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Optimizing Crop Nutrition

Editorial

Dear readers,

Economics of fertilizer use has always been of high concern. "In times like the present, when farming conditions and produce markets become difficult, some advise farmers that the best way to weather the storm is to cut costs: savings can be made on the outlay on fertilizers. They say that yield increases over the years have not matched the increase in fertilizer use; that yield targets have been set too high; that, when produce prices fall, lower yields are acceptable especially as higher yields will lower prices; that it is not necessary to build up soil fertility and that advice to do so leads to over-use of fertilizers… as far as maize growing in South Africa is concerned, these ideas are false." Although this sentiment is familiar to us today, this statement from South Africa is taken from IPI's Potash Review report dating back to 1980 and much is still relevant today.

"There is no doubt of the great importance of the prices in shaping the use of fertilizers. However, of even greater importance is the dissemination of technical knowledge. The better the command of the farmers of the technique of manuring, the higher the level to which they lift the limiting-yield curve". This is also relevant, yet is a quote from IPI's Potash Review published in 1956 - now over 50 years ago.

Clearly the question of the benefit-to-cost ratio of fertilization has always been an issue, and more so during times of high fertilizer price and economic constraint. Uncertainty of the benefit from fertilization may always exist (and even just because climate is so unpredictable), so knowing more about efficient fertilizer use is crucial.

As always, reducing fertilizer rates will impact on yield. But these days, farmers can employ better tools to make fertilizer use more efficient, including using more efficient delivery systems, monitoring nutrients in soil and plant, and using remote sensing images - and decision support systems. Using these will increase the benefit-to-cost ratio of fertilizer application. And so we reach the same conclusion as in 1956 stated above: the more knowledge, the higher the limiting-yield curve can be lifted.

I wish you all an enjoyable read.

Hillel Magen
Director

Research Findings

Field experiment in potato crop, Lípa. Photo by P. Cermák.

Nutrient Balance in Long-Term Field Experiments in the Czech Republic

Cermák, P.[(1)(2)], and M. Smatanová[(3)]

Abstract

Long-term field trials provide an invaluable source of information demonstrating the effects of continuous and specific rates of application of fertilizers over many years on soil properties and yields of crops. In the Czech Republic, The Central Institute for Supervising and Testing in Agriculture (CISTA) controls long-term field experiments set up under different soil and climatic conditions. Based on the results from these experiments, it is possible to calculate nutrient balance (nitrogen (N), phosphorous (P) and potassium (K)) and thereby determine optimal nutrient application rates for sustainable good quality crop production. From this data, we conclude that to achieve profitable yields whilst simultaneously maintaining soil fertility, on average annual rates of 100-120 kg of N, 30 kg of P_2O_5 and 100-150 kg of K_2O are required per hectare.

Introduction

Over the past twenty years, agriculture in Central and Eastern Europe (CEE) has been impacted by political and economic change. Following the breakdown of the communist regimes in 1990, crop yields declined by about 20 to 30 percent across most of the region. In the Czech Republic, this occurred as a result of a dramatic reduction in mineral fertilizer consumption which occurred simultaneously with a decrease in farm animal populations so that the return of nutrients to the soil from farmyard manure (FYM) also declined (Klír, 1999; ČSÚ, 1999, 2000).

From a long-term perspective of sustainable farming, agricultural practice throughout Europe must be based on uncompromising replacement of essential nutrients (N, P, K and Mg) removed from the soil. Yield and quality of products are thereby maintained whilst soil fertility is protected (Douthwaite, 1998). Nutrient balance calculations based on Soil Surface Balance (SSB) and Farm Gate Balance (FGB) are suitable means for assessing long-term effects on the agro-ecosystem from sustainability and economic points of views, as well as being able to provide environmental performance indicators for policy issues (van Beek *et al.*, 2003). Long-term field experiments (LTFE) have recently become regarded as an invaluable source of information

