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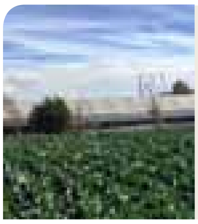

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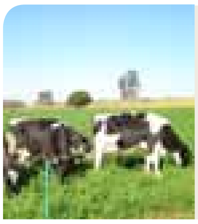

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Dear readers,

Recently, it seems everybody is talking about climate change, global warming and the impact of modern agriculture. Greenhouse gases (GHGs) from human activities are the most significant driver of observed climate change since the mid-20th century, and agriculture is responsible for 24% of all GHG emissions. In addition to being a significant user of land and consumer of fossil fuel, agriculture contributes directly to GHG emissions through practices such as rice production and the raising of livestock. But, as Bill Gates emphasized recently (www.gatesnotes.com/Energy/We-should-discuss-soil-as-much-as-coal), "We can't simply stop growing crops, using fertilizer, and raising livestock…at the end of the day, people need to eat."

Appropriate fertilizer use is essential in the fight against climate change. Fertilizers reduce pressure on forests and help avoid land use changes by increasing productivity of available arable land. This is crucial for climate change mitigation, as deforestation and land-use conversion combined represent about 30-50% of agricultural emissions.

One vivid example is the 'Fertilizers for Forest' mitigation initiative in West Africa to improve food security, protect biodiversity and reduce emissions from deforestation. The Guinean Rainforest, a global biodiversity hotspot, had been reduced to 18% of its original area. The principal driver of this environmental change has been the expansion of low-input, smallholder agriculture that depends on environmentally destructive practices like slash-and-burn and land clearing. Researchers at the International Institute of Tropical Agriculture (IITA) found that increasing fertilizer use on cocoa farms would have spared roughly 2 million hectares of tropical forest from being cleared, or becoming severely degraded, preventing 1.3 billion metric tonnes of CO_2 emissions from deforestation.

In this *e-ifc* edition, we present results from South India on the optimization of NPK supply for increased rice productivity. The second paper from Turkey shows that application of K, S, Ca and Mg significantly enhances cabbage yield and quality. And the third paper comes from Brazil and explains how spatial analyses of soil properties and yield are management tools for grazed alfalfa pasture.

We also report on IPI participation at the Second Global Session of the UN Science-Policy-Business Forum on the Environment, which was held in Nairobi, Kenya in March 2019. We are very pleased to announce the 13th IPI-CAU-ISSAS International Symposium on potash and polyhalite that will take place in Kunming, China in November 2019. Finally, we invite you to visit the newly renovated IPI website site, which is simpler to navigate, especially on your phone or tablet.

I wish you an enjoyable read.

Dr. Patricia Imas
IPI Scientific and Communications Coordinator

Photo cover page: Photo by IPI.

Research Findings

Photo 1. Rice experiment plots at Annamalai University experiment farm, Chidambaram, India. Photo by P.K. Karthikeyan.

Influence of Potassium Application Management on Rice Production in Coastal Regions of South India

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Abstract

Rice (*Oryza sativa*) production is pivotal to the economy and food security in India; the country is second only to China in annual production. Nevertheless, and in spite of a significant increase during recent decades, yields lag behind potential rice productivity. Accurate and sophisticated mineral nutrition is a promising approach to enhance rice yield. The objectives of the present study are to examine and demonstrate the effects of potassium (K) dose, the number and timing of MOP (muriate of potash, KCl) application during the crop cycle, and the contribution of foliar SOP (sulphate of potash, K_2SO_4) at the reproductive stage on crop performance and productivity. The experiment took place at Chidambaram, Tamil Nadu, between June and September (Kuruvai), and included nine treatments: unfertilized control; standard nitrogen (N) and phosphorus (P) at 100 and 50 kg ha^{-1} of N and P_2O_5, respectively; standard NP + 25 kg K_2O ha^{-1} (soil-applied MOP, split into two applications) + two sprays of SOP at 1%, or 2%; standard NP + 37.5 kg K_2O ha^{-1} (soil-

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applied MOP, split into two applications) + two sprays of SOP at 1%, or 2%; standard NP + 50 kg K_2O ha^{-1} (soil-applied MOP, split into four applications); and, standard NP + 50 kg K_2O ha^{-1} (soil-applied MOP, split into three applications) + a single SOP spray at 1%, or 2%. Grain yields gradually increased from 2.37 Mg ha^{-1} under unfertilized control to 3.7 Mg ha^{-1} under the 50% K rate, and further to 5.5 Mg ha^{-1} under the highest K dose + SOP. Foliar SOP applications during early reproductive stages (panicle initiation and heading) had a significant effect on yield, with stepwise yield increments of 5-14%, on average. Based on these results, it is postulated that further optimization of NPK supply, including split N and K doses and foliar applications, adjusted as required during crop development, would lead to increased rice productivity.

Keywords: Foliar spray; harvest index; MOP; *Oryza sativa*; SOP; split application.

Introduction

Rice (*Oryza sativa*) is the staple food of more than 60% of world's population. Rice production is pivotal to Indian agriculture, as it occupies about 44 million ha (FAOSTAT, 2017) and accounts for about 40% of total food grain production in the country (India today web desk, 2018). Second only to China, and with 168.5 million tonnes, India contributed 21.8% of global rice production in 2017 (FAOSTAT, 2017). In years 2015-2016, with about 8 million tonnes a year, Tamil Nadu was the fourth rice producing state in India (India Today web desk, 2018).

Average rice yields in India increased significantly from about 1.5 Mg ha^{-1} in the 1960's to above 3.5 Mg ha^{-1} in the last decade (FAOSTAT, 2017). Undoubtedly, the achievement of raising the yield in recent decades can be largely associated with the higher potential of improved rice varieties (Khush, 1995; Yoshida and Nagato, 2011; Crowell *et al.*, 2016). Enhanced irrigation technologies and plant protection practices have also made a significant contribution to the rise in rice productivity (Krauss, 2001). Nevertheless, the most marked yield fluctuations, as well as well-recognized yield responses, emerge from nutrient application practices that must be carefully managed in order to realize the full yield potentials of rice (Kiuchi and Ishizaka, 1961; Bhowmick and Nayak, 2000; Dobermann and Fairhurst, 2000; Wang *et al.*, 2011).

Historically, the use of nitrogen (N) and phosphorus (P) fertilizers was disseminated successfully and became widespread among farmers (Kaushik *et al.*, 2012). However, increasing doses of N and P fertilizers, especially in the context of high-yielding cultivars, seem to have reached a saturation level, which indicates the occurrence of a new limiting factor - crop potassium (K) requirements (Mengel and Kirkby, 1987; Marschner, 1995; Dobermann *et al.*, 1996; Mae, 1997; Krauss, 2001; Wang *et al.*, 2011).

Potassium is vital to photosynthesis and in carbohydrate translocation and storage in the plant (Zörb *et al.*, 2014). Furthermore, K is deeply involved in the governance of plant water status, stomatal aperture, and osmotic regulation (Marschner, 1995; Cakmak, 2005; Zörb *et al.*, 2014). Soil type and properties play a major role in determining nutrient availability for crops. Among the three major nutrients, K availability is greatly affected by the soil characteristics, especially under marginal K status (Dobermann *et al.*, 1996; Zörb *et al.*, 2014). Rice is particularly responsive to K nutrition (De Datta and Mikkelsen, 1985; Dobermann *et al.*, 1998; Surendran, 2000; Liu and Yang, 2001; Yang *et al.*, 2004; Fageria, 2015; Xue *et al.*, 2016). However, the synchronization of K availability and the varying K requirements during crop development is essential to realizing yield potential (Dobermann *et al.*, 1998; Surendran, 2000; Liu *et al.*, 2001; Yang *et al.*, 2004; Mansour *et al.*, 2008; Xue *et al.*, 2016; Zain and Ismail, 2016).

MOP (muriate of potash, known also as potassium chloride, KCl) is the most common K fertilizer. It is highly soluble and is immediately accessible to plant roots in the soil soluble phase. Nevertheless, as such, K^+ ions might be rapidly fixated to soil particles in certain soil types but, furthermore, they might be leached away from the rhizosphere under excess water supply (Zörb *et al.*, 2014). SOP (sulphate of potash, K_2SO_4), providing Cl-free K with the advantage of sulfur (S) supplement, is a suitable alternative to MOP. Nevertheless, under soil-applied SOP, the fate of K^+ ions is similar to that under MOP (Ali *et al.*, 2005). Foliar nutrient applications, in this case SOP, were shown to partially replace soil application (Surendran, 2000; Ali *et al.*, 2007). Therefore, aiming to enhance the accuracy of K application and fit it to crop requirements during its course of development, the combination of split soil applications with supplement foliar sprays seems promising.

The objectives of the present study are to examine and demonstrate the effects of K dose, the number and timing of MOP application during the crop cycle, and the contribution of foliar SOP at the reproductive stage on crop performance and productivity.

Materials and methods

A field experiment was carried out on field A-8 of the wetland block at Annamalai University experimental farm, Chidambaram. The experimental farm is geographically located at 11°24'N latitude and 79°41'E longitude, 6 km away from Bay of Bengal, at an altitude of 5.79 m above mean sea level (Map 1).

The soil of the experimental field was deep, moderately drained, clay in texture with pH 8.3. The soil was low in available N (239 kg ha^{-1}), medium in available P (15.0 kg ha^{-1}), medium in available K (240 kg ha^{-1}), and high in available S (15.6 mg kg^{-1}). Soil samples were taken and analyzed for various physico-chemical properties before planting (Table 1).

The field experiment was carried out during 110 days of the Kuruvai season (June-September), when precipitation rates increase but before the heavy monsoon rains begin, and while temperatures gradually decrease from the summer peak (Fig. 1).

The locally common short duration rice variety ADT-43 was planted at a spacing of 12.5 x 15 cm. The recommended fertilizer dose of 100, 50, and 50 kg ha^{-1} of N, P_2O_5, and K_2O, respectively, is referred to as the standard (100%). Half of the N dose was applied basally in the form of urea (46% N) and the remaining 50% was split into two equal amounts and top-dressed at tillering and panicle initiation stages. Phosphorus was applied basally in the form of superphosphate (SSP, 16% P_2O_5). Potassium was applied according to the designated treatments (Table 2) in the form of MOP to the soil, and SOP as foliar spray. The experiment included nine treatments, with the first two serving as controls: an absolute control (no fertilizer), and standard NP dose with no K fertilizer. In the other seven treatments, K dose was gradually increased from 50 to 100% and included different combinations of split K dose and foliar applications at different crop development stages. A detailed description of treatments is provided in Table 2. The experiment was laid out in a randomized block design (RBD) with three replications. Individual plot size was 5 x 8 m.

Map. 1. The experiment site at Chidambaram, Tamil Nadu, India (A), on the south-east coast (B), near the Kollidam river delta (C). *Source:* Google Earth.

Table 1. Soil properties at the experiment field, determined before planting.

Soil property	Value
Clay (%)	43.4
Silt (%)	15.8
Coarse sand (%)	15.3
Fine sand (%)	25.1
Soil textural class	Clayish
pH soil reaction	8.3
EC (dSm^{-1})	0.56
Organic carbon (g kg^{-1})	0.63
Available N ($KMnO_4$-N; kg ha^{-1})	239 (low)
Available P (Olsen's; kg ha^{-1})	15.0 (medium)
Available K (NH_4O-Ac; kg ha^{-1})	180 (medium)

Five representative samples from each plot were tagged randomly for the determination of crop developmental stages - tillering, panicle initiation, bloom, and harvest. The experimental crop was harvested plot-wise by cutting the stem closer to ground level. Grains were separated by hand threshing, winnowed, cleaned, and sun dried to bring the moisture content to the standard level (14%). The straw was sun dried. The grain and straw yields were determined separately and the harvest index calculated as the ratio between grain yield and the total aboveground dry biomass.

Results

Dry aboveground biomass

With the limits of measuring root biomass, the dry aboveground biomass is a principal indicator of environmental effects on primary production - photosynthesis and growth. The increasing contribution of fertilizer applications, as treatments climb from null through NP, and further to NPK with gradually intensified modes of K application, was obvious (Fig. 2). Almost each step of introducing more nutrients or of increased nutrient availability brought about a significant rise in dry matter (DM)

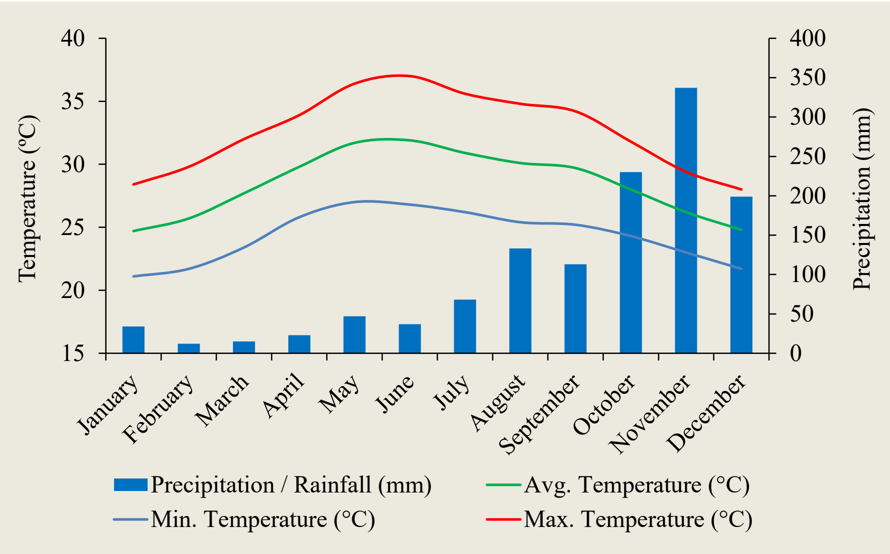

Fig. 1. Mean monthly temperatures and precipitation at Chidambaram, Tamil Nadu, India. *Source:* https://en.climate-data.org/asia/india/tamil-nadu/chidambaram-52335/#climate-graph.

production. The lowest DM yield, 6.3 Mg ha^{-1}, was obtained at the absolute control treatment, where no nutrients had been applied. Supplying NP alone increased the DM production by 25%, and the addition of a half dose K contributed about 17-25% more DM yield. Increasing K application to 75%, and further to the full-recommended dose of 50 kg K_2O ha^{-1} added about 15% DM rise each, resulting in 11.3 Mg ha^{-1}, which was about 80% more than at the absolute control. The role of the foliar SOP application during the later stages of crop development was remarkable. At the low and medium K rates (50 and 75%), increasing SOP concentration from 1 to 2% gave rise to significant growth of 7 and 10%, respectively, in the DM yield (Fig. 2). Furthermore, at the highest K rate (standard, 100%), a single foliar SOP application at 1% increased DM production by 11.4% above the standard, 4-split soil-applied MOP, while 2% SOP resulted in no further difference (Fig. 2). Finally, the standard NPK treatment, with 3-split soil-applied MOP, and a single foliar application at 1% SOP obtained the highest DM yield - 12 Mg ha^{-1}, 100% more than at the absolute control (Fig. 2).

Grain and straw yields

The pattern of the effects of fertilizer treatments on the grain yield was similar to that shown for the DM production but significantly greater (Fig. 3A). While the control grain yield was the lowest, 2.37 Mg ha^{-1}, the highest grain yield was obtained by the NP+K_{100}+1%SOP treatment, 5.45 Mg ha^{-1}, which was 130% greater. Also, in the case of grain yield, each step towards a higher rate or improved nutrient availability resulted in a significant yield increase; however, the rate of this increase was, on average, about 16.6% per each step, much higher than the corresponding rate of DM increase, 12.5%. Similar to DM production, the foliar SOP applications during the late stages of crop development had a significant effect on grain yield, as indicated by the upsurge of 11-13% whenever SOP concentration was raised from 1 to 2%. Another indication can be found in the increase from 75 to 100% K, where grain yield increase was substantially pronounced as a result of 1% SOP application, rather than following a 4-split soil-applied MOP (Fig. 3A). On the other hand, increased SOP concentration to 2% made no further contribution to the grain yield.

In contrast to grain yield, straw production response to the fertilizer treatments was significantly smaller (Fig. 3B). It increased from 3.64 Mg ha^{-1} at the control, to 4.7 Mg ha^{-1} (29%) in response to NP application, and rose further by an additional 15% when applied with the half K dose. However, the straw biomass remained quite constant at 5.4-5.8 Mg ha^{-1} under increasing K supply. The next significant rise in straw yield was obtained under the full K dose, with added foliar application of 1% SOP (Fig. 3B).

The response of the harvest index (HI) to the fertilizer treatments was particularly interesting, as it indicates the influence of the various nutrients and the timing or mode of application on the dry biomass allocation between vegetative

Table 2. A detailed description of the fertilizer treatments. The N dose, 100 kg ha^{-1}, was split to basal (50%) and two equal applications at tillering and panicle initiation. P_2O_5 was applied basally. The standard K dose (100%) was 50 kg K_2O ha^{-1}. MOP dose was evenly split among applications.

Treatment code	NP (%)	K (%)	Timing of MOP applications				Concentration and timing of SOP foliar applications	
			Basal	Tillering	Panicle initiation	Heading	Panicle initiation	Heading
Control	-	-	-	-	-	-	-	-
NP+K$_0$	100	0	-	-	-	-	-	-
NP+K50%+1%SOP	100	50	+	+	-	-	1%	1%
NP+K50%+2%SOP	100	50	+	+	-	-	2%	2%
NP+K75%+1%SOP	100	75	+	+	-	-	1%	1%
NP+K75%+2%SOP	100	75	+	+	-	-	2%	2%
NP+K100	100	100	+	+	+	+	-	-
NP+K100%+1%SOP	100	100	+	+	+	-	-	1%
NP+K100%+2%SOP	100	100	+	+	+	-	-	2%

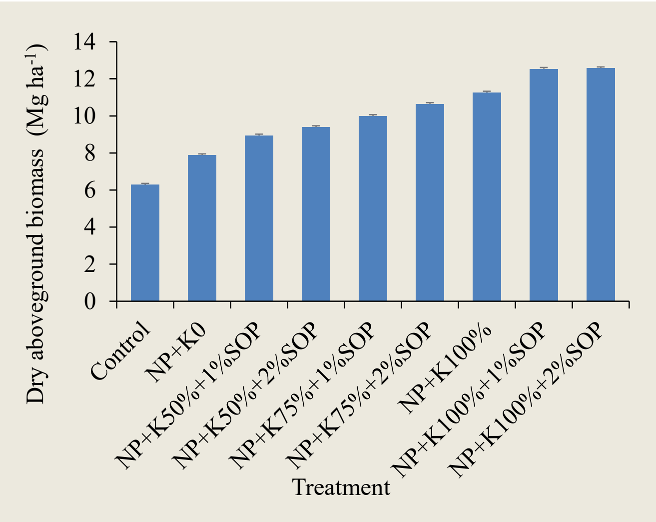

Fig. 2. Effects of fertilizer treatments on the dry aboveground biomass of rice grown at Chidambaram, Tamil Nadu, India. Detailed description of treatments is given in Table 2. Bars indicate $LSD_{0.05}$.

and reproductive growth (Fig. 3C). Nitrogen and P application slightly decreased HI from 0.377 to 0.364, at the control and NP treatments, respectively. Potassium application at half dose significantly shifted dry matter to the reproductive organs only when supported by foliar applications of 2% SOP. HI response to increasing K rates continued up to the K75% +2% SOP treatment, where it reached 0.44. However, HI did not respond to any further increase in K rate or availability (Fig. 3C).

