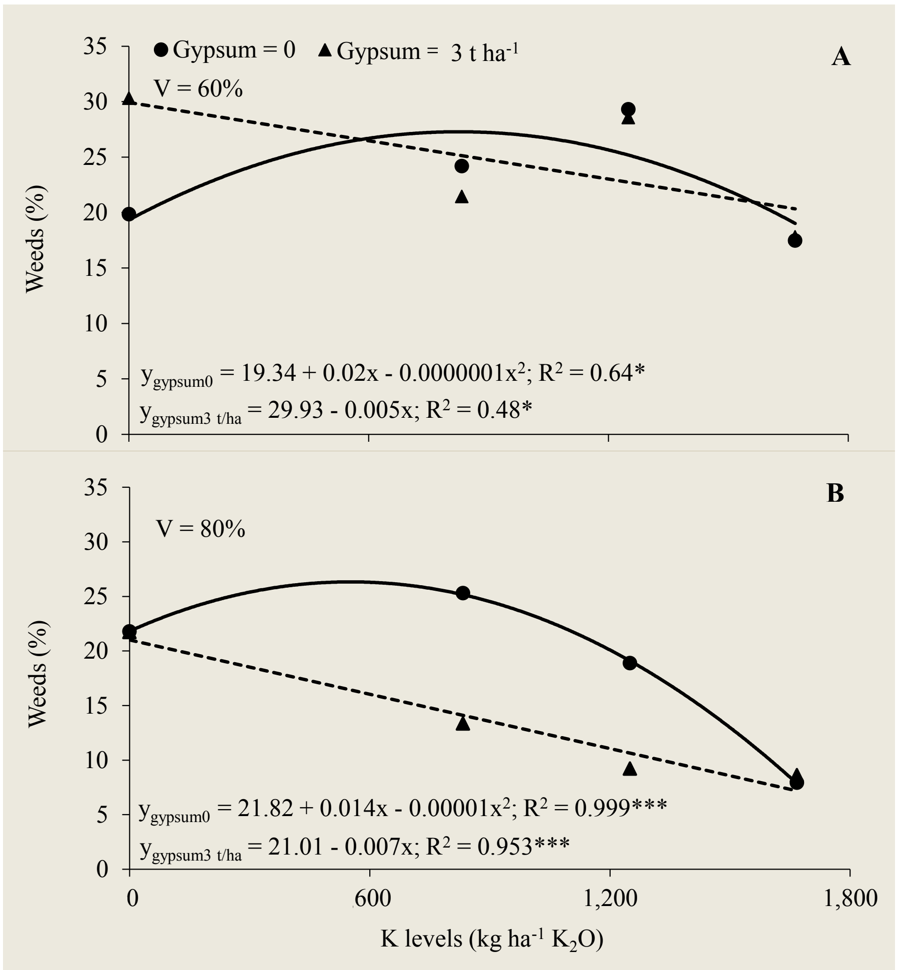


Fig. 2. Weed percentage (DW weed (kg)/DW alfalfa (kg)) of the total alfalfa dry matter yield due K fertilization, gypsum and at base saturation of 60% (A) and 80% (B).

References

Berg, W.K., S.M. Cunningham, S.M. Brouder, B.C. Joern, K.D. Johnson, J. Santini, and J.J. Volenec. 2005. Influence of Phosphorus and Potassium on Alfalfa Yield and Yield Components. Crop Science 45:297-304.

Bernardi, A.C.C., R.D. Cardoso, E.P. Mota, and R.P. Ferreira. 2013a. Produção, estado nutricional e qualidade da alfafa sob pastejo e ocorrência de plantas daninhas em resposta à calagem, gessagem e adubação potássica. Boletim de Indústria Animal, 70:67-74.

Bernardi, A.C.C., P.P.A. Oliveira, and O. Primavesi. 2012. Soil Fertility of Tropical Intensively Managed Forage System for Grazing Cattle in Brazil. *In:* Whalen, J.K. Soil Fertility Improvement and Integrated Nutrient Management - A Global Perspective. Rijeka, Croatia: Intechopen. p. 37-56.

Bernardi, A.C.C., J.B. Rassini, F.C. Mendonça, and R.P. Ferreira. 2013b. Alfalfa Dry Matter Yield, Nutritional Status and Economic Analysis of Potassium Fertilizer Doses and Frequency. International Journal of Agronomy and Plant Production 4:389-398.

Carvalho, M.C.S., and B. van Raij. 1997. Calcium Sulphate, Phosphogypsum and Calcium Carbonate in the Amelioration of Acid Subsoils for Root Growth. Plant Soil 192:37-48.

Honda, C.S., and A.M. Honda. 1990. Cultura da alfafa. Cambara: IARA. 245 p.

Kafkafi, U., R. Gilat, and D. Yoles. 1977. Studies on Fertilization of Field-Grown Irrigated Alfalfa. Plant Soil 46:165-173.

