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Optimizing Crop Nutrition

Editorial

Dear readers,

Digitization in agriculture is becoming a reality and provides major opportunities for the improvement of global agriculture at many levels. Digital agriculture is used in two major ways: 1) for improving farm management, like any 'enterprise resource planning' system is used to enhance a business; and 2) for integrating many data sources relevant to agronomy practices and with proper algorithms to respond and achieve a much higher efficiency at farm level. Known for its role in 'precision agriculture' as a decision support system, the practice of digital agriculture is becoming more widespread.

With regard to fertilizers, digitization of fertilization practices means better nutrient diagnostics in the field as well as its integration with big data sources such as fertility maps, climatic information and more. This 'smart farming' can save time and costs, while reducing impacts on the environment resulting in a more sustainable agriculture.

However, this digital revolution is not without its challenges, particularly as equipment and software are costly. Can farmers really pay to be part of digital agriculture? In addition, there is the critical question of data sharing and ownership.

None of the items in this current edition of *e-ifc* focus on the issue of digital agriculture, nevertheless, this topic will undoubtedly become more and more important for our attention as it will impact us all!

I wish you an enjoyable read.

Hillel Magen
Director

Photo cover page:
Tobacco crop in a Polyhalite experiment in Yunnan, China. Photo by E. Sokolowski.

Research Findings

Response of bread wheat to KCl fertilizer application in Jihur Kebele, Moretina Jiru woreda, Amhara region, Ethiopia (2014). Left: Plot receiving blended fertilizer and urea only. Right: Plot receiving the same treatment with 100 kg/ha KCl. *Source:* Obtained from ATA and MoANR collections, courtesy of Prof. T. Mamo.

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

Magen, H.[(1)*], and E.A. Kirkby[(2)]

The history of mineral fertilization of crops: a brief outline

From ancient times it was recognized that applications of animal manure, bird faeces and plant ash were beneficial to crop growth and soil fertility, although the reason was not understood. It was not until the early part of the 19th century that the fundamental significance of chemical elements on plant growth became clear. In 1807, the English chemist Humphry Davy (1778-1827) demonstrated the isolation of metallic potassium (K) using electrolysis in the Bakerian lecture at the Royal Society in London. In 1828, the German agricultural chemist Carl Sprengel (1787-1859) working on soil humus extracts reported a list of 20 chemical elements including nitrogen (N), phosphorus (P), K, sulfur (S), magnesium (Mg) and calcium (Ca) occurring as various salts in the rooting zone of a large number of soils. These he showed to be the 'real nutrients' that induced crop growth and not humus as had been previously believed. In this investigation, Sprengel also formulated the "Law of the Minimum" which states that if any one growth factor including one of these essential

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plant nutrients is limiting, improving any other growth factor is without effect. The same law was also proposed independently in two books written in 1840 and 1855 by another agricultural chemist, Justus von Liebig (1803-1873) working in Giessen, Germany, this work becoming better known to agronomists than that of Sprengel. Van der Ploeg *et al.* (1999) and others, however, have rightly rectified Sprengel's role as co-founder of agricultural chemistry with Liebig, and the Law of the Minimum is now referred to as the Sprengel-Liebig Law of the Minimum.

A significant development in the history of plant nutrition was the 57 year long, fruitful collaboration of two Englishmen, John Bennet Lawes (1814-1900) and Joseph Henry Gilbert (1817-1901) working on mineral crop nutrition at Rothamsted in Harpenden, England, as described in detail by Holden (1972). An innovative practical farmer full of ideas, Lawes took an interest in applying chemistry to agriculture. One of his greatest achievements was to take out a patent in 1842 for the manufacture of so called 'superphosphate' obtained by the treatment of calcium phosphate with sulphuric acid, a fertilizer still in use as one of the most important sources of P for crop plants. The appointment of the dedicated, trained chemist Gilbert in 1843 to support the experimental work marks the foundation of Rothamsted Experimental Station and the setting up of long-term field experiments to test the effects of different fertilizer combinations and omissions. Valuable results are still being obtained from these field trials which are the oldest in the world.

Throughout the 19th century, farmers were restricted in their choice of N fertilizer largely to Guano (sea bird excrement) imported from islands off the coast of Peru and saltpetre (potassium nitrate) from Chile. Deep concern was expressed that these finite resources would be unable to sustain long-term agriculture and the future needs of the world population. However, in 1909, two German chemists, Fritz Haber (1868-1934) and Carl Bosch (1874-1940) succeeded in synthesizing ammonia from N and hydrogen (H), first in the laboratory then later industrially. The process required a high temperature 450°C, a high atmospheric pressure of 200 atmospheres (200 times greater than atmospheric pressure) and an iron-based catalyst. This successful development meant that a key constraint to crop nutrition had been removed by allowing for the sustainable production of ammonium fertilizers. Both scientists received the Nobel Prize in Chemistry, Haber in 1918 and Bosch in 1931. It has been estimated that without the Haber-Bosch invention world food production would have been reduced by half (Smil, 2011). Nevertheless, as will be discussed later, the use of these N fertilizers requires careful agronomic management to obtain optimal crop yields and quality, as well as to avoid environmental pollution.

A major development in the 20th century of enormous significance to crop nutrition and fertilization was work of the American agronomist Norman Borlaug (1914-2009), Father of the Green Revolution (GR) of the 1960s and recipient of the Nobel Peace Prize in 1970. Working in Mexico from the mid-1940s, Borlaug used innovative techniques in breeding new wheat varieties. These included: the use of so called 'shuttle breeding' utilizing two very different photoperiods available in Mexico; selecting from multi-line varieties each with disease resistant genes; and finally incorporating the Japanese semi-dwarf strongly tillering Norin variety into the programme. In this way, he produced high yielding varieties that could be grown worldwide - varieties which were insensitive to daylight length, resistant to disease and with an abundance of short thick stems capable of supporting high grain yields in response to fertilizers. Using these semi-dwarf wheat varieties produced in Mexico, the GR moved into the Indian sub-continent in the mid-1960s where, in India and Pakistan, wheat yields almost doubled between 1965 and 1970. Other countries in Central America, Asia and Africa also benefitted greatly. The remarkable life of Borlaug and his outstanding scientific contribution has been well written up in three volumes, Vietmeyer (2008), Vietmeyer (2009) and Vietmeyer (2010).

The importance of potassium as a crop nutrient

Potassium is a major plant nutrient involved in the metabolism, growth, development, yield and quality of crops. Deficiency gives rise to problems in numerous physiological functions resulting in poor growth, reduced yield and decreased resistance to various stresses. Potassium activates about 60 enzymes in the cytoplasmic pool including those which control carbohydrate and protein metabolism; the fixation of carbon dioxide (CO_2) in photosynthesis; and the assimilation of nitrate by plants. Potassium in the vacuole plays a key role in water relations in the maintenance of turgor and control of stomatal movement. It is also essential in the regulation of cell growth. In the process of photosynthesis, K functions directly or indirectly at various stages including light interception, CO_2 availability and chlorophyll synthesis. Potassium is the predominant cation in plants and, in this form, functions in the transport of nitrate from root to shoot, as well as the loading of assimilates (sucrose and amino acids) into the phloem and their transport to fruits and storage organs. Crops well supplied with K are more resistant to stresses both biotic (e.g. pest attack) and abiotic (e.g. drought stress, cold stress and salt stress). For details see Cakmak (2005), Oosterhuis *et al.* (2014), Mengel and Kirkby (2001), and Marschner (2012). Potassium and N interact in the processes described above and both nutrients are required in relatively similar amounts. In crop fertilization these two nutrients must therefore be provided in a balanced supply in order to obtain high yields, as well as ensuring the most economic fertilizer use and restricting wastage of N fertilizer to reduce environmental pollution.

The importance of K fertilization for crops was recognized with the founding of the International Potash Institute (IPI) in 1952 in Switzerland. As described by Magen (2012), in a publication commemorating 60 years of its scientific work, the Institute's headquarters were originally located in Berne and research was undertaken with the support and guidance of a scientific board with scientists from 16 European countries. The aim of its agronomists and soil scientists was, and still is, to carry the message of 'Balanced Fertilization' and to demonstrate and disseminate the role of potash in yield performance in bringing more profit to the farmer. Over the years IPI has developed enormously worldwide; currently more than 50 ongoing field experiments and demonstration plots are executed each year and regular seminars, workshops and farmer field days take place. Contact with farmers, and their suppliers and advisors, is seen as a major role of the Institute. International symposia are held regularly demonstrating the essential role of K in optimized crop nutrition. The Institute also publishes quarterly its own online journal, International Fertilizer Correspondent (*e-ifc*). IPI's website also provides an enormous library giving information on many aspects of K in crop nutrition, published in several languages.

The paper presented here discusses the potential role of K supplied together with N and P fertilizers to enhance productivity of cropping systems, with particular reference to sub-Saharan Africa (SSA) and the principles involved in achieving this aim. It also considers, more generally, the global use of fertilizers in food production and the benefits of using fertilizers with greatest efficiency.

Fertilizer consumption

An enormous increase in global consumption of the three mineral fertilizers (N, P_2O_5 and K_2O) has taken place over the past 50 years. From the early 1960s, annual world usage increased steadily through the 1970s and 1980s, declined during 1988-1992 following the breakup of the USSR, but continued to increase rapidly from then on. From a total annual usage of 40 million metric tonnes (Mt) in 1961, consumption increased to as much as 182 Mt per annum by 2013 (Fig. 1A) (IFA). This very high value represents an eightfold increase of N usage (to 110 Mt) with corresponding threefold increases for both P_2O_5 and K_2O to 42 Mt and 30 Mt, respectively. However, in terms of fertilizer usage in various regions of the world, it is very clear that marked differences occur (Fig. 1B) (IFA). It is of immediate interest to observe that only 3% of global fertilizer usage is applied across the entire the continent of Africa – a value that has stagnated over the past 50 years. By contrast, the figure illustrates that the greatest rate in increases of fertilizer usage corresponds to the huge demands of East Asia (mainly China) and, to a lesser extent, to requirements in South Asia and Latin America, including the Caribbean. In West and Central Europe and North America, consumption has more or less stabilized since the early 1990s.

One of the soil K depletion factors in Ethiopia. *Source:* Istockphoto.

The similar worldwide trends for the consumption of potash (Fig. 1C) (IFA), again shows the high and steadily increasing usage of K_2O in East Asia, and to a lesser extent in South Asia and Latin America, including the Caribbean. The relative decrease in K usage in West and Central Europe and North America from the early 1990s is also obvious. The very low value of only 1.7% of K_2O global usage in Africa is in keeping with the low fertilizer use in general. This value is even lower in SSA because Africa includes countries with reasonable average potash usage per unit area i.e. the Republic of South Africa (8.5 kg ha^{-1}), Egypt (14 kg ha^{-1}), as well Morocco and Nigeria (FAOSTAT 7-2011). Currently, some 13% of the world's cultivated area is in SSA, yet the region accounts for less than 1% of global fertilizer use (Wendt, 2012); the figure for K_2O is likewise low. The very varied K fertilizer use within Africa is evident from Fig 2.

Wendt (2012) suggests that there is a need for rapid acceleration in fertilizer use in SSA to feed its growing population and to reverse environmental degradation

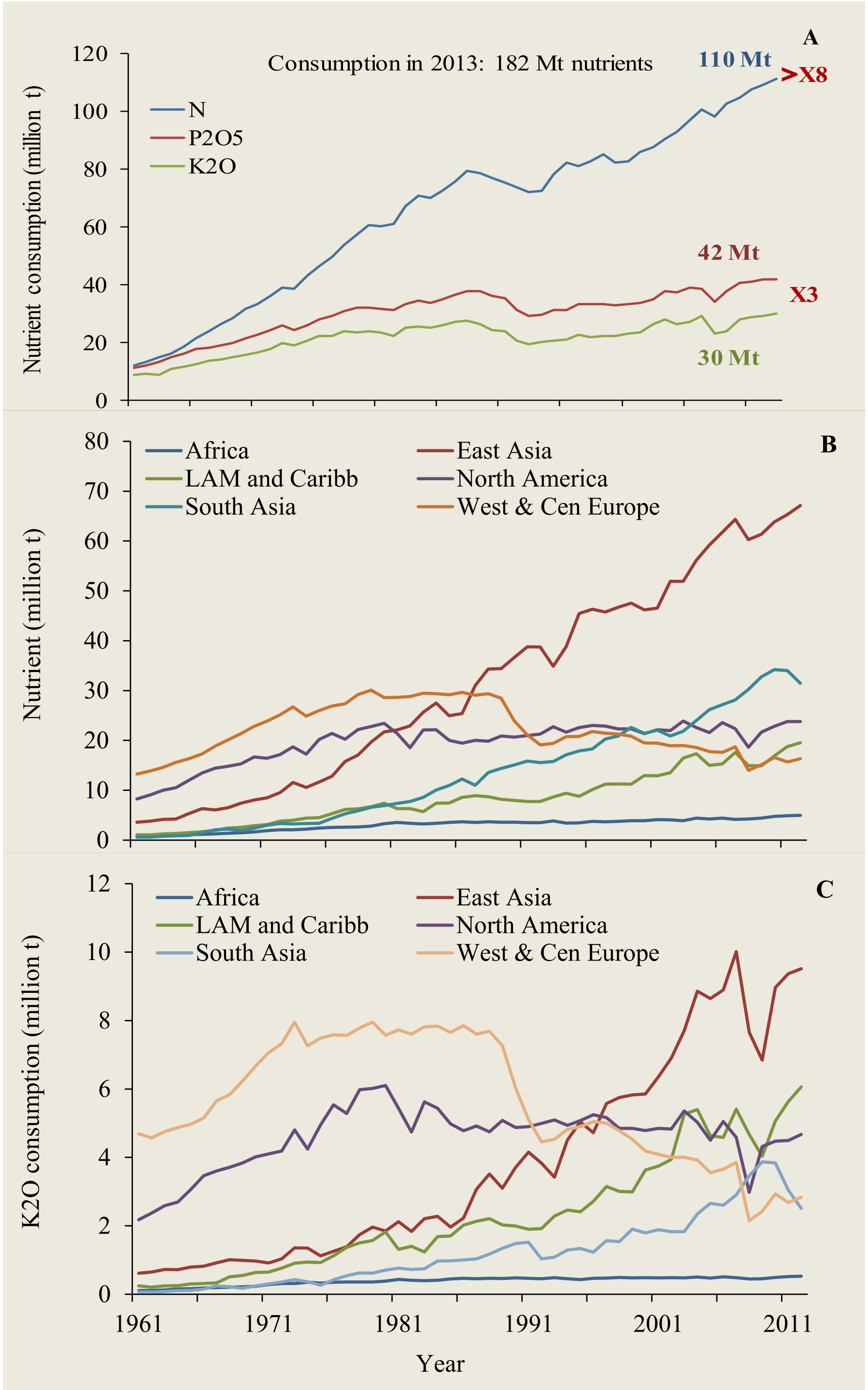

Fig. 1. A: Global N, P_2O_5 and K_2O consumption 1961-2013 (growth is interrupted only by global crisis). B: Growth in nutrient consumption (almost all regions). C: Potash consumption in regions 1960-2012.

and increase yields through agricultural intensification. Sustainable intensification has been discussed by Mueller *et al.* (2012) as a way of increasing yields on underperforming landscapes, while simultaneously diminishing the environmental impacts of agricultural systems. These authors point out that global yield variability is heavily controlled by fertilizer use, irrigation and climate and that large production increases (45-70% for most crops) are possible from closing yield gaps (i.e. differences between observed yields and those attainable in a given region) to 100% of attainable yields. We suggest that by closing yield gaps to 75% of attainable yields, while also eliminating input overuse, would require smaller net changes in nutrient inputs. This could be achieved by increasing N application by 9%, P_2O_5 application by 2.2%, and K_2O by 34% to reach these yields for maize, wheat and rice. The much greater need for K_2O than the other nutrients reflects the steady decline in K_2O:N ratio of fertilization from about 0.8 to 0.2, which has gradually taken place over the past 50 years (Magen, 2012) even though, as previously mentioned, most crops require and take up K and N in relatively similar amounts to achieve full yield potential.

Fertilizer contribution to food production

The marked increase in crop production that has accompanied higher nutrient consumption over the past 50 years is evident from Table 1 (Magen, 2012). Particularly high increases are shown in oil crops, vegetables, melons, sugarcane and fruit. As with fertilizer consumption, however, very large differences in production matching those of consumption are present in various regions of the world. There are many examples worldwide showing that increase in crop yield closely follows increasing fertilizer application. In cereals for example, North America and Western Europe starting from a baseline of just over 2 mt ha^{-1} 50 years ago, grain yields are now between 7-8 mt ha^{-1}. By comparison grain yields in Asia and South America, with an original baseline of about 1 mt ha^{-1} are now more than threefold greater at between 3-4 mt ha^{-1}. In Africa, however, average grain yields have stagnated at about 1 mt ha^{-1} (FAOSTAT).

Table 1. Production increase (metric tonnes) of seven crops over the past 50 years.

Crop	1961	2014	Increase
	----------------------*Million mt*----------------------		%
Oil crops	25.8	197.8	660
Vegetables and melons	222.6	965.7*	334
Sugarcane	448.0	1,900.0	324
Fruit (excl. melons)	175.0	609.2*	248
Cereals	876.9	2,800.7	219
Pulses	40.8	77.7	90
Roots and tubers	455.3	838.5	84

Note: *2010 data. *Source*: FAOSTAT.

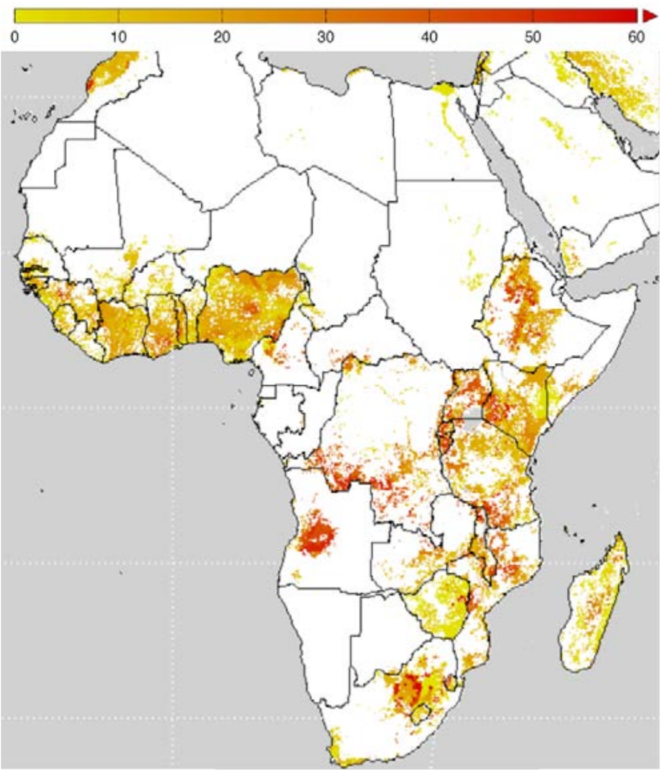

Fig. 2. Rate of potash application to major cereals from 0 to 60 K_2O kg ha^{-1} throughout Africa. *Source:* Mueller *et al.*, 2012.