Figure 4 illustrates the influence of the different fertilizer treatments on the development of the reproductive organs and, consequently, on the yield parameters. Unequivocally, the fertilizers had a direct effect on the number of grains per panicle (Fig. 4A), which grew gradually with each step towards a higher nutrient availability. The most significant effect, a 27% increase, was observed from unfertilized control to the NP treatment, whereas the relative effect of the increasing K rate or availability decreased each step but remained positive. The only case where grain number did not respond was when the SOP concentration was increased from 1 to 2% at the full dose K rate treatment (Fig. 4A).

While panicle length responded in a pattern similar to that of the number of grains (Fig. 4B), the influence of the fertilizer treatments on grain weight was much less consistent (Fig. 4C). The latter increased significantly in response to NP application, but the soil-supplemented K at its lower rate, including foliar SOP, did have any effect on grain weight. Nevertheless, raising the K rate to 75% of the standard dose, including foliar SOP applications, increased grain weight by about 7%, from 13.8 to 14.8 g $1{,}000^{-1}$. Interestingly, when the full standard K dose was soil-applied in the form of MOP, grain weight significantly

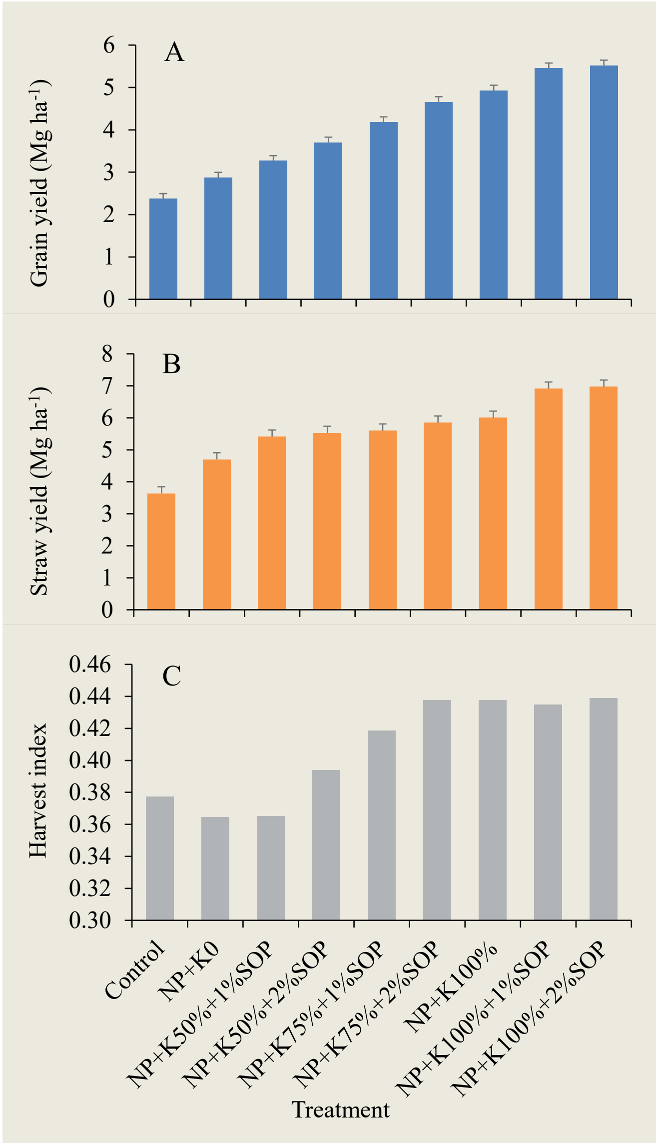

Fig. 3. Effects of fertilizer treatments on the grain (A) and the straw yields (B), and on the harvest index (C) of rice grown at Chidambaram, Tamil Nadu, India. Detailed description of treatments is given in Table 2. Bars indicate $LSD_{0.05}$.

declined by 5%, compared to the former reduced K level. However, when the standard K dose was applied in combination with a single foliar SOP spray (1% or 2%), grain weight surged by 5%, from 14.9 to 15.7 g $1{,}000^{-1}$.

Discussion

Rice production is pivotal to human nutrition as well as to the economy of India in general, and particularly Tamil Nadu. Therefore, effective means to enhance rice crop performance, yield, and quality are extensively sought. The present study successfully demonstrates how basic principles of crop nutrition, when wisely practiced, can become a useful tool to maximize rice yields.

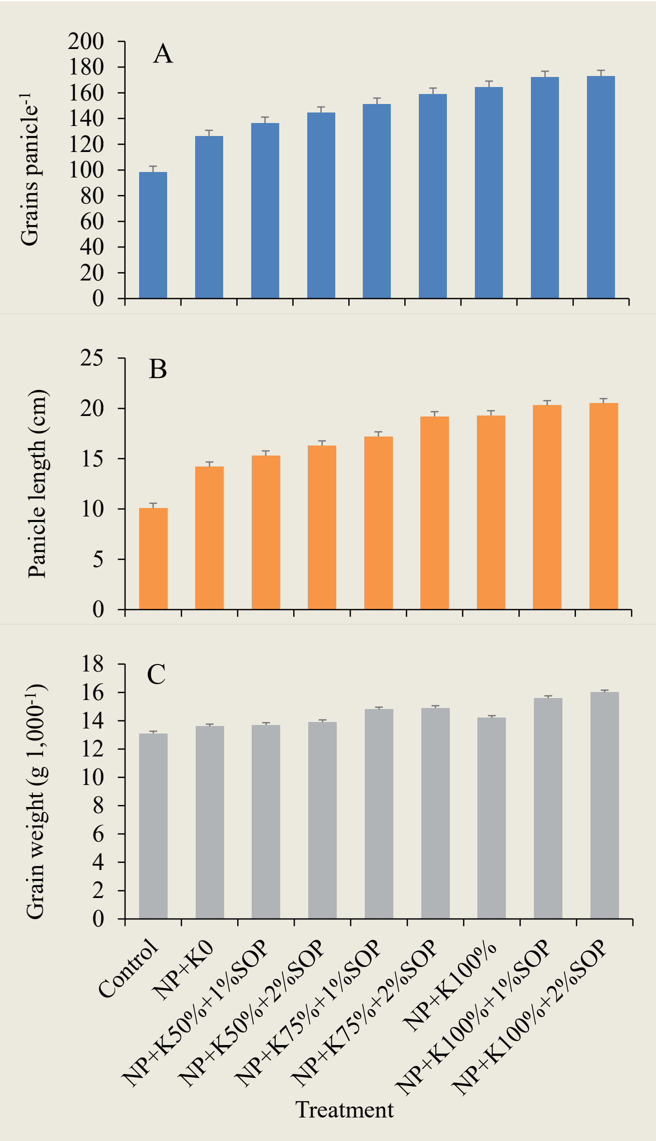

Fig. 4. Effects of fertilizer treatments on the number of grains per panicle (A), panicle length (B), and on grain weight (C) of rice grown at Chidambaram, Tamil Nadu, India. Detailed description of treatments is given in Table 2. Bars indicate $LSD_{0.05}$.

As expected, when no fertilizers are applied, rice biomass and grain yields are extremely low (Figs. 2 and 3). As most farmers already know and practice, applying N and P significantly increase yields; in the present study, this fundamental nutrition practice gave rise to 25, 20, and 30% more biomass, grains, and straw, respectively (Fig. 5). When applied in the form of urea, which is a relatively short-term fertilizer under warm and humid conditions (Rawluk *et al.*, 2001), N dose should be split during the crop cycle and applied at the most relevant stages of development (Mae, 1997; Krauss, 2001). Phosphate fertilizers are usually much more stable, and hence a single basal application would be appropriate (Dobermann *et al.*, 1998).

Potassium, in spite of its fundamental roles in plant physiology and its tremendous potential to enhance the performance and yield of numerous crop species (Marschner, 1995; Cakmak, 2005; Zörb *et al.*, 2014), including rice (De Datta and Mikkelsen, 1985; Fageria, 2015; Zain and Ismail, 2016), is still ignored by most farmers (Kaushik *et al.*, 2012). Applying half of the recommended K dose, with two additional foliar sprays of SOP (1%), was sufficient to raise rice dry biomass, grains, and straw by 14-15% (Fig. 5). These results suggest that at basic levels, K is required, in concert with N and P, for the buildup of plant vegetative biomass thus determining its potential productivity. The yield obtained by this fertilization practice (recommended N and P doses + 50%K+1%SOP) is close to the average rice yield level in India in 2017, 3.85 Mg ha^{-1} (FAOSTAT, 2017), providing some indication with regards to rice nutrient status in the country.

Nonetheless, stepwise increases of K dose or K availability clearly demonstrated the significance of K role in the reproductive phase and the consequent determination of the grain yield. Thus, on a similar background of 50% K dose but with doubled SOP concentration at the two foliar applications, grain yield increased further by 13.3%, with much lower contribution to the straw yield (Fig. 5). Similar patterns of relative increase in grain and straw yields were observed when the soil-applied K dose was raised to 75% with 1% SOP sprays, and again, when SOP concentration was doubled. The shift from the vegetative to the reproductive phase prior to panicle initiation brings about significant changes in plant nutrition. Before that shift, soil-applied nutrients dominate plant mineral uptake and balance, with root function playing a key role in the process. Sufficient K supply positively affects root development and subsequently enhances shoot growth and overall plant biomass (Cai *et al.*, 2012; Zhao *et al.*, 2016). After the shift, all plant resources are conveyed to construct and secure the next generation - the grains. Stored carbohydrates and nutrients are remobilized and translocated to the reproductive organs (Araki, 2001). Potassium has key functions in remobilizing carbohydrates (Yang *et al.*, 2004; Xue *et al.*, 2016; Zain *et al.*, 2016). While root growth and mineral uptake decline during the reproductive phase (Poethig, 2010), the internal K status of the plant might often be a serious limiting factor. Foliar applications at this stage appear to be very useful in such cases, as shown clearly in the present study. Under lower levels of soil-K availability, foliar SOP applications brought about significant increases in the aboveground dry biomass (Fig. 2), especially through a substantial rise in the grain yield, which is strongly reflected in the dramatic change in the harvest index (Fig. 3). It appears that the main effect of SOP sprays at panicle initiation and heading was at a very early and sensitive stage - grain set - as they influenced grain number and panicle length, rather than grain weight (Fig. 4).

Another example of the significance of foliar K applications at late developmental stages was found in crop response when the full K dose had been administered through soil MOP applications. Under no SOP application (NP+K100%), crop performance improved very slightly compared to the former treatment (NP+K75%+2%SOP), while grain weight even declined (Fig. 4C). The upsurge in most parameters in response to a single foliar SOP application at heading (Fig. 5) suggests that the additional K absorbed through the canopy promoted supplementary resource recruiting from the roots to the shoots. Alternatively, it could have expanded the carbon assimilation period. Altogether, the surplus K in the leaves generated significant growth, which was allocated equally to grains and straw.

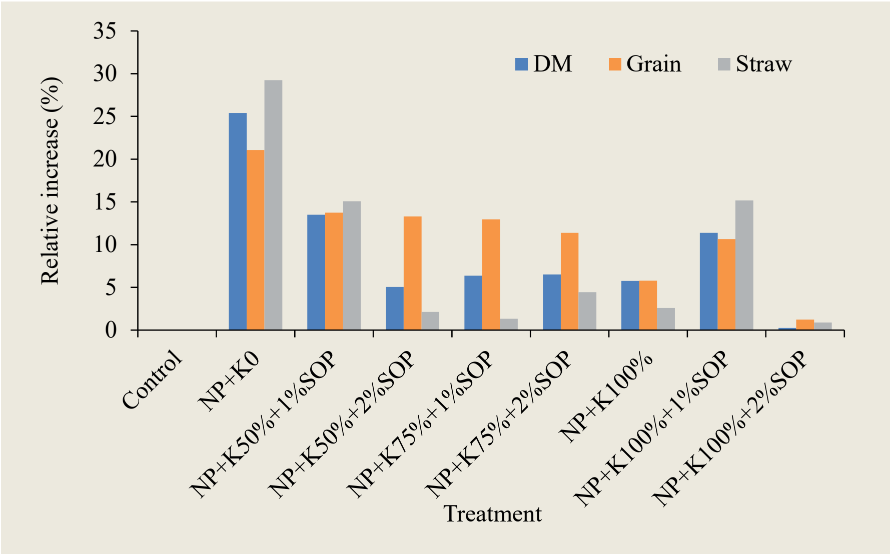

Fig. 5. The response of DM, grain and straw yields to stepwise rises in nutrients dose and availability in rice grown at Chidambaram, Tamil Nadu, India. Values represent the relative increase at each step.

Photo 2. +K and -K in early stages of growth in rice. Photo by P.K. Karthikeyan.

Testing K rates higher than the recommended dose (50 kg K_2O ha^{-1}) was beyond the frame of the present study. It may be assumed, however, that attempts to further increase rice yields under this set of conditions by additional K supply would encounter some limiting factors. Increasing the N and P doses might open new horizons for higher K rates in an attempt to raise rice yields even more. The yield levels obtained in the present study at the highest K rates, about 5.5 Mg ha^{-1} (Fig. 3A), are 50% higher than the current average rice yield in India. However, as indicated by the current average rice yield in USA (about 7.9 Mg ha^{-1}), there is still substantial potential to improve. A solid way to enhance rice crop performance further would be to optimize N, P, and K doses and application practices, including accurate timing and quantities of K applications during the course of crop development.

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The paper "Influence of Potassium Application Management on Rice Production in Coastal Regions of South India" also appears on the IPI website.

Research Findings

Photo 1. Experimental site. Photo by the authors.

Effect of Different Potassium and Sulfate Fertilizer Types on Cabbage Yield and Quality

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Abstract

Cabbage (*Brassica oleracea* var. *capitata* f. *alba*) is one of the most important vegetable crops in Turkey. The transition from traditional to modern agriculture includes revision of mineral nutrition practices. Beyond the common basal nitrogen (N) and phosphorus (P) application, potassium (K), which is usually ignored by Turkish farmers, is required to enhance yield and quality. There is also increasing awareness that sulfur (S) is an essential macronutrient, particularly for Brassicaceae crop species that produce highly appreciated secondary metabolites such as glucosinolates and antioxidants. Muriate of potash (MOP) and sulfate of potash (SOP) are very common fertilizers. Both are donors of soluble K, and the latter also supplies S. Polyhalite is a natural mineral, which occurs in sedimentary marine evaporates, and consists of a hydrated sulfate of K, calcium (Ca) and magnesium (Mg) with the composition of 14% K_2O, 48% SO_3, 6% MgO, and 17% CaO. The objective of this study was to compare the effects of three different K sources - polyhalite, SOP, and MOP - on cabbage

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yield, quality, and nutrient content and uptake. Standard N and P_2O_5 rates of 250 and 100 kg ha^{-1}, respectively, were employed throughout all five treatments included in the experiment. The control treatment was applied with N and P only, while the other four treatments received an equal dose of 300 kg K_2O ha^{-1} in the forms of MOP, SOP, polyhalite, or polyhalite+SOP. While MOP application significantly enhanced cabbage crop performance, the additional S, provided through SOP or polyhalite, obtained much higher yields and better quality. The best treatment was polyhalite+SOP, with a marketable yield of 81 Mg ha^{-1}, 60% higher than the control. While leaf S content and uptake did not differ among SOP, polyhalite, and polyhalite+SOP, polyhalite significantly raised leaf Ca and Mg contents, which may explain its advantage over SOP. Whereas polyhalite application as the sole K source is impractical, a suitable combination of polyhalite with SOP provides a promising solution for Turkish cabbage growers. The optimum rates for the two fertilizers should be determined considering crop requirements, soil nutrient status, and fertilizer cost vs. the expected benefits.

Keywords: Brassica oleracea var. *capitata* f. *alba*; MOP; polyhalite; SOP.

Introduction

Vegetables are very important in Turkish cuisine. In 2017, more than 0.8 million ha were used in Turkey to grow vegetables, with about 30 million tonnes of produce (www.dunyagida.com.tr). Among vegetables, cabbage (*Brassica oleracea* var. *capitata* f. *alba*) has gained special attention due to its culinary, as well as nutritional, significance (Avato and Argentieri, 2015; Šamec *et al.*, 2017; Ware, 2017). Cabbage is consumed in many different ways: raw, pickled, fermented, stewed, steamed, sautéed, braised, and stuffed. Over the last three decades, Brassicaceae crops have been the focus of intense research based on their human health benefits (Stoewsand, 1995; Björkman *et al.*, 2011; Šamec *et al.*, 2017; Ware, 2017). Sulfur (S) -containing secondary metabolites, such as glucosinolates, have been associated with some anti-cancer activities (Higdonm *et al.*, 2007; Cartea and Velasco, 2008; Sarıkamış, 2009) and with a reduced risk for degenerative diseases, cardiovascular diseases and diabetes (Björkman *et al.*, 2011, and references therein). Some S-containing compounds are desired as flavor components in cooked Brassica vegetable products (Schutte and Teranishi, 1974; Engel *et al.*, 2002). Glucosinolates contents largely depend on S availability and significantly varies with S fertilization (Falk *et al.*, 2007).

Sulfur is recognized as the fourth major plant nutrient after nitrogen (N), phosphorus (P) and potassium (K) (Khan *et al.*, 2005), and has been associated with high production goals (Zhao *et al.*, 1999; Hawkesford, 2000; Saito, 2004; Jamal *et al.*, 2010; Kovar and Grant, 2011; Steinfurth *et al.*, 2012). A good response to S application has been reported with respect to Brassica genera crop yields (McGrath and Zhao, 1996; Girondé *et al.*, 2014; Tiwari *et al.*, 2015), and particularly to cole crops (*Brassica oleracea*) (Susila and Locacsio, 2001). Nevertheless, crop responses to S application have been found to vary widely due to differences in location, soil type, various S-containing compounds in the soil and consequent S availability, crop genotype, environmental conditions and crop management (Björkman *et al.*, 2011). Cole crops have a significant S requirement; where the availability of this mineral is limited, crop yield and quality often decline (Haneklaus *et al.*, 2008). Over the last 25 years, due to strict regulations against industrial S emissions, the yearly global S atmospheric deposition has significantly declined (Kovar and Grant, 2011). During the same time, demands for food production have increased with the growing human population. Subsequently, requirements for S fertilizers have risen dramatically to meet annual crop demands.