Liebman, M. and A.S. Davis. 2000. Integration of Soil Crop and Weed Management in Low External Input Farming Systems. Weed Research 40:27-47.

Lillak, R., A. Linke, T.R. Viiral, and T. Laidna. 2005. Invasion of Broad-Leaved Weeds into Alfalfa Stand During Time of Utilisation of Alfalfa Stands in Low-Input Farming System. Agron. Res. 3:65-72.

Moreira, A., A.C.C. Bernardi, and J.B. Rassini. Correção do solo, estado nutricional e adubação da alfafa. 2008. *In:* Ferreira, R.P., J.B. Rassini, A.A. Rodrigues, A.R. Freitas, A.C. Camargo, and F.C. Mendonça. (eds.). Cultivo e utilização da alfafa nos trópicos. São Carlos, Embrapa Pecuária Sudeste. p. 95-138.

Moyer, J.R. 1992. Alfalfa Yield in Establishment and Subsequent Years After Herbicide and Phosphorus Application During Establishment. Canadian Journal of Plant Science 72:619-625.

Peters, E.J., and D.L. Linscott. 1988. Weeds and Weed Control. *In:* Hanson, A.A., D.K. Barnes, and R.R. Hill (eds.). Alfalfa and Alfalfa Improvement. Madison: ASA, CSSA, SSSA, p. 705-735.

Rando, E.M. and R.I. Silveira. 1995. Desenvolvimento da alfafa em diferentes níveis de acidez, potássio e enxofre no solo. Revista Brasileira de Ciência do Solo 19:235-242.

Rassini, J.B., and A.R. Freitas. 1998. Desenvolvimento da alfafa (*Medicago sativa*) sob diferentes doses de adubação potássica. Revista Brasileira Zootecnia 27:487-490.

P. Sarmento, M. Corsi, and F.P. Campos. 2001. Resposta da alfafa a fontes de fósforo associadas ao gesso e à calagem. Scientia Agricola 58:81-390.

Smith, D. 1975. Effects of Potassium Topdressing a Low Fertility Silt Loam Soil on Alfalfa Herbage Yields and Composition and on Soil K. Agron. J. 67:60-64.

Syed-Omar, S.R., and M.E. Sumner. 1991. Effect of Gypsum on Soil Potassium and Magnesium Status and Growth of Alfalfa. Communications in Soil Science and Plant Analysis 22:2017-2028.

Vilela, D. 1992. Potencialidade da alfafa na região Sudeste do Brasil. Inf. Agropec. 16(175):50-3.

Vilela, D., R.P. Ferreira, A.A. Rodrigues, J.B. Rassini, and O. Tupy. 2008. Prioridades de pesquisa e futuro da alfafa no Brasil. *In:* Ferreira, R.P., J.B. Rassini, A.A. Rodrigues, A.R. Freitas, A.C. Camargo, and F.C. Mendonça (eds.). Cultivo e utilização da alfafa nos trópicos. São Carlos, SP: Embrapa Pecuária Sudeste. p. 457-469.

The paper "Soil Fertility Management and Weed Occurrence in Alfalfa Pasture" also appears on the IPI website at:

Regional activities/Latin America

Events

December 2014

Centenary of the Annals of Applied Biology: Challenges for Crop Production and Quality
9-10 December 2014, Rothamsted Research, Harpenden, UK

Report by
Dr. Ernest A. Kirkby, Life Fellow, Faculty of Biology, University of Leeds, UK

On the 9th and 10th of December 2014, a two day conference was held at Rothamsted Research, Harpenden, UK to mark the centenary of the Annals of Applied Biology. The Association of Applied Biologists has played a major role in furthering the application of biology to agriculture. This international conference was, therefore, both appropriate and timely in reviewing how science has contributed to agriculture over the past 100 years and in considering future directions in the context of the challenges ahead. The conference focused on one of the greatest challenges facing mankind in the 21st century: the "Challenges for Crop Production and Quality" in meeting the requirements of an increasing global population against the background of a changing climate, limiting resources and increased awareness of the environmental footprint of man. Serious challenges have to be faced during the next four decades: resources, including water, land, energy and crop nutrients are limited but production must increase to meet rising demand. Even now, demand for agricultural produce is at an unprecedented high level due to an expanding population and greater consumption per capita. It is estimated that during the next 40 years, as much food has to be produced as in the previous 8,000 years. Sustainable agricultural systems are needed to maintain food security while at the same time minimizing environmental damage.

In the 1960s, the first 'Green Revolution' took place, utilizing crop cultivars which gave good yield responses when supplied with fertilizers and irrigation and protected with pesticides and herbicides. The challenge ahead is to develop crops and agronomic systems that will yield well with fewer inputs, to improve the eco-efficiency of agriculture. The conference addressed the application of science to this enormous challenge by considering four themes: Maximizing Yield Potential; Protecting Crop Potential (Biotic and abiotic stresses); Agriculture and the Environment; and Diet and Health. In all, it featured more than 25 oral presentations and 29 posters, with well over 100 delegates attending. All the presentations are to be published in the Annals of Applied Biology and the abstracts may be obtained online.