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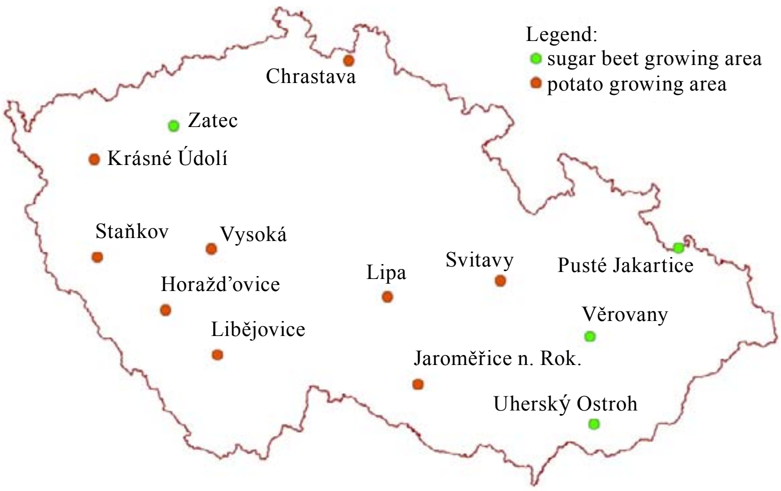

Map of LTFE experimental locations in the Czech Republic (Table 1).

Table 1. LTFE experimental sites (see also map).

Experimental site	Growing area	Elevation above sea-level	Climatic conditions ∅ annual rainfall	∅ annual temperature	Soil type	Soil texture	Soil organic carbon-C_{ox}
		m	*mm*	*°C*			*%*
Horažďovice	PGA	472	573	7.4	cambisol	loamy-sand soil	1.22
Chrastava	PGA	345	798	7.1	orthic luvisol	loamy-sand soil	0.75
Jaroměřice	PGA	425	535	7.5	orthic luvisol	loamy soil	1.13
Krásné Údolí	PGA	645	605	6.1	cambisol	sandy-loam soil	1.48
Libějovice	PGA	460	606	7.6	orthic luvisol	sandy-loam soil	1.23
Lípa	PGA	505	629	7.6	cambisol	sandy-loam soil	1.25
Staňkov	PGA	370	511	7.8	orthic luvisol	loamy soil	1.17
Svitavy	PGA	460	624	6.5	orthic luvisol	sandy-loam soil	0.96
Vysoká	PGA	595	655	7.4	planosol	loamy soil	1.66
Pusté Jakartice	SBGA	290	650	8.0	orthic luvisol	loamy soil	1.04
Uherský Ostroh	SBGA	196	551	9.2	orthic luvisol	loamy soil	1.26
Věrovany	SBGA	207	562	8.5	chernozem	loamy-clay soil	1.30
Žatec	SBGA	247	451	8.3	chernozem	loamy-clay soil	1.62

Note: Data of rainfall and temperature are 50 year averages; data of soil organic carbon was analysed in 1971 before establishment of the trials.

on the effects of agricultural measures on the soil environment especially at the present time, when the low intensity of fertilization and liming is beginning to be reflected in a marked deterioration of reserves of available nutrients in the soil and in increased soil acidity.

Based on results from the CISTA LTFE, it is possible to calculate nutrient balances and thereby determine optimal rates of nutrient application for sustainable good quality crop production. Below we discuss some of the findings obtained from LTFE and discuss their relevance to practical farming.

Material and methods

Characteristics of experimental sites

CISTA has collected soil and crop nutrient data from 13 experimental sites since 1972 from several kinds of LTFE under different soil and climatic conditions of the Czech Republic (Table 1 and Map). These soil and climatic differences have determined growing areas of sugar-beet and potatoes:

- Sugar-beet growing areas (SBGA): higher soil fertility, more conducive climatic conditions (higher temperatures).
- Potato growing areas (PGA): lower soil fertility, less conducive climatic conditions (lower temperatures).

Some combinations from the first (and simultaneously the oldest) LTFE for observing yields of crops were re-calculated as Cereal Units (CU). Measurements were made on nutrient concentrations in crops and soil properties, under the various rates of nutrient application. This data was used for the nutrient balance calculation.

Combination of fertilization and crop rotations

The experimental design of the CISTA LTFE includes 12 combinations of fertilization (6x repeated). The crop rotations (nine years 1972-1980 and 1981-1989; next two eight years 1990-1997 and 1998-2005) contain 50 percent of cereals, 25 percent of root crops and 25 percent of fodder crops.

Nitrogen, phosphorus and potassium fertilizers were applied at three levels - low (level 1), medium (level 2) and high (level 3) (Tables 2 and 3). Farmyard manure (FYM) was applied twice during a crop rotation cycle before root crops in combinations No. 2-12. The application rate was 35 mt ha^{-1} of FYM in the years 1972-1989 and 40 mt ha^{-1} of FYM in the last two crop rotations (since 1990).