In the last decade, the cabbage harvested area in Turkey was constant at 26,000 ha. During this period, cabbage production increased by 20% from 0.648 to 0.779 million tonnes, which resulted from an increasing annual average yield from 24.8 to 29.4 Mg ha^{-1} (FAOSTAT, 2017). These data reflect the dichotomy currently characterizing Turkish agriculture; while most farmers still stick to traditional practices (low input - low output), an increasing number have adopted and employ modern technologies, which has resulted in a significant rise in yields (Abukari *et al.*, 2016; Gökalp and Çakmak, 2016). Optimized mineral nutrition is essential to achieve consistently high-yield levels. Traditionally, Turkish cabbage growers apply complex fertilizer (N:P:K at 15:15:15 or 20:20:20) at planting, and ammonium nitrate (AN) or calcium ammonium nitrate (CAN) for later applications (side dressing). Additional K fertilizer is not applied very often due to economic considerations. In cabbage, carbohydrates stored in the cole during the vegetative phase are remobilized to furnish the reproductive phase. Potassium is vital to photosynthesis and to carbohydrate translocation and storage (Marschner, 1995; Zörb *et al.*, 2014). Therefore, an adequate K supply is necessary to guarantee the desired size and quality of cabbage heads.

Soil type and properties play a major role in determining nutrient availability for crops. Among the three major nutrients, K availability is greatly affected by the soil characteristics, especially under marginal K status (Zörb *et al.*, 2014). MOP (muriate of potash, known also as potassium chloride, KCl) is the most common K fertilizer. It is highly soluble and is immediately accessible to plant roots in the soil soluble phase. Nevertheless, as such, K^+ ions might be rapidly fixated to soil particles in certain soil types but, furthermore, they might be leached away from the rhizosphere under excess water supply (Zörb *et al.*, 2014). SOP (sulfate of potash, K_2SO_4), providing Cl-free K with the advantage of S supplement, is a suitable alternative to MOP. Nevertheless, the fate of K^+ ions is similar to that under MOP.

Polysulphate (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, calcium (Ca) and magnesium (Mg) with the formula: $K_2Ca_2Mg(SO_4)_4 \cdot 2(H_2O)$. The deposits found in Yorkshire in the UK typically consist of 14% K_2O, 48% SO_3, 6% MgO, and 17% CaO. In addition to being a natural, multi-nutrient fertilizer, polyhalite is much less soluble. Thus, with significantly slower nutrient release rates, base application of polyhalite at planting provides extended nutrient availability during cabbage crop development. In Turkey, polyhalite use might appear practical and beneficial compared to traditional practices.

The objective of this study was to compare the effects of three different K sources - polyhalite, SOP, and MOP - on cabbage yield, quality, and nutrient content and uptake.

Map. 1. The location of the experiment. Turkey, located at the northeast edge of the Mediterranean basin (above); Antalya region in the south of Turkey. *Sources:* https://c.tadst.com/gfx/citymap/tr-10.png?9; and, https://upload.wikimedia.org/wikipedia/commons/6/61/Antalya_in_Turkey.svg, respectively.

Materials and methods

A field experiment was carried out in the Antalya region of Turkey (Map 1). Soil was sandy loam, calcareous, slightly alkaline, with poor P and K availability (Table 1). The experiment included five different fertilizer treatments: Control (standard N+P); SOP (N+P+K, with 100% K applied in the form of SOP); polyhalite+SOP (N+P+K, with K divided evenly between polyhalite and SOP); polyhalite (N+P+K, with K fully applied through polyhalite); and, MOP (N+P+K, with K fully applied through MOP). All fertilizers were applied pre-planting. Fertilizer doses were 250, 100, and 300 kg ha^{-1} of N, P_2O_5, and K_2O, respectively. A detailed description of nutrient and fertilizer quantities is provided in Table 2. The layout of the experiment was a randomized block design with four replications. Cabbage seedlings (cv. Oren 07) were transplanted at the end of September 2016, and harvested at the end of January (2017). Irrigation was practiced when necessary and all other agricultural practices were carried out on time according to recommendations.

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

Soil properties		
pH (1:2.5)	8.2	Slightly alkaline
$CaCO_3$ (%)	19.9	High
EC micromhos cm^{-1} (25°C)	89	No salinity
Sand (%)	61	
Clay (%)	11	Sandy loam
Silt (%)	28	
Organic matter (%)	2.1	Medium
Available P (mg kg^{-1}) (Olsen)	5	Poor
Available K (mg kg^{-1})	58	Poor
Available Ca (mg kg^{-1})	2,631	Medium
Available Mg (mg kg^{-1})	102	Medium
Available Fe (mg kg^{-1})	7.6	High
Available Mn (mg kg^{-1})	5.8	Sufficient
Available Zn (mg kg^{-1})	0.2	Insufficient
Available Cu (mg kg^{-1})	0.8	Sufficient

Results

Total cabbage yield increased from 65 in the control to 103 Mg ha^{-1} under the combined polyhalite and SOP treatment (Fig. 1). The rate of marketable yield ranged from 70-80% of the total yield and was not influenced by the fertilizer treatments. Potassium application in the form of MOP in addition to the standard NP application tended to raise the marketable and total yields by 10 and 25% above the control, respectively; however, this response was statistically significant only for the total yield. SOP was much more efficient, contributing 28 and 16% marketable yield increases, compared to the control and MOP treatments,

Table 2. Detailed description of the fertilizer treatments according to nutrient supply under fertilizer type and dose.

Treatment	Nutrient						Fertilizer		
	N	P_2O_5	K_2O	CaO	MgO	SO_3	Polyhalite	SOP	MOP
	---kg ha^{-1}								--
Control	250	100	-	-	-	-	-	-	-
SOP (K_2SO_4)	250	100	300	-	-	270	-	600	-
Polyhalite+SOP	250	100	300	182	64	649	1,071	300	-
Polyhalite	250	100	300	364	128	1,028	2,140	-	-
MOP (KCl)	250	100	300	-	-	-	-	-	500

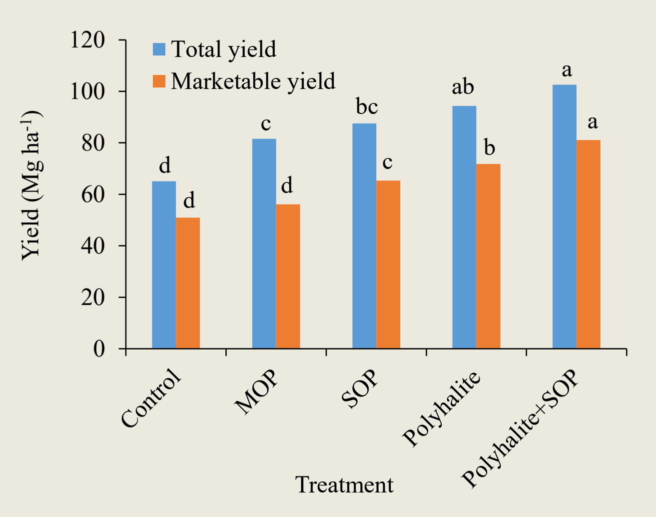

Fig. 1. Effect of fertilizer treatments on the total and marketable cabbage yields. *Note:* Identical letters indicate no significant difference ($p<0.001$) between treatments within each yield category. For further details of the treatments, refer to Table 2.

respectively. When polyhalite alone was the K donor, the marketable yield further increased by an additional 10% compared to MOP, and 40% above the control. The combination of polyhalite and SOP gave rise to the highest marketable yield, 81 Mg ha^{-1}, with significant increases of 13 and 59% more than polyhalite and the control, respectively (Fig. 1).

Corresponding to their effects on yield, fertilizer treatments produced a significant influence on the measures of the cabbage head. Marketable cabbage head weight increased from 2.68 kg under the control to 4.22 kg under the polyhalite+SOP treatment (Fig. 2A).

The content of total soluble solids (TSS) increased significantly in response to K application, with no further difference between the K sources (Fig. 2B). The content of phenolic compounds was significantly higher under S application, with the highest level under the combined polyhalite+SOP treatment (Fig. 2C). Antioxidant activity varied significantly among treatments, with the lowest values obtained under the control and SOP, and the highest under MOP, polyhalite, and polyhalite+SOP (Fig. 2D).

As may have been expected, no differences occurred between treatments in the leaf N and P contents, which were at the optimum range for cabbage according to Maynard and Hochmuth (2007) (Table 3). Potassium content was significantly lower and below the recommended optimum under the control. When K was applied at 300 kg K_2O ha^{-1},

Photos 2 and 3. Cabbage at harvest and at early stage. Photo by the authors.

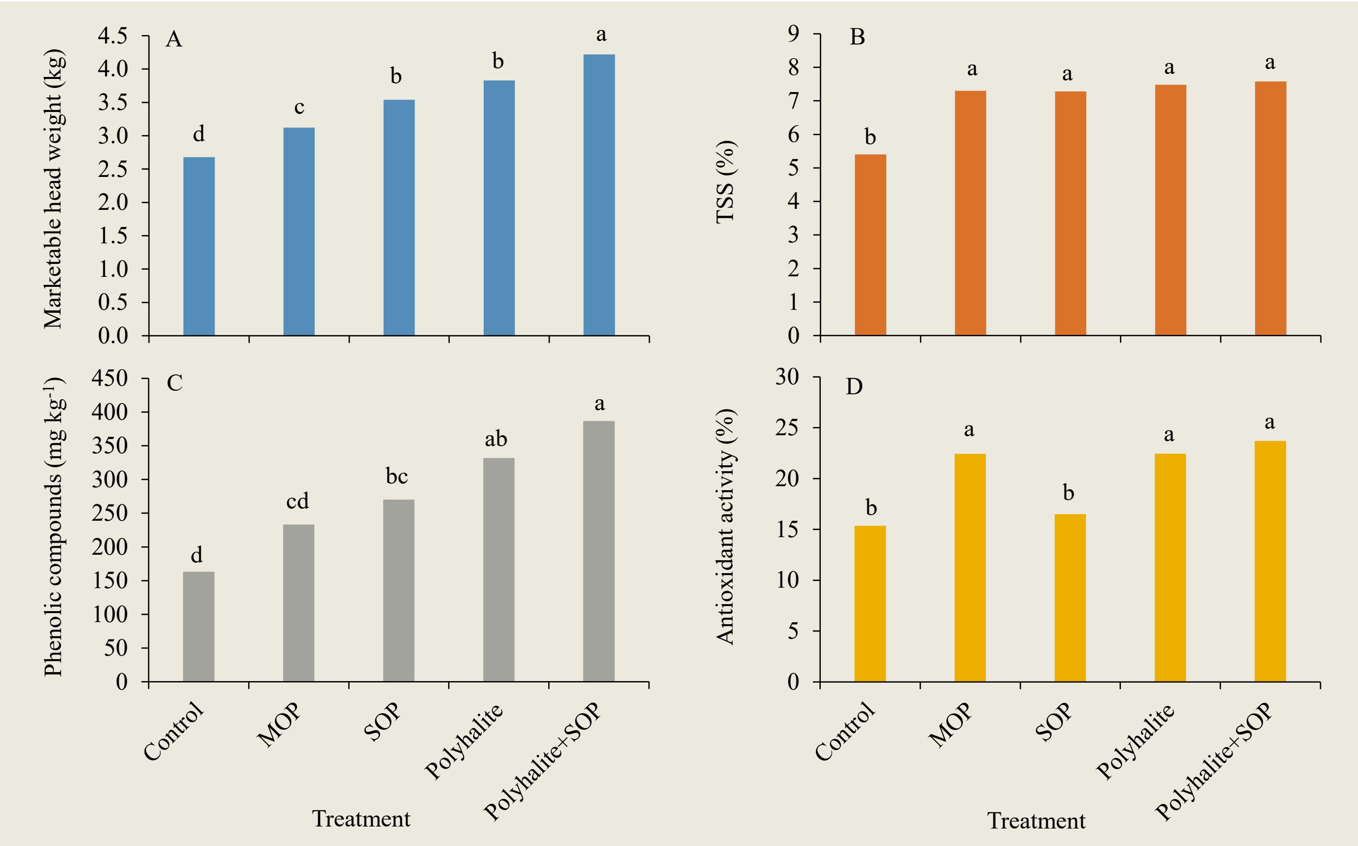

Fig. 2. Effect of fertilizer treatments on cabbage quality parameters. *Note:* Identical letters indicate no significant difference ($p<0.01$) between treatments. For further details of the treatments, refer to Table 2.

leaf K contents ranged from 2.8-3.1%, within the optimum range, and with little differences among the various K sources (Table 3). With no external Ca source, this nutrient was at the minimum edge of the recommended optimum range. Polyhalite application raised Ca leaf content above 2%, slightly beyond the recommended range (Table 3). On the other hand, leaf Mg content, which was also delivered through polyhalite, did not differ among treatments. Leaf S content was much higher than the lower threshold of 0.3% (Maynard and Hochmuth, 2007), but was significantly higher under the S-donor fertilizers (Table 3). No significant differences occurred in leaf S content between SOP, polyhalite+SOP, and polyhalite, in spite of the huge differences in SO_3 doses (Table 2).

Table 3. Macro-element contents of cabbage leaves.

	N	P	K	Ca	Mg	S
			%			
Control	3.58	0.38	1.89c	1.69b	0.27	0.59b
MOP (KCl)	3.50	0.36	2.82b	1.63b	0.25	0.56b
SOP (K_2SO_4)	3.73	0.37	3.10a	1.50b	0.24	0.76a
Polyhalite	3.64	0.36	2.93ab	2.19a	0.28	0.69a
Polyhalite+SOP	3.47	0.35	2.87b	2.01a	0.27	0.73a
	ns	ns	***	***	ns	***
References values[1]	3.0-4.0	0.3-0.5	2.3-4.0	1.5-2.0	0.25-0.45	>0.30

***: $p\geq0.001$; ns: non-significant; [1]Maynard and Hochmuth, 2007.

Micro element application was not included in the different fertilizer treatments. Leaf iron (Fe) content was far beyond the optimum range and differed substantially, although inconsistently, among treatments (Table 4). In contrast, leaf contents of manganese (Mn), zinc (Zn), and copper (Cu) were below or at the lower threshold of the optimum range, and were not affected by the fertilizer treatments.

Nutrient uptake corresponded to crop biomass and nutrient content. Nitrogen uptake responded to K application by a significant increase compared to the control. Furthermore, S application, in addition to K, gave rise to considerably greater N uptake (Fig. 3), which did not necessarily correlate with the various S doses (Table 2). A similar response pattern was observed with P and K uptake (Fig. 3). Naturally, Ca and Mg uptake was

Table 4. Micro-element contents of cabbage leaves.

Treatment	Fe	Mn	Zn	Cu
	--	*mg kg⁻¹*	--	
Control	69.3abc	18.9	21.7	4.83
MOP (KCl)	48.5bc	19.0	20.5	4.32
SOP (K_2SO_4)	81.9a	20.1	22.1	4.75
Polyhalite	43.8c	18.5	21.7	4.35
Polyhalite+SOP	70.3ab	18.9	20.9	4.44
	*	ns	ns	ns
References values[1]	20-40	20-40	20-30	4-8

*: p≥0.05; ns: non-significant; [1]Maynard and Hochmuth, 2007.

the highest under polyhalite application, although smaller increases occurred also under MOP or SOP treatments. Consequently, S uptake was very high in treatments with S-donor fertilizers. Interestingly, uptake rates provided an empiric perception of the differences in SO_3 dose between treatments but with no direct quantitative correlation (Fig. 3).

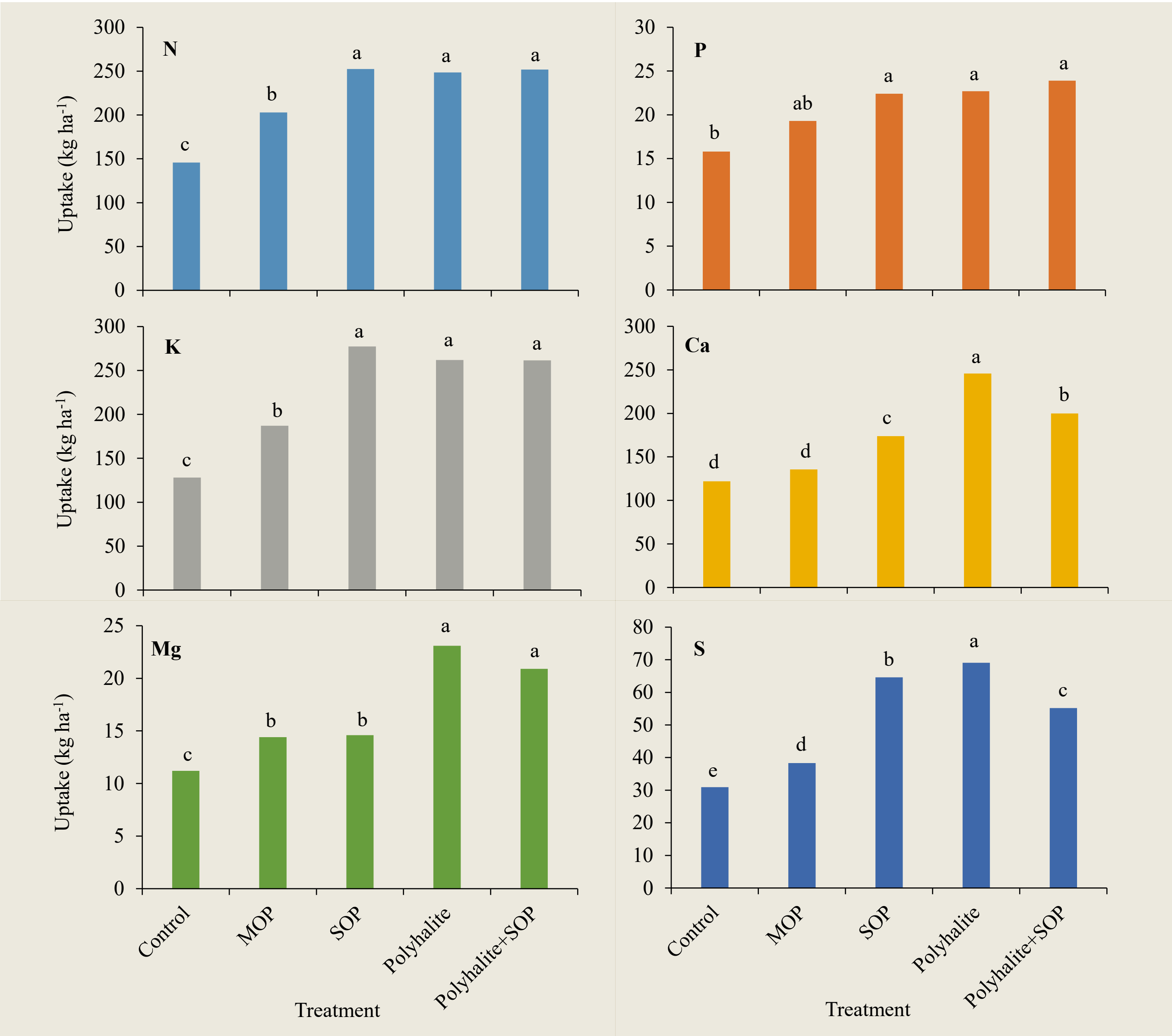

Fig. 3. Effect of fertilizer treatments on cabbage macronutrient uptake. *Note:* Identical letters indicate no significant difference (p<0.01) between treatments. For further details of the treatments, refer to Table 2.