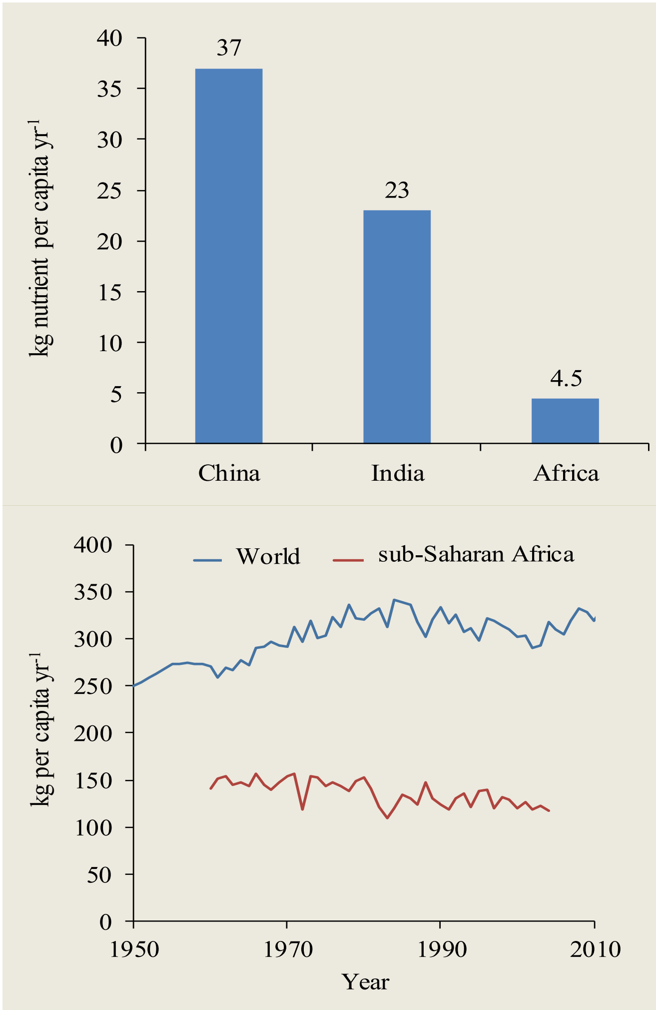

Fig. 3. Nutrient consumption per capita per year and kg of grain produced per capita. *Source:* Nutrient consumption per capita calculated from FAOSTAT and IFA; nutrient consumption per kg of grain produced per capita grain from Worldwatch, USDA and UNPOP.

A useful means of expressing fertilizer usage is the relationship between nutrient consumption per capita per year and kilograms of grain produced (Fig. 3). Interestingly the very marked differences in kg nutrient use per capita between China, India and Africa (37, 23, and 4.5 respectively) relate to relatively similar current total population numbers (China 1.36 billion, India 1.25 billion and Africa 1.11 billion). Per capita grain production in China, however, has doubled since 1949 (and is above the world average), a success story, with only 7% of the world's arable land and 5% of its water resources but the need to feed 20% of its population (Zhang, 2011). By contrast the much lower grain production in SSA, more or less stagnating between 100-150 kg per capita, demonstrates the requirement of increased fertilizer use to feed its growing population and to reverse environmental degradation. To improve the present position Wendt (2012) suggests that SSA may draw upon the experience and achievements of other countries over the past four decades including China and Latin American countries with similar soils, agro-ecologies and cropping systems.

The extent to which crop yield is dependent on nutrient inputs and specifically on commercial fertilizers has been assessed by Stewart *et al.* (2005). Several long-term studies in the USA, England and the tropics were evaluated, along with the results from an agricultural chemical use study and nutrient budget information of several crop species. This data represents 362 seasons of crop production. Significant variation in crop response to fertilizer inputs depends on crop species, soil conditions, climate, geographical location and other factors. All of these factors, however, are integrated into long-term harvested yields. The average percentage of yield attributable to fertilizer was generally found to range from 40 to 60% in the USA and England. The continuous maize yield attributable to N, P, and K fertilizer and lime over 46 years in the University of Illinois Morrow plots shows a mean value of 57% (Fig. 4). Stewart and his collaborators (2005) reported a very much higher attributable yield of crop to fertilizers in tropical soils because these soils are usually extremely weathered with low nutrient reserves. The same high response to well managed fertilization is to be expected from SSA nutrient deficient soils.

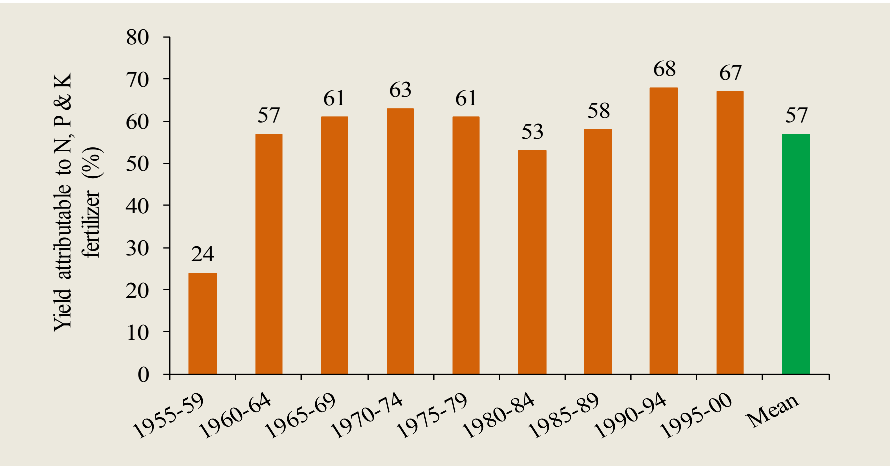

Fig. 4. Continuous maize yield attributable to N, P and K fertilizer and lime over 46 years in the University of Illinois Morrow plots. *Source:* Stewart *et al.*, 2015.

Evidence of K as the most limiting macronutrient was revealed in a study examining nutrient balances in common cropping systems on degraded soils of the Red River Valley in Vietnam (Mussgnug *et al.* 2006). Various cropping systems were investigated in these long-term experiments with mean yields over five years reported. Mean harvested grain yields for the cropping systems for rice (spring season), rice (summer season) and maize (autumn-winter season), in relation to fertilizer treatments, are shown in Fig. 5. The highest yields for both rice treatments and maize were obtained when recommended NPK rates were complemented by farmyard manure (FYM) application. The use of cumulative yield gaps indicated that K was the most yield limiting macronutrient in all crops with the exception of spring season rice when there was a stronger response to N than K, which resulted in a greater yield for the NP treatment than the control. The largest response to K application was observed in maize. These findings show that degraded soils were quickly depleted of K and required regular K fertilization to meet crop demand for K and ensure yield responses to N and P. The authors suggest that the beneficial effect of FYM may possibly have resulted from the additional Mg input because of the extremely low levels of available Mg in these degraded soils.

Dietary mineral nutrient deficiencies (MND) are widespread throughout Africa and not easy to assess. Joy *et al.* (2014) estimated MND risks due to inadequate

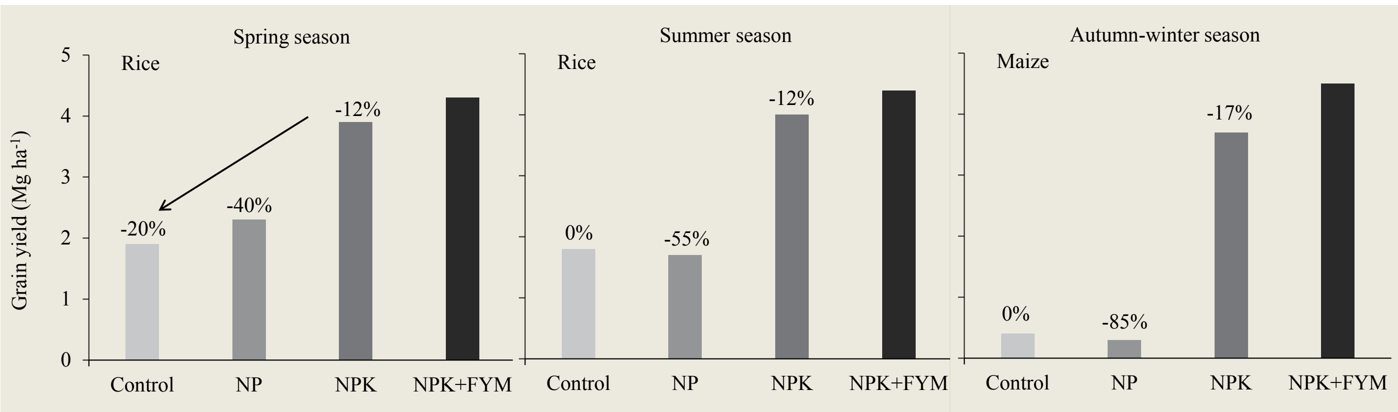

Fig. 5. Average yields (mean of five years) in a long-term cropping system experiment in the Red River Delta, Vietnam. Percentages indicate cumulative yield gaps. *Source*: Mussgnug *et al.*, 2006.

intakes of seven mineral nutrients in Africa, using food supply and composition data from 46 countries throughout the continent, to determine per capita supply for various mineral nutrients and phytate. Deficiency risks were quantified using an estimated average requirement. Highest MND risk was found for Ca (54% of the population) followed by zinc (40%), selenium (28%), and iodine (19%). Copper (1%) and Mg (>1%) deficiency were low. Deficiency of iron (Fe) was lower than expected (5%). Under conditions of low bioavailability of Fe, however, as with a high phytate and low animal-protein diet, commonly occurring in many areas, an estimated value of 43% was obtained.

Nutrient, water and energy use efficiency

Nutrient use efficiency

Balanced nutrient supply is a key factor in crop fertilization. This is especially the case for the closely interrelated nutrients K and N where increasing the K application rate can increase nitrogen use efficiency (NUE) and the resulting economic returns of K input can be large. This relationship was investigated in the cultivation of winter wheat and maize on the North China Plain in response to K fertilization (Niu *et al.*, 2011; Niu *et al.*, 2013). Field experiments were set up comparing three levels of K fertilization (K0 = no K, K1 = medium K rate (75 kg K_2O ha^{-1}) and K2 = high K rate (150 kg K_2O ha^{-1})) at an application rate of 225 kg N ha^{-1} for wheat and 240 kg N ha^{-1} for maize. On average, in the wheat experiments, K fertilization significantly increased all three yield components, namely kernel number per spike, spike per hectare and kilo-grain weight. The beneficial influence of K fertilization on NUE in wheat can be seen in enhanced N uptake in the grain (%) with increasing rates of K application, with similar results also being obtained for maize (Fig. 6). Maize grain yields increased by 15.7 and 21.0% with medium and high K rates respectively. Numerous other examples can be cited showing similar benefits of balanced N and K supply in crop nutrition (Brar and Imas, 2014). The benefits of balanced fertilization are particularly relevant to nutrient poor soils as in SSA where responses to fertilizer in increased yields and biomass can be particularly high. Residual biomass can be returned to the soil to augment organic matter thereby improving moisture retention and soil productivity as well as reducing the risk of soil erosion. Well managed and balanced fertilizer use thus has the advantage of increasing both food production as well as reducing soil degradation in nutrient poor fragile soils.

In the above experiments, profits increased up to the highest rate of K application. Profits were measured in terms of Yuan per hectare (economic profit) and by value cost ratio i.e. the increase in grain yield in kg ha^{-1} above the treatment without K application x price of the grain per kg/F_k (the amount of fertilizer applied in kg ha^{-1}) x P_k (the price of the fertilizer at the specific site per kg). In general, in order to maximize profit, efficient farmers need to produce a given crop output at minimum cost. As proposed by Lingard (2002), this implies that marginal productivity (MP) or agronomic efficiency per Dollar spent is the same across all nutrient inputs in keeping with the Sprengel-Liebig Law of the Minimum. Thus $MP_N/P_N = MP_P/P_P = MP_K/P_K$, where MPs are the marginal productivities of the various nutrients (and the contribution to yield of the last 10 kg unit applied) and Ps are the relative prices for 10 kg of N, P and K. Interrelationships between nutrients have to be taken into account as is the case for the remedial inputs of K to increase NUE to produce large economic returns, as demonstrated above in the experiments of Niu *et al.* (2011) and Niu *et al.* (2013) with maize and wheat respectively on the North China Plain.

Water Use Efficiency

Water scarcity is one of the major global constraints to the increased food production required by the expanding population over the next 50 years. Only 3% of the world's water is freshwater and 70% of that is present in glaciers and permanent snow cover. The remainder is mostly groundwater, so surface water represents only a very small fraction of global freshwater (Laegrid *et al.*, 1999). Water resources throughout the world are unevenly distributed with large parts of Africa, including SSA, likely to experience or expect chronic shortage. Irrigation must be carried out with care under these conditions. Nutrient

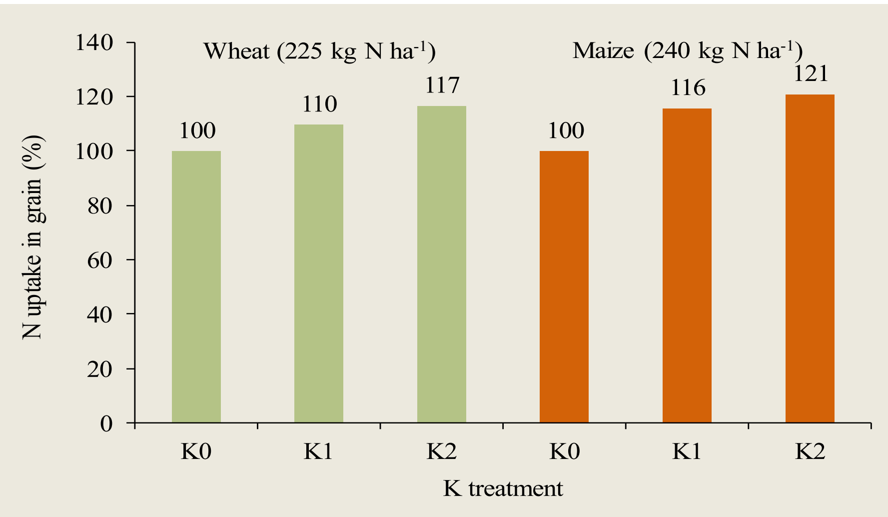

Fig. 6. Improving nitrogen use efficiency by better K application. Data calculated from: Niu *et al.*, 2013 (wheat) and Niu *et al.*, 2011 (maize).

acquisition by crops is closely dependent on soil moisture regimes, so judicious water and fertilizer use is also needed in increasing and stabilizing yields of dryland crops. The beneficial effect of K fertilization in alleviating drought stress in wheat, as measured by higher rates of photosynthesis in K treated plants, is very clear from the work of Cakmak (2005).

Irrigation systems vary greatly in their efficiency, and the impact they have on crop water use efficiency (Rangely, 1987). Losses of water in transport and application to fields can be in the range of 10-70%. On the other hand more sophisticated techniques have very much higher percentage efficiencies, including sprinkler systems (60%) and drip irrigation (85%). Crops also differ in their needs for irrigation and forms of irrigation. The yields of some crops, such as potatoes and maize, can be particularly increased by irrigation, although marked differences between experimental sites can occur. This is evident from average grain yields between 2008 and 2010 in relation to water use efficiency reported in experimental data from Israel and China. In Israel 20 mt ha^{-1} grain was obtained with 400 mm water, i.e. 200 kg water per kg grain. By contrast in China, only half the yield was obtained with twice the amount of irrigation water applied, 800 kg water being required per kg of grain produced (Magen, 2013).

Energy Use Efficiency

With a rapidly rising global population, unprecedented demands are being placed on agriculture to meet the world's needs for food production, security and sustainability. To achieve these goals, increasing fertilizer use and its efficient application in food production, is paramount. Agriculture, including deforestation, contributes to 30-35% of 'greenhouse gas' (GHGs) emissions, producing carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). The global warming potential (GWP) of these gases are detailed in an Intergovernmental Panel on Climate Change (IPCC) report (2001). Global warming potential is a relative measure of how much heat is trapped by GHGs in the atmosphere. Over a 100 year period, CO_2 GWP is given as 1; in comparison to CO_2, the GWP increases to 23 for CH_4 and 296 for N_2O.

Deforestation and conversion to agricultural land accounts for approximately 12% of global GHG emissions (Bellarby, 2008), and is the second largest global source of anthropogenic CO_2 to the atmosphere after fossil fuel combustion (van der Werf *et al.*, 2009). Methane is generated in high amounts in cattle production as a result of bacterial digestion in the rumen. Large CH_4 quantities are also released during rice cultivation. Nitrous oxide is an intrinsic component of the nitrogen (N) cycle and is produced in the soil by nitrification in the conversion of ammonium to nitrate, as well as by denitrification of nitrate. Nitrous oxide is released from the soil by applications of mineral and organic N fertilizers, but there is no clear relationship between N fertilizer application rate and nitrous oxide emission (IFA/FAO, 2001).

Global food production, as we have seen, is critically dependent on the manufacture of NH_3 based fertilizers by the Haber Bosch process in which N from the atmosphere combines with H. The energy to drive this process is provided by natural gas which also acts as a source of methane as a feeder of H_2. The primary steam reaction with methane produces H_2 and CO_2 which is released into the atmosphere. According to Bellarby *et al.* (2008) this CO_2 release amounts globally to 410 million mt eq per year to make up 0.8% of global CHG emissions. As considered earlier, approximately 100 million mt ammonium derived N fertilizer are consumed annually on a global scale which implies that every kg of N applied to the crop represents the release of somewhere in the region of 4 kg CO_2 eq. The industrial manufacture of ammonia is extremely energy efficient but requires a high net energy consumption of approximately 34.6 GJ mt N (Jenssen and Kongshaug, 2003). Upgrading the ammonia to urea or urea ammonium nitrate requires even more energy (41.8 GJ mt N and 36.6 GJ mt N respectively). Additional energy costs are involved in transport and application. For maize this amounts to about 0.53 MJ per kg N for transport and 0.48 MJ per kg N for application. By contrast the energy required in manufacturing P and K fertilizers is very low. The consumption of the net energy in manufacturing potash (muriate of potash) is 2.5 GJ mt K_2O, mainly arising from mixing and drying. In maize cultivation the equivalent cost of application is also considerably lower than that of N (Sawyer *et al.,* 2010). The very small energy contribution of K to the total energy used in N and K fertilization of six crop species, ranging between 0.1-2.5% is evident in Table 2 (Pimental and Pimental, 2008).

The very high energy costs in producing and applying N fertilizers (in comparison with P and K) means that N fertilizers must be applied judiciously so that greatest benefit to crop yield and quality can be obtained from their use by nutritionally

Table 2. Energy inputs and costs in various crops.

Crop	Country	N fertilizer	K fertilizer	Total energy	$Energy_k$/total
mt ha^{-1}		*------------------Energy input, MJ------------------*			*%*
Maize (8)	US	11,246	749	29,485	2.5
Wheat (2.67)	US	5,342	29	17,805	0.1
Rice (6.7)	US	11,714	769	49,720	1.5
Soybean (3)	US	290	202	10,085	2.0
Potato (39)	US	18,035	1,520	71,845	2.1
Cassava (12.4)	Thailand	3,591	588	54,647	1.0

Adapted from Pimentel and Pimentel, 2008. Food, Energy and Society. 3rd edition. CRC Press.

balanced fertilization. Over the past 50 years, although food production overall has hugely increased, consumption of N P and K has been skewed towards N, causing K depletion in soils and reduction in yields. Furthermore, excess N fertilization, as well as being a waste of money, is a cause of pollution by increasing N_2O emissions from the soil as well as nitrate leaching from the soil profile to induce eutrophication.