It is not an easy task to write a brief report of such an important and interesting conference, which attracted so many high quality papers and posters. Space permits that only a few representative publications can be selected for review. Below, therefore, is a brief account of a number of papers that it is hoped should provide a flavour of the meeting and encourage the reader to look at the remaining abstracts.

Annals of Applied Biology senior editors.
Left to right: Prof. Martin Parry, Dr. Alf Keys, Prof. Peter Lea, Prof. Jari Valkonen and Prof. Ricardo Antunes de Azevedo. Photo by Prof. Peter Lea.

Dr. Achim Dobermann,
Director Rothamsted Research.

Dr. Malcolm Hawkesford,
Rothamsted Research.

The Conference was opened by Professor Jari Valkonen of the University of Helsinki, Finland and Editor-in-Chief for the Annals of Applied Biology. This was followed by two inaugural presentations. Firstly, Ian Crute CBE (Director, Agriculture and Horticulture Development Board, Stoneleigh Park, Warwickshire, UK) spoke on *"The Sustainable Intensification of European Crop Production: Illusion or Balancing Act?"* The second presentation was given by the recently appointed Director of Rothamsted Research, Achim Dobermann, who spoke on *"Agriculture in the Post-2015 Sustainable Development Agenda"*. These two stimulating presentations set the scene for the papers which followed, directed to the four themes of the meeting.

In relation to maximizing yield potential, photosynthesis is among the best known plant processes that falls far below its theoretical efficiency in modern crops, and this was the theme of Stephen Long FRS (Director, Bill and Melinda Gates Foundation RIPE Project, Institute of Genomic Biology, Departments of Crop Science and of Plant Biology, University of Illinois, Urbana, USA), who spoke on *"Maximizing Yield Potential in the Face of Global Atmospheric Change"*. There is both theoretical and experimental evidence to suggest that at different levels of organization, from metabolism to crop canopy structure the process could be improved, particularly in the context of global atmospheric change. Such transformations have begun to validate some of these suggestions, leading to greater production in the field. The theme was continued by Christine Raines (School of Biological Sciences, University of Essex Colchester, UK), whose paper on *"Metabolic Engineering to Enhance Photosynthesis and Increase Crop Yield"* provided compelling evidence that manipulation of the Calvin cycle can increase crop yield and maximize production. Techniques were discussed to support the production of multigene constructs for introduction to transgenic plants.

Estimates of yield potential determine our expectations of feasible yield progress. This theme was taken up by Roger Bradley-Sylvester *et al.* (ADAS, Boxworth, Cambridge) in their paper on *"Mapping a Route towards Enhanced Crop Productivity in the UK"*. In setting up a yield enhancement network (YEN), they considered various ongoing improvements, including breeding, innovative management of resources, and farming system technologies. From this approach it was concluded that in the UK, the potential cereal yield was around 20 t ha^{-1} and that of oilseeds 9 t ha^{-1}. The 20:20 Wheat programme at Rothamsted Research similarly aims to provide the knowledge base and tools to the wheat breeding industry to increase wheat yields to 20 t ha^{-1} in the UK within the next 20 years, as discussed by Malcolm Hawksworth (Rothamsted Research, Harpenden, Herts, UK) in his paper on *"Sustainably Achieving 20:20 Wheat"*. Much work is still to be done to minimize the gap between the current 8 t ha^{-1} farm gate yield and the 20 t ha^{-1} target, by addressing both abiotic and biotic stress limitations in the canopy and the roots, and by optimizing nutritional inputs as well as increasing the resilience of the crop to extreme weather events. Increased input use, including fertilizers and water, must also be considered for sustainability.

In the section on Agriculture and the Environment, a number of papers argued that agricultural production had become more disconnected from the environment and that this process had caused significant environmental damage. In their paper on *"Future Food: Reconnecting Agriculture and the Environment"*, Iain Gordon and Scot Ramsay (James Hutton Institute, Invergowrie and Aberdeen) suggest a reconnection between agriculture and the environment in creating a sustainable and secure high-quality food supply. They point out that to feed the increasing population, meat production has to double and crop production must increase by almost 50%. Protection of the environment can be of great benefit but this will have to be achieved in the face of rising costs of fuel and fertilizers, a scarcity of resources (soil and water), and greater legislation affecting food biosecurity and pesticides.