Photo 4. A view of the experimental field. Photo by the authors.

Discussion

Cabbage yield and quality displayed a significant positive response to K application, as was directly indicated by the MOP treatment. Total yield increased by 25% (Fig. 1) due to a larger head weight (Fig. 2A). The contents of TSS and phenolic compounds considerably increased, as well as the rate of antioxidant activity (Fig. 2). Quite often, improved plant K status brings about increases in the content of other nutrients, such as N or P (Marschner, 1995; Jamal *et al.*, 2010). This was not the case in the present study (Table 3); however, the better K status resulted in significant biomass growth, which, in turn, increased the overall uptake of N, and to a lesser extent - P (Fig. 3). The improvement of crop K status was similar also under SOP, polyhalite, and the combined treatment, as indicated by the increased leaf K contents (Table 3). Nevertheless, the direct effects of K contribution in these cases was masked by the additional S influences.

The effect of S alone on cabbage performance was not examined in the present study. Unequivocally, S had a significant additive effect on cabbage yield (Fig. 1). The rate at which cabbage S requirements are fulfilled is difficult to determine, since the differences in S content (Table 3) and S uptake (Fig. 3) between the relevant treatments are relatively much smaller and inconsistent with the dissimilarities in S rates (Table 2). Considering K and S uptake, SOP application alone seemed to meet cabbage requirements for these nutrients. Yet, polyhalite, and moreover polyhalite+SOP, obtained significantly higher yields (Fig. 1) and better produce quality (Fig. 2C and D). Enhanced Ca and Mg uptake, the main donor of which was polyhalite, provides an explanation for the advantage of treatments with polyhalite. Without polyhalite, the leaf contents of these two nutrients were at or below the minimum edge of the optimum range (Maynard and Hochmuth, 2007).

In conclusion, application of K, S, Ca, and Mg significantly enhanced cabbage yield and quality in agreement with some previous studies (Susila and Locascio, 2001; Satisha and Ganeshamurthy, 2016). While SOP contributes only K and S, polyhalite provides significant amounts of Ca and Mg, in addition to K and a substantial rate of S. The advantage of polyhalite obtaining significantly higher yields is obvious. Nevertheless, since K_2O content in polyhalite is low (14%) compared to MOP and SOP, a large quantity of this fertilizer would be required to provide sufficient crop K requirement, whereas the accompanying SO_3 rates would be far beyond crop needs. Therefore, applying polyhalite alone as the K, S, Ca, and Mg fertilizer seems impractical. On the other hand, a suitable combination of polyhalite with SOP (or with MOP, a combination that was not tested in the present study) appears much more practical for Turkish cabbage growers. The optimum rates of the two fertilizers was not determined here, and should therefore be determined in future experiments, considering crop requirements, soil nutrient status, and fertilizer cost vs. the expected benefits.

Acknowledgement

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Research Findings

Photo by A.C.C. Bernardi.

Spatial Variability of Soil Properties and Yield of a Grazed Alfalfa Pasture in Brazil

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Abstract

Knowledge of the spatial variability of soil properties and of forage yield is needed for informed use of soil inputs such as variable rate technology (VRT) for lime and fertilizers. The objective of this research was to map and evaluate the spatial variability of soil properties, yield, lime and fertilizer needs and economic return of an alfalfa pasture. The study was conducted in a 5.3 ha irrigated alfalfa pasture in Sao Carlos, SP, Brazil that was directly grazed and intensively managed in a 270-paddock rotational system. Alfalfa shoot dry matter yield was evaluated before grazing. Soil samples were collected at 0-0.2 m depth, and each sample represented a group of 2 or 3 paddocks. Apparent soil electrical conductivity (ECa) was measured with a contact sensor. The cost of producing 1 ha of alfalfa was estimated from the amount of lime and fertilizer needed and was then used to estimate the total cost of production for the dairy system. The alfalfa dry matter

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yield was used to simulate the pasture stocking rate, milk yield, gross revenue and net profit. The spatial variability of soil properties and site-specific liming and fertilizer needs were modeled using semi-variograms with VESPER software, the soil fertility information and economic return were modeled with SPRING software. The results showed that geostatistics and GIS were effective tools for revealing soil and pasture spatial variability and supporting management strategies. Soil nutrients were used to classify the soil spatial distribution map and design site-specific lime and fertilizer application maps. Spatial variation in forage and spatial estimates of stocking and milk yield are adequate pasture management tools. Spatial analyses of needs, forage availability and economic return are management tools for avoiding economic problems, as well as potential environmental problems, caused by unbalanced nutrient supplies and over- or under-grazing.

Introduction

Long-established, properly managed and fertilized pastures are the main source of food for cattle. They also constitute the most practical and least-cost approach to cattle feeding (Camargo *et al.*, 2002). In dairy production systems, intensive pasture grazing increases productivity and allows for higher stocking rates (Corsi and Nussio, 1993; Primavesi *et al.*, 1999).

Among the controllable factors that determine forage yield and quality, soil fertility, including fertilizer use, is one of the most important. Tropical acidic soils are naturally poor in plant nutrients. Therefore, soil liming and a balanced nutrient supply are essential to ensure high yields and high forage quality (Corsi and Nussio 1993; Primavesi *et al.*, 1999; Camargo *et al.*, 2002). Alfalfa is extremely demanding on soil fertility; therefore, an adequate nutrient supply is important for forage production and essential for maintaining high forage quality and profitable yields (Moreira *et al.*, 2008; Bernardi *et al.*, 2013a, 2013b). The application of fertilizer is the main cost of maintenance of permanent pasture (Gillingham, 2001). Fertilization may represent as much as 27 % of the total production cost of alfalfa for intensive dairy cattle production in typical Brazilian systems (Vinholis *et al.*, 2008).

Precision agriculture (PA) contributes to long-term sustainability of agriculture by managing inputs to reduce losses caused by excess fertilizer application or nutrient imbalances (Bongiovanni and Lowenberg-Deboer, 2004). Although all these technologies are available and can be successfully used for pasture management, PA has been developed and applied mostly to annual crops (Schellberg

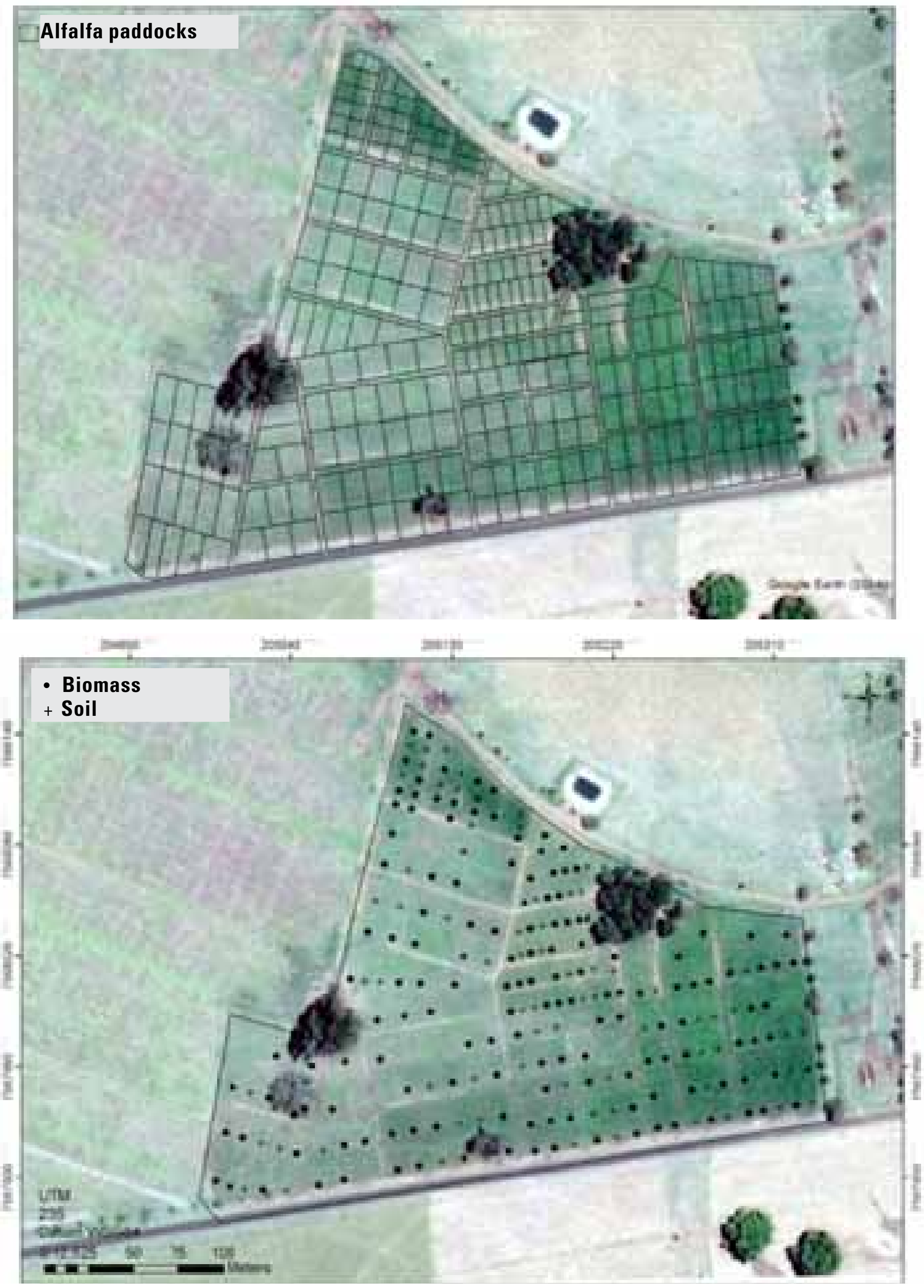

Fig. 1. Division of the 270 paddocks of alfalfa pasture under grazing in Brazil. Soil(+) and biomass(•) sampling points.

et al., 2008). The benefits of PA are the precise identification and mapping of small-scale variability, and the development of variable rate technology (VRT, Gillingham 2001). Fu *et al.* (2010) indicated that fertilizer use efficiency and agronomic and environmental management may be improved by adjusting fertilizer inputs based on spatial variability in soil fertility. According to Schellberg *et al.* (2008), detecting spatial variation in pastures is the major challenge; the primary objective of PA is the management of that heterogeneity in the field.

Knowledge of the spatial variability of soil properties and forage yield is useful for the informed use of inputs, such as variable rate application (VRA) of lime and fertilizers. To reduce the need for expensive and intensive sampling, PA and forage management require rapid low-cost sensors and methods for revealing spatial variability (McBratney and Pringle, 1999). Measurement of the spatial variability of pasture soil and vegetation is the basis for VRT (Serrano *et al.*, 2010) and grazing management. According to Stefanski and Simpson (2010), VRA is adequate for pasture-based systems, since the irregular distribution of nutrients are a probable cause of irregular biomass productivity. The economic benefits of using VRA instead of using a uniform rate in pasture systems have been demonstrated (Gillingham and Betteridge, 2001). Besides the potential to optimize nutrient use, there has been little research exploring the potential for VRA in pasture systems (Trotter *et al.*, 2014).

Measurements of apparent soil electrical conductivity (ECa) can provide easily measured spatial data for characterizing variation in soil and yield (Kitchen *et al.*, 2003; Serrano *et al.*, 2010). Apparent soil electrical conductivity (ECa) integrates texture and moisture availability, two soil characteristics that affect crop and forage yield, as shown by Kitchen *et al.* (1999), Luchiari *et al.* (2001) and Serrano *et al.* (2010). In Brazil, Machado *et al.* (2006) verified that values of soil ECa reflected spatial variation in soil clay content and were adequate for establishing the limits of management zones.

Evaluating PA tools to determine alfalfa fertilization needs and the resulting economic return to dairy production systems is required for establishing conditions under which the response will be maximized, particularly when pastures have acidic, low-fertility soils.

Hence, the effects of various management practices, including PA, and related issues are important for achieving profitable dairy production.

The objective of this research was to map and evaluate the spatial variability of soil properties, yield, liming and fertilizer need and economic return of an alfalfa pasture.

Materials and methods

The study was conducted at Embrapa Pecuaria Sudeste, in Sao Carlos (22°01'S and 47°54'W; 856 m above sea level), State of Sao Paulo, Brazil. A 5.3 ha irrigated alfalfa (*Medicago sativa* cv. Crioula) pasture had been intensively managed for 2 years in a rotational system; 270 paddocks were divided by electric fencing into 80, 160 and 240 m^2 units. The pastures were managed under an annual rotation system with 1 day of grazing and 30 days between the cycles. Alfalfa shoot dry matter yield was periodically evaluated before grazing, when 10 % of the crop was flowering. All the cuts were made 0.10 m above ground. Alfalfa samples were dried at 65°C for 72 h, for determining the dry matter yield.

Soil samples were collected at 0-0.2 m depth using the zone sampling technique (Fleming *et al.*, 2000). Each zone was established based on alfalfa yield and weed occurrence, since Bernardi *et al.* (2013a) had showed for the same area an inverse correlation between soil fertility level and weed on alfalfa pasture. Each soil sample was a result of at least 10 sub-samples collected at the paddocks at the same zone. Figure 1 illustrates the spatial distribution of soil sampling points. The chemical properties were determined using the methods of Primavesi *et al.* (2005). Soil pH measurements were made in $CaCl_2$, organic carbon was determined by wet combustion and available P was assessed using the resin method. Exchangeable K^+, Ca^{2+}, Mg^{2+} and H + Al were also measured. Cation exchange capacity (CEC) was measured at the actual soil pH value, and base saturation (V%) was determined. Soil particle size fractions (clay content) were determined by the densimeter method. Soil apparent electrical conductivity was measured using the Veris model 3100 sensor (Veris Technologies, Salina, KS, USA) (Lund *et al.*, 1999).

Liming, P and K fertilization rates were calculated from soil testing. The criteria were those described by Moreira *et al.* (2008) and Bernardi *et al.* (2013a, 2013b): lime to increase basis saturation to 80 %, P fertilizer (super single phosphate, 18 % P_2O_5) to increase soil P to 20 mg dm^{-3} and K fertilizer (KCl, 60 % K_2O) to increase exchangeable K to 5 % of soil cation exchange capacity.

The amount of liming and fertilizer was used to simulate the cost of producing 1 ha of alfalfa. The cost of alfalfa production as a percentage of total dairy production costs was then estimated. All other fixed and variable costs were based on the data of Vinholis *et al.* (2008) for a Brazilian intensive dairy cattle production system with the following characteristics: cows' diet consisted of 20 % alfalfa pasture and 80% *Panicum maximum* cv. Tanzania (grazed during the rainy season) and maize silage (dry season).

The results obtained for alfalfa dry matter yield in each paddock were used to estimate total dry matter yield in a year and to simulate pasture stocking rate, milk yield and gross revenue. The following data were used in the simulation: (a) average cow live weight (LW) = 550 kg, (b) cow dry matter (DM) consumption = 3.05 % of the LW, corresponding to 16.8 kg day^{-1} of DM, (c) the alfalfa pasture grazing represented 20 % of the forage consumption. The estimates were derived from the following equations:

Cost of alfalfa production

$$AC = APC + LFC$$

where AC = cost of production of 1 ha of alfalfa, USD ha^{-1} year^{-1}; APC = cost of production of 1 ha of alfalfa (Vinholis *et al.*, 2008), includes variable and fixed costs, excluding lime and fertilizer inputs, USD ha^{-1} year^{-1} (AP = USD 1894 ha^{-1} year^{-1}); LFC = lime (USD 0.03 kg^{-1}) and fertilizer costs (SSP = USD 0.48 kg^{-1} and KCl = USD 0.39 kg^{-1}).

Stocking rate

$$SR = \frac{DM \times GE}{AGN \times GI \times DIFC}$$

where SR = stocking rate in the alfalfa pasture, animal ha^{-1}; DM = dry matter yield, kg ha^{-1}; GE = grazing efficiency (GE = 0.7); AGN = annual number of grazing events (12 grazing events year^{-1}); GI = grazing interval, days (30 days); DIFC = daily individual forage consumption, kg of dry matter cow^{-1} day^{-1}.

Milk yield

$$MY = \frac{SR \times MYd \times 365}{1 + (TPIA + SCIA) \times SR}$$

where MY = annual milk production, l ha^{-1} year^{-1}; MYd = daily milk yield, l cow^{-1} day^{-1} (20 l cow^{-1}, 4 % fat content); TPIA = tropical pasture individual area, ha cow^{-1} (TPIA = 0.125 ha cow^{-1}); SCIA = sugarcane individual area, ha cow^{-1} (SCIA = 0.043 ha cow^{-1}); Obs.: TPIA and SCIA are the areas of tropical and sugarcane pastures used for feeding the cows that also graze in 1 ha of alfalfa.

Gross revenue

$$GR = MY \times MP$$

where GR = gross revenue, USD ha^{-1}, MY = annual milk production, l ha^{-1} year^{-1}, MP = milk price, USD l^{-1} (MP = USD 0.40 l^{-1}).

Total cost of production

$$TCP = AC + TCPD$$

where TCP = cost of production, USD ha^{-1} year^{-1}; AC = cost of production of 1 ha of alfalfa, USD ha^{-1} year^{-1}; TCPD = total production cost of dairy system (Vinholis *et al.*, 2008), USD ha^{-1} year^{-1} (TDC = USD 6,068 ha^{-1} year^{-1}).

Net profit

$$NP = GR - TCP$$

where NP = net profit, USD ha^{-1}; GR = gross revenue, USD ha^{-1}; TCP = production cost, USD ha^{-1}.

Statistical parameters were estimated and geostatistical analyses were conducted for all variables, focusing on the spatial continuity and dependence of soil and forage properties.