Nutrient balance calculation

Nutrient balance calculations at field level are based on the difference between nutrient input and nutrient output. Modelling fertilizer rates (N) and grain yield data from field experiments has also been used in nutrient balance calculations (Olness *et al.*, 1998; Vagstad and Eggestad, 1998). Essentially, it is necessary to keep nutrient inputs and outputs in balance to maintain soil fertility.

Soil surface balance (SSB)

Nutrient inputs were calculated for fertilizers and manure applications. Nutrient outputs were calculated for offtake by the removal of the harvested crop, and straw or haulm removal of the various crops. Crop and soil nutrient

Table 2. The experimental design.

Combinations of fertilization	Organic manure	Mineral fertilization	Method of fertilization	Lime application
1	0	0		without
2	Twice FYM during	0		where necessary,
3	a crop rotation cycle	$N_2P_2K_0$	P and K as a	according to results
4	before root crops	$N_2P_2K_1$	"reserve" fertilization	of annual soil testing
5	|	$N_2P_2K_2$	|	|
6	|	$N_2P_2K_3$	|	|
7	|	$N_2P_0K_2$	|	|
8	|	$N_2P_1K_2$	|	|
9	|	$N_2P_3K_2$	|	|
10	|	$N_1P_1K_1$	|	|
11	|	$N_3P_3K_3$	|	|
12 SBGA	|	$N_3P_3K_3$	P and K every year	|
12 PGA	|	$N_3P_3K_3$	P and K as a reserve	without

Note: combinations 1, 2, 5, 10 and 11 were used for nutrient balance calculation.

Table 3. Average annual doses of nutrients (elemental and oxide forms) in mineral and organic fertilizers (kg ha^{-1}).

Fertilizers	Level of nutrients	SBGA			PGA		
		N	P_2O_5	K_2O	N	P_2O_5	K_2O
		kg ha^{-1}					
$N_1P_1K_1$	1 - low	58	48	61	58	53	69
$N_2P_2K_2$	2 - medium	87	76	97	88	80	108
$N_2P_2K_3$	3 - high	115	112	143	117	116	158
FYM		25	17	43	25	17	43

Table 4. Average annual yields for the period 1972-2009 in both SBGA and PGA areas (in CU ha^{-1} units, average of 37 years).

Treatment		SBGA		PGA	
		Ave. CU yield	Change	Ave. CU yield	Change
		mt ha^{-1}	*%*	*mt ha^{-1}*	*%*
T_1	Without fertilization	6.33	100.00	4.78	100.00
T_2	FYM	6.92	109.32	5.31	111.00
T_3	FYM + $N_1P_1K_1$	7.85	124.04	7.21	150.70
T_4	FYM + $N_2P_2K_2$	7.94	125.45	7.72	161.30
T_5	FYM + $N_3P_3K_3$	8.06	127.33	8.13	170.00

Note: rate of nutrients applied (in T_3-T_5) corresponds to level of nutrients (low 1-high 3) in Table 3.

determinations were made according to the analytical methods used by CISTA (Zbíral, J. a kol., 2005).

Results

Average annual yield in growing areas

In the SBGA, with soils of higher fertility, application of manure (FYM) increased yields by approximately 9 percent and mineral fertilization by about 24-27 percent. In the PGA, the effect of the nutrients was higher and fertilizers increased yield by about 50 to 70 percent (Table 4). Overall, the combination of nutrients from fertilizers and from manure played a significant role in increasing the yields: not only did the average, maximum CU yield in the PGA exceed that of the SBGA (8.13 and 8.06 mt ha^{-1}, respectively), but also the rate of increase was much higher (in the PGA), raising the profitability of fertilization.

Nitrogen balance

In the SBGA the nitrogen balance (Fig. 1A) i.e. N offtake as measured by total harvest production (roots + haulm) compared with N fertilizer application, was negative up to a high level of N fertilizer supply, i.e. 140 kg of N ha^{-1}. Only at the high level of N-fertilization (T_5) was there a positive balance for the main product (the roots) and that was only +19 kg of N ha^{-1}. A similar situation occurs in the PGA (Fig. 1B) where a positive N-balance of the main product (tubers) only accounted for +17 kg of N ha^{-1} at the high level of N fertilization (T_5).

In this simplified form of balance, the amounts of nitrogen from atmospheric deposition and from biofixation were not taken into account. Had these contributions been included, offtake and input of N would probably have been fairly well balanced or slightly positive even at a medium level of N fertilization. When N is supplied in excess of that taken up by the crop, the higher the N application, the more N is going to be lost by leaching and in gaseous form.