A very well received paper was that of Ismail Cakmak (Sabanci University, Faculty of Engineering and Natural Sciences, Istanbul, Turkey), on *"Agricultural Strategies in the Fight against Micronutrient Malnutrition"*. About 30% of the world population is estimated to suffer from micronutrient deficiencies, particularly iron (Fe) and zinc (Zn). These deficiencies occur mainly in the developing world and are associated with low dietary intake, where cereal-based foods represent major daily calorie intake and are inherently low in bioavailable Fe and Zn. Crop acquisition of these two micronutrients can be extremely low, particularly when growing in calcareous soils that are low in soil moisture and organic matter. There are, however, various well established agronomic techniques to boost Fe and Zn concentrations in cereals. These include soil and/or foliar applications of micronutrient-enriched fertilizers, as well as the generation of new cereal genotypes rich in bioavailable Fe and Zn. Eradication of Fe and Zn micronutrient deficiencies is therefore an achievable aim. In this respect, previous field experiments directed by Ismail Cakmak in the 1990s on Zn fertilization in Turkey have already had an enormous impact in enhancing wheat yields. These increases, in some cases as much as tenfold, are part of a great success story for wheat cultivation in 4.5 million hectares of Central Anatolia.

A valuable contribution was made by Peter Shewry and colleagues (Rothamsted Research) on *"Improving the Contribution of Wheat to Human Health"*. It is well recognized that wheat is an important component of a healthy diet. As well as providing vitamins, minerals and phytochemicals with bioactive properties, it is one of the most important sources of dietary fibre (DF). The work of this group centres on arabinoxylan (AX), which is the major component of dietary fibre in whole grain and white flour. Importantly, it is known that the AX content of flour can vary considerably in different sources of wheat. Work was discussed in relation to breeding new wheat varieties and additionally using bioinformatics and transcriptomics to identify candidate genes encoding key enzymes in the synthesis of AX. The research also includes collaborative studies to relate the structure and properties of AX to specific health benefits.

Following the presentations, time was set aside for general discussion, which was wide ranging. All those attending, who represented highly diverse backgrounds, recognized the huge challenges ahead in responding to a doubling in human food demand by 2050. Considering the breadth of conference contributions, it was perhaps somewhat surprising that only a very few papers dealt specifically with the major plant nutrients, and these were devoted to nitrogen (N) with scarcely a mention of phosphorus (P) or potassium (K).

In this context, it is worth noting that in 2012, Mueller *et al.* reported in Nature (490:254-257) a global study of fertilizer and irrigation requirements that would need to be met in order to close yield gaps for the three most important world cereals - maize, wheat and rice - in relation to doubling of human food production by 2050. Their findings showed that in 73% of the underachieving areas worldwide, yield gaps could be closed to an acceptable level (a 29% global increase) solely by focusing on nutrient inputs. The required increases in N, P and K application relative to baseline global consumption were calculated as 18, 16 and 35% respectively. This higher requirement of K is of interest. Adequate K supply ensures the efficient use of both N and P fertilizers. It also plays a fundamental role in photosynthesis, protein synthesis, plant-water relations, carbohydrate transport within the plant, protection against reactive oxygen species (ROS) and mitigating abiotic and biotic stresses.

Events (cont.)

IPI Events

July 2015 (date not final)

IPI will conduct a one day **Potash Symposium in Tanzania** with the aim to identify future needs for K research in the country. For more details contact Mr. Hillel Magen, IPI Director.

September 2015 (tentative date, not final)

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

International Symposia and Conferences

April 2015

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

July 2015

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

October 2015

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

November 2015

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

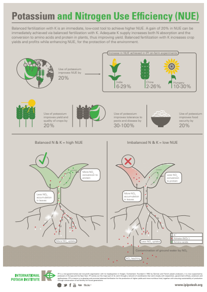
First quarter 2016

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

Publications

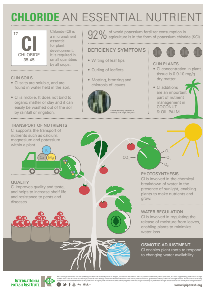
IPI has developed two new *Infographics* dedicated to the following subjects:

Potassium and Nitrogen Use Efficiency (NUE)



Balanced fertilization with K is an immediate, low-cost tool to achieve higher NUE. A gain of 20% in NUE can be immediately achieved via balanced fertilization with K. Adequate K supply increases both N absorption and the conversion to amino acids and protein in plants, thus improving yield. Balanced fertilization with K increases crop yields and profits while enhancing NUE, for the protection of the environment.

Chloride an Essential Nutrient

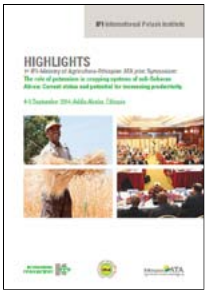


Chloride (Cl) is a micronutrient essential for plant development. It is required in small quantities by all crops.

92% of world potassium fertilizer consumption in agriculture is in the form of potassium chloride (KCl).

The infographics are available on our website.

For hardcopies of the infographics, please contact IPI head office at ipi@ipipotash.org with a return postal address.



HIGHLIGHTS from the 1st IPI-Ministry of Agriculture-Ethiopian ATA joint Symposium: The Role of Potassium in Cropping Systems of sub-Saharan Africa: Current Status and Potential for Increasing Productivity

4-5 September 2014, Addis Ababa, Ethiopia

The five sessions of the symposium included papers describing the development and challenges of agriculture in East Africa and, in particular, the fertilizer sector in Ethiopia. Evidence was presented from the Ethiopian soil mapping project, and important information was shared on the role of potassium in soil and plant systems, including data from experiments in potash fertilization, both in Ethiopia and other East African countries.