Photosynthesis of carbohydrates by higher plants underpins higher life on the planet. In considering energy use of fertilizers it has to be taken into account that fertilizers, as suppliers of essential plant mineral nutrients, significantly increase solar energy capture by plants. The use of fossil energy required particularly in the production of N fertilizers thus enables the capture of considerably larger quantities of solar energy as discussed in Dawson's (2008) thought provoking essay. Figure 7 taken from his presentation illustrates the energy involved in growing and fertilizing a hectare of wheat and the energy contained in the increased biomass as a result of the fertilizer. The extra energy captured is more than six times greater than that involved in the manufacture and application of the N fertilizer used. During photosynthesis five times as much CO_2 is removed from the atmosphere in the production of carbohydrate than is released during the manufacture of N fertilizer used. The carbon in the carbohydrate is current CO_2 as opposed to the 'fossil' carbon in the methane used in the manufacture of the fertilizer. This hugely enhanced amount of carbohydrate attained is urgently needed for food production, and as pointed out by Dawson (2008) the use of fertilizer to produce the extra carbohydrate required is neither optional nor an irresponsible use of fossil fuel.

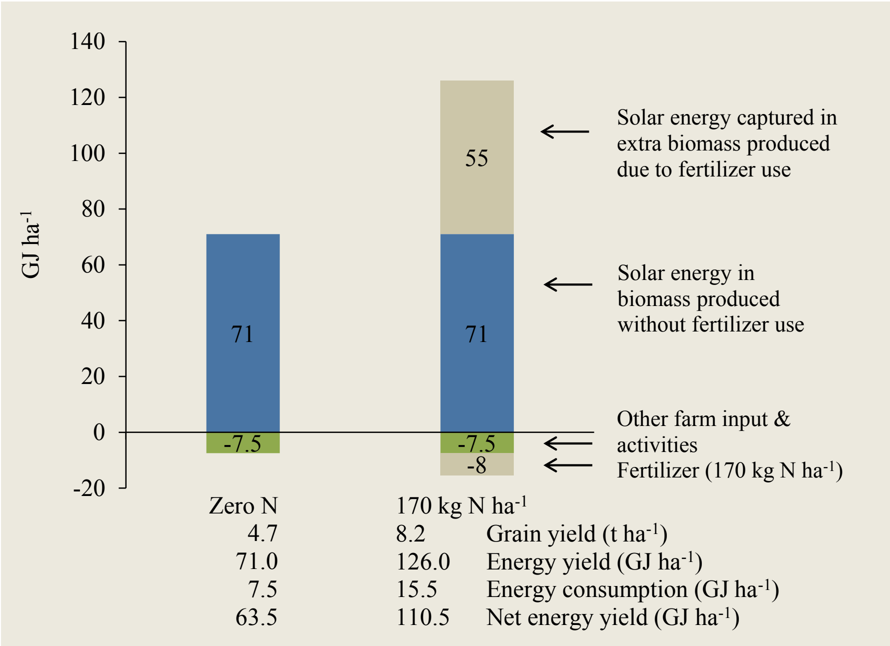

Fig. 6. Illustration of the solar energy captured by a hectare of wheat (8.2 t ha^{-1}) and the energy invested in its production (after EFMA, 2006).

Conclusions

1. Fertilizers frequently account for more than 50% of yield produced. In soils with low nutrient reserves, as in SSA, attributable yields can be much higher.
2. Fertilizer use in Africa and particularly in SSA is very much lower than other regions of the world.
3. Using fertilizers efficiently and judiciously is financially beneficial to the farmer and advantageous to the environment.
4. In order to feed the world, intensification is required. It is a basic principle of plant nutrition that those nutrients removed from the soil by a harvested crop must be replaced. In this respect the Potash Development Association fertilization recommendation calculator (phosphate and potash deficiency correction and nutrient offtake calculator) should be used.
5. Efficiency in water and nutrient use is an important area of development. In particular a balanced supply of N and K fertilizer should be supplied to crops to improve both yield and quality of crops and to avoid the damaging effects on the environment as a consequence of excess N supply.
6. Use of fertilizers for food production enables the capture of solar energy. In efficient wheat cultivation, for example, more than five times the amount of energy used in manufacture, transport and application of fertilizers (particularly N) can be found in the increased biomass of the harvested crop as a result of the fertilizer applied. The crop also removes five times as much CO_2 from the atmosphere while growing, as is emitted during the production of the fertilizer that it uses.
7. Fertilizer demand will continue to rise to meet the corresponding demands of an increasing world population.

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Regional activities/sub-Saharan Africa

Research Findings

General view of the experimental site at the Main Agricultural Research Station, University of Agricultural Sciences, Dharwad, India, at harvest. Photo by authors.

Effects of Soil and Foliar Potassium Application on Cotton Yield, Nutrient Uptake, and Soil Fertility Status

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Abstract

A field experiment was carried out to study the effect of graded levels of potassium fertilizers on Bt cotton hybrid MRC-7351 at the Main Agricultural Research Station, University of Agricultural Sciences, Dharwad, India, on a Vertisol under rainfed conditions during 2012-13 and 2013-14. The experiment layout was a randomized complete block design with nine treatments and three replications. A basal application of 75 kg K_2O ha^{-1}, 50% more than the recommended dose, gave a yield increase of 13.4%. Foliar potassium nitrate (KNO_3) applications at the reproductive phase (70, 90, and 110 days after sowing), doubled the yield increment. Petiole K concentrations were highly correlated with seed cotton yields, suggesting a potential for monitoring tools for plant K status. Improved plant K status also promoted the uptake of other macro and micronutrients, indicating an improved capacity of

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the root system. Nevertheless, the very low efficiency of the soil K application (20%) calls for an alternative approach of K fertilization practice, such as splitting the dose into several applications during the season. Foliar applications are instrumental in correcting nutrient deficiencies during the reproductive phase, whenever required. Thus, the potential of K fertilizers to enhance cotton production has been clearly demonstrated but is still far from being fully exploited. To maintain profitable production, cotton producers may need to change from traditional soil fertility programs to an integrated system consisting of soil and foliar applied nutrients.

Keywords: *Gossypium hirsutum*, foliar spray, potassium nitrate, petiole K test, soil fertility.

Introduction

India is the world's second largest consumer and exporter of cotton (*Gossypium hirsutum*); in 2013-14, India exported and consumed 7.5 and 23 million bales, respectively (Anon., 2014b). Cotton enjoys a predominant position amongst all of India's cash crops; its production in 2013-14 increased 3.5 times from the previous decade, reaching a peak of 39 million bales with a productivity of 565.4 kg ha^{-1} (Anon., 2014a).

Nutrient management of cotton is complex due to the simultaneous production of vegetative and reproductive structures during the active growth phase. High and sustainable cotton productivity is associated with the application of balanced nutrients and their availability to plants (Singh *et al.*, 2006). Balanced use of plant nutrients corrects nutrient deficiency, improves soil fertility, increases nutrient and water use efficiency, enhances crop yields and farmer's income, and maintains crop and environmental quality. Cotton, being a deep-rooted crop, removes large quantities of nutrients from the soil profile. For every 100 kg of seed cotton produced, the crop depletes the soil by 6-7 kg nitrogen (N), 1.9-2.5 kg phosphorus (P), 6-8 kg potassium (K) and 1.2-2.0 kg sulfur (S) (Cassman *et al.*, 1989; Pettigrew, 2008). Generally, farmers tend not to apply these nutrients in a balanced proportion. Consequently, the soil nutrient balance is quite often degraded. By and large, the cotton growers apply mainly N and P, and application of K is usually ignored, as well as S and micronutrients (Singh and Blaise, 2000). Potassium has been recognized as an important plant nutrient in cotton because of its high uptake rate and the relative efficiency of cotton as a K absorber (Kerby and Adams, 1985). An adequate K supply is crucial throughout the period of cotton growth and development (Makhdum *et al.*, 2007) mainly due to its vital role in: biomass production (Zhao *et al.*, 2001); enzyme activation; sucrose transport; starch and fat/oil synthesis; leaf area expansion; carbon dioxide (CO_2) assimilation (Reddy *et al.*, 2004); photosynthesis; leaf pressure potential; transpiration and water use efficiency (Pervez *et al.*, 2004); boll weight and size; and lint yield (Akhtar *et al.*, 2003). The need for K increases dramatically when bolls are set on the plant because they are the major sink for K (Leffler and Tubertini, 1976). The total K quantity taken up by the plant is related to the K available from soil and fertilizer (Kerby and Adams, 1985). Gormus (2002) reported that splitting K applications decreased yields and boll weight as compared with applying the whole rate. Hence, K nutrition in cotton appears to be indispensable. Potassium requirements of cotton can be met by pre-plant soil application and/or by mid-season side dress applications of K fertilizers. Foliar K applications offer an opportunity to correct the deficiency more quickly (within 20 hrs) and efficiently, especially late in the season, when soil K application is much less effective (Abaye, 2009).

The petiole test is highly instrumental in evaluating the current requirement for foliar K fertilizer application, providing a useful tool for keeping up plant health, to evaluate soil fertility status, and to guide farmers through nutrient management decisions aimed at obtaining profitable crop yields. Petiole analysis allows for an early, pre-symptom monitoring of emerging nutrient deficiencies, and subsequent corrective measures as and when required in a timely manner. A complete petiole testing program can be designed to predict nutrient deficiencies up to two weeks in advance, before any yield reduction occurs. Based on petiole nutrient contents, critical decisions can be made for supplemental applications of fertilizer (Kichler, 2006). The present study was aimed to study the effect of graded levels of soil and foliar applied K fertilizers on yield, to determine K concentrations in cotton leaf petiole, estimate nutrient uptake by Bt cotton, and to evaluate soil fertility status at harvest.

Materials and methods

In order to investigate the effect of soil and foliar K application on yield, nutrient uptake, and soil fertility status at harvest of Bt cotton hybrid MRC-7351, a field experiment was conducted at Main Agricultural Research Station (MARS), University of Agricultural Sciences (UAS), Dharwad, India, during 2012-13 and 2013-14. The experimental field was situated at 15°29'647"N; 74°59'254"E, 695 m above sea level. The surface soil (Vertisol type) was characterized as of clay texture, neutral pH (7.3), non-saline, low in available N (230.5 kg ha^{-1}), medium in available P_2O_5 (31.60 kg ha^{-1}) and medium in available K_2O (334.0 kg ha^{-1}). The spacing adopted was 90 cm x 60 cm, as recommended for hybrid cotton cultivars. The experiment was arranged in a randomized complete block design with three replications and nine treatments, T_1-T_9, as detailed in Table 1. T_1 resembled situations of K deficiency but with recommended N and P doses. T_2 served as a control, resembling the standard recommended N-P-K doses. In T_3 and T_4, soil K application was increased by 25 and 50% above the recommended dose, respectively. The set of T_5-T_8 was similar

Table 1. Detailed description of the fertilization treatments.

Treatment	Soil-applied $N:P_2O_5:K_2O$ (kg ha^{-1})	Description
T_1	100:50:50	RDNP (recommended dose of N and P)
T_2	100:50:0	RDF (recommended dose of N, P, and K) - Control
T_3	100:50:62.5	RDNP + 125% RDK (recommended K dose)
T_4	100:50:75	RDNP + 150% RDK
T_5	100:50:0	RDNP + foliar sprays of KNO_3 (2%) at 70, 90, and 110 DAS
T_6	100:50:50	RDF + foliar sprays of KNO_3 (2%) at 70, 90, and 110 DAS
T_7	100:50:62.5	RDNP + 125% RDK+ foliar sprays of KNO_3 (2%) at 70, 90, and 110 DAS
T_8	100:50:75	RDNP + 150% RDK+ foliar sprays of KNO_3 (2%) at 70, 90, and 110 DAS
T_9	100:50:50	RDF + water sprays at 70, 90, and 110 DAS

and respective to T_1-T_4, with additional foliar sprays of KNO_3 (2%) at 70, 90, and 110 days after sowing (DAS). T_9 provided an additional control for T_2 and T_6, testing the influence of water spray at the three application dates. Farm-yard manure (FYM) was spread evenly to all treatments, at a dose of 5 t ha^{-1}.

To avoid a patchy crop stand, gap filling was carried out after 7 DAS. To maintain the desired plant density, thinning of seedlings was carried out at around 20 DAS. The entire recommended P and K doses and 50% of N dose were applied after germination by ring method. The remaining N dose was applied at 60 DAS (Photo 1), according to the common practice. Adequate plant protection measures were applied evenly to all treatments as recommended for Bt cotton cultivars, upon the requirements at various growth stages. During growth of the crop, and at maturity, different yield parameters like sympodial branches, number of bolls and boll weight were recorded.

Twenty fully expanded main stem leaves (fourth mature leaf from the top) (Howard *et al.*, 1997; Lopez *et al.*, 2010) were collected from three replications for petiole K analysis, before and a week after KNO_3 foliar spray. In the laboratory, the petioles were separated, washed with distilled water, dried under shade and then oven dried at 60°C until constant weight, ground to a fine powder and stored in butter paper bags. Whole plant samples were also collected at 60, 90, 120 DAS and at harvest; plants were uprooted carefully and underwent a similar process and the fine powder samples were analyzed for N, P, and K using standard procedures and micronutrients content using the DTPA method (Lindsey and Norvell, 1978).

Photo 1. General view of experimental site on Vertisol at 60 DAS (block E, MARS, UAS, Dharwad). Photo by authors.

Results and discussion

Yield attributes

Yield parameters were higher in the second season: the mean boll numbers per plant were 36.0 and 38.6; boll weights were 6.23 and 6.49 g; and seed cotton yields were 2,141 and 2,356 kg ha^{-1} in 2012-13 and 2013-14, respectively. However, plant performance and the response of the yield parameters to the different fertilization treatments were very similar in both experimental seasons, and therefore pooled data from both years are presented throughout this report.

An adequate soil K application is indispensable to obtain considerable cotton yields under the present experimental conditions. All yield parameters of T_1 and T_5, which received an RDNP soil application with no, or solely foliar K application, respectively, had the smallest number of bolls per plant, the lowest boll weight, and consequently, the lowest yields (Fig. 1). Seed cotton yield of T_1 and T_5 declined by 12 and 8.6%, respectively, as compared to T_2, the control. Potassium deficiency results in early abscission of leaves and carbohydrates accumulation in main stem leaves, so the top cotton bolls suffer incomplete development (Gormus, 2002).

Nevertheless, it appears that the recommended K dose is also inadequate; additional soil-applied K at 25 or 50% of the recommended dose gave rise to significant increases in boll number and weight, and consequently, to 8 and 13.4% higher seed cotton yield, as compared to T_2 (Fig. 1). The sequential KNO_3 sprays on 70, 90, and 110 DAS brought about much smaller but significant increases in seed cotton yields. The foliar spray increased the seed cotton yields by 3.9, 3.2, 12.6, and 11.7% in T_{5-8}, as compared to their respective treatments, T_{1-4}. This yield increase may be attributed mainly to the significant rise in the number of bolls but

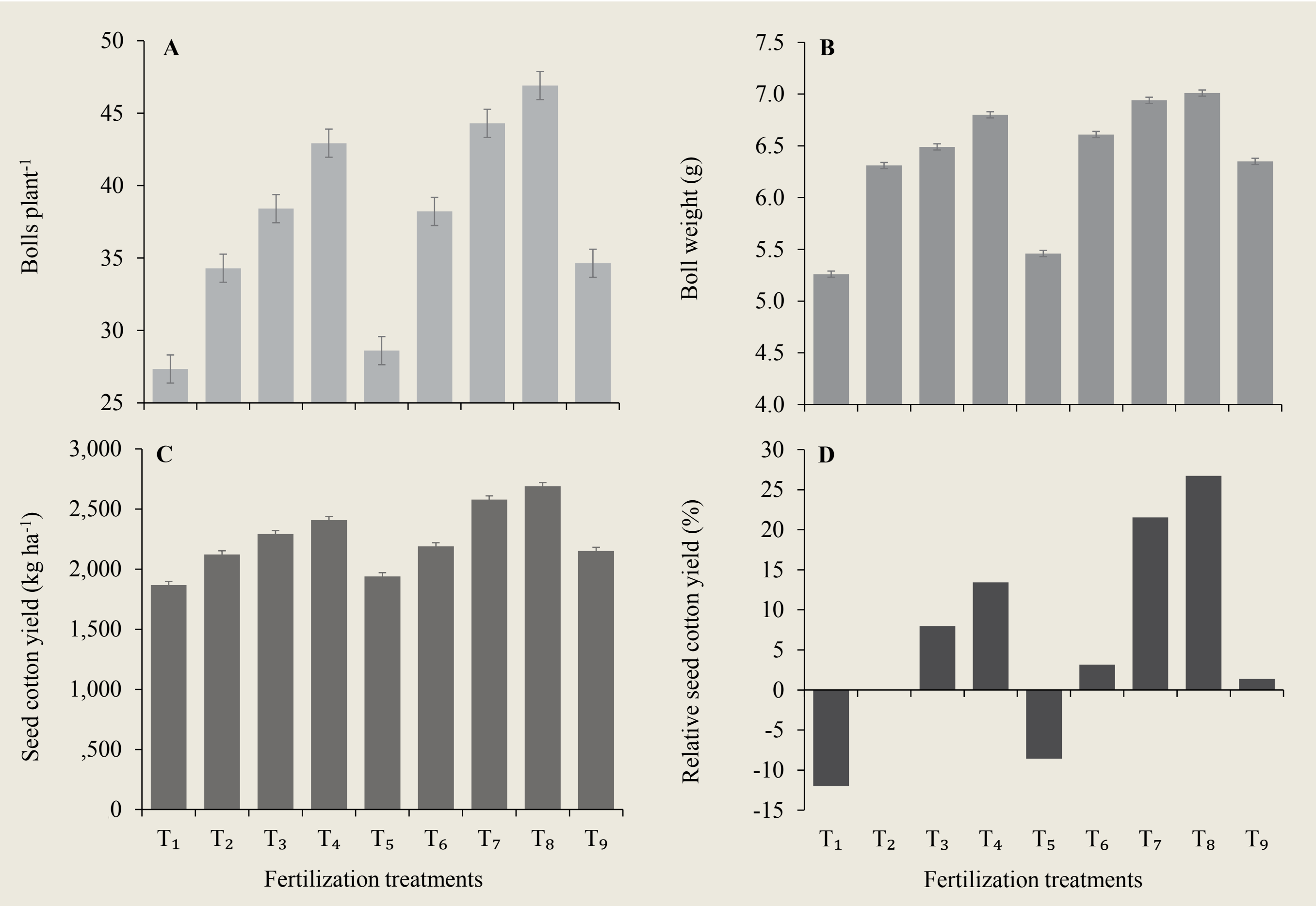

Fig. 1. Bt cotton yield parameters, pooled from seasons 2012-13 and 2013-14. D: values are relative to the T_2 control. Bars indicate LSD at 5%. T_1-T_9 are detailed in Table 1.