Phosphorus balance

Phosphorus offtake and input were already well-balanced at low levels of phosphorus fertilization (i.e. FYM + 30 kg P_2O_5 ha^{-1}) (Figs. 1C and 1D respectively). Increasing rates of fertilizer application increased phosphorus balance surplus. Interestingly the difference between the phosphorus total offtake (harvest plus haulm) and offtake by the harvested part of the crop only was quite small (not more than 10 kg ha^{-1}). This implies that for the P SSB calculation, there was no significant difference between the two types of calculation.

Potassium balance

For the potassium balance a clear difference was evident between the two growing areas (SBGA and PGA; Fig. 1E and 1F). In the SBGA, the potassium balance was negative at all levels of fertilization for the harvest of total production (i.e. total offtake). But at the harvest of the main product only, potassium balance was positive at all levels of mineral fertilization.

In the PGA, the potassium balance was positive at the high level (K3) of fertilization at harvest for total production. The

Field experiment in winter wheat crop, Jaromerice. On the left, unfertilized plot, and on the right, a $N_3P_3K_3$ combination, separated by a border belt (center). Photo by P. Cermák.

second potassium level (K2) showed a positive K balance at harvest of the main product only. On the other hand, at this level (K2) a negative balance resulted for harvest of total production. A similar situation also occurs at the first level of potassium fertilization (K1). In the PGA the positive effect of by-product on balance was evident.

Conclusions

Application of manure (FYM) increased yields modestly by approximately 9% in the SBGA and about 11% in the PGA areas. However, when applying only FYM, nutrient balance was similar to the control and highly negative in both growing areas, at a range of 100-150, 20 and 100 kg of N, P and K ha^{-1}, respectively.