The symposium also delivered new fertilizer recommendations for the continent, informed by the latest developments in soil analysis.

This publication is available on the IPI website as a pdf for download. For hardcopies, please contact Mr. Eldad Sokolowski, IPI Coordinator sub-Saharan Africa.

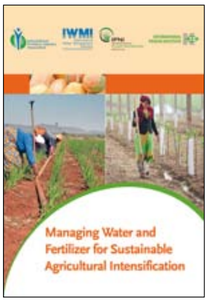
钾素与氮肥利用率

施钾对提高氮肥利用率的作用

Potassium and Nitrogen Use Efficiency

Role of potassium in improving nitrogen use efficiency

This publication in Chinese is now available for download from the IPI website. You can order hardcopies from Dr. Tian Youguo, NATESC, Ministry of Agriculture, China.



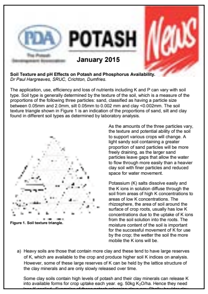
Managing Water and Fertilizer for Sustainable Agricultural Intensification

Drechsel, P., P. Heffer, H. Magen, R. Mikkelsen, and D. Wichelns. Published by IFA, IWMI, IPNI and IPI. 270 p. First edition, Paris, France, January 2015.

A reference guide to improve general understanding of the best management practices for the use of water and fertilizers throughout the world to enhance crop production, improve farm profitability and resource efficiency, and reduce environmental impacts related to crop production.

This publication is available on the IPI website as a pdf for download. For hardcopies, please contact ipi@ipipotash.org.

Publication by the PDA



Soil Texture and pH Effects on Potash and Phosphorus Availability

POTASH News, January 2015.

The application, use, efficiency and loss of nutrients including K and P can vary with soil type. Soil type is generally determined by the texture of the soil, which is a measure of the proportions of the following three particles: sand, classified as having a particle size between 0.05 mm and 2.0 mm, silt 0.05 mm to 0.002 mm and clay <0.002 mm. Read more on the PDA website.

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

Scientific Abstracts

K in the Literature

Follow us on Twitter on: https://twitter.com/IPI_potash
Follow our Facebook on: https://www.facebook.com/IPIpotash?sk=wall

Potassium Fertilizer and Other Materials as Countermeasures to Reduce Radiocesium Levels in Rice: Results of Urgent Experiments in 2011 Responding to the Fukushima Daiichi Nuclear Power Plant Accident

Naoto Kato, Nobuharu Kihou, Shigeto Fujimura, Masaharu Ikeba, Naruo Miyazaki, Yukio Saito, Tetsuya Eguchi and Sumio Itoh. 2015. Soil Sci. Plant Nutr. DOI 10.1080/00380768.2014.995584.

Abstract: Huge amounts of radionuclides, particularly radiocesium, were discharged from the Fukushima Daiichi Nuclear Power Plant (FDNPP), and widespread of contamination of the land, including paddy fields, was observed. Because rice is a staple food in Japan, contamination of paddy fields is a serious problem, and practical countermeasures to reduce radiocesium contamination of rice are urgently required. Potassium (K) fertilization was previously shown to be an effective countermeasure in fields contaminated by the Chernobyl accident, but researchers did not study the effects on rice (*Oryza sativa* L.). In the present study, we performed urgent field experiments to test the use of K fertilization, as well as other soil amendments, to reduce radiocesium contamination of rice. We found that K fertilization was an effective and practical countermeasure to reduce radiocesium uptake by rice from several soil types in Japanese paddy rice culture. Other treatments, including the application of expanded vermiculite or manure, were effective, and the effect appears to be explained by their K content. Based on these results, the recommended level of exchangeable soil potassium to lower the radiocesium content of rice to acceptable levels is about 200 mg K kg^{-1} soil before the usual fertilization. This K fertilizer application criterion was applied in a wide, low-contaminated area from the 2012 cropping season, and satisfactory results have been obtained generally.

Potassium Uptake by Corn and Soybean, Recycling to Soil, and Impact on Soil Test Potassium

Oltmans, R.R., and A.P. Mallarino. 2014. Soil Sci. Soc. Amer. J. 79(1):314-327. DOI 10.2136/sssaj2014.07.0272.