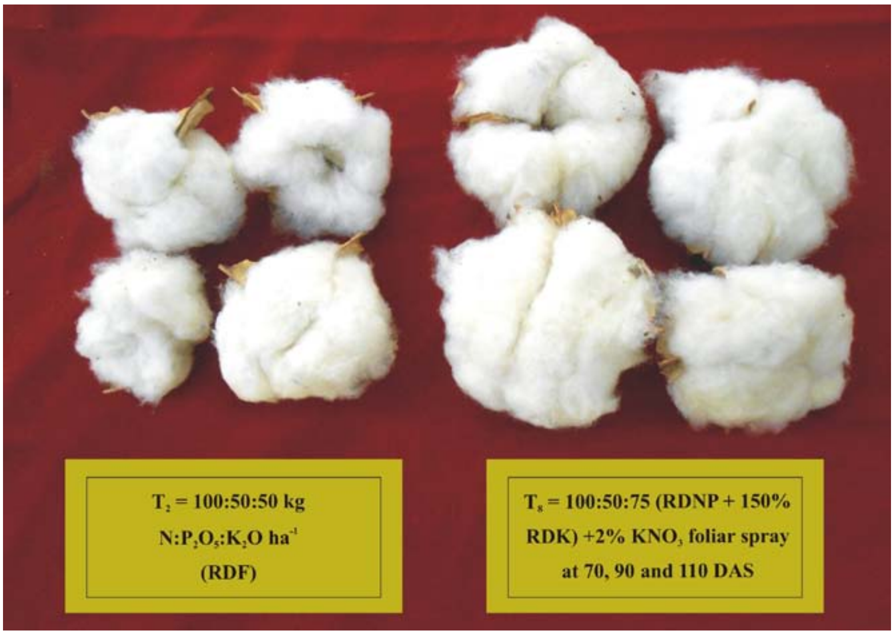

Photo 2. Differences in cotton boll size and quality between the highest level of K application (T_8) and the control (T_2). Photo by authors.

also to the slighter surge in boll weight (Fig. 1). Beyond the direct influence of the foliar K applications, it appears that this treatment is more constructive where adequate soil K application are provided.

The highest seed cotton yield, 2,689 kg ha^{-1}, was obtained at T_8 (RDNP+150%RDK+foliar KNO_3 sprays), 26.7% more than the control (T_2, RDF). The difference lies in the number of bolls per plant, 46.9 vs. 34.3, and boll weight, 7.11g vs. 6.33g, in T_8 vs. T_2, respectively (Photo 2). The supply of sufficient K quantities at critical periods, particularly during the boll development stage, resulted in retention of greater numbers of bolls per plant, as compared to the non-sprayed controls (Channakeshava *et al.*, 2013). The higher boll weight is also attributed to additional nutrition due to the foliar KNO_3 spray that might have enhanced dry matter translocation and accumulation in bolls (Kumar *et al.*, 2011). These results demonstrate the significance of synchronizing the nutrient supply at different developmental stages using foliar application to enhance growth and consequent higher yields.

Effect of soil and foliar K application on K concentration in cotton leaf petiole

Petiole K concentrations declined gradually from an average of 3.89% to 3.55%, 2.98%, and 0.98%, from 70 to 90, 110 DAS, and at harvest, respectively. This constant decrease could be observed even at a daily time scale: in treatments with no foliar KNO_3 applications (T_1-T_4, T_9), petiole K concentrations were consistently lower at the latter of two subsequent tests (Table 2). Petiole K concentrations were tightly and positively associated with soil K application rates. However, foliar KNO_3 applications brought about significant increases in petiole K concentration at the immediate as well as the longer time scale (Table 2). While only decelerating the declining petiole K in the K deficient T_5, petiole K concentration responded to the KNO_3 sprays with an immediate rise of

Table 2. Potassium concentration (% of dry matter, DM) in leaf petioles sampled before, and after KNO_3 sprays at 70, 90, 110 DAS, and after harvest. For detailed description of treatments please refer to Table 1.

Treatment	Days after sowing						
	70		90		110		
	Before	After	Before	After	Before	After	At harvest
T_1	3.23	3.16	3.11	3.04	2.39	2.31	0.81
T_2	3.67	3.62	3.24	3.18	2.65	2.57	0.92
T_3	4.26	4.21	3.55	3.51	3.16	3.10	1.01
T_4	4.51	4.46	3.92	3.83	3.47	3.41	1.07
T_5	3.23	3.20	3.15	3.09	2.45	2.34	0.83
T_6	**3.66**	**3.85**	**3.45**	**3.52**	**2.77**	**2.93**	**1.04**
T_7	**4.28**	**4.66**	**4.11**	**4.30**	**3.54**	**3.83**	**1.12**
T_8	**4.51**	**4.76**	**4.16**	**4.46**	**3.74**	**3.93**	**1.16**
T_9	3.65	3.59	3.24	3.18	2.67	2.60	0.90
SEm	0.06	0.03	0.04	0.04	0.05	0.02	0.02

Note: SEm = standard error of means.

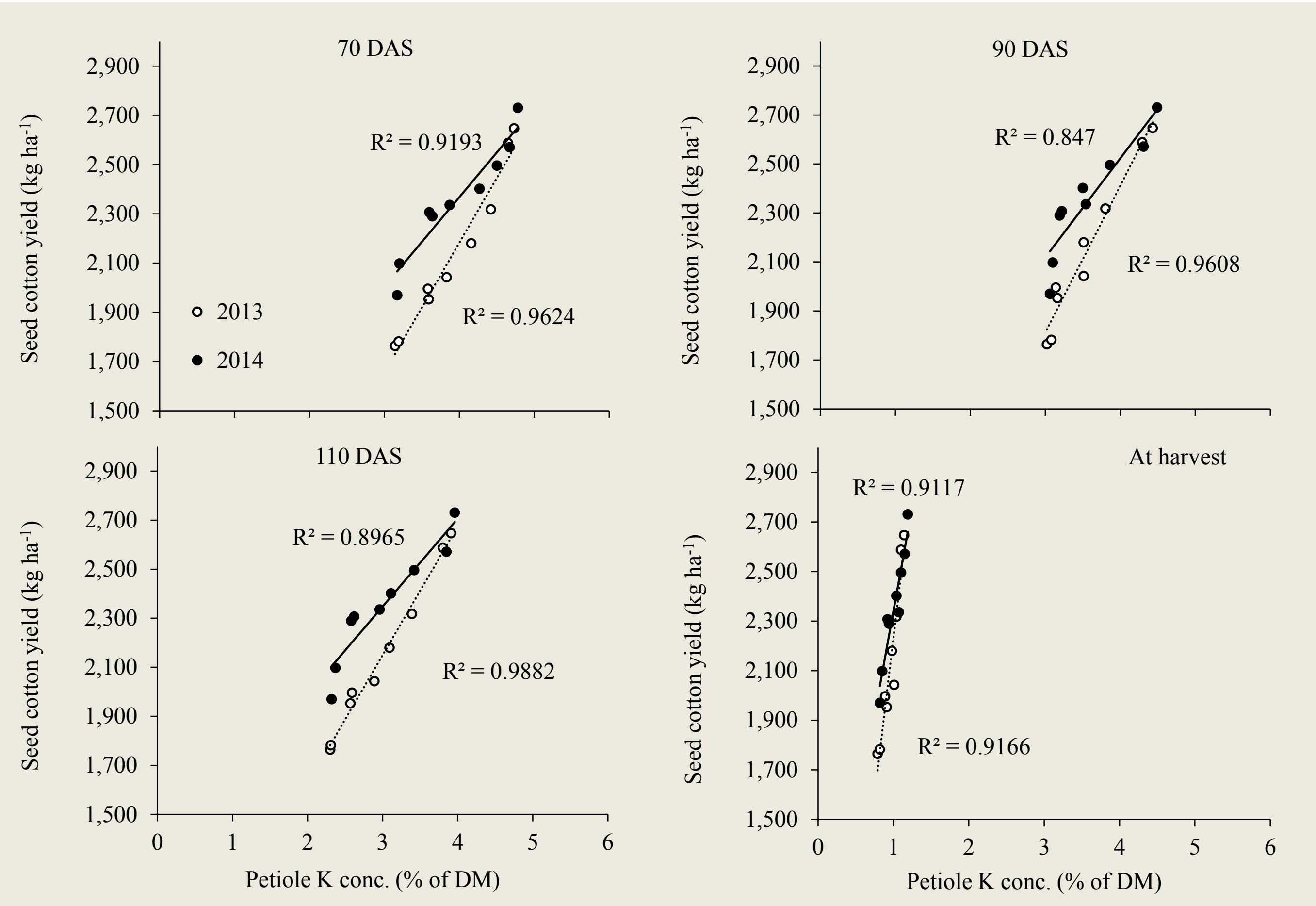

Fig. 2. Correlations between petiole K concentration and seed cotton yield at 70, 90, 110 DAS and at harvest during the two successive experiments which ended in 2013 and 2014.

2-9%. Furthermore, the foliar applications supported consistently higher petiole K levels throughout the season, until harvest (Table 2). The developing cotton bolls are the largest K and carbon sink in the cotton plant (Howard *et al.*, 1998). During the critical period of simultaneous boll set, growth, and development, K supply from the roots might be inadequate, causing boll abortion and shedding (Pettigrew, 2008). In agreement with Oosterhuis *et al.* (1990), combined soil and foliar K applications increase K availability within the canopy, as indicated by petiole K concentration, thus enhancing boll survival and growth.

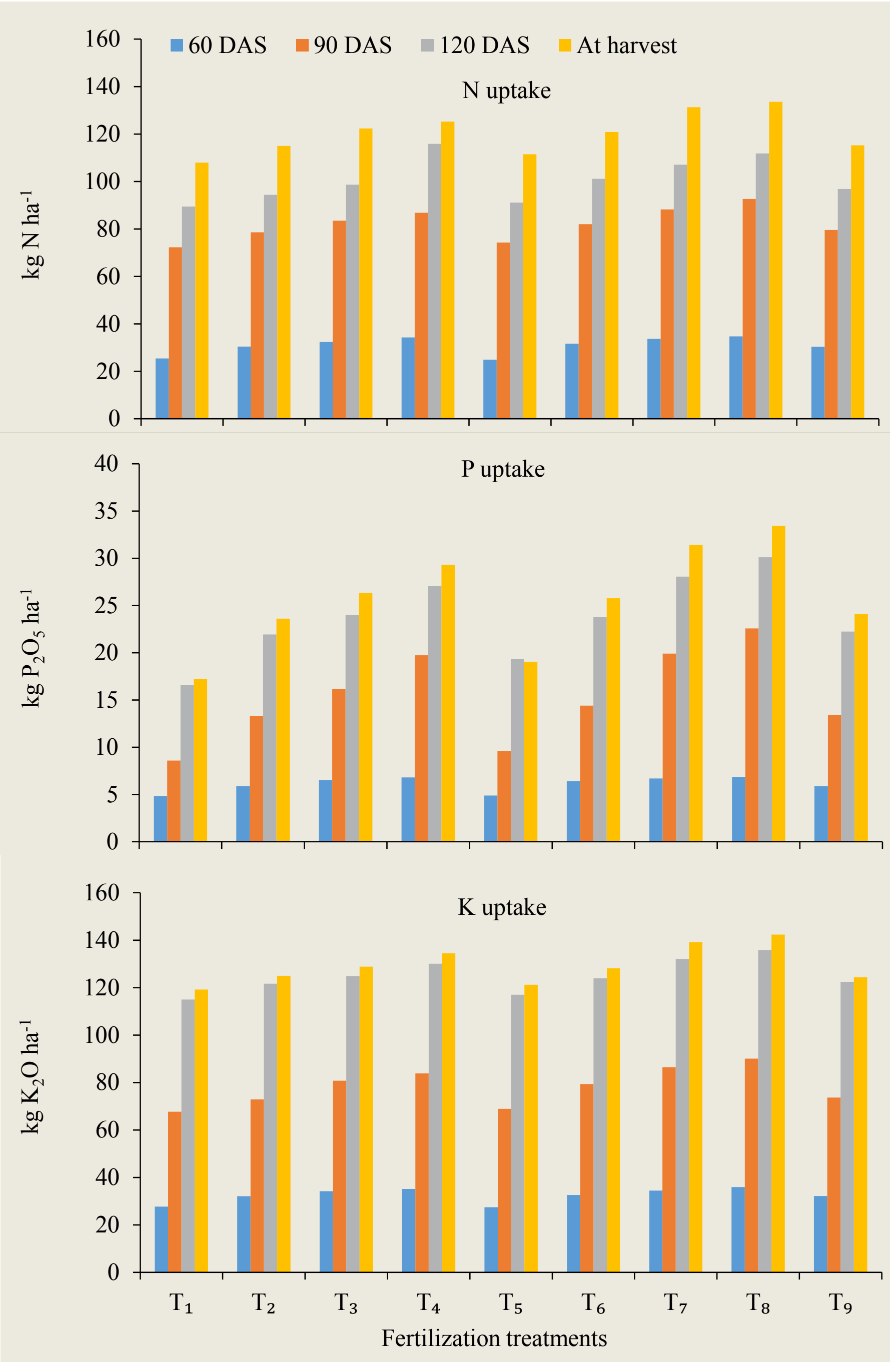

Fig. 3. Effect of K fertilization treatments on N, P, and K uptake by Bt cotton at 60, 90, and 120 DAS, and at harvest. For detailed description of treatments please refer to Table 1.

Petiole K concentrations were highly and significantly correlated with the final seed cotton yields (Fig. 2), supporting previous findings by Lopez *et al.* (2010). Apparently, such correlations may suggest using this parameter for yield prediction. Nevertheless, the relationships change among plant developmental stages and between years (Fig. 2). In as much, petiole K concentration may be employed to monitor the plant nutritional status at particular phenological phases and within certain limits (Bennett *et al.*, 1965; Kafkafi, 1990).

Effect of soil and foliar K application on nutrient uptake by Bt cotton

Nutrient uptake by plants usually reflects their dry biomass. Shortage of one or more nutrients would restrict plant growth and development. In the present study, K was the limiting factor, the replenishment of which brought about a significant rise in crop biomass, and a resulting surge in N and P uptake (Fig. 3). Interestingly, the remarkable differences between treatments in soil K application did not result in proportionate increases in K uptake. The difference in K uptake between T_4, which received 75 kg K_2O ha^{-1}, and T_1, with null K application, was only 15 kg ha^{-1}. These results indicate that the cotton crop relied mostly on soil K reserves, at about 120 kg K_2O ha^{-1}. The differences between treatments was acquired during the early period of 60 DAS, with no further changes later on (Fig. 3). It can be, therefore, concluded that a basal K application predominantly supports the early vegetative phase of the cotton crop, and fades away, probably through leaching, during the most K demanding reproductive phase. This scenario of inefficient K fertilization practice calls for an alternative approach in which the annual K dose is split and broadcasted during the season. The success of the foliar KNO_3 applications to increase yield is marginal and indicative of the major concept change required.

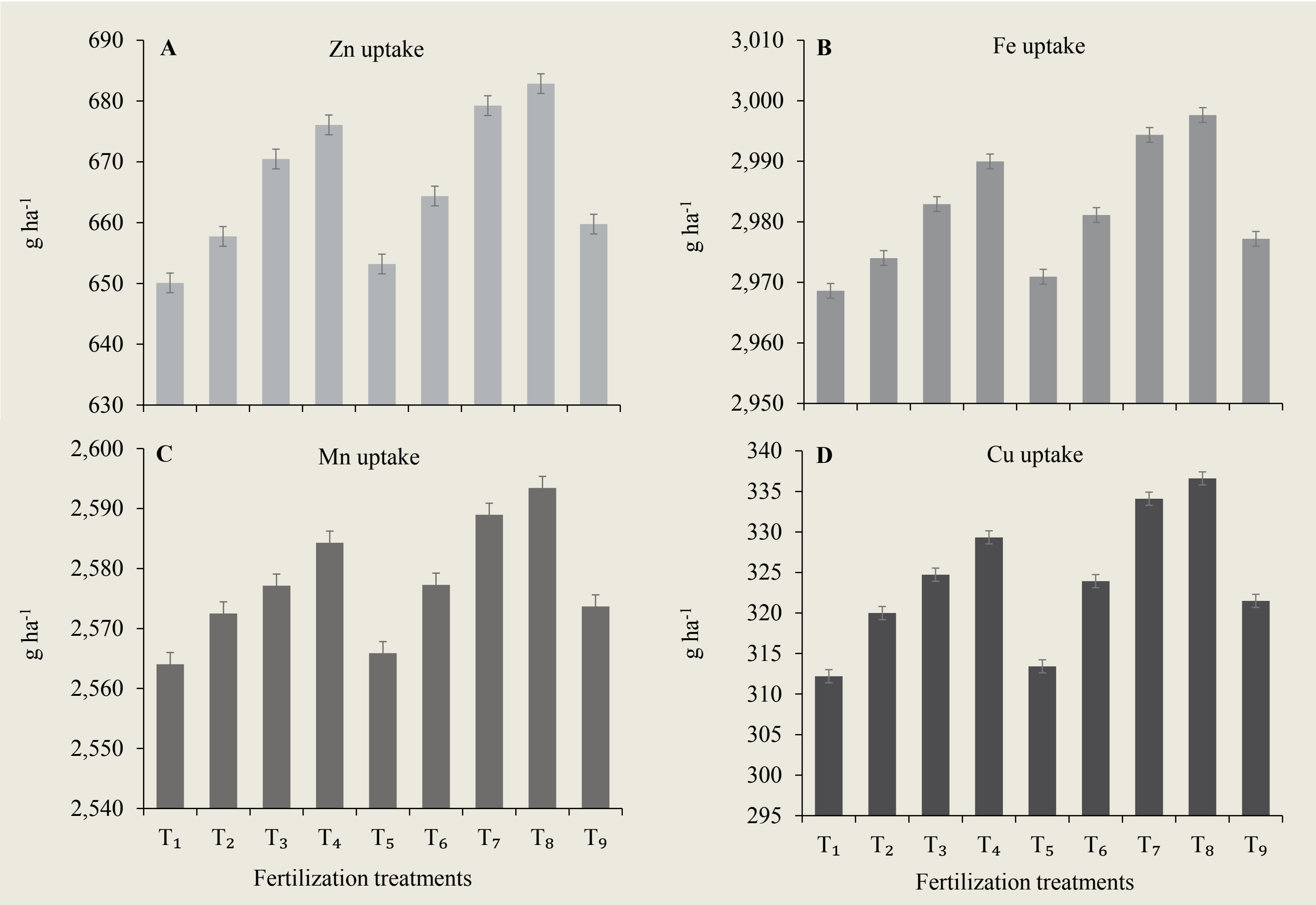

Fig. 4. Effects of K fertilization treatments on zinc (Zn), iron (Fe), manganese (Mn), and copper (Cu) uptake by Bt cotton, at harvest. For detailed description of treatments please refer to Table 1.

This is in accordance with Makhdum *et al.* (2007), who stated that shifting dry matter from vegetative to reproductive organs is dependent on sustained supply of nutrients throughout the season.