Empirical directional semi-variograms were calculated for the x- and y-directions. Semi-variograms were fitted to empirical models using VESPER (Minasny *et al.*, 2005) to estimate the structure of the spatial variation. Contour maps of all variables were estimated using ArcGIS 10.1 (ESRI, 2009). SPRING (Camara *et al.*, 1996), a free object-based georeferenced information system (www.dpi.inpe.br/spring), was used to integrate the soil fertility maps. Using the spatial analyst extension of ArcGIS 10.1, net profit was estimated and mapped by subtracting the production cost from gross revenue.

Results and discussion

Descriptive statistical parameters of all the analyzed variables are given in Table 1. The parameter mean, variance, coefficient of variation, minimum value, maximum value, skewness and kurtosis were estimated to verify the existence of a central tendency and the dispersion of the data.

The verification of normality is important because kriging performs better when the data are normally distributed (Carvalho *et al.*, 2002). In a data set that approaches the normal distribution, the skewness and kurtosis coefficients must be between 0 and 3 (Carvalho *et al.*, 2002). The skewness and kurtosis of soil P were inconsistent with the normal distribution (Table 1). All other variables were normally distributed.

Using the classification suggested by Pimentel-Gomes (1984), coefficients of variation -CV of soil pH, CEC, base saturation, clay and milk yield displayed low variability, with a CV below 10 %. Soil organic matter (O.M.), Ca, Mg, dry matter yield and stocking rate were the variables with medium variability (CV between 10 and 20 %). Trotter *et al.* (2014) had found CV ranging from 35 to 66 % for P, K and S. All other parameters had high variability. According to Kravchenko (2003), the degree of variability is important in site-specific management because highly variable soil properties are potentially better candidates for site-specific management than are more uniformly distributed soil properties. However, mapping soil properties with higher variability can be less accurate than mapping soil properties with lower variability. Trends in the variation of soil attributes obtained in this study are consistent with those observed by Mulla and McBratney (2000) and Machado *et al.* (2004) for soil parameters.

Table 1. Descriptive statistics for variables of a grazed alfalfa pasture in Brazil.

Variables	μ	σ	Minimum	Maximum	CV (%)	Kurtosis	Skewness	n
pH_{CaCl_2}	5.7	0.340	5.2	6.6	5.965	1.081	1.166	73
OM (g kg^{-1})	25.5	3.122	19.0	34.0	12.24	0.547	0.492	73
P_{resin} (mg dm^{-3})	35.0	29.82	9.0	141.0	85.20	4.298	2.096	73
K ($mmol_c$ dm^{-3})	3.5	1.345	0.6	5.4	38.43	-0.783	-0.571	73
Ca ($mmol_c$ dm^{-3})	37.0	5.509	26.0	55.0	14.89	2.161	0.763	73
Mg ($mmol_c$ dm^{-3})	17.2	3.597	12.0	25.0	20.91	-1.001	0.497	73
CEC ($mmol_c$ dm^{-3})	79.6	5.401	69.0	92.0	6.785	-0.387	-0.137	73
Base saturation (%)	72.4	7.105	58.0	86.0	9.814	-0.889	0.109	73
Clay (g kg^{-1})	631.3	19.24	595	674	0.03	-0.258	0.245	73
EC_a (mS m^{-1})	7.7	4.642	0.0	42.8	60.29	1.273	0.622	4,794
Lime (kg ha^{-1})	627.8	495.9	0.0	1,584.0	78.99	-1.349	0.071	73
Single superphosphate (kg ha^{-1})	408.0	414.4	0.0	1,166.7	101.6	-1.434	0.391	73
KCl (kg ha^{-1})	126.8	169.1	0.0	525.0	133.4	-0.182	1.096	
Dry matter yield (kg ha^{-1})	18,540	3,279.9	9,060	28,710	17.69	0.362	-0.266	153
Stocking rate (cows ha^{-1})	15	2.606	7	23	17.37	0.501	-0.265	153
Milk yield (kg ha^{-1} $year^{-1}$)	30,610	1,795.3	23,483	34,519	5.865	2.063	-1.204	153

CV coefficient of variation equals standard deviation (σ) divided by sample mean (μ).

Experimental semi-variograms for all variables were computed, and all fitted models were bounded (Table 2). The plots of semi-variograms are also shown (Fig. 2). Geostatistics is a useful tool for soil fertility because it can be used to estimate and map soil attributes in areas that were not sampled. The results showed that the spatial scale encompassed the full extent of variation of the parameters studied. The spherical model was the best adjusted to experimental variograms of soil pH, Mg, CEC, K fertilization, ECa and milk yield. Trangmar *et al.* (1985) showed that this model best describes the behavior of variograms of soil attributes. For soil O.M., available P, exchangeable K and dry matter yield, the variogram was fitted with a Gaussian model. For soil Ca, base saturation, lime, P fertilizer and stocking rate, an exponential model was used to describe the spatial dependence.

The ratio of nugget to total semi-variance can be used as a criterion for classifying the spatial dependence of variables (Cambardella *et al.*, 1994). Soil pH, O.M., P, Ca, Mg, base saturation, lime, P and K fertilization had weak spatial dependence (>75%). Soil K, CEC, dry matter yield and stocking rate showed moderate spatial dependence, with ratios between 25 and 75 %. Soil ECa and milk yield showed strong spatial dependence, with ratios greater than 75 %. Figure 2 illustrates the semi-variograms of soil properties, with models that are described in Table 2. The

Table 2. Parameters for semi-variograms models of characteristics of a grazed alfalfa pasture in Brazil.

Variable	C_0	C_1	A(m)	Model	Nugget/sill $100[C_0(C_0+C_1)^{-1}]$	Spatial dependence
pH_{CaCl_2}	0.003285	5.81	10,000	Spherical	99.9	Weak
OM (g kg^{-1})	2.664	9.34	84.81	Gaussian	77.8	Weak
P_{resin} (mg dm^{-3})	62.66	959.1	66.29	Gaussian	93.9	Weak
K ($mmol_c$ dm^{-3})	0.963	2.013	165	Gaussian	67.6	Moderate
Ca ($mmol_c$ dm^{-3})	3	39	71	Exponential	92.9	Weak
Mg ($mmol_c$ dm^{-3})	2	11.17	62.2	Spherical	84.8	Weak
CEC ($mmol_c$ dm^{-3})	9.33	20.7	64.57	Spherical	68.9	Moderate
Base saturation (%)	1	81	102	Exponential	98.8	Weak
Clay (g kg^{-1})	9.63	535.9	208.8	Spherical	98.24	Weak
EC_a (mS m^{-1})	17.22	5.75	184.6	Spherical	25.0	Strong
Lime (kg ha^{-1})	8,363	244,748	97	Exponential	96.7	Weak
Single superphosphate (kg ha^{-1})	13,209	213,942	107	Exponential	94.2	Weak
KCl (kg ha^{-1})	4,415	18,997	90	Spherical	81.1	Weak
Dry matter yield (kg ha^{-1})	7,725,788	4,380,353	19.77	Gaussian	36.2	Moderate
Stocking rate (cows ha^{-1})	4.543	3.026	36.33	Exponential	40.0	Moderate
Milk yield (kg ha^{-1} $year^{-1}$)	2,790,218	780,683	63.57	Spherical	21.9	Strong

The parameters are: C_0 the nugget variance; C_1 the sill of the autocorrelated variance; *A* the range of the spatial dependence.

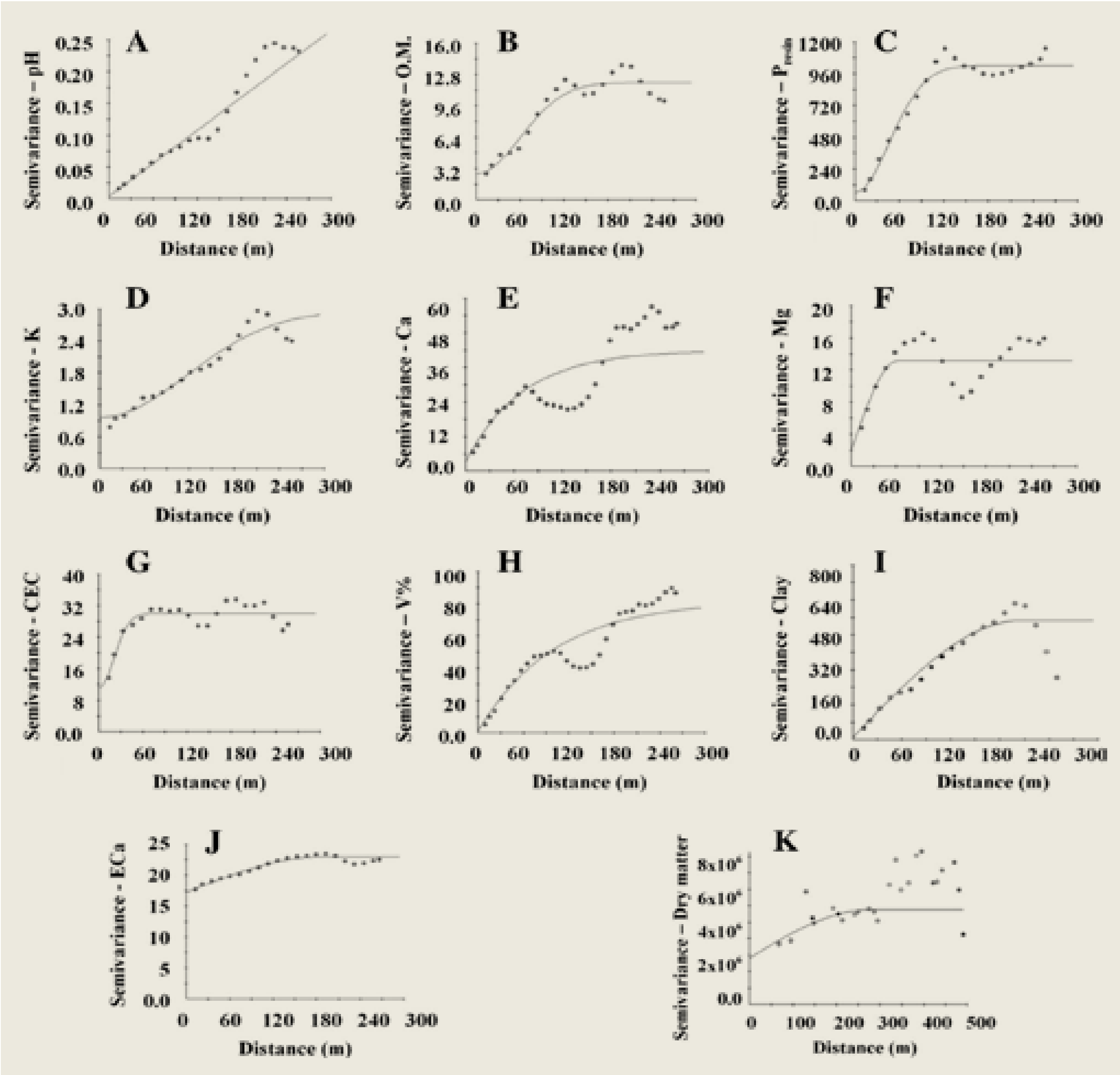

Fig. 2. Semi-variograms of pH (A); organic matter (B); available P (C); exchangeable K (D); Ca (E); Mg (F); cation exchange capacity (CEC) (G); base saturation-V% (H); clay (I); soil apparent electrical conductivity (ECa) (J); and dry matter yield (K) of a grazed alfalfa pasture in Brazil.

spatial variability of soil properties may be affected by intrinsic and extrinsic factors, such as soil formation factors and soil management practices, respectively (Cambardella *et al.*, 1994). The ranges for the soil parameters were between 62 and 10,000 m (Table 2). These results indicate that a grid spacing of 62 m would be adequate for characterizing the spatial variability of the soil characteristics at this site. Therefore, 2.6 samples ha^{-1} could adequately represent soil spatial variation at this site.

Figure 3 shows the spatial patterns of the soil parameters generated by kriging from the semi-variograms. The range values for soil organic matter (from 19 to 34 g kg^{-1}) and cation exchange capacity (from 69 to 92 $mmol_c$ dm^{-3}) are considered medium and high, respectively, according to Alvarez Venegas *et al.* (1999) to Brazilian tropical soils.

The minimum values of soil Ca and Mg (26 and 12 $mmol_c$ dm^{-3})

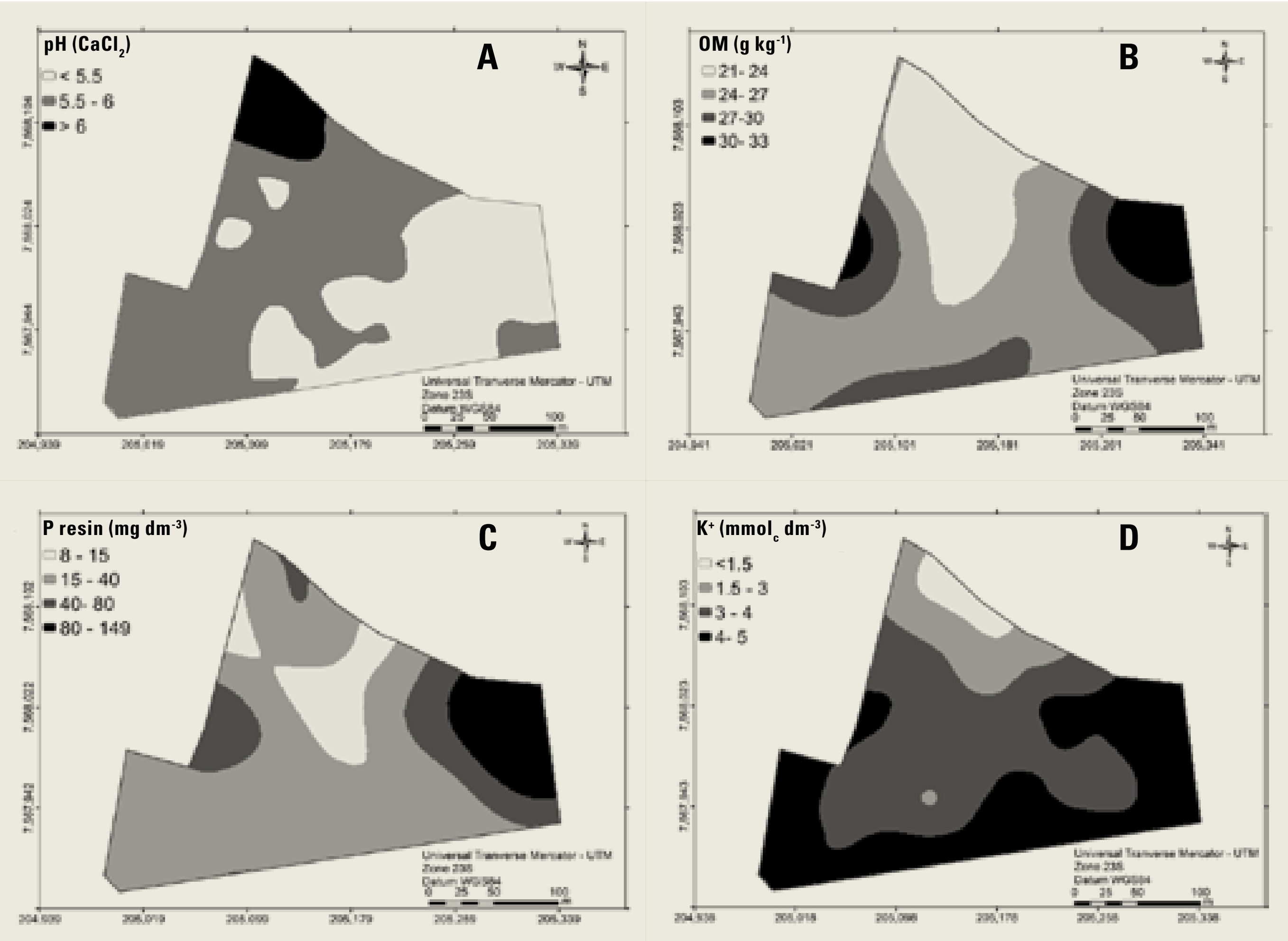

Fig. 3A-D. Kriged maps for pH (A); organic matter (B); available P (C); exchangeable K (D); of a grazed alfalfa pasture in Brazil.

were higher than 7 and 8 mmol$_c$ dm^{-3}, which is considered high (Raij *et al.*, 1997). These results could indicate that the soil Ca and Mg were sufficient, but the requirement for lime is also determined by the base saturation.

There is a direct relationship between soil pH and base saturation because negative charge formation is dependent on the pH of the soil solution. The pH values were considered low (up to 6.0) to very low (over 6.0), and base saturation ranged from medium (51–70 %) to high (71–90 %) (Raij *et al.*, 1997).

The most variable classifications were obtained for soil P and K. Soil P levels (Fig. 3C) were classified into four groups (Raij *et al.*, 1997): low (6-12 mg dm^{-3}), medium (13-30 mg dm^{-3}), high (31-60 mg dm^{-3}) and very high (>60 mg dm^{-3}). The class considered medium represented 65 % of total area, and the high and very high levels represented 25 %. Soil K levels also were classified into four groups: low (0.8-1.5 mmol$_c$ dm^{-3}), medium (1.6–3.0 mmol$_c$ dm^{-3}), high (3.1-6.0 mmol$_c$ dm^{-3}) and very high (>6.0 mmol$_c$ dm^{-3}). The higher K levels included 84% of the total area. These levels will affect the fertilizer needs, the productivity standards (Stefanski and Simpson, 2010) and production costs.

Kriged estimates for soil texture and ECa were contoured and mapped, and their patterns of variation in the field are shown in Fig. 4. The soil texture was clay and very homogenous, and less than 2 % of the studied area had less than 600 g kg^{-1} of clay content. ECa values ranged from 2 to 11 mS m^{-1}.