Abstract: Research is needed to quantify better plant nutrients recycling to the soil. This study investigated K recycling by corn (*Zea mays* L.) and soybean [*Glycine max* (L.) Merr.] from physiological maturity (PM) to spring. Aboveground plant

samples were collected from 19 Iowa K field response trials (33 sites years for corn and 14 for soybean). Dry matter (DM) yield and K accumulation were measured in vegetative tissue at PM, in all tissues at grain harvest, and in residue four times until spring. Soil test K (STK) was measured at grain harvest each year and in the last 2 yr the following spring. On average, K accumulation in grain or residue at harvest was 68 and 34 kg K ha^{-1} in soybean and 29 and 52 kg K ha^{-1} in corn. The K accumulation increase from fertilization was more frequent and greater in residue than in grain (60 and 9% for soybean and 57 and 7% for corn). Potassium accumulated in vegetative tissue at PM that remained in residue 2 mo after harvest was 50% in corn and 19% in soybean and decreased to 31 and 12% by April. The K loss decreased as precipitation increased (R^2 0.64 for soybean and 0.38 for corn) and affected more the K loss in soybean than corn. Soil test K increased from fall to spring, and the increase was related to the K lost from residue (R^2 0.56 in soybean and 0.16 in corn). Crop type and precipitation strongly influenced K recycling and affected STK temporal variation.

Wheat Responses to Sodium Vary with Potassium Use Efficiency of Cultivars

Krishnasamy, K., R. Bell, and Q. Ma. 2014. Front. Plant Sci. DOI 10.3389/fpls.2014.00631.

Abstract: The role of varied sodium (Na) supply in K nutrition of wheat (*Triticum aestivum* L.) is not well understood especially among cultivars differing in K efficiency. We examined the response of K-efficient and K-inefficient Australian wheat cultivars to Na supply (low to high Na) under K-deficient and K-adequate conditions. In a pot experiment, wheat *cvv* Wyalkatchem, Cranbrook (K-efficient), and *cvv* Gutha, Gamenya (K-inefficient) were grown for 8 weeks in a sandy soil containing 40 or 100 mg K/kg in combination with nil, 25, 50, 100, or 200 mg Na/kg. High soil Na levels (100, 200 mg Na/kg) greatly reduced plant growth in all four cultivars especially at low soil K (40 mg K/kg). By contrast, low to moderate soil Na levels (25, 50 mg Na/kg) stimulated root dry weight at low K supply, particularly in K-efficient cultivars compared with K-inefficient cultivars. At low K supply, low to moderate Na failed to increase shoot Na to a concentration where substitution of K would be feasible. However, low to moderate Na supply increased shoot K concentration and content in all four wheat cultivars, and it increased leaf photosynthesis and stomatal conductance to measured values similar to those under adequate K and nil Na conditions. The results showed that low to moderate Na stimulated K uptake by wheat particularly in K-efficient cultivars and through increased shoot K enhanced the photosynthesis. We conclude that increased photosynthesis supplied more assimilates that led to increased root growth and that greater root growth response of K-efficient cultivars is related to their greater K-utilization efficiency. However, the process by which low to moderate Na increased shoot K content warrants further investigation.

Expression Level of the Sodium Transporter Gene *OsHKT2;1* Determines Sodium Accumulation of Rice Cultivars under Potassium-Deficient Conditions

Takuji Miyamoto, Kumiko Ochiai, Yasunori Nonoue, Kazuki Matsubara, Masahiro Yano, and Toru Matoh. 2015. Soil Sci. Plant Nutr. DOI 10.1080/00380768.2015.1005539.

Abstract: Under potassium (K)-deficient conditions, rice (*Oryza sativa* L.) actively takes up and utilizes sodium (Na) as an alternative element to K. In this study, we cloned a gene responsible for cultivar differences in shoot Na accumulation using a map-based cloning method. The responsible gene *OsHKT2;1* encodes an Na transporter associated with Na uptake in root tissues, and its expression level was positively correlated with Na uptake potential in 11 rice cultivars. We found that *OsHKT2;1* overexpression promoted shoot Na accumulation under low K supply and proposed that *OsHKT2;1* expression level is a key factor in the Na accumulation potential in rice cultivars. However, under sufficient K supply, *OsHKT2;1*-overexpressing rice plants accumulated Na in roots but not in shoots. This result suggests that Na transfer from root to shoot may be regulated by another Na transporter.

Exchangeable Cs/K Ratio in Soil is an Index to Estimate Accumulation of Radioactive and Stable Cs in Rice Plant

Motohiko Kondo, Hideo Maeda, Akitoshi Goto, Hiroshi Nakano, Nobuharu Kiho, Tomoyuki Makino, Mutsuto Sato, Shigeto Fujimura, Tetsuya Eguchi, Mayumi Hachinohe, Shioka Hamamatsu, Hirotaka Ihara, Toshiyuki Takai, Yumiko Arai-Sanoh, and Takeshi Kimura. 2014. Soil Sci. Plant Nutr. 61(1):133-143. DOI 10.1080/00380768.2014.973347.