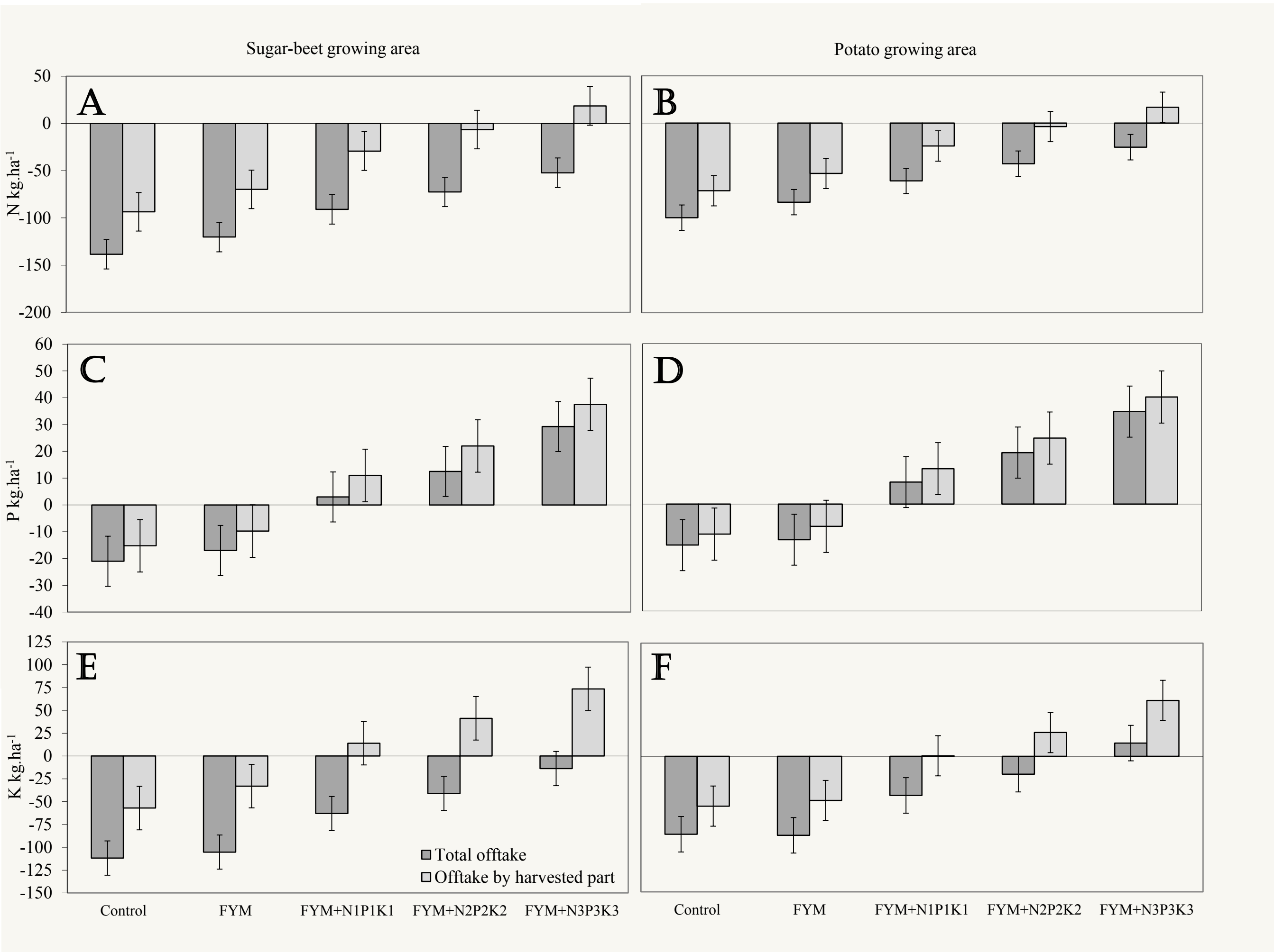

Fig. 1. (A-F): Average nitrogen (A & B), phosphorus (C & D) and potassium (E & F) balance in SBGA (left column) and PGA (right column). Data represents the average over 37 years; kg of nutrient ha^{-1} in four locations; bars represent standard error (SE).

Due to its lower initial fertility, the beneficial effect of fertilizers in the PGA, increased yields by about 50 to 70% (depending on the increasing application rates), whereas in the SBGA, with soils of higher fertility, yields increased to a lesser extent, by about 24-27%.

In both growing areas the nitrogen balance was negative up to a high level of N fertilization. Even at the highest levels of N application, once crop and haulm were removed, N balance was negative.

For phosphorus, offtake and input were already well-balanced at the first level of P fertilization. Increasing P application rates increased the P balance surplus in both the SBGA and the PGA.

In both the SBGA and the PGA, potassium balance was sensitive to the level of K application and to the offtake: clearly, the management of haulm or the non-harvested part of the crop affected K balance. When all plants parts were removed, K balance was always negative, except at the high level of K application in the PGA. However, when only the harvested part accounted for offtake of K, K balance was positive at the higher two K rates.

Based on these results, we conclude that optimal average application of nutrients for plant nutrition in SBGA should be approximately 160 kg of N, 20 kg of P (50 kg of P_2O_5) and 125 kg of K (150 kg K_2O). We also conclude that in the PGA (lower soil fertility and less conducive climatic conditions due to lower temperatures), nutrient requirements to maintain nutrient balance are slightly lower, at approximately 140 kg of N, 20 kg of P (50 kg of P_2O_5) and 125 kg of K (150 kg K_2O).

Effective average annual rates for obtaining adequate yields and simultaneous preservation of suitable contents of nutrients in the soil are: 100-120 kg of N, 13 kg of P (30 kg of P_2O_5) and 80-125 kg of K (100-150 kg of K_2O) = in sum of elementary nutrients 193-258 kg ha^{-1}, or 230-300 kg of oxide form of nutrients per hectare. Upper limits are suitable for poorer and pervious soils in the PGA.

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The paper "Nutrient Balance in Long-Term Field Experiments in the Czech Republic" also appears at:

Regional Activities/Centrel Europe

Research Findings

Foliar K increases fruit yield of clementine var. *Cadoux*. Photo by the authors.

Response of Clementine Citrus var. *Cadoux* to Foliar Potassium Fertilization; Effects on Fruit Production and Quality