The soil fertility maps (Fig. 3) obtained from VESPER (Minasny *et al.*, 2005) in the raster mode were converted to vector mode in ArcGIS [Environmental Systems Research Institute (ESRI)] Inc., 2009). Vector polygons were then created for each soil fertility class. Numerical values were assigned to the classifications: 1 for low, 2 for medium, 3 for high and 4 for very high. Using SPRING

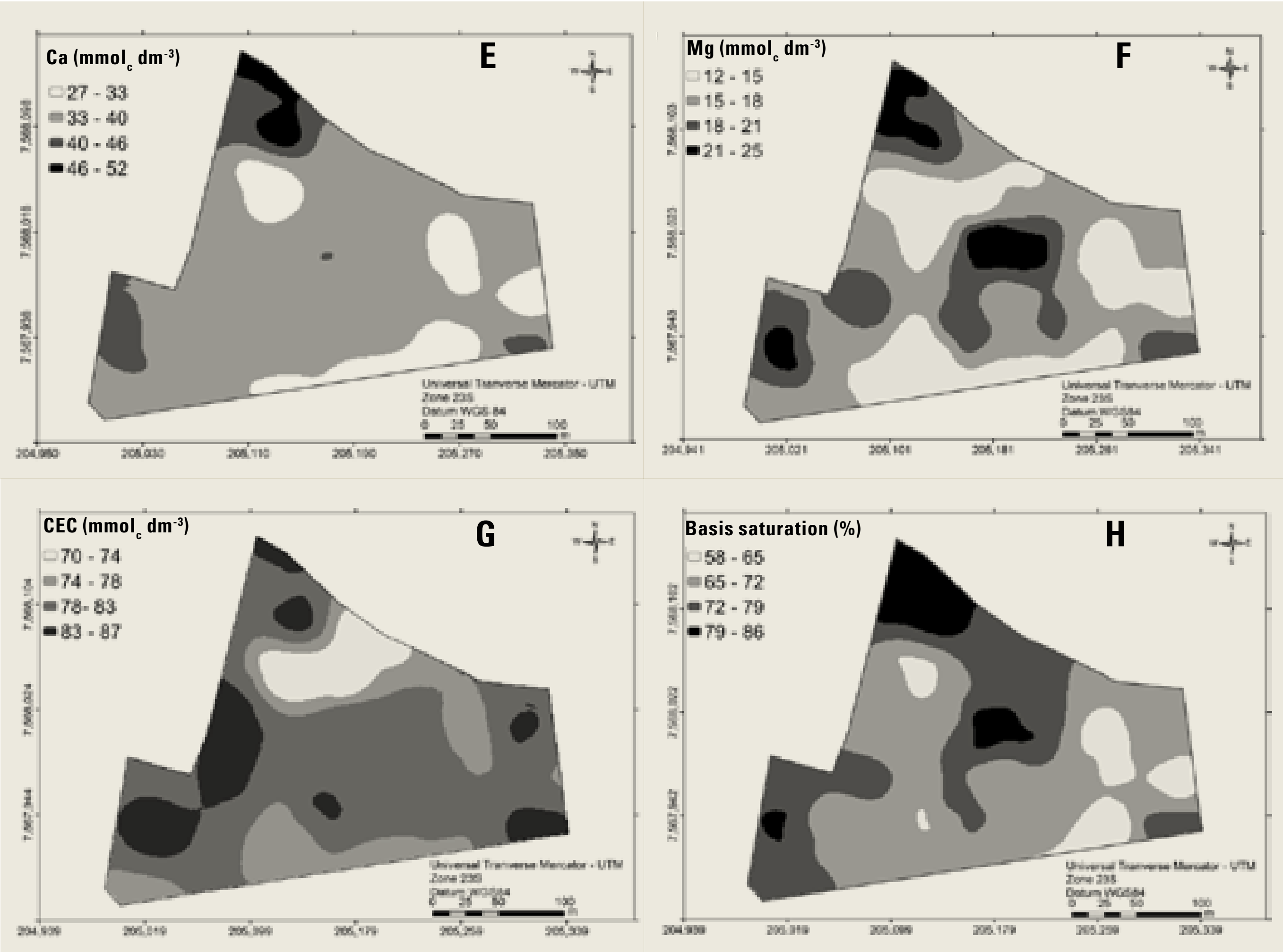

Fig. 3E-H. Kriged maps for Ca (E); Mg (F); cation exchange capacity (CEC) (G); and base saturation-V% (H) of a grazed alfalfa pasture in Brazil; of a grazed alfalfa pasture in Brazil.

(Camara *et al.*, 1996), all the vector polygons were converted to matrix mode and compared in a soil fertility classification map (Fig. 4C) that represented the average of all polygons. Two soil fertility classes, medium and high, were established. Because soil ECa integrates soil properties such as soil texture, soil organic matter, cation exchange capacity and exchangeable basis, the regions with lower values are the same as the regions classified as ''medium soil fertility''. One aspect that can affect the correlation of ECa with other soil properties is the different soil layer assessed. Serrano *et al.* (2010) had observed positive correlations of ECa with soil pH and pasture dry matter yield, but there were no significant correlations between the EC and parameters such as clay and soil organic matter.

Liming and fertilizer site-specific recommendations for alfalfa pasture were based mainly on soil analysis (Moreira *et al.*, 2008). Limestone rates are calculated to raise soil base saturation (V%) as a percentage of the soil cation exchange capacity (CEC) at pH 7.0. In alfalfa pastures, V% should be increased to 80 % (Moreira *et al.*, 2008) for the best results. Liming is the lower cost and more efficient way to neutralize soil acidity, reducing Al and Mn toxicity, improving P, Ca and Mg availability, increasing CEC, promoting N_2 fixation and improving soil structure (Moreira *et al.*, 2008). The amount of liming in Fig. 5A was calculated to reach V = 80 %. The liming recommendation map indicated that the application rate should be up to 1.2 t ha^{-1} in 44 % of the area (2.4 ha) and up to 1.6 t ha^{-1} in 9 % of the area. Twenty-two percent of the area needs less than 360 kg ha^{-1}, and 25 % should receive up to 770 kg ha^{-1}.

The P recommendation was based on ion exchange resin-extractable P availability and the amount needed to reach 20 mg dm^{-3} (Moreira *et al.*, 2008). The site-specific map (Fig. 5B indicated that 68 % of the area should receive up to 500 kg ha^{-1}

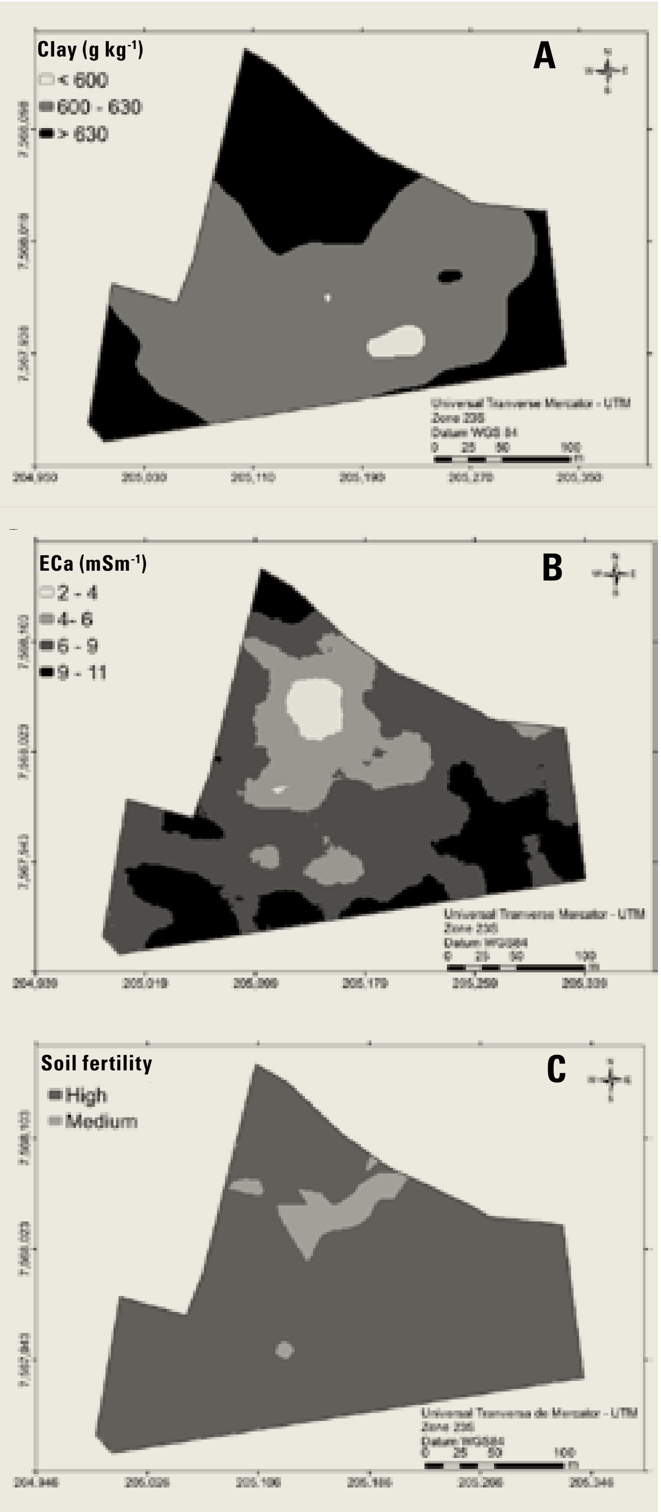

Fig. 4. Kriged maps for clay (A), soil apparent electrical conductivity ECa (B) and fertility (C) of a grazed alfalfa pasture in Brazil.

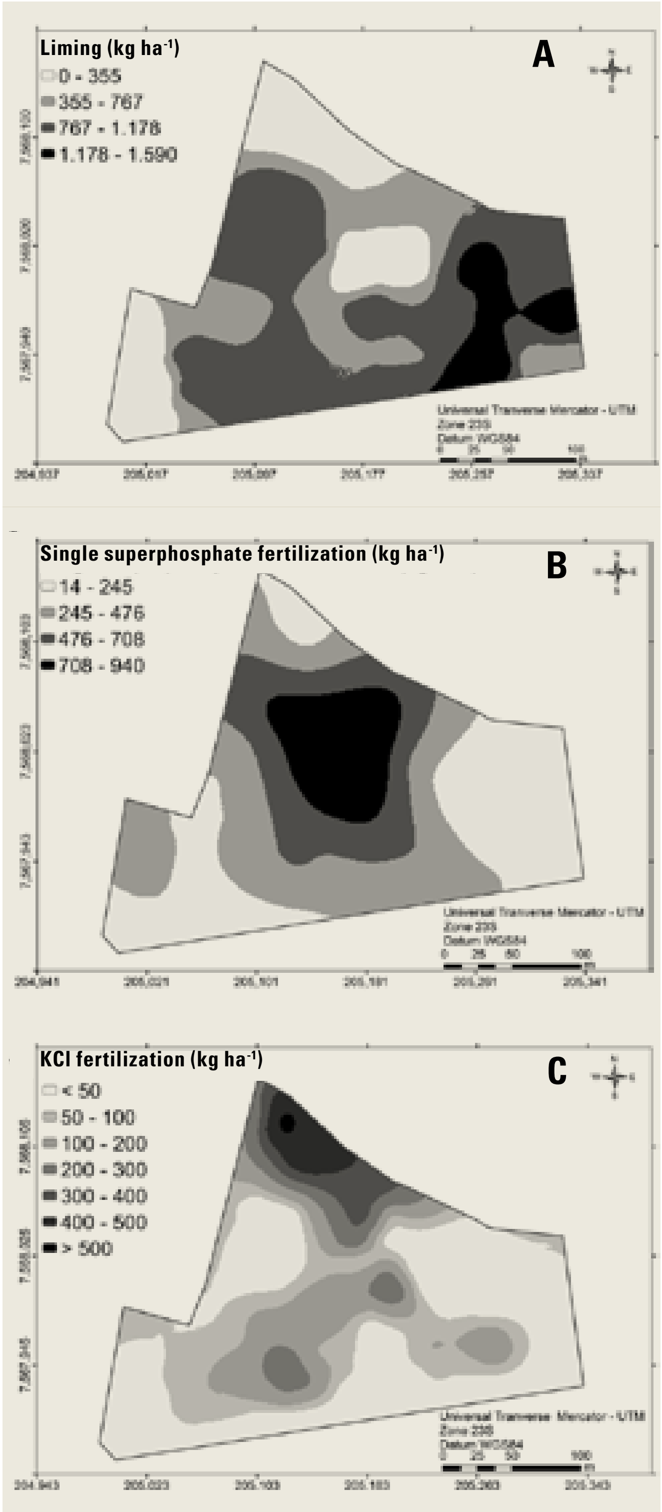

Fig. 5. Kriged maps for liming (A), single superphosphate fertilization (B), and KCl fertilization (C) of a grazed alfalfa pasture in Brazil.

of single superphosphate. Single superphosphate is needed to increase soil P levels and improve the N-fixing capacity of alfalfa pasture. Gillingham (2001), McCormick *et al.* (2009) and Serrano *et al.* (2010) also reported great differences in P levels of pasture soils. Higher amounts were recommended for the rest of the area (42 %). Potassium rates were recommended based on the values of soil exchangeable K needed to reach 5 % of the cation exchange capacity (CEC), according to the recommendation of Bernardi *et al.* (2013b). Most of the area (85 %) should receive up to 200 kg ha^{-1} of KCl (Fig. 5C). The results of this study suggest that lime and fertilizers VRA could provide improvements in biomass yield and optimization in nutrient use. McCormick *et al.* (2009), Fu *et al.* (2010) and Trotter *et al.* (2014) also successfully established site-specific nutrient fertilizer maps based on soil nutrient availability for grazing systems. However, a proper diagnosis of the limiting factors of pastures have to be implemented, since increasing nutrient application rates where pasture growth is constrained by factors other than soil fertility may not lead to increased yields (Gillingham, 2001).

Stocking rate is a key management variable for determining productivity and profitability of grazing systems. This rate determines the quality of forage, forage use efficiency, animal performance and milk production per area (Fales *et al.*, 1995). Figure 6 illustrates that the simulation based on dry matter yield allowed estimation of stocking rates and milk yield within the area. Maps of this type may be used to avoid over- or under-grazing. Gillingham and Betteridge (2001) already had shown the variability in production within dairy farm paddocks on dairy farms.

Milk yield determines gross revenues. The results of this simulation have shown that an alfalfa pasture adequately supplied with lime and fertilizer can support high stocking rates that result in high milk production per hectare. Therefore, as shown by Fales *et al.* (1995), the optimal stocking rate for a given dairy farm depends on individual farm resources (e.g., land, buildings, cows, etc.). The rate can be adjusted according to local resource constraints, thus avoiding or minimizing significant adverse economic impacts. This approach can help farm managers predict future scenarios and support their management decisions.

The challenges for alfalfa pasture in Brazil are persistent unbalanced soil nutrients that may lead to low forage and milk yields. Research data (Bernardi *et al.*, 2013a; 2013b) showed that large gains in pasture productivity and nutrient maintenance are possible when soil fertility constraints are overcome. Precision agriculture tools help reveal nutrient heterogeneity (Gillingham and Betteridge, 2001; Schellberg *et al.*, 2008; Trotter *et al.*, 2014) and indicate where to implement PA in a competitive and cost-efficient manner.

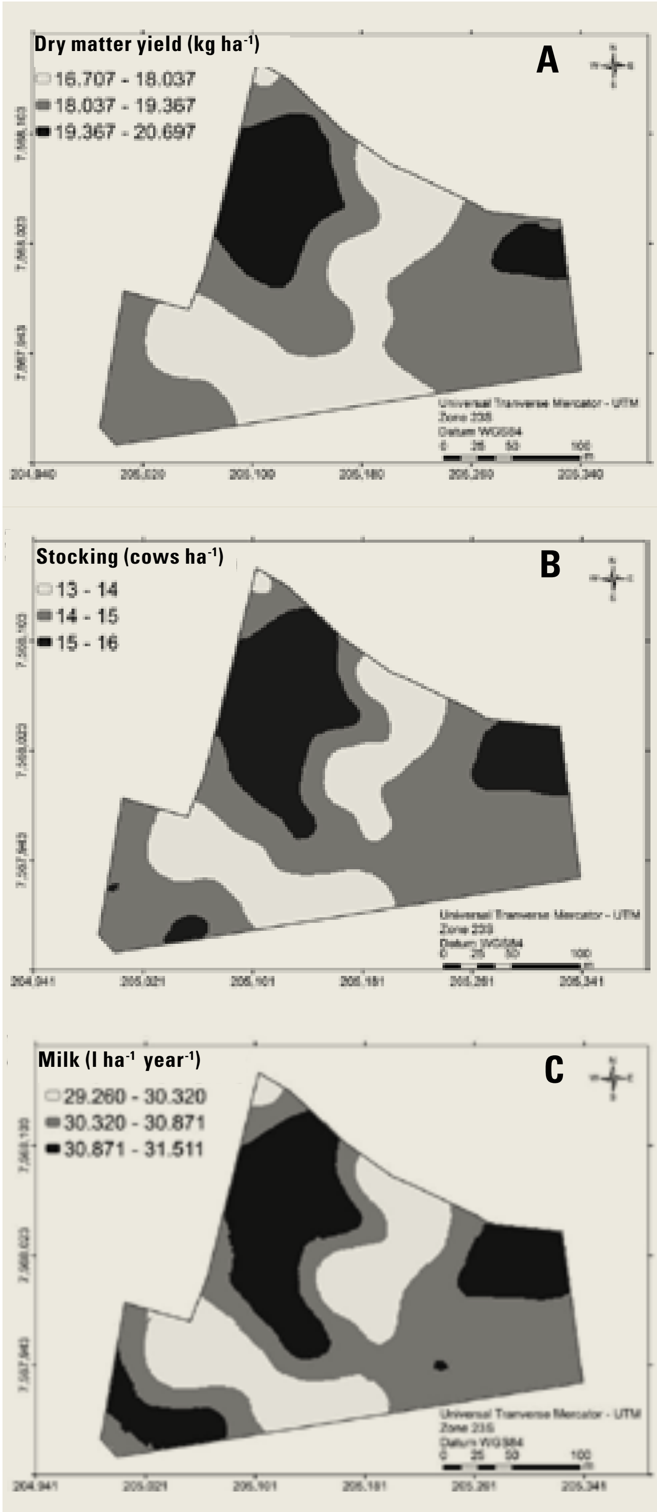

Fig. 6. Kriged maps for dry matter yield (A), stocking rate (B), and milk yield (C) of a grazed alfalfa pasture in Brazil.