Abstract: Pot and field experiments were conducted to clarify the effect of soil exchangeable potassium (K) and cesium-137 (^{137}Cs) on ^{137}Cs accumulation and to establish soil index in rice (*Oryza sativa* L.). Four paddy soils in Fukushima Prefecture, Japan, showing different transfer factors for radioactive Cs derived from the accident of Fukushima Daiichi Nuclear Power Station in the field were compared in terms of ^{137}Cs accumulation in rice in a pot experiment. ^{137}Cs accumulation in shoots and brown rice widely varied among soils with the transfer factor ranging from 0.018 to 0.068 for shoots and 0.004 to 0.065 for brown rice. ^{137}Cs concentration in brown rice and shoots tended to decrease with higher levels of soil exchangeable K, and they were more closely related to the exchangeable Cs/K ratio. Similar relationships between the Cs/K ratio and Cs accumulation in plants were obtained for the stable isotope cesium-133 (^{133}Cs).

The distributions of ^{137}Cs and ^{133}Cs in grains were also similar and variable among soils. The transfer factors obtained in pot experiments mostly agreed with field observations. The results imply that the exchangeable $^{137}Cs/K$ can be a potential soil index to estimate ^{137}Cs accumulation in rice.

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

Motohiko Kondo, Tomoyuki Makino, Tetsuya Eguchi, Akitoshi Goto, Hiroshi Nakano, Toshiyuki Takai, Yumiko Arai-Sanoh, and Takeshi Kimura. 2014. Soil Sci. Plant Nutr. 61(1):144-151.

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

Growth, Photosynthesis, Solute Accumulation, and Ion Balance of Tomato Plant under Sodium- or Potassium-Salt Stress and Alkali Stress

Xiaoping Wang, Shujuan Geng, Yiqiao Ma, Decheng Shi, Chunwu Yang, and Huan Wang. 2015. Agron. J. 107(2):651-661. DOI 10.2134/agronj14.0344.

Abstract: In this study, tomato (*Lycopersicon esculentum* Mill.) plant seedlings were subjected to Na- or K-salt stress and Na- or K-alkali stress. The growth, photosynthesis, and concentrations of solutes and inorganic ions in dry samples of stressed seedlings were measured to identify the physiological adaptive mechanisms by which tomato plants tolerate alkali stresses. The results showed that alkali stresses (Na- and K-alkali stresses) significantly inhibited growth and photosynthesis, and the inhibitory effects of K-salt stress on photosynthesis were greater for Na-salt stress. The ions accumulation and balance were closely related to types of salts which were applied to. Under Na-salt stress, Na^+, K^+ and Cl^- were the main osmolytes in both the roots and leaves, whereas K-salt stress decreased the contribution of Na^+ and increased the contribution of K^+. In the stems, the contribution of NO_3^- increased under all stresses. Compared to salt stresses, the alkali stresses decreased the contribution of Cl^- and increased the contribution of organic acids (OAs) in the stems and leaves. However, the roots revealed a different mechanism of ion accumulation and governing ionic balance. In addition to Na^+, K^+ and OAs, the contributions of Ca^{2+} and Mg^{2+} should not be ignored. Although K and Na possess similar atomic characteristic, consisting with osmotic or high-pH stress, they showed a distinct effect on plant photosynthesis and ion accumulation.

Nutrient Uptake, Partitioning, and Remobilization in Modern Soybean Varieties

Bender, R.R., J.W. Haegele, and F.E. Below. 2015. Agron. J. 107(2):563-573. DOI 10.2134/agronj14.0435.

Abstract: The absence of recent data regarding the nutritional needs of modern soybean [*Glycine max* (L.) Merr.] production systems necessitates a greater comprehensive understanding of nutrient uptake, partitioning, and remobilization. The objective of this study was to evaluate macro- and micronutrient accumulation and partitioning in current soybean cultivars. Across 3 site-years, plants were sampled at seven growth stages and divided into four plant tissue fractions for quantification of nutrient uptake. Accumulation (per ha) of 275 kg N, 21 kg P (48 kg P_2O_5), 172 kg K (207 kg K_2O), 113 kg Ca, 50 kg Mg, 19 kg S, 335 g Zn, 371 g Mn, 325 g B, 849 g Fe, and 63 g Cu were required to produce approximately 3500 and 9500 kg ha^{-1} of grain and total biomass, respectively. Supplemental fertility modestly increased biomass and yield (2%), but did not alter nutrient partitioning or harvest index. Nutrients with high harvest index (i.e., percentage of total nutrient accumulation partitioned to grain) values included P (81%), N (73%), Cu (62%), and S (61%), which may serve as a limitation to high yield. Seasonal patterns of nutrient accumulation suggested that K and Fe were acquired primarily during late vegetative growth while the uptake of N, P, Ca, Mg, S, Zn, Mn, B, and Cu were more equally distributed between vegetative and seed-filling growth phases. These results document the rate and duration of macro- and micronutrient accumulation in soybean, and highlight the importance of adequate nutrient availability during key crop growth periods.

Potassium Fertilization: Paradox or K Management Dilemma?
Bar-Yosef, B., H. Magen, A.E. Johnston, and E.A. Kirkby. 2015. Cambridge Journals. Renewable Agriculture and Food Systems 30(2):115-119.