The basal soil K application, also supported by the second N application at 60 DAS, had an obvious effect on N uptake, which rose by up to 10%, respective to the increase in K dose (Fig. 3). However, the influence of soil K application on P uptake was dramatic; it gradually increased in direct relationship to K rates, up to 29.3 kg P_2O_5 ha^{-1} in T_4, about 90% more than T_1 (Fig. 3). Foliar KNO_3 applications further enhanced this nutrient uptake pattern (Fig.3). Moreover, a similar, and even stronger pattern was observed regarding the effect of K application on the uptake of microelements, such as zinc (Zn), iron (Fe), manganese (Mn), and copper (Cu) (Fig. 4), suggesting that improved K status can promote root expansion and exploration of larger soil volumes (Abaye, 2009). These results are consistent with previous studies suggesting that improved plant K status has a significant impact on the uptake and metabolism of macro as well as micronutrients (Mengel *et al.*, 1976; Silberbush and Lips, 1991; Brar and Brar, 2004; Pettigrew, 2008; Zörb *et al.*, 2014). The advantage of foliar application is, however, in the precise delivery of nutrients to target tissues and organs (Baloch *et al.*, 2008; Saravanan *et al.*, 2013).

Soil fertility status

The fertilization treatments did not have any significant effect on soil pH, salinity (ECe), or organic carbon (OC) (Table 3). Soil available N and P slightly increased during the two years of experiments, but this increase declined with the increasing soil K applied. This pattern may be ascribed to the more intensive nutrient uptake by plants benefiting from improved K supply (Cassman *et al.*, 1989). Soil available K displayed a similar pattern, except in T_1 and T_5, where no changes occurred from the initial levels, in spite of the two successive crops and null supply of K fertilizers.

Table 3. Effects of different K fertilization treatments on Vertisol fertility status following two successive years of Bt cotton production. For detailed description of treatments please refer to Table 1.

Treatment	pH	ECe	Organic carbon	Available			DTPA extractable micronutrients			
				N	P	K	Zn	Fe	Mn	Cu
	1:2.5	*dS m^{-1}*	*g kg^{-1}*	*kg ha^{-1}*			*mg kg^{-1}*			
Initial	**7.81**	**0.30**	**7.63**	**230.5**	**31.60**	**334.0**	**0.70**	**2.65**	**6.80**	**2.23**
T_1	7.84	0.33	7.61	257.5	38.92	333.0	0.68	2.62	6.45	2.26
T_2	7.74	0.32	7.57	253.8	36.24	358.6	0.66	1.95	6.41	2.23
T_3	7.90	0.33	7.52	248.4	34.36	353.2	0.64	1.85	6.35	1.98
T_4	7.87	0.33	7.49	244.1	33.66	347.7	0.62	1.58	6.26	1.90
T_5	7.86	0.33	7.55	255.6	36.93	332.0	0.66	2.59	6.45	2.25
T_6	7.84	0.34	7.54	250.1	35.00	356.5	0.65	1.81	6.38	2.23
T_7	7.85	0.33	7.50	241.9	33.57	342.8	0.62	1.65	6.30	1.87
T_8	7.88	0.32	7.46	239.8	32.44	341.2	0.60	1.55	6.24	1.85
T_9	7.88	0.33	7.56	252.2	36.11	357.8	0.65	1.93	6.36	2.21
SEm	0.03	0.01	0.03	0.57	0.39	1.21	0.01	0.03	0.02	0.02
CD at 5%	NS	NS	NS	1.71	1.17	3.62	0.03	0.10	0.05	0.05

Note: SEm = standard error of means; CD = critical difference.

At the harvest at the end of the second season, levels of DTPA extractable micronutrients (Zn, Fe, Mn, and Cu) were generally lower than the initial ones. The drop in Fe levels was especially significant, suggesting that this nutrient should be routinely replenished (Table 3). Also here, enhanced K supply brought about higher biomass production and yield, and consequently, led to faster soil nutrient depletion.

Conclusions

The Vertisol on which the two successive Bt cotton crop experiments took place is rather fertile. The rate at which new K is released to the available phase is sufficient to support considerable cotton yield levels. However, when commercial yield levels are anticipated, significant K supplementation is required. In the present study, a basal application of 75 kg K_2O ha^{-1}, 50% more than the recommended dose, gave rise to a yield increase of 13.4%. Foliar KNO_3 applications at the reproductive phase (70, 90, and 110 DAS), doubled the yield increment. Petiole K concentration was highly correlated with seed cotton yield, suggesting a potential for monitoring tools of plant K status. Improved plant K status also promoted the uptake of other macro and micronutrients, indicating an improved capacity of the root system. Nevertheless, the very low efficiency of the soil K application (20%) calls for an alternative approach of K fertilization practice, such as splitting the dose into several applications during the season. Foliar applications are instrumental in correcting nutrient deficiencies during the reproductive phase, whenever required. Thus, the potential of K fertilizers to enhance cotton production has been clearly demonstrated but is still far from being fully exploited.

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Regional activities/India

Research Findings

Tea plantation in Vietnam. Photo by G. Kalyan.

Polyhalite Application Improves Tea (*Camillia sinensis*) Yield and Quality in Vietnam

Article from report contributed by PVFCCo, Vietnam[1]

Abstract

The tea industry in Vietnam has a 3,000 year history and plays a vital role in income improvement and poverty alleviation in rural areas. Improving resource utilization efficiency has recently been determined as the major strategic goal of the industry. Appropriate mineral nutrition practices are pivotal to achieving these goals. However, consequent to the rising productivity of tea plants, the mineral status of soils has been compromised. The availability of alkaline elements, particularly potassium (K), calcium (Ca), and magnesium (Mg), is steadily declining.

Polyhalite, a natural marine sedimentary mineral, consisting of a hydrated sulfate of K, Ca, and Mg, was examined as a potential additive to composite N-P-K fertilizers, as part of an alternative fertilization program for the tea industry in the Lam Dong district. Polyhalite enhances the density, weight and size of tea buds, thus increasing tea productivity by 14-15.5%, and improves tea quality parameters. Overall, polyhalite gave rise to profit increases of 10 and 12.7%, in the Kim Tuyén and TB14 cultivars, respectively. While no direct effect of S could be observed, yield enhancement may be attributed to facilitated N uptake and metabolism.

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Polyhalite demonstrated the ability to supply plant Ca and Mg requirements and maintained soil fertility, whilst supporting greater biomass production, as compared to the alternative fertilization programs.

Keywords: Calcium; *Camellia sinensis*; mineral nutrition; polyhalite; Polysulphate; potassium; sulfur.

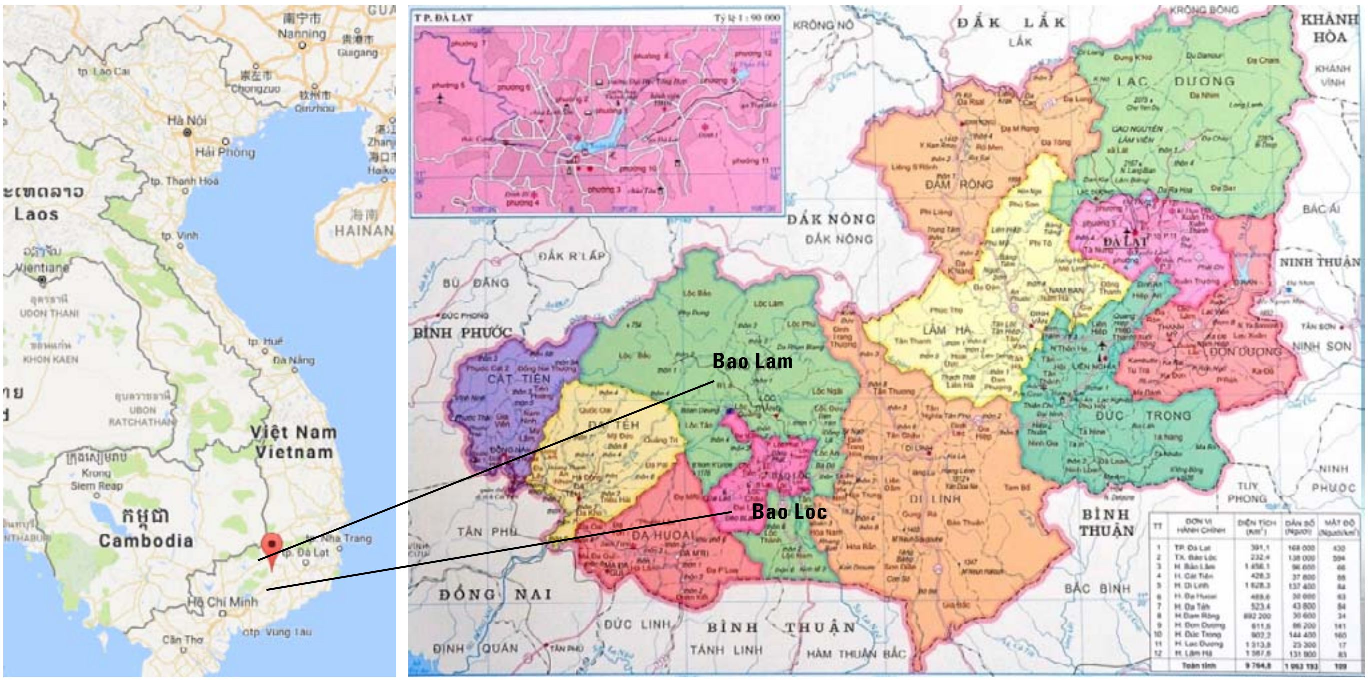
Introduction

With a 3,000 year history, Vietnam is known as one of the most ancient homes of tea. The tea industry in Vietnam plays a vital role in income improvement and poverty alleviation in rural areas (Khoi *et al*., 2015). Following China and India who dominate world tea production (about 60%), and Kenya and Sri Lanka (8% and 7%, respectively), Vietnam is the fifth largest tea producer in the world (about 4%), with 214,230 tons produced each year (FAO, 2014; Khoi *et al*., 2015). In the Lam Dong province, there are 22,000 ha of bud tea (Lam Dong Portal, 2016).

Nevertheless, the tea industry in Vietnam is currently experiencing significant challenges. Improving the resource utilization efficiency has recently been determined as the major strategic goal of this industry (Hong and Yabe, 2015). Furthermore, updating tea farming technologies to increase yield and quality is essential to restoring the traditional status of the Vietnamese tea industry (Khoi *et al*., 2015). Appropriate mineral nutrition practices are pivotal to achieving these goals.

The young vegetative buds of the tea plant are repeatedly harvested, thus a maintenance of continuous new growth is essential. In addition to suitable ranges of temperature and air humidity, and water availability (Wilson, 2004; Namita *et al*., 2012), tea requirements for soil mineral nutrition must be carefully met (Wang *et al*., 2016). Moreover, the mineral composition of the leaves affects produce quality and depends very much on local soil properties and nutritional status (Ferrara *et al*., 2001; Erturk *et al*., 2010). Due to the low soil pH and the precipitation regime in tea growing regions, phosphorus (P) nutrition has become a concern (Zoysa *et al*., 1999). Practically, P is supplied using fused calcium-magnesium phosphate (Ca-Mg-P, P_2O_5 15%, SiO_2 20%, MgO 12%, CaO 45%, at pH 8.5). In contrast, an acidic root environment (pH 4-5) promotes nitrogen (N) uptake and biomass growth (Ruan *et al*., 2007). The form of N has significant importance; tea plants acquire NH_4^+ far better than NO_3^- (Ruan *et al*., 2007), justifying the traditional N supply through urea. Potassium (K) has seldom been supplied in tea plantations in Vietnam.

In recent years, intensive farming practices have been introduced to the Vietnamese tea industry. The consequent rise in productivity has generated significant pressure on the mineral nutrition status of the soil. The availability of alkaline elements - in particular K, calcium (Ca), and magnesium (Mg) - is steadily declining. The tropical climate of Lam Dong and frequent heavy precipitation accelerates soil weathering and loss of nutrients through leaching below or away from the root zone. Consequently, deficiency symptoms often occur in plantations that were previously highly productive.



Map 1. Vietnam map (left, Google Maps); and right the two experiment sites, Bao Lam and Bao Loc, in Lam Dong province (http://www.lamdong.gov.vn/EN-US/HOME/ABOUT/Pages/Lam-Dong-map.aspx).

The recently introduced composite N-P-K fertilizers (Phu My products) are not diverse enough to meet all nutrient requirements at each stage of growth, and on differing soils. To obtain suitable fertilization formulas, Phu My NPK fertilizers are used in combination with additives, such as urea (NH_4^+), ammonium sulphate ($\{NH_4\}_2SO_4$) and potassium chloride (KCl). However, these do not provide a sufficient solution for the declining alkaline cations.

Sulfur (S) is recognized as the fourth major plant nutrient after N, P, and K (Khan *et al.*, 2005), and has been associated with high productivity (Zhao *et al.*, 1999; Saito, 2004; Kovar and Grant, 2011). Sulfur often interacts with N to significantly enhance crop productivity (Jamal *et al.*, 2010). However, current information regarding S application to acidic soils under tropical climates is scarce.

Polysulphate (produced by Cleveland Potash Ltd., UK) is the trade mark of the natural mineral 'polyhalite', which occurs in sedimentary marine evaporates and consists of a hydrated sulfate of K, Ca, and Mg, with the formula: $K_2Ca_2Mg(SO_4)_4 \cdot 2(H_2O)$. The deposits found in Yorkshire, England typically consist of 14% K_2O, 48% SO_3, 6% MgO, and 17% CaO. Polyhalite has slow-release properties and due to this, it is postulated that if integrated into a fertilization program as an additive to Phu My N-P-K products, a more balanced and stable flow of nutrients could be achieved.

The objectives of the present study were to evaluate the agricultural efficiency of Polysulphate for tea production in Vietnam, and to test, economically, two novel alternative fertilization programs in comparison to traditional practice.

Materials and methods

Two parallel experiments were conducted in two districts of the Lam Dong province, Vietnam (Map 1). Seven year old tea plantations were employed at both sites, with Kim Tuyén and TB14 cultivars at Bao Loc and Bao Lam districts, respectively. The experiments lasted from April to December 2015.

Three fertilization programs were tested (Table 1): CT1 (control), simulated the common farmers' practice through which N was applied using urea, K through KCl (60% K_2O), and P through a local blend containing fused Ca, Mg, and P; CT2 employed commercially available Phu My composite fertilizers, one of which included S but none included Ca and Mg; CT3 was similar to CT2 but was fortified with Polysulphate. Fertilizer rates were twice as high at Bao Loc (cv. Kim Tuyén), excluding Polysulphate (200 and 150 kg ha^{-1}, at Bao Loc and Bao Lam, respectively), and KCl administration aimed at balancing K supply between the programs.

Fertilizer application began in mid-April with N, P_2O_5, and K_2O basal doses with 1,472, 503, and 499 kg ha^{-1} at Bao Loc, and 736, 252, and 280 kg ha^{-1} at Bao Lam, respectively. The rest of the annual fertilizer dose was distributed during the season, as detailed in Table 2.

The soil at both sites was acidic, with $pH_{(KCl)}$ ranging from 4.2-4.28. Table 3 demonstrates that soil organic matter content was higher at Bao Loc (8.5%) than at Bao Lam (5.7%). Soil fertility was better at Bao Loc, as indicated by the slightly higher N content, and by the significantly higher levels of available P and K (Table 3). Also, the soil at Bao Lam contained much less Ca and Mg than that of Bao Loc. However, no differences were observed regarding soil S contents.

Three-leaf buds were continuously picked throughout the harvesting season. Bud density was determined at each harvest and samples were taken for measurements of bud weight and length. Once a month, 200 buds were sampled from each plot and the infection rates of red spider and green bug were recorded. The elemental (N, P, K, Ca, Mg, and S) composition of the tea buds was examined a few days before, and 20 days after fertilizer application

Table 1. Fertilizer compositions and programs (CT1, CT2, and CT3) examined in tea plantations at Bao Loc and Bao Lam districts, Vietnam.

Fertilizer	Bao Loc (cv. Kim Tuyén)			Bao Lam (cv. TB14)		
	CT1 (Control)	CT2 (Phu My Fertilizer)	CT3 (Phu My Fertilizer + Polysulphate)	CT1 (Control)	CT2 (Phu My Fertilizer)	CT3 (Phu My Fertilizer + Polysulphate)
	Amount of fertilizer (kg ha^{-1})					
Polysulphate	0	0	200	0	0	150
NPKS (16-16-8-13)	0	800	800	0	400	400
NPK (15-15-15)	0	1,000	1,000	0	500	500
NPK (25-9-9)	0	1,500	1,500	0	750	750
NPK (27-6-6)	0	1,500	1,500	0	750	750
Urea	3,200	900	900	1,600	450	450
Fused Ca-Mg-P	3,353	0	0	1,677	0	0
KCl	832	100	53	466	100	65

Table 2. Time of year of fertilizer applications during the season.

Time of year	Fertilizer
Mid-April	Polysulphate; NPKS (16-16-8-13)
Early June	NPK (12-10-9)
Mid-July	NPK (25-9-9)
Mid-September	Polysulphate; NPK (27-6-6)
Early November	Urea; KCl

Table 3. Soil properties at the two experimental sites before and after the growing season.

Location	Soil property	Treatment					
		Before			After		
		CT1	CT2	CT3	CT1	CT2	CT3
Bao Loc	pH_{KCl}	4.21	4.25	4.22	4.18	4.20	4.18
	OM (%)	8.51	8.55	8.55	8.30	8.42	8.44
	Total soil N (%)	0.281	0.278	0.280	0.282	0.284	0.286
	Total soil P_2O_5 (%)	0.23	0.22	0.23	0.23	0.23	0.23
	Total soil K_2O (%)	0.14	0.14	0.14	0.14	0.14	0.15
	Available P_2O_5 (mg/100 g)	15.4	15.6	15.7	15.5	15.8	15.8
	Available K_2O (mg/100 g)	26.7	26.3	26.5	26.8	26.9	27.0
	Ca^{++} (meq/100 g)	3.1	3.3	3.1	3.2	3.0	3.2
	Mg^{++} (meq/100 g)	2.5	2.5	2.4	2.7	2.1	2.6
	S (%)	0.018	0.018	0. 017	0.016	0.019	0.018
Bao Lam	pH_{KCl}	4.28	4.23	4.26	4.22	4.20	4.22
	OM (%)	5.62	5.66	5.70	5.41	5.48	5.59
	Total soil N (%)	0.246	0.241	0.247	0.248	0.249	0.250
	Total soil P_2O_5 (%)	0.20	0.21	0.21	0.20	0.21	0.22
	Total soil K_2O (%)	0.11	0.12	0.11	0.11	0.12	0.12
	Available P_2O_5 (mg/100 g)	9.4	9.4	9.5	8.5	8.7	8.8
	Available K_2O (mg/100 g)	16.6	16.5	16.7	16.8	16.9	17.0
	Ca^{++} (meq/100 g)	2.6	2.7	2.5	2.7	2.3	2.5
	Mg^{++} (meq/100 g)	1.9	1.9	1.9	1.9	1.6	2.0
	S (%)	0.015	0.015	0.016	0.015	0.015	0.016

Table 4. Effect of fertilizer treatments on leaf N, P, K, Ca, Mg, and S contents (%) in Kim Tuyén and TB14 tea cultivars.