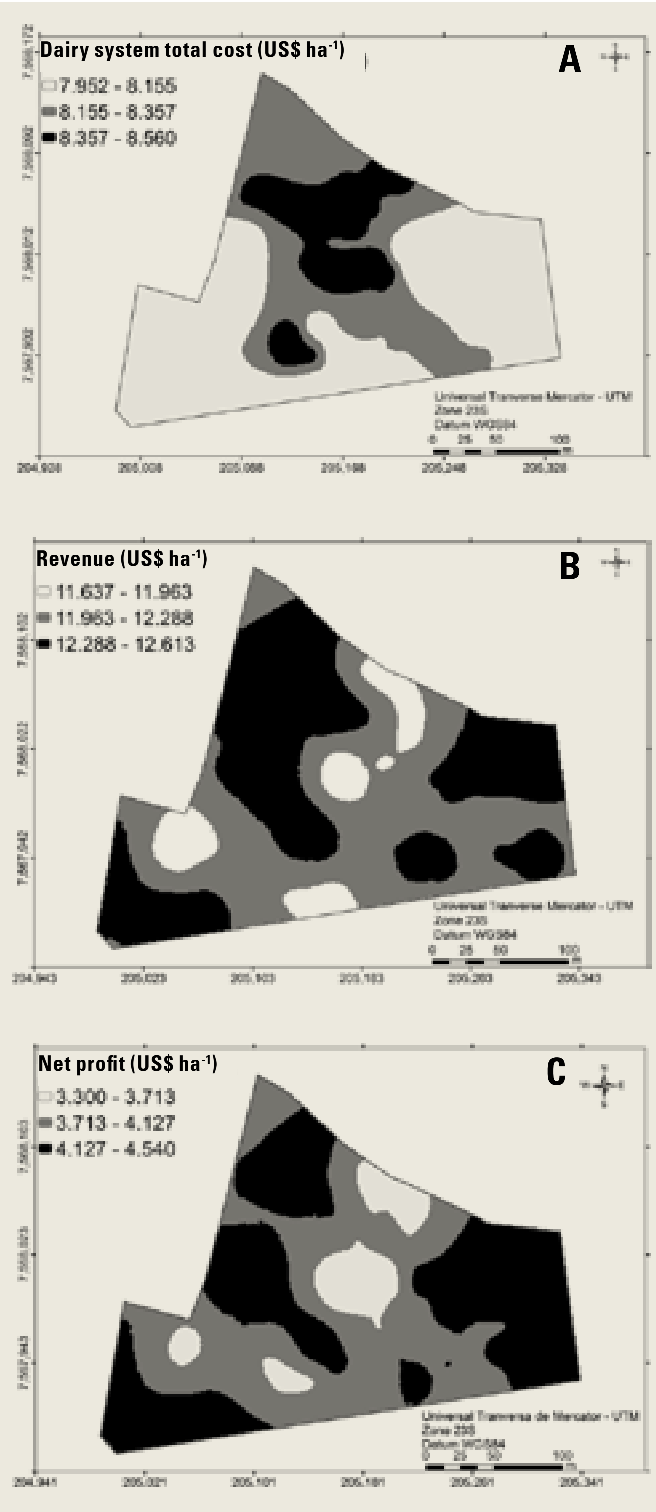

Fig. 7. Kriged maps for production cost (A), gross revenue (B), and net profit (C) of a grazed alfalfa pasture in Brazil.

In a dairy system, low economic returns may reduce farm investment and pasture productivity. This is particularly true when alfalfa is grown on tropical soils, where the constant replenishment of nutrients is a major constraint. Economic profitability of this dairy system was estimated based on the cost of production, including the VRT application of lime and P and K fertilizer, and the revenue from milk yield. The maps in Fig. 7 illustrate the spatial heterogeneity of costs (a), revenue (b) and net profit (c). Almost 10 % of the alfalfa pasture area is approximately 19 % less profitable than the best area. The cost of P fertilizer may be a decisive factor in the economic balance of the system as Fu *et al.* (2010), Serrano *et al.* (2011) had also demonstrated. The results obtained in this research confirm the advantages of using PA tools to support management decisions in pasture systems. Results of Gillingham and Betteridge (2001) also had shown that within a 2 ha paddock with three management zones and the VRT recommendation could save about one-third of the usual fertilizer applied without reducing pasture production. According to Gillingham (2001), Fu *et al.* (2010), Serrano *et al.* (2011) and Trotter *et al.* (2014) these kind of maps provide useful information for agronomic and also for environmental management.

The results from this study showed the advantages of the methodology that allows the identification of areas for differentiated paddocks management, instead of homogeneous fertilizer application. So the situation can be further complicated when cattle are involved, since the implementation of precision agriculture in pasture is difficult for the associated temporal variability (Schellberg *et al.*, 2008). Grazing animals are a remarkable source of variability of nutrients in the soil as a result of the heterogeneous deposition of excreta (McCormick *et al.*, 2009). Nevertheless, results from Serrano *et al.* (2011) had shown that temporal stability changes over time and pasture fields should be managed according to the current year's conditions.

Conclusions

The results showed that geostatistics and GIS were effective tools for revealing soil and pasture spatial variability and supporting management strategies. Soil nutrients were used to classify the soil spatial distribution map and design site-specific lime and fertilizer application maps. Spatial variation in forage and spatial estimates of stocking and milk yield are adequate pasture management tools. Spatial analyses of needs, forage availability and economic return are management tools for avoiding economic problems, as well as potential environmental problems, caused by unbalanced nutrient supplies and over- or under-grazing.

Acknowledgments

The International Potash Institute (IPI) provided funding for this research.

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The paper "Spatial Variability of Soil Properties and Yield of a Grazed Alfalfa Pasture in Brazil" also appears on the IPI website.

Events

March 2019

Second Global Session of the UN Science-Policy-Business Forum on the Environment, Nairobi, Kenya 9-10 March 2019

Special event "Healthy Food for a Healthy Planet" on 10 March 2019.

The "Second Global Session of the UN Science-Policy-Business Forum on the Environment" was held at the UN Headquarters in Nairobi, Kenya from 9 to 10 March 2019 in the lead up to the fourth session of the United Nations Environment Assembly (UNEA-4). IPI Coordinator for SSA/Eastern Africa, Dr. Lilian Wanjiru Mbuthia played a key role in two of the sessions' events.

Dr. Lilian Wanjiru Mbuthia, IPI Coordinator for SSA/Eastern Africa.

Organized by the United Nations Environment Program (UNEP), the International Fertilizer Association (IFA), the International Rice Research Institute (IRRI) and the UN Standing Committee on Nutrition, the special event "Healthy Food for a Healthy Planet" took place on 10 March 2019. The event explored the responsibility of businesses and policymakers to bring about transformative change in agriculture and human nutrition. Dr. Lilian Wanjiru Mbuthia represented IFA at this event and presented exciting fertilizers innovations and explained how careful, targeted use of fertilizers benefits crops, farmers, consumers and the wider environment.

Tackling soil health was the theme of another event titled "Innovative Actions Towards a Pollution Free-Planet: Implementing the UNEA-3 Resolution on Soil Pollution". Organized by IFA, UNEP, the World Health Organization and CropLife, the event on 12 March 2019 discussed innovative ways to address soil pollution and identify effective ways to sustainably scale up these actions. Dr. Lilian Wanjiru Mbuthia gave a presentation on "The new fertilizer generation for increased nutrient efficiency".

IPI - as part of the IFA delegation - were pleased to actively engage in the UNEA-4 activities in Nairobi, emphasizing the industry's commitment to reducing the environmental footprint of fertilizers while helping to close agricultural yield gaps and improve food security.

IPI event

November 2019

The 13th IPI-CAU-ISSAS International Symposium will take place in Kunming, China, 6-8 November 2019. This symposium on "Potash and Polyhalite: Potassium, Sulphur, Magnesium and Calcium for Efficient Balanced Plant Nutrition" is organized by International Potash Institute (IPI), China Agricultural University (CAU), Institute of Soil Science of Chinese Academy Science (ISSAS), and co-organized by National Agro-Tech Extension and Service Center (NATESC) and China Inorganic Salts Industry Association (CISIA).

It will address the issues related to the role and benefits of potash and polyhalite fertilizers for Chinese agriculture, including soil fertility, plant nutrition, efficient use of fertilizers and balanced fertilization practices.

This symposium will be of interest to soil and plant nutrition scientists, agronomists, and extension officers from universities and research organizations, government offices, and agribusinesses who share an interest in improving food production and quality.

The symposium will be chaired by Prof. Fusuo Zhang, academician of the Chinese Academy of Engineering and Director of the National Institute of Green Agricultural Development at China Agricultural University.

Main Themes:

- Potassium Management in Different Cropping Systems
- Polyhalite as a Multi-Nutrient Fertilizer
- Effect of Polyhalite Application on the Yield and Quality of Different Crops

Events (cont.)

- Role of S, Mg and Ca Nutrients in Plant Nutrition
- Potassium and Biotic and Abiotic Stresses
- Loss of Soil Fertility and Stagnation of Agricultural Production
- Nutrient Mining and Input-Output Balances at Farm and Regional Levels
- Crop Management Techniques for Efficient Fertilization

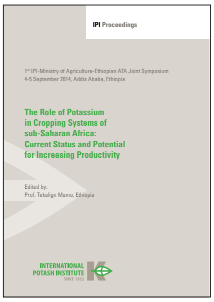
The symposium speakers:

- Surinder K. Bansal, Potash Research Institute of India, India
- Alberto C. de Campos Bernardi, Brazilian Agricultural Research Corporation (Embrapa), Brazil
- Michael Castellano, Iowa State University, USA
- Fang Chen, Chinese Academy of Sciences, Wuhan Botanical Garden, China
- Xinping Chen, Southwest University, Chongqing, China
- Zhenling Cui, China Agricultural University, Beijing, China
- Mingshou Fan, Inner Mongolia Agricultural University, Hohhot, China
- Shiwei Guo, Nanjing Agricultural University, Nanjing, China
- Ping He, Chinese Agricultrual Academy of Sciences, China
- Patricia Imas, IPI, Switzerland
- Chunjian Li, China Agricultural University, Beijing, China
- Guohua Li, ICL, China
- Ti Li, Sichuan Agricultural University, China
- Ruixian Liu, Jiangsu Academy of Agricultural Sciences, Nanjing, China
- Jianwei Lu, Huazhong Agricultural University, Wuhan, China
- Hillel Magen, IPI, Switzerland
- Guohua Mi, China Agricultural University, Beijing, China
- Uri Nachshon, Agricultural Research Organization, Israel
- Jiwan P. Palta, University of Wisconsin, USA
- Tao Ren, Huazhong Agricultural University, Wuhan, China
- Jianyun Ruan, Tea Research Institute, Chinese Academy of Sciences, Hangzhou, China
- Mollie Sacks, Ministry of Agriculture, Israel
- Xiaojun Shi, Southwest University, Chongqing, China
- Guangyu Sun, Northwest A&F University, China
- Youguo Tian, NATESC, China
- Tran Minh Tien, Soils and Fertilizers Research Institute, Vietnam
- Fabio Vale, IPI, Switzerland
- Huoyan Wang, Institute of Soil Science, Chinese Academy of Sciences, Nanjing, China
- Min Wang, Nanjing Agricultural University, Nanjing, China
- Xiaofeng Wang, China Inorganic Salts Industry Association, China
- Yi Wang, China Agricultural University, Beijing, China
- Zhengyin Wang, Southwest University, Chongqing, China
- Lilian Wanjiru Mbuthia, IPI, Switzerland
- Philip J. White, The James Hutton Institute, UK
- Zhijian Wu, Chinese Academy of Sciences Qinghai Institute of Salt Lakes, China
- Guohua Xu, Nanjing Agricultural University, Nanjing, China
- Minggang Xu, Institute of South Asian Tropical Crops, Chinese Academy of Tropical Agricultural Sciences, China
- Baige Zhang, Guangdong Academy of Sciences, Guangdong, China, Southwest University, Chongqing, China
- Chaochun Zhang, China Agricultural University, Beijing, China
- Fusuo Zhang, Chinese Academy of Engineering, College of Resources and Environmental Sciences, CAU, China
- Hongyan Zhang, China Agricultural University, Beijing, China
- Huimin Zhang, Chinese Agricultural Academy of Sciences, China

For updates and registration please go to the symposium website https://events.ipipotash.org/.

For more information please contact IPI's Coordinator for China, Mr. Eldad Sokolowski (eldad.sokolowski@icl-group.com) or IPI's Scientific and Communications Coordinator, Dr. Patricia Imas (patricia.imas@icl-group.com).

Publications



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

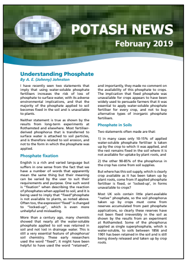
Proceedings from the 1st IPI-Ministry of Agriculture-Ethiopian ATA Joint Symposium 4-5 September 2014, Addis Ababa, Ethiopia. Edited by Prof. Tekalign Mamo, Ethiopia. 186 p.

In many regions of the world, increasing rates of mineral fertilizer application over the past 50 years have been accompanied by growing crop yields. Consequently, production is usually more than adequate to supply food for both domestic purposes and exports. By marked contrast, however, in most parts of Africa fertilizer application rates have increased at a much lower rate, resulting in relatively poor yields that nowhere near satisfy the demands of a rapidly rising population. On a global scale, demand for agricultural produce is currently at unprecedented levels as a result of increasing populations and consumption per capita. In sub-Saharan Africa (SSA), the world's poorest region, the already high population is set to more than double by 2050 to 2.2 billion. Feeding this huge population increase presents a major challenge to mankind; today, over 200 million Africans are chronically undernourished and 5 million die of hunger every year. To add to these difficulties, are the challenges presented by the impacts of global climate change and the effects of human conflict.

Editing of the symposium proceedings was carried out with great dedication by Professor Takalign Mamo of the Ministry of Agriculture, Addis Abba, Ethiopia and the final draft of the manuscript was ready for publication in late August 2017. Very sadly, and most unexpectedly, however, Professor Mamo passed away on September 4th. This volume is therefore dedicated to his memory as a token of respect.

You can download this publication on the IPI website. For more information, please contact Mr. Eldad Sokolowski, IPI Coordinator for China and SSA/Ethiopia (eldad.sokolowski@icl-group.com). If you wish a hardcopy, please contact ipi@ipipotash.org.

Publications by the PDA



Understanding Phosphate

By A.E. (Johnny) Johnston.
POTASH News, February 2019

I have recently seen two statements that imply that using water-soluble phosphate fertilisers increases the risk of loss of phosphate to surface water, with its adverse environmental implications, and that the majority of the phosphate applied to soil becomes fixed in the soil and is unavailable to plants. Neither statement is true as shown by the results from long-term experiments at Rothamsted and elsewhere. Most fertiliserderived phosphorus that is transferred to surface water is attached to soil particles, and is therefore related to soil erosion, and not to the form in which the phosphate was applied. 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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Effect of Long-Term Application of Rice Straw, Farmyard Manure and Inorganic Fertilizer on Potassium Dynamics in Soil

Saroj Kumar Yadav, Dinesh Kumar Benbi, and Amardeep Singh Toor. 2018. Archives of Agronomy and Soil Sci. 65(3):374-384. DOI: https://doi.org/10.1080/03650340.2018.1505040.

Abstract: Knowledge of K-dynamics in soils can help devise practices for efficient K management in intensive rice-wheat systems. We studied the effect of long-term application of rice straw, farmyard manure (FYM) and inorganic fertilizer on total K and its distribution among different forms in 60 cm soil profile after 14 years of rice-wheat cropping. The exchangeable, the non-exchangeable and the lattice K respectively comprised 1%, 3-10% and 89-95% of total K in surface soil under different treatments. Application of rice straw and FYM positively impacted total K status of soil and its distribution among different forms. The greatest concentrations of total K, lattice K, exchangeable K and NH_4OAc-extractable K were observed in plots receiving both rice straw and FYM together and the lowest in inorganic fertilizer treated plots. On the contrary, the non-exchangeable K was the highest in inorganically fertilized plots and the lowest in rice straw amended plots. The exchangeable, the water soluble and the NH_4OAc-extractable K decreased with soil depth and did not indicate K movement beyond the rooting zone of the crops. The results showed that incorporation of rice residue in soil, instead of burning, besides reducing environmental pollution led to improved K-fertility of soils.

Impact of Soil - Applied Potassium on Cotton Yield

Morgan, G., R. Boman, T. Cutts, D. Delaney, D. Dodds, K. Edmisten, H. Frame, D. Fromme, A. Jones, M. Jones, K. Lewis, R. Nichols, R. Norton, T. Raper, and B. Robertson. 2018. The Fluid Journal 26(4):102.

Overview: Potassium (K) plays a key role in several critical cotton (*Gossypium hirsutum* L.) plant processes, including photosynthesis, activation of protein enzymes, disease and drought stress mitigation, and fiber development. Across the U.S. Cotton Belt K deficiency symptoms in cotton have increased over the past decade, which may be reducing lint yield and fiber quality in these areas. In 2015, a project was initiated at 12 locations across the Cotton Belt with the objectives of: 1) quantifying soil K levels, at depth, from major cotton production regions in the Cotton Belt experiencing K deficiencies, and 2) evaluate the impact of application method and K rate on cotton lint yield, quality, and return on investment (ROI). Based on these results, the goal was to reevaluate soil K recommendations and modify as appropriate to optimize yields. Both granular (0-0-60) and fluid (0-0-15) muriate of potash (KCl) sources of K were applied two to four weeks prior to planting cotton at rates of 8, 40, 80, 120, and 160 lbs./A K_2O. In 2016, trial locations were divided with nine being designated as new sites, meaning that a new field location was selected each year of the study (Alabama, Arkansas, Louisiana, Mississippi, North Carolina, Oklahoma, Texas (Lubbock and Williamson Counties), and Virginia. Discussion of results will include soil potassium concentrations at depths of 0 to 6 inches, 6 to 12 inches, and 12 to 24 inches, and cotton lint yield. Locations other than Texas and Oklahoma generally had soil K levels less than 150 mg/kg critical level of K, Mehlich III extractant, and as such, a yield response to applied K fertilizer was expected. In 2015 and 2016, a significant treatment effect was determined at three of the locations. Two of those, Williamson County, TX, and Virginia, had lower yields than other locations. A positive lint yield response to knife-injected 0-0-15 was determined in 2015 at the Lubbock County, TX, location.

Slow and Fast-Release Boron Sources in Potash Fertilizers: Spatial Variability, Nutrient Dissolution and Plant Uptake

da Silva, R.C., R. Bairda, F. Degrysea, and M.J. McLaughlina. 2018. SSSAJ 82(6):1437-1448. DOI:10.2136/sssaj2018.02.0065.

Abstract: Boron (B) supply to crops is a challenging fertilization practice, due to its high mobility in soil, its narrow window between deficiency and toxicity and the necessity to evenly apply this micronutrient to the soil. We aimed to increase B fertilizer efficacy through the use of slow- and fast-release borate compounds in a macronutrient carrier fertilizer. Borax, ulexite, and colemanite (alone or combined) were compacted with muriate of potash (MOP) to produce B-enriched fertilizers varying in proportion of water-soluble B. One such fertilizer was assessed for spatial B distribution compared with a bulk blend equivalent in a soil tray, while others were assessed for nutrient release in a soil column, and canola (*Brassica napus* L.) growth in a leached and non-leached pot trial. The compacted MOP+B fertilizer improved B distribution in soil compared to a simulated bulk blend. The release of B was fastest for borax (>93% released within 2.5 pore volumes [PV]) and slowest for colemanite (<20% released after 20 PV). The combination of slow- and fast-release B sources resulted in initial fast-release of B followed by a constant slower B release. In leached soil, the higher B losses (up to 80% of applied B) resulted in lower canola B uptake with increasing borax and decreasing colemanite in the formulation. In non-leached soils, there was no difference in B uptake among fertilizer treatments. The use of dual release B sources in MOP+B fertilizer formulations effectively addresses the risk of B loss, and better matches crop B demands during growth.