Abstract: In 2014, Khan *et al.* presented evidence that soil exchangeable K (Exch-K) increases over time without addition of potassium (K) to the soil despite the removal of K in crops on a soil rich in montmorillonite and illite. The authors term this behavior 'The potassium paradox'. From their review of the literature, the authors also report a lack of crop response to potassium chloride (KCl) fertilization. Close evaluation of these findings reveals that their observations can be interpreted and predicted using current knowledge of K in soil chemistry and its uptake by plants, and there is no paradox in K behavior in the soil-plant system. There is also no evidence of a detrimental effect of KCl on crop yield or quality. Their conclusion that the widely used Exch-K soil test is inadequate for managing K fertilization is discussed and some possible modifications to improve its performance are included. We believe that measurement of Exch-K is an essential and valuable tool and its use should be continued, along with improvements in recommending K fertilizer application.

Read on

Role of Education is Paramount in the Growth of Agriculture
Radha Mohan Singh. 2015. India Infoline News.

The Rising Pressure of Global Water Shortages
Eliasson, J. 2015. Nature 517:6. DOI 10.1038/517006a.

Effect of Potassium, Boron and Zinc on Nitrogen Content in Bast and Core Fibres for Two Kenaf Varieties (*Hibiscus cannabinus* L.)
Rabar Fatah Salih *et al.* 2014. International Journal of Development Research (IJDR) 4(12):2581-2586. ISSN: 2230-9926.

Yield and Potassium Use Efficiency of Cotton with Wheat Straw Incorporation and Potassium Fertilization on Soils with Various Conditions in the Wheat-Cotton Rotation System
Ning Sui *et al.* 2015. Science Direct. Field Crops Research 172:132-144.

Temporal and Spatial Variation of Soil Available Potassium in China (1990–2012)
Ping He *et al.* 2015. Science Direct. Field Crops Research 173:49-56.

Modification of Non-Stomatal Limitation and Photoprotection due to K and Na Nutrition of Olive Trees
Erel, R. *et.al.* 2015. Science Direct. J. Plant Phys. 177:1-10.

Gates Priorities: Improvements in African Agriculture, Health, Education and Banking
Eunjung Cha, A. 2015. The Washington Post. Health & Science.

Down to Earth: A Concerted Focus on Soils will Benefit Society in Untold Ways and Should be Embraced
2015. Nature 517:411-412. DOI 10.1038/517411b.

Agriculture: State-of-the-Art Soil
Cernansky, R. 2015. Nature 517:258-260. DOI 10.1038/517258a.

International Year of Soils: United Nations Highlights Soil Crisis
Lin, H., and R. Horn. 2015. Nature 517:553.

Healthy Soils for Healthy Life
International Year of Soils. 2015. Nutrients4Soils.

Microbial Denitrification Dominates Nitrate Losses from Forest Ecosystems
Yunting Fang *et al.* 2014. PNAS 112(5):1470-1474. DOI 10.1073/pnas.1416776112.

Potassium Management in Potato Production in Northwest Region of China
Shutian Li *et al.* 2015. ScienceDirect. Field Crops Research 174:48-54.

Why Soil Rocks
Handelsman, J. 2015. White House. Office of Science and Technology Policy.

Effects of Fertilization and Liming on Tree Growth, Vitality and Nutrient Status in Boreal Balsam Fir Stands
Ouimet, R., and J.D. Moore. 2015. ScienceDirect. Forest Ecology and Management 245:39-49.

Why Do Farmers Use Fertilizers?
DeJoia, A. 2015. Soils Matter. Farming, Food.

Potassium Salts Can Lower the Risk of Developing Osteoporosis, Study Finds
Hamilton, C. 2015. The Independent. Health News.

Western and Central African Countries Gain Expertise in Digital Soil Mapping
FAO. 2015.

Impressum *e-ifc*

ISSN 1662-2499 (Online); ISSN 1662-6656 (Print)

Publisher:	International Potash Institute (IPI)
Editors:	Ernest A. Kirkby, UK; Susanna Thorp, WRENmedia, UK; Patrick Harvey, Green-Shoots, UK; Hillel Magen, IPI
Chief editor Chinese edition:	Youguo Tian, NATESC, Beijing, China
Layout & design:	Martha Vacano, IPI
Address:	International Potash Institute Industriestrasse 31 CH-6300 Zug, Switzerland
Telephone:	+41 43 810 49 22
Telefax:	+41 43 810 49 25
E-mail:	ipi@ipipotash.org
Website:	www.ipipotash.org

Quarterly e-mail newsletter sent upon request and available on the IPI website. Links in this newsletter appear in the electronic version only.

To subscribe to the *e-ifc*, please go to the subscription page on the IPI website.
To unsubscribe from the *e-ifc* mailing list, please use the unsubscribe link at the bottom of the quarterly newsletter email.

IPI member companies:
Cleveland Potash Ltd., Dead Sea Works Ltd., and Iberpotash S.A.