Variety	Element	Before fertilization			After fertilization		
		CT1	CT2	CT3	CT1	CT2	CT3
		-------------------------------------			%-------------------------------------		
Kim Tuyén	N	3.07	3.05	3.06	3.38	3.41	3.37
	P	0.155	0.154	0.154	0.167	0.163	0.166
	K	1.24	1.24	1.22	1.41	1.37	1.40
	Ca	0.38	0.40	0.39	0.61	0.33	0.58
	Mg	0.19	0.17	0.18	0.55	0.16	0.53
	S	0.14	0.14	0.14	0.13	0.27	0.30
TB14	N	3.03	3.05	3.03	3.35	3.32	3.34
	P	0.155	0.153	0.152	0.162	0.164	0.161
	K	1.23	1.22	1.21	1.38	1.38	1.39
	Ca	0.35	0.37	0.34	0.51	0.31	0.50
	Mg	0.16	0.16	0.15	0.46	0.14	0.44
	S	0.12	0.13	0.12	0.11	0.25	0.27

(Table 2). Tea bud quality was inferred by dry matter content and by the rates (%) of the soluble fraction, tannins, and caffeine in the dry matter.

The experimental plan at each site comprised of nine 0.11 ha plots using a completely randomized block design with three repetitions.

Results and discussion

The impact of the different fertilization programs on soil fertility parameters was complex (Table 3). Soil acidity and content of organic matter (OM), tended to increase during the growing season at both locations. This tendency may indicate active soil degradation processes that require a significant supplementation of organic manure. The total N-P-K levels remained stable or slightly increased. Available P_2O_5 increased a little at Bao Loc, but significantly dropped at Bao Lam. Available K_2O showed some increase in both locations. No differences could be observed between treatments regarding the above mentioned soil parameters. These results indicate that N-P-K were sufficiently applied in all three cases.

However, significant differences between treatments did occur with regard to Ca and Mg. While the content of these elements remained stable or even increased at CT1 and CT3, they declined markedly at CT2, suggesting a fragile balance between soil availability and tea crop requirements of Ca and Mg. At Bao Loc, soil S content slightly decreased at CT1 but remained stable at CT2 and CT3, while no changes were observed at Bao Lam (Table 3).

The influence of the different fertilization programs on nutrient content in the leaves was examined shortly before, and 20 days after the fertilizer application (Table 1). Nitrogen content increased from 3.06 to roughly 3.4% of dry leaf weight, however, no differences occurred between treatments. Similarly, leaf contents of P and K increased slightly, from 0.155 to 0.165%, and from 1.24

to 1.4%, respectively, with no significant effect of particular treatment. These results show the efficiency of a balanced N-P-K application, in spite of employing different types of fertilizers.

The response was different with Ca, Mg, and S; Ca and Mg contents increased significantly in CT1 and CT3 and slightly decreased in CT2. No advantage was observed for any of the fertilizers, fused Ca-Mg-P or Polysulphate, as a source of Ca or Mg. Leaf contents of S doubled at CT2 and CT3, with Polysulphate proving to be slightly more effective than the N-P-K-S fertilizer, as an S source (Table 4). Interestingly, Ca, Mg, and S leaf contents were somewhat lower in the TB14 cultivar than in Kim Tuyén.

Tea yield components, such as three-leaf-bud density, weight, and length, were significantly affected by the different fertilization programs (Fig. 1). There were dramatic differences in all yield

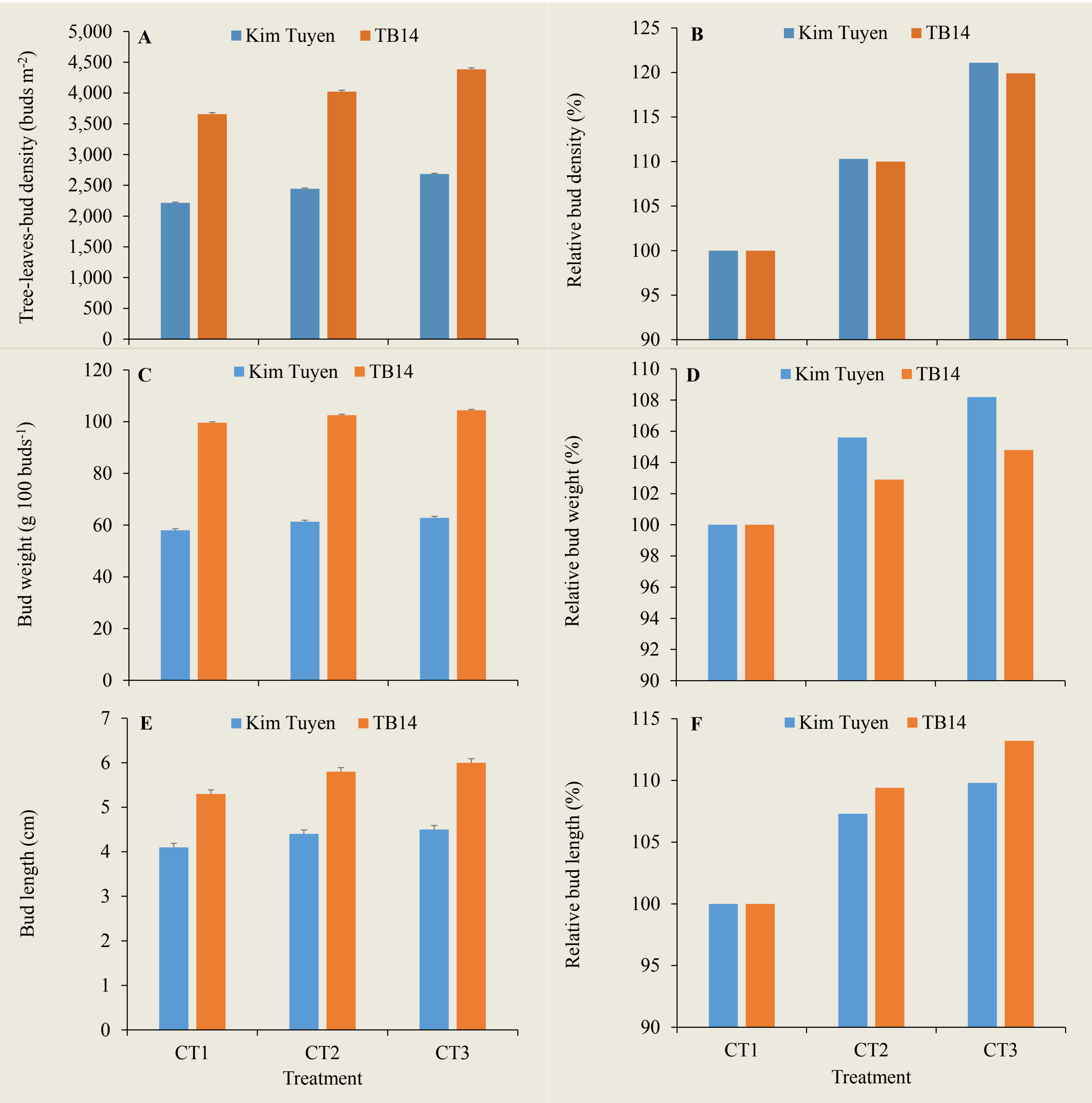


Fig. 1. Effect of fertilizer treatments on three-leaf-bud absolute and relative yield components (density, weight, and length) of the Kim Tuyén and TB14 cultivars. Bars indicate LSD at 5%.

parameters between the two cultivars. TB14 displayed much higher bud density, weight, and length (Fig. 1A, C, E). Bud density increased by 10 and 20-21% at CT2 and CT3, respectively, relative to CT1, showing no differences between the cultivars (Fig. 1B). Bud weight, which was more responsive in cultivar Kim Tuyén, increased by 5.6 and 8.5% at CT2 and CT3, respectively and relative to CT1, while, in TB14, bud weight increased by only 2.9 and 4.8%, respectively (Fig. 1D).

In contrast, bud length was more responsive in TB14, where it increased by 9.4 and 13.2% at CT2 and CT3, respectively and relative to CT1. Bud length of Kim Tuyén increased by 7.3 and 9.8% in response to CT2 and CT3, respectively (Fig. 1F).

In general, TB14 obtained much greater yields than Kim Tuyén (35.4 vs. 12.9 Mg ha^{-1}) at the control treatment, CT1 (Fig. 2A). The overall increase of the tea bud yield was 9.3 and 10.5% for Kim Tuyén and TB14, respectively, at CT2 relative to CT1. The increase is significantly higher at CT3, 15.5 and 14.1%, respectively (Fig. 2B).

The different fertilization programs did not seem to have any influence on the rates or severity of the green bug infections (1-2% of 200 plants examined), or the red spider infections (2-2.5%).

Considering that N-P-K rates and application timings were similar among all fertilization programs, the advantage displayed by CT2 may be attributed to S enrichment through the N-P-K-S fertilizer. Nevertheless, with a similar S rate, split to two applications, CT3 brought about a more significant yield increase. The advantage of CT3 may also be attributed to soil enrichment with Ca and Mg, both provided through the Polysulphate application, but absent in CT2. Additionally, the slow-release effect of Polysulphate with regard to S and K availability might have had a positive influence on plant growth.

Table 5 indicates that the lack of Ca and Mg appears to influence green tea quality parameters. CT2 consistently obtained lower rates of dry matter content, soluble fraction, tannins, and caffeine, compared to CT1. Conversely, CT3 displayed the highest rates for these parameters. In this regard, cultivar Kim Tuyén displayed

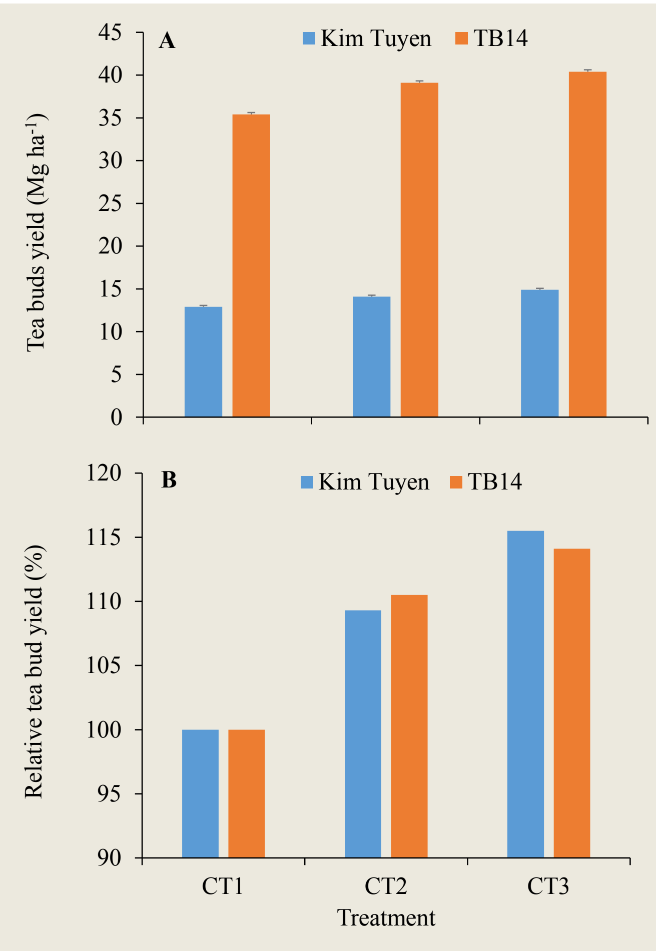


Fig. 2. Effect of fertilizer treatments on the absolute and relative yield of Kim Tuyén and TV14 tea cultivars in Vietnam. Bars indicate LSD at 5%.

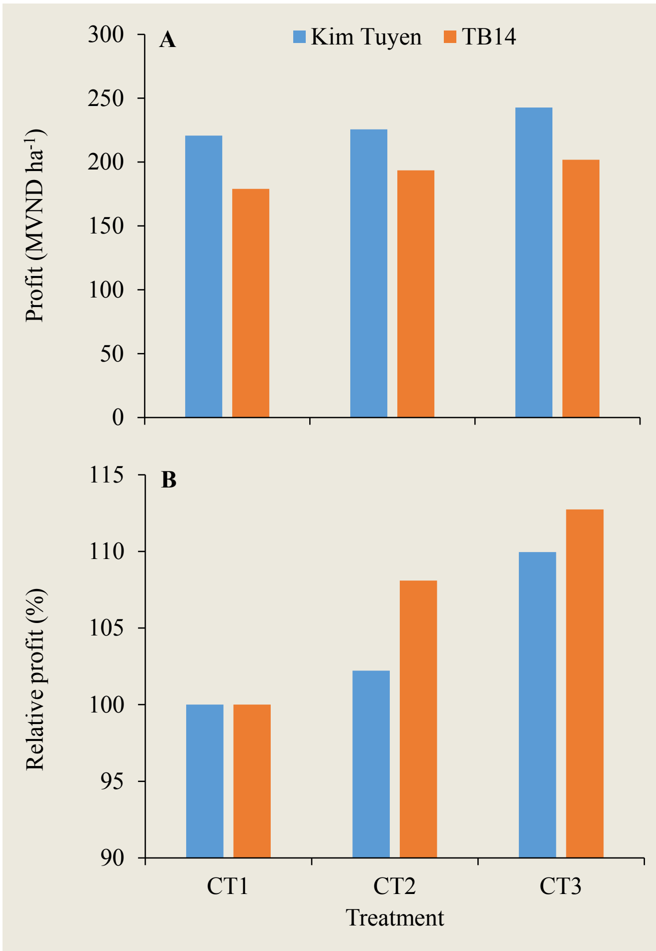


Fig. 3. Effect of fertilizer treatments on the profit of two tea cultivars in Vietnam.

consistently higher quality rates than TB14.

The Kim Tuyén cultivar is highly appreciated in green tea markets and its high retail cost compensates for relatively low yields (Fig. 2). Thus, in spite of the almost doubled fertilizers input (Table 1), Kim Tuyén is more profitable than TB14 for any of the tested fertilization programs (Fig. 3). In both cultivars, CT2 was significantly more profitable than CT1, and CT3 more than CT2. These results suggest that the common tea fertilization practice (CT1) in these regions of Vietnam may be considerably improved using additional S fertilizers, although the exact role of this element in tea plants is still obscure.

The availability of nutrients, such as Ca and Mg, appears to be significant for tea crop production and their increased application should be considered. Polyhalite, comprising Ca, Mg, K and S seems to provide the most profitable solution, particularly due to significant yield improvement at a reasonable cost (Fig. 3; Table 6).

Table 5. Effects of fertilizer treatments on physical and chemical quality parameters of two tea cultivars in Vietnam.

Variety	Treatment	Dry matter	Soluble fraction	Tannins	Caffeine
		% of fresh weight	-------------------*% of dry weight*	------------------	
Kim Tuyén	CT1	73.55	44.36	26.91	3.05
	CT2	72.09	43.11	25.64	2.93
	CT3	74.00	45.12	27.41	3.11
TB14	CT1	72.75	40.10	24.82	2.86
	CT2	71.52	39.66	23.71	2.74
	CT3	73.11	41.26	25.59	2.97

Table 6. Economic balance of three fertilization programs for Kim Tuyén and TB14 green tea cultivars grown in Vietnam.

Cultivar	Fertilization program	Total cost	Total income
		---------------------*million VND ha^{-1}*	---------------------
Kim Tuyén	CT1	75.9	296.7
	CT2	98.6	324.3
	CT3	99.9	342.7
TB14	CT1	93.6	272.6
	CT2	107.5	301.1
	CT3	109.3	311.1

Conclusions

Polysulphate, added to a systematic N-P-K fertilization program for tea plants grown on reddish brown soil in Lam Dong, Vietnam, enhanced the density, weight and size of tea buds, thus increasing tea productivity by 14-15.5%. Also, Polysulphate slightly improved tea quality parameters such as dry matter content and the concentrations of soluble substances, tannins, and caffeine. Overall, Polysulphate gave rise to profit increases of 10% and 12.7%, in the cultivars Kim Yuyén and TB14, respectively. While no direct effect of S nutrient could be observed, some of the yield enhancement may be attributed to facilitated N uptake and metabolism. Polysulphate demonstrated the ability to supply plant Ca and Mg requirements and maintain soil fertility, while supporting greater biomass production, compared to the alternative fertilization programs.

Tea plantations in Vietnam. Photos by Nguyen Duy Phuong.

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The paper "Polyhalite Application Improves Tea (*Camillia sinensis*) Yield and Quality in Vietnam" also appears on the IPI website at:

Regional activities/Southeast Asia

Research Findings

Ready to harvest sugar beet field at Layyah in Pakistan. Photo by A. Wakeel.

Sugar Beet Response to Potassium Fertilizer under Water Sufficient and Water Deficient Conditions*

Mubarak, M.U.[(1)**], M. Zahir[(1)], M. Gul[(2)], M. Farooq[(3)], and A. Wakeel[(1)]

Introduction

Sugar beet (*Beta vulgaris* L.) is an industrial crop, grown as a sugar crop contributing ~25% of total sugar production worldwide. In Pakistan, however, sugar is mostly extracted from sugarcane. Sugar beet has high sucrose content, even more than that in sugarcane; and sugar beet yield can be sustained, or even can be further increased by potassium (K) fertilization. In Pakistani soils K concentration is higher, because these soils are developed from mica minerals. However, its high concentration in soil K does not represent plant available K for sustainable plant growth. Due to strong binding within clay minerals, K is not released at required rate for the optimum plant growth. K increases root growth and improves drought resistance and plays a critical role in enzyme activation, osmoregulation, and charge

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balance in plants (Cakmak, 2005). This study was conducted to investigate the effect of K on the sugar beet yield.

Materials and Methods

A pot experiment was conducted in the wire house at Institute of Soil and Environmental Sciences, University of Agriculture, Faisalabad. Treatments were K_0 (No K), K_1 (148 kg ha^{-1}) and K_2 (296 kg ha^{-1}). Levels of irrigation used were water sufficient at 60% water holding capacity and water deficient at 40% water holding capacity. The growth, yield and beet quality data were analyzed statistically using LSD with factorial design. The crop was irrigated with distilled water and plants were harvested 200 days after transplanting, beet size including length and diameter was measured with the help of measuring scale and vernier caliper. Fresh weight of shoot and beet were recorded and then shoot and beets were oven dried at 80°C in an oven after isolating the fresh beet sample for sugar analyses. Oven-dried shoot and beet samples were digested by dry ashing method (Chapman and Pratt, 1961) and Boron (B) in filtrate was measured by colorimetric method using Azomethine-H (Bingham, 1982) as an indicator. Sodium (Na) and potassium (K) in shoot and beet were determined in plant samples by wet digestion procedure using a mixture of nitric and perchloric acids with ratio 2:1. K and Na were determined by flame photometer according to the method described by Chapman and Pratt (1961). Chlorophyll contents were measured with a chlorophyll meter (SPAD 502 P).