Critical Dilution Curves for Nitrogen, Phosphorus, and Potassium in Potato Group Andigenum

Gómeza, M.I., S. Magnitskiy, and L.E. Rodrígueza. 2018. Agron. J. 111(1):419-427. DOI: 10.2134/agronj2018.05.0357

Abstract: The critical dilution curves (CDC) for nitrogen (Nc), phosphorus (Pc), and potassium (Kc) obtained from total dry biomass (*W*) and leaf area index (LAI) were used as a diagnostic tool to determine nutrient status and to adjust fertilization rates in two cultivars of potato (*Solanum tuberosum* L.) group Andigenum. The research determined allometric ratios of Nc, Pc, and Kc (%) and nutrition index (NI) based on W and LAI in cultivars Diacol Capiro (Capiro) and Pastusa Suprema (Suprema). Additionally, optimal fertilization rate was evaluated to achieve maximum yields during two growth cycles in contrasting environments of the Andean zone of Colombia. The CDC was validated using *W* in Capiro: $Nc = 6.23W^{-0.320}$; $Pc = 0.523W^{-0.198}$; $Kc = 9.02W^{-0.269}$ and in Suprema: $Nc = 6.74W^{-0.327}$; $Pc = 0.536W^{-0.186}$; $Kc = 6.58W^{-0.135}$ and presented higher robustness than the CDC obtained from LAI. Capiro presented a lower dilution coefficient b for Kc than Suprema. The NI ranged between 0.25 and 1.32 with better fit in Capiro and relative yields (RY) starting from 40% without fertilization; for Suprema, null to marginal response to fertilization was obtained, indicating a luxury uptake of N (NI 1-1.5) with RY starting from 70%. Except for this research, Nc, Pc, and Kc have not been validated for cultivars of group Andigenum. The CDC for this cultivated group could serve to identify deficiency, sufficiency, or excess of N, P, and K, and to predict final yield per cultivar under highland equatorial conditions.

Potential Root Foraging Strategy of Wheat (*Triticum aestivum* L.) for Potassium Heterogeneity

Li Ruan, Xiuli Xin, Jiabao Zhang, Bingzi Zhao, Hao Cheng, Congzhi Zhang, Donghao Ma, and Lin Chen. 2018. Front. Plant Sci. DOI: https://doi.org/10.3389/fpls.2018.01755.

Abstract: Potassium (K) distribution is horizontally heterogeneous under the conservation agriculture approach of no-till with strip fertilization. The root foraging strategy of wheat for K heterogeneity is poorly understood. In this study, WinRHIZO, microarray, Non-invasive Micro-test Technology (NMT) and a split-root system were performed to investigate root morphology, gene expression profiling and fluxes of K^+ and O_2 under K heterogeneity and homogeneity conditions. The split-root system was performed as follows: C. LK (both compartments had

low K), C. NK (both compartments had normal K), Sp. LK (one compartment had low K) and Sp. NK (the other compartment had normal K). The ratio of total root length and root tips in Sp. NK was significantly higher than that in C. NK, while no significant differences were found between Sp. LK and C. LK. Differential expression genes in C. LK vs. C. NK had opposite responses in Sp. LK vs. C. LK and similar responses in Sp. NK vs. C. NK. Low-K responsive genes, such as peroxidases, mitochondrion, transcription factor activity, calcium ion binding, glutathione transferase and cellular respiration genes were found to be up-regulated in Sp. NK. However, methyltransferase activity, protein amino acid phosphorylation, potassium ion transport, and protein kinase activity genes were found to be down-regulated in Sp. LK. The up-regulated gene with function in respiration tended to increase K^+ uptake through improving O_2 influx on the root surface in Sp. NK, while the down-regulated genes with functions of K^+ and O_2 transport tended to reduce K^+ uptake on the root surface in Sp. LK. To summarize, wheat roots tended to perform active-foraging strategies in Sp. NK and dormant-foraging strategies in Sp. LK through the following patterns: (1) root development in Sp. NK but not in Sp. LK; (2) low-K responsive genes, such as peroxidases, mitochondrion, transcription factor activity, calcium ion binding and respiration, were up-regulated in Sp. NK but not in Sp. LK; and (3) root K^+ and O_2 influxes increased in Sp. NK but not in Sp. LK. Our findings may better explain the optimal root foraging strategy for wheat grown with heterogeneous K distribution in the root zone.

The Effect of Potassium on Yield, Nutrient Uptake and Efficiency of Teff (*Eragrostis tef* Zucc. Trotter) on Vertisols of North Western Ethiopian Highlands

Misskire, Y., T. Mamo, A.M. Taddesse, and U. Yermiyahu. 2019. J. Plant Nutr. 42(4):307-322. DOI: https://doi.org/10.1080/01904167.2018.1554681

Abstract: Vertisols are characterized by deficiency of nutrients and recently, potassium (K), a major plant nutrient in crops, is gaining attention because of crop removal, fixation by clay minerals and leaching. A field experiment was conducted during the 2015 and 2016 main cropping seasons to test the effect of potash fertilizer on Vertisols of East Gojjam at Gudalima and Dejen/Tik sites using teff crop. The K rates (applied as muriate of potash) were 0, 50,100, and 150 kg ha^{-1}. The experiment was laid out in a randomized complete block design in three replications. The results indicated that the plant height, panicle length, number of effective tillers, dry matter and grain yield of teff increased significantly ($P<0.05$) with applied K. The highest dry matter and grain yield (6966.4 and 2418.2 kg ha^{-1}, respectively) were obtained from the application of 100 kg ha^{-1} KCl. Total uptake of N, P, and K were enhanced significantly with K treated plots than those without and K efficiency was improved due to the rate of K. The present study demonstrated the importance of K application to supplement NPS for optimum dry matter and grain yield of teff on Vertisols of the study sites.

This research was financially supported by the International Potash Institute (IPI). We gratefully acknowledge IPI for funding the project. We are also grateful to all farmers and extension workers who participated in the study.

Avoiding Potassium Deficiency in Cotton

Mulvaney, M. 2019. IFAS Extension, University of Florida.

Every year, I see more potassium (K) deficiency in cotton. This isn't surprising, since yields have increased with modern cultivars and yield expectations (Fig. 1). The bolls we're asking plants to carry is a lot higher than they used to be. Keep in mind that K is particularly needed during boll set and fiber elongation (along with stomatal regulation and resulting evapotranspiration). In fact, cotton is one of the few crops where demand for K is greater than N.

Finding a Solution to Declining Bahiagrass Pastures

Sollenberger, L.E. 2019. Hay and Forage Grower.

Solving some present-day problems requires revisiting decades-old knowledge. This is the case for pasture decline observed in recent years in Florida beef cow-calf operations.

Several years ago, numerous reports surfaced of bahiagrass pasture decline. Bahiagrass is a hardy perennial that is used on approximately 2.5 million acres in Florida. It is very popular in low-input systems because it tolerates low soil fertility, poorly or excessively drained soils, and less than optimal grazing management. It also has relatively few significant pests. Thus, when producers complain about bahiagrass stand loss, it gets our attention.

Before we try to understand the current situation, let's step back in time to the late 1980s and early 1990s. One of our extension colleagues at the time indicated that "existing recommendations for phosphorus (P_2O_5) and potassium (K_2O) fertilization for bahiagrass may be too high." This statement might cause you to wonder whether the science behind the P_2O_5 and K_2O recommendations was correct.

Actually, the underlying science turned out not to be the problem. Instead, producers were no longer applying the recommended amount of increasingly expensive nitrogen fertilizer, but they had not lowered the amounts of P_2O_5 and K_2O accordingly. In Florida's sandy soils, nitrogen is nearly always the most limiting nutrient for grass growth. If less nitrogen is applied, plant growth slows and less P_2O_5 and K_2O are needed by the plant.

As it became clear that producers were not applying recommended nitrogen fertilizer levels, researchers and extension specialists put their heads together and developed a sliding scale for bahiagrass pasture fertilization. It included low, moderate, and high-nitrogen options for the producer to choose from, with recommendations for P_2O_5 and K_2O depending on the amount of nitrogen applied.

If a producer chose to apply the low nitrogen option (about 50 pounds of nitrogen per acre per year), the new recommendation was to apply no P_2O5 and K_2O in the first year. However, it was recommended that P_2O_5 and K_2O be applied according to soil tests every third or fourth year to avoid excessive depletion of those nutrients. Producers were enthusiastic about reducing fertilizer cost by not applying P_2O_5 and K_2O, and the practice was widely adopted.

Cotton and Soil Responses to Annual Potassium Fertilization Rate

Mozaffari, M. 2018. Scientific Research 9(6):765-775. DOI: 10.4236/as.2018.96054

Abstract: The objective of this study was to evaluate the effect of potassium (K) fertilization rate (0, 27.9, 56.4, 84.7, 112.9, and 141.1 kg K ha^{-1}) and cotton (*Gossypium hirsutumn* L.) cultivars of slightly differing maturity on seedcotton yield and Mehlich-3 soil-test K concentrations. The cotton cultivars "Stoneville 4892" and "Stoneville 5599" represented long-season cultivars while "Paymaster 1218" and "Deltapine 444" represented early-season cultivars. The same K fertilizer treatments were applied to the same plots during the three years of the study. Higher order interactions of cropping year, cotton cultivar and K-fertilization rates were not significant ($P \geq 0.50$), indicating the two cultivars of slightly different maturity respond similarly to K-fertilization. Cropping year and K-fertilizer application rates significantly affected seedcotton yield ($P < 0.0001$). Potassium fertilization did not significantly influence seedcotton yield in the first year but significantly increased seedcotton yield in second and third year ($P \leq 0.0074$), as well as 3-year average, and total seedcotton yields ($P \leq 0.0006$). Seedcotton yields ranged from 3,418 to 4,127 kg·ha^{-1} and 2,980 to 3,487 kg·ha^{-1} in the second and third year respectively while 3-year average and total seedcotton yields were 2,943 to 3,443 and 8,832 to 10,330 kg·ha^{-1}. The relation between annual, 3-year average, and total K application rates and seedcotton yield was linear ($R^2 \geq 0.82$, $P \leq 0.0125$). Potassium fertilization significantly increased post-harvest (fall) Mehlich-3 extractable soil K in all three years ($P \leq 0.0002$). This study indicated that, in a representative Mississippi River Delta silt loam soil, when Mehlich-3 extractable K was <98 mg·kg^{-1}, K fertilization was needed to increase seedcotton yield and prevent soil K depletion. This supports the current University of Arkansas fertilizer recommendations for irrigated cotton production, where application of 56 kg of K ha^{-1} is recommended to optimize seedcotton yield and prevent soil K reserve depletion when Mehlich-3 extractable soil test K is medium (91-130 mg kg^{-1}).

Potassium Fertilisation with Humic Acid Coated KCl in a Sandy Clay Loam Tropical Soil

Rosolem, C.A., D.S. Almeida, K.F. Rocha, and G.H.M. Bacco. 2017. Soil Research 56(3):244-251. DOI: https://doi.org/10.1071/SR17214.

Abstract: Loss of potassium (K) by leaching after potassium chloride (KCl) application is common in light-textured, low cation exchangeable capacity (CEC) soils with predominance of 1 : 1 clay minerals, and is aggravated as soil K concentration increases. Coating of KCl with humic acids may be a strategy to avoid loss and supply K over the plant cycle. The objective of this study was to evaluate the response of maize (*Zea mays*) and soybean (*Glycine max*) to regular KCl and KCl coated with humic acid, as well as K leaching as affected by application of these fertilisers in single or split application to soils with different K levels. Field experiments with maize and soybean were conducted on soil with very low, low, and medium exchangeable K levels, in Botucatu, Brazil. Soybean and maize grain yields were higher with a single application of coated KCl compared with regular KCl, in soil with very low K level; however, when the rate was split, yields were higher with regular KCl. This shows the importance of fertiliser K release synchronisation as the plant develops, avoiding possible K losses by leaching in low CEC soils. Potassium leaching was observed in soil with medium K level. Potassium chloride coated with humic acids is an adequate source of K in low CEC soils with very low K level when applied in a single application at planting, as opposed to regular KCl that must be split. However, the coated fertiliser is not effective for avoiding K leaching in soils that are medium or high in K.

Effects of Potassium Fertilisation on Late Potato Blight and Yield - Short Communication

Kowalska, J., and D. Drożdżyński. 2018. Plant Protect. Sci. 54: 87-91. Czech Academy of Agricultural Sciences. DOI: https://doi.org/10.17221/79/2017-PPS

Abstract: Potato yields and infestation by P. *infestans* are related to the supply of potassium. Potassium was applied as soil fertilisation combined with split foliar applications or only as split foliar treatments at a maximum dose of 150 kg ha^{-1} K_2O in both strategies, Lord and Ditta cultivars were used. Additionally, water spraying was included as an alternative treatment in order to maintain uniform moisture in the rows of plants. Plants fertilised with foliar spraying only were more infested than plants fertilised with combined methods. The fertiliser increased the protection impact of copper treatments against P. *infestans*. This may suggest a possible synergistic effect in reducing the symptoms of the disease, however not always statistically significant in both cultivars. Plants sprayed with water but without soil application of fertiliser showed a statistically significantly higher infestation

rate, both in Lord and Ditta cultivars, compared to plants with soil application of fertiliser but without watering.

Olive Response to Potassium Applications Under Different Water Regimes and Cultivars

Ferreira, I.Q., M. Arrobas, J. Moutinho-Pereira, C. Correia, M.Â. Rodrigues. 2018. Nutrient Cycling in Agroecosystems 112(3):387-401.

Abstract: Although potassium (K) is a macronutrient few studies have evaluated the response of olive tree to K fertilization. In this work results of two field and two pot K fertilizer experiments are presented. One of the field trials was conducted in a commercial young olive grove. The second was conducted in a plantation purposely established for this study. In the two field and the first pot experiment, the K supply was the single variation factor. The second pot experiment was arranged as a factorial with two K rates, two water regimes and two cultivars ('Arbequina' and 'Cobrançosa'). K supply did not increase olive tree growth or yield. Accumulated olive yield in the first field experiment, for instance, varied from 2.46 and 2.84 kg tree^{-1}, respectively in K treated and untreated plants. K supply increased the shoot/root ratio (1.6-2.0 from the control to the most fertilized treatment) and the concentration of K in roots (2.9-11.2 g kg^{-1}) to a greater extent than in leaves (7.0-11.9 g kg^{-1}), suggesting that shoots are a priority sink for K and roots may store the nutrient as a reserve. Plant water status and chlorophyll a fluorescence were not significantly affected by K applications. Plants suffering from water stress yielded less phytomass (40.2-56.4 g pot^{-1}, respectively in control and well-watered plants) and showed higher K concentrations in leaves (14.2-11.6 g kg^{-1}) and lower in roots (4.9-6.8 g kg^{-1}) which is probably due to the reduction of K uptake from the dry soil. 'Cobrançosa' appeared to be more tolerant to water stress than 'Arbequina'. These experiments showed a poor response of olive tree to K fertilization. Considering that K is usually applied by farmers every year, it seems that further studies on K fertilization in olive are needed in order to adjust K fertilizer rates to crop needs.

Read On

5 Reasons Why Fertilizers are Key for Transforming Agriculture

2019. IFA.

Norman Ernest Borlaug, American Scientist

Nobel Peace Prize Winner and "Father of the Green Revolution". 2019. By the Editors of Encyclopaedia Britannica. 2019.

It's an Uphill Battle: The MYB_{59}-$NPF_{7.3}$ Regulatory Module and its Role in Nutrient Transport

Castroverde, C.D.M. 2019. The Plant Cell. DOI: https://doi.org/10.1105/tpc.19.00032

We Should Discuss Soil As Much As We Talk About Coal

Gates, B. 26 March 2019. Gates Notes.

Clipboard

New IPI Website: Perfect Balance of Old and New

The IPI has a new website. After months of work planning, building, and testing we are pleased to announce that the new site is now live and ready for you to use.

Combining historic strength with modernity

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As with all good websites, development of the new IPI site does not end here. We expect it to evolve and grow to meet the needs of the IPI, and also of our online visitors. We already have plans to extend the site further, adding new features and tools - all with the goal of developing and promoting balanced fertilization.

Obituary for Dr. Ricardo Melgar

IPI remembers Dr. Ricardo Melgar

"Agricultural production cannot do without fertilizers and consequently the value chain that feeds the industry," said Dr. Ricardo Melgar a few years ago. Today, we are saying goodbye to him with deep regret after he passed away on 3 February 2019 after struggling with a severe illness.

Ricardo was an agronomist who received his degree in 1978 from the National University of the Northeast, Argentina. He joined the National Agricultural Research Institute (INTA) with a scholarship and began his career at the INTA experimental station of Bella Vista, Corrientes. In 1989, he obtained a PhD in soil fertility from the State University of North Carolina in the US and, in 2001, completed a Master's in agribusiness at the Faculty of Agronomy at the University of Buenos Aires.

In 1994, Ricardo became Coordinator of the Soil Management Program at INTA Pergamino, where he worked as a Principal Researcher, coordinating research groups on soil fertility and fertilizer management - a role he also undertook for the sub-program of the Soil Management Institute for the Humid Regions. He conducted and coordinated countless fertilizer experiments during his fertile career and his work has led to an increase in more balanced nutrient use in Argentina, as well as improved sustainability of agricultural soils.

Ricardo had more than 30 years of experience across Argentina and Mercosur and was a senior consultant for various fertilizer and agribusiness companies, operating in fertilizer and grain markets in Argentina and the wider region. He created and coordinated FERTILIZAR, a joint project between INTA and Argentinean fertilizer companies, which carried out field work on fertilization for increased crop production and maximimum farmer profit.

As a leader in transferring knowledge on soil fertility and fertilizer use to farmers, Ricardo was also the author of countless technical publications related to fertilization. His impressive body of work addresses the whole chain, from field experiments and detailed basic research, to last mile delivery in the form of publications, courses, meetings and electronic media.

Ricardo generously shared his talent and skills and exemplified the qualities of an outstanding, dedicated professional, who had a gift in making complex subjects understandable.

An accomplished communicator, he was a humble and approachable person who loved to share information with students and farmers. As a true collaborator, Ricardo worked seamlessly with researchers, field workers, students, agronomic consultants from private companies, extension workers, farmers associations, international institutions and, of course, farmers.

Ricardo was also a longtime collaborator with IPI. As a prolific IPI partner, we highlight, in particular, an extensive long-term fertilizer research across six experimental stations over five seasons, which yielded crucial information regarding nutrient uptake and soil fertility management in Argentina.

From IPI, we recognize Ricardo's valuable contribution to crop fertilization and we thank him for his dedication to the care and sustainability of soils. We will miss him a lot. Rest in peace, our friend.

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