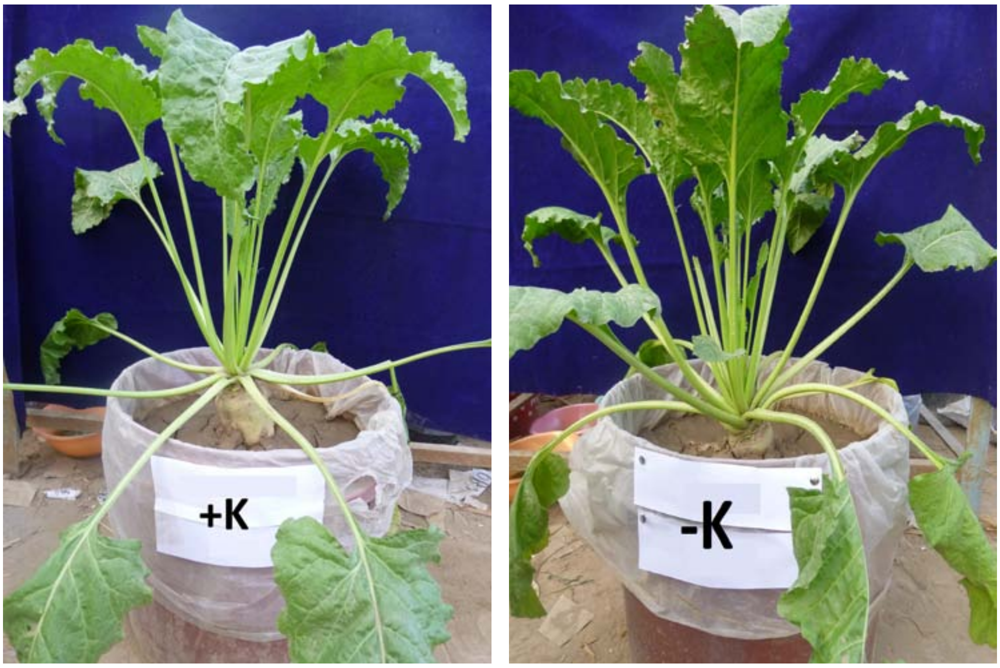
Results and Discussion

Sugar beet growth and yield responded well to K fertilization and the plant height, beet diameter and length of sugar beet were improved over the control. The K application at the rate of 296 kg ha^{-1} (K_2) with water sufficient showed further increase, and maximum plant height (23 cm), beet diameter (6.88 cm) and length (21 cm) of sugar beet was achieved in K_2 (Table 1). It was observed that increase in K fertilization up to 296 kg ha^{-1} can increase the sugar yields significantly at both water levels. Sugar yield per hectare was increased from 3.45 to 5.5 ton ha^{-1} at water sufficient level, whereas the increase was 2.1 to 3.4 ton ha^{-1} at water deficient level (Table 1). All physiological parameters aresignificantly influenced by increasing the levels of K fertilizers in different crops (Celik *et al.*, 2010). Potassium fertilization significantly ($p<0.05$) increased K^+ concentration in shoot and beet of sugar beet at both water levels. Application of K fertilizer significantly decreased the Na^+ concentration in shoot as well as in beet under water sufficient and water deficient conditions (Table 2). Interestingly application of K fertilizers improved the concentration of Boron (B) in shoot as well as in beet showing a synergistic effect, at both fertilizer levels (Table 2). Significant effect of K fertilization on the chlorophyll contents as compared to control at water sufficient and water deficient levels was observed (Table 2).

Table 1. Effect of potassium on the plant growth and yield of sugar beet under water sufficient and water deficient conditions.

Irrigation level	K fertilizer treatments	Plant height	Beet diameter	Beet length	Sugar yield*
		-----------------------	-------*cm*-------	-----------------------	*t ha⁻¹*
Water sufficient	K_0 (No K fertilizer)	15.75 c	4.57 bc	13.5 c	3.45 cd
	K_1(148 kg K_2O ha^{-1})	20.37 b	6.35 ab	16.5 b	4.8 b
	K_2 (296 kg K_2O ha^{-1})	23 a	6.86 a	21 a	5.5 a
Water deficient	K_0 (No K fertilizer)	12 e	3.95 d	11 d	2.1 e
	K_1(148 kg K_2O ha^{-1})	13.5 de	5.22 d	14.5 c	2.9 d
	K_2 (296 kg K_2O ha^{-1})	13.5 de	5.38 cd	16.5 bc	3.4 c

**This is extended yield calculated from pot experiment.*



Comparison of sugar beet grown in pots having 45 kg soil with and without potassium fertilization.
Photos by U. Mubarak.

Table 2. Effect of potassium on the concentration of K, Na, B and chlorophyll contents in shoot and beet.

Irrigation level	K fertilizer treatments	Shoot			Beet			
		K	Na	B	K	Na	B	Chl. content
		-------------------*mg/kg*-------------------			-------------------*mg/kg*------------------			*μgg^{-1}*
Water sufficient	K_0 (No K fertilizer)	1108.2 cd	119.6 a	48.0 cd	190.7 e	19.4 a	48.0 cd	26 c
	K_1 (148 kg K_2O ha^{-1})	1286.7 ab	90.5 c	54.0 ab	388.7 c	13.5 c	54.5 ab	35.7 ab
	K_2 (296 kg K_2O ha^{-1})	1409.0 a	71.5 e	57.25 a	503.2 a	9.1 e	58.2 a	40.3 a
Water deficient	K_0 (No K fertilizer)	845.6 d	99.7 b	44.0 d	129.0 f	18.3 b	44.2 d	22.2 d
	K_1 (148 kg K_2O ha^{-1})	962.8 bc	80.7 d	51.5 bc	239.2 d	12.1 d	52.0bc	27 c
	K_2 (296 kg K_2O ha^{-1})	1183.3 ab	63.0 f	53.5 ab	452.2 b	6.8 f	54.3ab	34.2 b

Conclusion

Application of K fertilizers showed significant increase in quality and yield of sugar beet under water sufficient as well as in deficient conditions.

Sugar beet with and without potassium fertilizer grown in wire house in large plastic pots. Photo by A. Wakeel.

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The paper "Sugar Beet Response to Potassium Fertilizer under Water Sufficient and Water Deficient Conditions" also appears on the IPI website at:

Regional activities/WANA

Events

International Symposia and Conferences

October 2016

CropWorld Global, 24-25 October 2016, Amsterdam RAI, Netherlands.

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

November 2016

International Conference on the "Significance of Potash Use in Pakistani Agriculture", 24-25 November 2016, Institute of Agricultural Sciences, University of the Punjab, Quaid-e-Azam Campus, Lahore Pakistan.

This two day International Conference on Significance of Potash use in Pakistani Agriculture will explain the importance of potassium in plant nutrition and the diet of humans and animals, and describes the role of potassium based fertilizers in Pakistan's agriculture. For more details, including event brochure see IPI website. For more information contact Dr. Sajid Ali (sajid.iags@pu.edu.pk).

November/December 2016

13th Advanced Level Training in Soil Testing, Plant Analysis and Water Quality Assessment 29 November-19 December 2016, Division of Soil Science and Agricultural Chemistry, ICAR-Indian Agricultural Research Institute, New Delhi, India.

The 13th Advanced Level Training will be conducted with the major objective of improving awareness and skills of the participants in modern techniques of analysis of soil, water and plant for research and extension activities in agriculture and allied fields, use of instruments and their general upkeep/maintenance, interpretation of analytical data and formulation of reports/recommendations. The course is designed to cover soil characteristics, testing techniques and methods of interpretation of data, so as to make it more useful in the context of global competition in quality and precision of analysis for agricultural export market. See more information on the IPI website/Events.

7th International Nitrogen Conference (INI 2016) "Solutions to Improve Nitrogen Use Efficiency for the World", 4-8 December 2016, Melbourne Cricket Ground, Victoria, Australia.

More information on this triennial event, which is supported by both IPNI and IFA, is available online on the conference website.

January 2017

Frontiers of Potassium - an International Conference, 25-27 January 2017, Rome, Italy.

The understanding of potassium behavior in soil and its vital role in plant health has been expanding rapidly. This conference will allow global experts to gather and discuss the frontiers of potassium science. IPNI will organize the conference to facilitate discussion of key technical questions and develop a pathway for additional potassium research and for improved nutrient management. See further details on the conference website.

March 2017

The 15th New Ag International Conference & Exhibition, 15-17 March 2017, Maritim Hotel, Berlin, Germany. The World's Leading Event on High-Tech Agriculture.

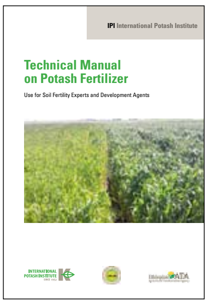
The three day meeting will feature selected presentations delivered by world renowned speakers/organisations. For more information go to the New Ag conference website.

Publications

IPI Profile Infographic and Brochure

IPI's mission is to develop and promote balanced fertilization for higher yields and more nutritious food ensuring sustainable production through conservation of soil fertility for future generations.

This IPI profile infographic illustrates the work of the IPI. To download the infographic go to the IPI website/Infographics.



Technical Manual on Potash Fertilizer Use for Soil Fertility Experts and Development Agents

Compiled by experts from The Ministry of Agriculture and Natural Resources (MoANR) and Agricultural Transformation Agency (ATA) led by Prof. Tekalign Mamo. 2016. 32 p.

The African continent is home to more than one billion people. With current population growth rates, Africa will need to accommodate more than two billion by 2050. However, food production in sub-Saharan Africa is significantly lower than other parts of the world: less than 150 kg of grain per capita are produced in the region each year compared to more than 300 kg of grain per capita in other parts of the world. If a growing population is to be fed, this worrying level of agricultural productivity must change rapidly. One of the immediate tools to stimulate improved yields and crop quality is balanced use of fertilizers.

This Technical Manual on Potash Fertilizer Use for Soil Fertility Experts and Development Agents provides concise and accurate information on potash fertilization to enable effective and responsible knowledge transfer to Ethiopian farmers. IPI is honored to have the opportunity to work with its Ethiopian partners in achieving this worthwhile mission.

To download the booklet go to the IPI website/Publications. For hardcopies contact Mr. Eldad Sokolowski, IPI Coordinator SSA/Ethiopia and China.

Balancing Use of Fertilization with Potassium

by Abdul Wakeel, IPI Consultant in Pakistan, developed in collaboration with FAO. 2016. In English and Urdu.

Crops need at least 17 essential elements for optimum growth. Of these, nitrogen (N), phosphorus (P), and potassium (K) are required in large amounts and are also deficient in most soils of the world.

Among others, most of the essential elements are either provided by soil or deficient elements are required in smaller amounts. While N, P and K have to be supplemented by fertilizers in optimum ratio as soil reserves are depleting and unable to support the plant growth. Application of adequate amounts of such fertilizers is called "Balanced Fertilization", and is explored in this leaflet.

To download the leaflet in English or Urdu, go to the IPI website/Publications/Leaflets.

Publication by the PDA

POTASH News, August 2016.

Crop Nutrition Assignment by Melissa Gorst of Newcastle University

This year the PDA sponsored the Crop Nutrition essay at Newcastle University and Melissa Gorst, a 2nd year agricultural degree student, won the prize with the essay below. It describes the benefits and planning of Potash use. The scenario was set so that it would be written as an adviser not as an academic, and Melissa has achieved this admirably.

The Scenario: You are an adviser on a conventional mixed farm with a rotation of 1st wheat, 2nd wheat, winter barley and oilseed rape followed by a 4 year grass-ley. Arable crop yields have been below average over recent years. The soil type is a clay loam and all the cereal straw is baled and used for animal bedding in the beef unit. You are looking to address the issue of low yields and you recently had soil samples taken and analysed in the spring of 2015 where the following results were obtained pH 6.4, OM% 3.42, soil P concentration range of 19-32 mg/litre (Olsen's P) and soil K concentration range of 56-85 mg/litre. This supports your belief that the essence of the problem is a lack of K caused by K application holidays, lack of regular analyses etc.

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 in the Literature

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Calcium and Potassium Supplementation Enhanced Growth, Osmolyte Secondary Metabolite Production, and Enzymatic Antioxidant Machinery in Cadmium-Exposed Chickpea (*Cicer arietinum* L.)

Parvaiz Ahmad, Arafat A. Abdel Latef, Elsayed F. Abd_Allah, Abeer Hashem, Maryam Sarwat, Naser A. Anjum, and Salih Gucel. 2016. Front. Plant Sci. http://dx.doi.org/10.3389/fpls.2016.00513.

Abstract: This work examined the role of exogenously applied calcium (Ca; 50 mM) and potassium (K; 10 mM) (alone and in combination) in alleviating the negative effects of cadmium (Cd; 200 µM) on growth, biochemical attributes, secondary metabolites and yield of chickpea (*Cicer arietinum* L.). Cd stress significantly decreased the length and weight (fresh and dry) of shoot and root and yield attributes in terms of number of pods and seed yield (vs. control). Exhibition of decreases in chlorophyll (Chl) *a*, Chl *b*, and total Chl was also observed with Cd-exposure when compared to control. However, Cd-exposure led to an increase in the content of carotenoids. In contrast, the exogenous application of Ca and K individually as well as in combination minimized the extent of Cd-impact on previous traits. *C. arietinum* seedlings subjected to Cd treatment exhibited increased contents of organic solute (proline, Pro) and total protein; whereas, Ca and K-supplementation further enhanced the Pro and total protein content. Additionally, compared to control, Cd-exposure also caused elevation in the

contents of oxidative stress markers (hydrogen peroxidase, H_2O_2; malondialdehyde, MDA) and in the activity of antioxidant defense enzymes (superoxide dismutase, SOD; catalase, CAT; ascorbate peroxidase, APX; glutathione reductase, GR). Ca, K, and Ca + K supplementation caused further enhancements in the activity of these enzymes but significantly decreased contents of H_2O_2 and MDA, also that of Cd accumulation in shoot and root. The contents of total phenol, flavonoid and mineral elements (S, Mn, Mg, Ca and K) that were also suppressed in Cd stressed plants in both shoot and root were restored to appreciable levels with Ca- and K-supplementation. However, the combination of Ca + K supplementation was more effective in bringing the positive response as compared to individual effect of Ca and K on Cd-exposed *C. arietinum*. Overall, this investigation suggests that application of Ca and/or K can efficiently minimize Cd-toxicity and eventually improve health and yield in *C. arietinum* by the cumulative outcome of the enhanced contents of organic solute, secondary metabolites, mineral elements, and activity of antioxidant defense enzymes.

Production and Evaluation of Potassium Fertilizers from Silicate Rock

Wedisson Oliveira Santos, Edson Marcio Mattiello, Leonardus Vergutz, and Rodolfo Fagundes Costa. 2016. J. Plant Nutr. Soil Sci. 179(4):547-556. DOI 10.1002/jpln.201500484.

Abstract: Rising price and limited geographical availability of traditional sources of potassium (K) fertilizers have stimulated a search for alternative K sources in different parts of the world. We evaluated mineral transformations and agronomic properties of an alternative source of K produced through thermal and chemical treatment of the verdete rock (VR). Chemical and mineralogical characteristics were evaluated before and after each treatment. Four K sources (verdete rock, KCl, acidified verdete, and calcinated verdete) were applied to a Typic Hapludox at different rates. Eucalyptus and sequentially cropped maize and grass were grown in the treated soils. Verdete rock, which contained glauconite and microcline as K crystalline minerals, had very low solubility in water and in citric acid. Thermal and chemical treatments increased the concentration of water soluble K and citric acid soluble K. These treatments also caused crystalline K minerals to collapse and form sylvite and arcanite. Untreated verdete rock was not suitable as a K source for maize (*Zea mays* L.) and eucalyptus (*Eucaliptus urograndis* I144). Thermal and chemical treatments increased agronomic performance of VR to be similar to KCl. When K was applied as K-calcined verdete, 82% of the total K was recovered in maize and grass cultivations. Less K was recovered in plant following addition of K-acidified verdete and KCl (72% and 77%, respectively). Potassium recoveries by eucalyptus were about 52, 53, and 60% of the amount applied of calcined verdete, acidified verdete, and KCl, respectively. Both calcination and thermal treatment increased the K uptake and dry matter production for all plant species tested to be similar to KCl suggesting that this silicate rock could be beneficiated to be an effective K fertilizer.

Identification and Characterization of Potassium Solubilizing Bacteria (KSB) from Indo-Gangetic Plains of India

Madhumonti Sahaa, Bihari Ram Maurya, Vijay Singh Meena, Indra Bahadur, and Ashok Kumar. 2016. Biocatalysis and Agricultural Biotechnology 7:202-209.

Abstract: The present investigation comprises a total of fifty potassium solubilizing bacterial (KSB) strains which were isolated from *Oryza sativa, Musa paradisiaca, Zea mays, Sorghum bicolor* and *Triticum aestivum* L. These strains were evaluated for their ability to solubilize the fixed K from waste biotite (WB). On the basis of K-solublization, the seven most efficient KSB strains were evaluated for K-solublizing dynamics from the WB at 7, 14 and 21 DAI (days after incubation) on MAMs (Modified Solid Aleksandrov Medium). Further, these screened seven KSB strains were used for their morphological, physiological and molecular chacterization. The KSB strains *Bacillus licheniformis* BHU18 and *Pseudomonas azotoformans* BHU21 showed significantly higher K-solublization 7.22 and 6.03 µg mL^{-1} at 30 °C and pH 7.0, respectively. A significantely higher zone of solubilization significantly higher was recorded with *Pseudomonas azotoformans* BHU21 (3.61 cm). *Bacillus licheniformis* BHU18 produced significantly higher (~23 µg mL^{-1}) concentrations of indole-3-acetic acid. The diversity of KSB as bioinoculants to release potassium provides a win-win situation. Therefore, it is crucial to adopt efficient KSB strain interventions for the judicious use of chemical and biological resources for maximizing food production while reducing pollution and rejuvenating degraded land for agricultural benefit.

Potassium (K) Supply Affects K Accumulation and Photosynthetic Physiology in Two Cotton *(Gossypium hirsutum* L.) Cultivars with Different K Sensitivities

Wei Hu, Nan Jiang, Jiashuo Yang, Yali Meng, Youhua Wang, Binglin Chen, Wenqing Zhao, Derrick M. Oosterhuis, and Zhiguo Zhou. 2016. Field Crops Research 196:51-63. http://dx.doi.org/10.1016/j.fcr.2016.06.005.

Abstract: A two-year field experiment was established to investigate the differences in the process of potassium (K) accumulation and photosynthetic physiology of functional leaves of two cotton (*Gossypium hirsutum* L.) cultivars with contrasting K sensitivity (Simian 3, low-K-tolerant cultivar and Siza 3, low-K-sensitive cultivar) under three K levels (0,150 and 300 kg K_2O ha^{-1}). Results in 2012 and 2013 indicated that

the maximum theoretical accumulation of K, the maximum and average accumulation rate of K increased in the K-supply treatments (150 and 300 kg K_2O ha^{-1}), and the K accumulation in reproductive and reproductive organs was increased by K application. Decreased net photosynthetic rate (P_n) in the 0 kg K_2O ha^{-1} treatment was attributed to stomatal limitation at the boll setting stage for Simian 3 and at the peak flowering stage for Siza 3. After which, non-stomatal factors (low chlorophyll content, unbalanced chlorophyll a to chlorophyll *b* ratio, negative chlorophyll fluorescence parameters and decreased carboxylation efficiency) dominated the reduction in P_n under K deficiency. High total and initial Rubisco, sucrose phosphate synthase and sucrose synthase (SuSy) (except SuSy in Simian 3) activities did not result in high hexose, sucrose and starch contents in the K-supply treatments, because of a higher rate of sucrose export. Compared with Simian 3, the sensitivity of Siza 3 to low-K was showed in the following aspects: (1) the duration of K rapid-accumulation was increased by K application; (2) P_n, chl a + b and chlorophyll fluorescence parameters, especially *q*N, under K deficiency were more negative; (3) the occurring time of non-stomatal limitation under K deficiency was earlier; (4) the net photosynthetic rate of unit chlorophyll was significantly promoted by K application; (5) Siza 3 needed higher leaf K content to maintain Rubisco activation state; and (6) SuSy activity was increased by K application.

Comparison between *Arabidopsis* and Rice for Main Pathways of K^+ and Na^+ Uptake by Roots

Manuel Nieves-Cordones, Vicente Martínez, Begoña Benito, and Francisco Rubio. 2016. Front. Plant Sci. 5 July 2016. http://dx.doi.org/10.3389/fpls.2016.00992.

Abstract: K^+ is an essential macronutrient for plants. It is acquired by specific uptake systems located in roots. Although the concentrations of K^+ in the soil solution are widely variable, K^+ nutrition is secured by uptake systems that exhibit different affinities for K^+. Two main systems have been described for root K^+ uptake in several species: the high-affinity HAK5-like transporter and the inward-rectifier AKT1-like channel. Other unidentified systems may be also involved in root K^+ uptake, although they only seem to operate when K^+ is not limiting. The use of knock-out lines has allowed demonstrating their role in root K^+ uptake in *Arabidopsis* and rice. Plant adaptation to the different K^+ supplies relies on the finely tuned regulation of these systems. Low K^+-induced transcriptional up-regulation of the genes encoding HAK5-like transporters occurs through a signal cascade that includes changes in the membrane potential of root cells and increases in ethylene and reactive oxygen species concentrations. Activation of AKT1 channels occurs through phosphorylation by the CIPK23/CBL1 complex. Recently, activation of the *Arabidopsis* HAK5 by the same complex has been reported, pointing to CIPK23/CBL as a central regulator of the plant's adaptation to low K^+. Na^+ is not an essential plant nutrient but it may be beneficial for some plants. At low concentrations, Na^+ improves growth, especially under K^+ deficiency. Thus, high-affinity Na^+ uptake systems have been described that belong to the HKT and HAK families of transporters. At high concentrations, typical of saline environments, Na^+ accumulates in plant tissues at high concentrations, producing alterations that include toxicity, water deficit and K^+ deficiency. Data concerning pathways for Na^+ uptake into roots under saline conditions are still scarce, although several possibilities have been proposed. The apoplast is a significant pathway for Na^+ uptake in rice grown under salinity conditions, but in other plant species different mechanisms involving non-selective cation channels or transporters are under discussion.

The Influence of Potassium to Mineral Fertilizers on the Maize Health

Jan Bocianowski, Piotr Szulc, Anna Tratwal, Kamila Nowosad, and Dariusz Piesik. 2016. Journal of Integrative Agriculture 15(6):1286-1292.

Abstract: Field experiments (2009-2011) were conducted at the Department of Agronomy at Poznań University of Life Sciences on the fields of the Research Institute in Swadzim. We evaluated the health of maize plants of two types, depending on the variations in mineral fertilization. The conducted research recorded the occurrence of pests such as oscinella frit (*Oscinella frit* L.) and the European corn borer (*Pyrausta nubilalis* Hbn.). Diseases recorded during the research included two pathogenes: *Fusarium* (*Fusarium* ssp.) and corn smut (*Ustilago maydis* Corda). It was shown that the meteorological conditions during the maize vegetation had a significant influence on the occurrence of pests. Adding potassium to mineral fertilizers increased the maize resistance to *Fusarium*. Cultivation of "stay-green" cultivar shall be considered as an element of integrated maize protection. The occurrence of oscinella frit was correlated with the occurrence of *Fusarium* as well as the occurrence of the European corn borer for both examined cultivars.

A Modified Plate Assay for Rapid Screening of Potassium-Solubilizing Bacteria

Mahendra Vikram Singh Rajawat, Surender Singh, Satya Prakash Tyagi, and Anil Kumar Saxena. 2016. Pedosphere 26(5):768-773. http://dx.doi.org/10.1016/S1002-0160(15)60080-7.

Abstract: The utility of microorganisms for solubilizing the unavailable forms of potassium (K) from soil has led to renewed interest in fabrication of rapid and sensitive plate assays for their isolation and screening. The present study developed a modified plate assay and compared it with previously reported methods for

the isolation and screening of K-solubilizing bacteria. The newly developed plate assay is based on improved visualization of halo zone formation around the colonies on agar plates, through inclusion of an acid-base indicator dye, bromothymol blue (BTB), to modify the previously reported Aleksandrov medium. The halo zone exhibited a significant correlation ($R = 0.939$) with K released in liquid medium. The visualization of potential K solubilizers was improved using this method, which would help in detection of weak/non-acid producers based on secretion of organic acids in the medium. Organic acids in plate diffuse radially and form halo zones in response to reaction with the acid-base indicator dye BTB. Furthermore, K solubilization on plates with this method can be observed within 48-72 h, against the incubation time of 4-5 d needed in the earlier method. Therefore, the newly developed protocol for the plate assay was time saving, more sensitive, and beneficial in comparison to the previously reported Aleksandrov plate assay.

Foliar Application of Moringa Leaf Extract, Potassium and Zinc Influence Yield and Fruit Quality of 'Kinnow' Mandarin

Maryam Nasir, Ahmad Sattar Khan, S.M. Ahmad Basra, and Aman Ullah Malik. 2016. Scientia Horticulturae 210:227-235. http://dx.doi.org/10.1016/j.scienta.2016.07.032.

Abstract: 'Kinnow' mandarin (*Citrus nobilis* L. × *Citrus deliciosa* T.) is the most important commercial citrus cultivar grown in Pakistan. Poor nutrient management practices in citrus orchards had significantly reduced its yield and fruit quality. Recent reports of *Moringa olifera* as a promising growth enhancer showed its potential for application in agriculture sector. Moringa leaf extract (MLE) is enriched with phytohormones, phenolics and minerals. Hence, present study was conducted to evaluate efficacy of MLE alone or in combination with zinc (Zn) (as $ZnSO_4$) and potassium (K) (as K_2SO_4) on 'Kinnow' mandarin during two consecutive years (2013–2015). In first experiment, trees were sprayed with 3% MLE, 0.6% $ZnSO_4$ and 0.25% K_2SO_4 alone and in combination with 3% MLE at fruit set stage (year-I); whilst, in second experiment trees were sprayed with 3% MLE at pre-mature stage and 3% MLE, 0.6% $ZnSO_4$ and 0.25% K_2SO_4 at fruit set stage (year-II). Data were collected regarding leaf nutrient and ascorbic acid contents, yield and fruit quality. Leaf nitrogen (N), phosphorous (P), K, calcium (Ca), manganese (Mn) and Zn were significantly increased with all treatments in both experiments. Combined application of MLE, K and Zn at fruit set stage in both experiments resulted in significantly lower fruit drop and higher fruit set, yield, fruit weight, juice weight, soluble solid contents (SSC), vitamin C, sugars, total antioxidants and total phenolic contents. Activities of SOD and CAT enzymes in fruit juice were significantly increased with 3% MLE application in both experiments. Conclusively, combined foliar application of 3% MLE, 0.6% $ZnSO_4$ and 0.25% K_2SO_4 at fruit set stage can be used effectively to improve leaf nutrient status, fruit yield and quality of 'Kinnow' mandarin trees.

Fertilization Ratios of N-P_2O_5-K_2O for Tifton 85 Bermudagrass on Two Coastal Plain Soils

William Anderson, Myron B. Parker, Joseph Edward Knoll, and R. Curt Lacy. 2016. Agron. J. 108(4):1542-1551. DOI 10.2134/agronj2015.0585.

Abstract: Bermudagrass [*Cynodon dactylon* (L.) Pers.] is widely grown throughout the southeastern United States and many other countries for forage. Tifton 85, a hybrid between *C. dactylon* and *C. nlemfuensis*, is currently the recommended cultivar for grazing and hay. This study was conducted to determine the response of Tifton 85 to six rates of N fertilization (224, 336, 448, 560, 672, and 784 kg ha^{-1}) and three rates of PK fertilization (50, 100, and 150% replacement of P and K removal) on two different soils, Carnegie (fine, kaolinitic, thermic Plinthic Kandiudult) and Fuquay (loamy, kaolinitic, thermic Arenic Plinthic Kandiudult), for 4 yr. In a randomized split-plot design, whole plots were N rates with PK rates randomized within whole plots. The optimal fertilization rate to provide maximum profits was determined. Though yields began to level off only at the 560 kg ha^{-1} N application rate, rates from 224 to 448 kg ha^{-1} N with 100% replacement of P and K uptake resulted in maximum economic return. At these N rates, based on actual nutrient uptake, the N-P_2O_5-K_2O ratio for fertilization of Tifton 85 should be approximately 4-1-5. At 336 to 448 kg ha^{-1} N, a grower could expect approximately 19.6 to 23.0 Mg ha^{-1} yr^{-1} hay at 150 g kg^{-1} moisture. Crude protein (CP) concentration and in vitro dry matter digestibility (IVDMD) of the harvested forage both responded positively to increasing rates of N application beyond the economically optimum rates.

Combined Application of Polymer Coated Potassium Chloride and Urea Improved Fertilizer Use Efficiencies, Yield and Leaf Photosynthesis of Cotton on Saline Soil

Xiuyi Yang, Jibiao Geng, Chengliang Li, Min Zhang, Baocheng Chen, Xiaofei Tian, Wenkui Zheng, Zhiguang Liu, and Chun Wang. 2016. Field Crops Research 197:63-73. http://dx.doi.org/10.1016/j.fcr.2016.08.009.

Abstract: Conventional potassium fertilizers had been used widely, but few studies paid attention to controlled-release potassium fertilizer. The objective of this study was to explore the effects of polymer coated potassium chloride (PCPC) -an innovation product, especially the interaction application of PCPC and polymer coated urea (PCU) on cotton yield, fiber quality, leaf photosynthesis and fertilizer use efficiencies under salinity stressed conditions. A two-year experiment was conducted in two nearby fields with the similar fertility but varying salinity,

using a split-plot design in the Yellow River Delta area of China. The main plots were assigned to the types of K fertilizers (K1-180 kg ha^{-1} K from potassium sulfate, K2-90 kg ha^{-1} K from potassium sulfate + 90 kg ha^{-1} K from PCPC, K3-54 kg ha^{-1} K from potassium sulfate + 126 kg ha^{-1} K from PCPC, hereafter referred to as 0, 50% and 70% PCPC), while the types of N fertilizers (N1-220 kg ha^{-1} N from urea, N2-110 kg ha^{-1} N from urea + 110 kg ha^{-1} N from PCU, N3-66 kg ha^{-1} N from urea + 154 kg ha^{-1} N from PCU, hereafter referred to as 0, 50% and 70% PCU) were assigned to the subplots. The results indicated that the lint yield, number of bolls, boll weight, lint percentage, fiber qualities, leaf photosynthesis and fertilizer use efficiencies were significantly affected by the types of K, N fertilizers and their interaction. The K and N release characteristics of PCPC and PCU under field condition were closely matched to the nutrients requirements of cotton growth. The contents of soil available K and inorganic N were significantly augmented from the first bloom stage to the initial boll-opening stage by using PCPC and PCU compared to potassium sulfate and urea treatments. Meanwhile, PCPC and PCU interaction increased lint yields by 11.16-26.44% and 14.17-32.11% in comparison with potassium sulfate and urea in 2014 and 2015, respectively, and the maximum lint yield was achieved by the combination of 70% PCPC and 50% PCU. Besides, the boll number and boll weight were improved 5.2–18.2% and 4.75-10.29% by the PCPC and PCU treatments compared to both potassium sulfate and urea treatments, respectively. The potassium recovery efficiency (KRE) and nitrogen recovery efficiency (NRE) of PCPC and PCU treatments were significantly raised by 24.34-33.77% and 19.68-36.25%, respectively, compared with potassium sulfate and urea treatments in 2014 and 2015. PCPC owned the great potential to alter the current application of potassium fertilizer due to its ubiquitous traits. The interaction of PCPC and PCU at optimal dose was significant on cotton growth in saline soil. Consequently, the application of 70% PCPC in combination with 50% PCU is recommended to increase cotton yield and fertilizer use efficiency, and to improve the fiber quality and leaf photosynthesis properties in the Yellow River Delta area of China.

An *Arabidopsis* Zinc Finger Protein Increases Abiotic Stress Tolerance by Regulating Sodium and Potassium Homeostasis, Reactive Oxygen Species Scavenging and Osmotic Potential

Dandan Zang, Hongyan Li, Hongyun Xu, Wenhui Zhang, Yiming Zhang, Xinxin Shi, and Yucheng Wang. 2016. Front. Plant Sci. 24 August 2016. http://dx.doi.org/10.3389/fpls.2016.01272.

Abstract: Plant zinc finger proteins (ZFPs) comprise a large protein family and they are mainly involved in abiotic stress tolerance. Although *Arabidopsis* RING/FYVE/PHD ZFP At5g62460 (*AtRZFP*) is found to bind to zinc, whether it is involved in abiotic stress tolerance is still unknown. In the present study, we characterized the roles of *AtRZFP* in response to abiotic stresses. The expression of *AtRZFP* was induced significantly by salt and osmotic stress. *AtRZFP* positively mediates tolerance to salt and osmotic stress. Additionally, compared with wild-type *Arabidopsis* plants, plants overexpressing *AtRZFP* showed reduced reactive oxygen species (ROSs) accumulation, enhanced superoxide dismutase and peroxidase activity, increased soluble sugars and proline contents, reduced K^+ loss, decreased Na^+ accumulation, stomatal aperture and the water loss rate. Conversely, *AtRZFP* knockout plants displayed the opposite physiological changes when exposed to salt or osmotic stress conditions. These data suggested that *AtRZFP* enhances salt and osmotic tolerance through a series of physiological processes, including enhanced ROSs scavenging, maintaining Na^+ and K^+ homeostasis, controlling the stomatal aperture to reduce the water loss rate, and accumulating soluble sugars and proline to adjust the osmotic potential.

Comparison of Langmuir and Freundlich Adsorption Equations within the SWAT-K Model for Assessing Potassium Environmental Losses at Basin Scale

Chunying Wang, Laurie Boithias, Zigong Ning, Yuping Han, Sabine Sauvage, José-Miguel Sánchez-Pérez, Kanta Kuramochi, and Ryusuke Hatano. 11 August 2016. Agricultural Water Management. http://dx.doi.org/10.1016/j.agwat.2016.08.001.

Abstract: Potassium (K) is an important nutrient for agricultural crop growth. Adsorption of K in soil involves fertilizer optima for enhancing crop productivity and efficient nutrient management. Adsorption is often necessary to predict K transport and losses, such as solid/liquid distribution in soil, plant uptake, and transportation with water and suspended sediments. Based on the Soil and Water Assessment Tool (SWAT), the SWAT-K model has been developed to quantify daily K losses and budget at watershed scale. In this study, Langmuir and Freundlich adsorption equations were both applied and compared in the SWAT-K model to predict K adsorption in the soil and K losses in the volcanic Shibetsu River Watershed (672 km^2, Hokkaido, Japan). Both the Langmuir and Freundlich adsorption equations well fitted the solid/liquid distribution of K in soil. The Freundlich and Langmuir equations showed similar performances to fit the measured data of K sorbed to soil ($R^2 = 0.91$ for both cases) and Freundlich equation showed slightly better performances of dissolved K load in stream than Langmuir equation (Nash-Sutcliffe efficiency coefficient (E_{NS}) = 0.66 and 0.60, respectively). Overall, Langmuir and Freundlich equations predicted similar K budgets, including soil K surplus with a difference of 1.2%. The uncertainty related to the choice of the adsorption equation is negligible. Hence, both Langmuir and Freundlich adsorption equations are recommended to predict the K adsorption in soil and in-stream K load when using the SWAT-K model in watershed similar to the study case.

Their applicability deserve to be tested in other agricultural watersheds characterized by different soils.

Crop Yield, and Nutrients in the Soil Profile after 20 Years of No-Till and Conventional Tillage

Chervet, A., L. Ramseier, W.G. Sturny, M. Zuber, M. Stettler, P. Weisskopf, U. Zihlmann, I. Martinez, and T. Keller. 2016. Recherche Agronomique Suisse 7(5):216-223.

Abstract: No-till and conventional plough tillage have been compared since 1994 in the Oberacker longterm field experiment at Inforama Ruetti in Zollikofen (Switzerland) on a slightly humic sandy loam soil. Crops were grown in a six-year crop rotation (peas, winter wheat, field beans, winter barley, sugarbeets and silage maize) in a strip trial with six adjoining plots. Twenty years into the trial, soil nutrient status was investigated and crop yields were statistically analysed. Soil was sampled layer-by-layer down to a depth of 50 cm, and analysed for soil organic carbon (Corg), total nitrogen content (Ntot), phosphorus (P), calcium (Ca), potassium (K) and magnesium (Mg) content, as well as pH and bulk density. Unlike in the conventional tillage system, Corg, Ntot, K and Mg were concentrated in the surface layer in the no-till system; in addition, the pH was lower and P and Ca had slight concentration maxima at around 20 cm depth. Although the distribution of Corg and nutrients differed significantly between no-till and conventional tillage, stocks of Corg and of all investigated nutrients were similar in both systems. The relative yield averaged over 20 years was 2.6% higher in no-till than in conventional tillage, but the difference was not significant. Winter cereals and legumes had significantly higher yields in the no-till system than in conventionally tilled soils. We conjecture that one of the reasons for the higher crop yields in no-till in the Oberacker long-term field experiment (since 2000 without potatoes) was the well-balanced crop rotation, including cover crops.

Effects of Different Leaf-Fruit Ratios on Uptake and Partitioning of N and K in 'Uenishiwase' Persimmon Trees

Seong-Tae Choi, Seong-Cheol Kim, Gwang-Hwan Ahn, Doo-Sang Park, and Eun-Seok Kim. 2016. Scientia Horticulturae 212:69-73. http://dx.doi.org/10.1016/j.scienta.2016.09.025.

Abstract: To supply appropriate amount of nutrients to persimmon trees with high crop load is critically important for the stable production year after year. This study was conducted to determine absorption and partitioning of nitrogen (N) and potassium (K) in 13-year-old 'Uenishiwase' persimmon trees with different crop loads. The leaf-fruit (L/F) ratio was adjusted to 20 (high) and 10 (low) by fruit thinning on July 2 after the June drop. The trees were harvested in early spring and late autumn, and increases of dry weight (DW) and N and K in different tree parts during the growing season were calculated. As the L/F ratio decreased from 20 to 10, total fruit DW increased from 4.3 to 7.6 kg per tree. Of the total DW increase in a season, fruit accounted for 14% in a high and 24% in a low L/F tree. DW in older than 1-year-old woods accounted for 44% in a high and 41% in a low L/F tree. Different L/F ratios did not significantly affect the increase of tree total DW. Upon decreasing the L/F ratio, the amount of fruit N increased by 1.7-fold where N partitioning to fruit increased from 10% to 17% of the tree total, whereas fruit K increased by 2-fold, increasing its partitioning from 25% to 44%. It was noted that N and K increases were lower in aerial woods of the low L/F trees. Total N per tree increased by about 170 g in both the high and low L/F trees, but the total K increases were 175 g and 202 g in a high and low L/F tree, respectively. The results suggested that a fertilization program for high crop-load trees should take two points into consideration, namely, the magnitude of nutrients removed from the tree by fruit harvest and the reduced nutrients in woody organs essential for tree development the next season.

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