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Abstract

Clementine var. *Cadoux* is a citrus fruit that is well appreciated by consumers. However, this cultivar tends to produce fruits of small to medium size that are less accepted commercially. In this field study, we evaluated the effects of various rates and frequencies of foliar potassium (K) fertilization, as either potassium nitrate (KNO_3) or potassium sulfate (K_2SO_4), on fruit production (fruit size, weight and yield) and quality parameters (skin thickness, firmness, color index, maturity index, juice content, acidity and total soluble sugars). Application rates of tested foliar fertilizers were 5 percent and 8 percent KNO_3, and 2.5 percent and 4 percent for K_2SO_4, applied either two or three times during fruit growth on orchards of three planting densities (D_1: 6 x 6 m, D_2: 5 x 6 m and D_3: 6 x 3.5 m tree spacing). The levels of K in leaves of clementine var. *Cadoux* increased by up to 40 percent two weeks after the last foliar K application. Fruit weight increased with K application rate and frequency. K fertilization treatments in three foliar applications showed the best percentages of fruits of extra size class, whatever the source of K (KNO_3 or K_2SO_4) or plant density. Foliar applications of K increased fruit color, firmness and rind thickness. Fruit juice content, acidity and total soluble sugars were slightly increased by foliar K application. Raising K concentration and the number of foliar applications increased tree fruit production. In terms of efficiency of foliar K fertilizers, 4 percent K_2SO_4 in three applications resulted in a maximum gain of fruits per kg of foliar fertilizer.

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Introduction

The citrus industry plays an important role in Moroccan agriculture. Morocco is the world's fourth largest fresh citrus exporter and the third for clementine (USDA, 2010). Citrus exports amount to around 500,000 tons per year, generating annual revenue of 3 billion dirhams. An area of 85,000 ha is devoted to citrus cultivation with an annual production of 1,300,000 tons of fruit. In social terms, the citrus sector provides more than 21 million workdays and is the main source of income for 13,000 farming families.

The national average yield of citrus is 17 tons per hectare, which is considered low compared with other major citrus producing countries. The identified constraints to citrus productivity are ageing orchards, scarcity of water, management inefficiencies and losses due to pests and diseases.

Given the global market requirement for quality citrus fresh fruit in the context of globalization and the emergence of new citrus producing countries, Morocco is expected to review its citrus sector strategy to improve its competitiveness. The Morocco Green Plan agricultural strategy considers the citrus industry as a pilot sector and provides a plan for renewal of old orchards and greater utilization of drip irrigation.

Increasing citrus exports is very often restricted because fruit quality is not high enough to meet the standards imposed by foreign markets. Citrus packing stations, for example, record high reject rates of above 25 percent. Several factors are responsible for this, such as fruit damage from pests and diseases, inadequate mineral nutrition, etc. For clementines and mandarins, it is mainly small fruit size which is considered the principal reason for rejection. Several techniques are used to combat this, such as application of growth hormones, tree pruning etc. The final fruit size in a given year depends on several factors, including tree fruit load, precipitation, fertilization program, tree pruning and combination of variety/rootstock. Of all these factors, fertilization practices are probably the easiest to control. Potassium (K) fertilization, in particular, is known to greatly affect fruit quality.

Citrus fruit quality for the fresh market, in the case of Moroccan exports, is judged by fruit size and skin texture. K deficiency leads to the production of small fruits with thin skin, while an excess of K results in production of large fruit with thick skins and a coarse texture. Regarding the quality of the juice, excess K induces high acidity. K fertilization is thus an important tool to optimize the quality of citrus fruit and juice.

Until recently, fertilization practices were primarily directed towards obtaining high yields and it is only recently that interest has grown in the positive effect of fertilization on citrus fruit quality, particularly in relation to phosphorus (P) and K. Foliar fertilization with K is a practice that now offers a means of reaching these goals of high yield and improved fruit quality.

The research results presented in this article reveal the improvement of both production and fruit quality of clementine citrus var. *Cadoux* in response to foliar K fertilization by application of different rates and frequencies of potassium nitrate (KNO_3) or potassium sulfate (K_2SO_4).

Material and methods

Experimental site

The experiment was conducted in 2007 at Sidi Allal Tazi experiment station of INRA, located in the Gharb plain of Morocco. The soil type is clay and the citrus clementine variety used was *Cadoux*, grafted on *citrange Carrizo*. Healthy and homogeneous trees, aged 23 years, showing no signs of mineral deficiency were selected for this experiment. The experimental design was a split plot design with three blocks, three increasing planting densities (D_1: 6 x 6 m, D_2: 5 x 6 m and D_3: 6 x 3.5 m tree spacing) (large plots) and nine foliar K fertilization treatments (small plots).

Soil analysis indicated that the different horizons had sufficient and acceptable contents of organic matter, P and K for production of clementine (Table 1).

Table 1. Soil pH, organic matter, P and K content of the experimental site.

Soil horizon	pH (water)	Organic Matter	P_2O_5	K_2O
cm		*%*	----------*ppm*----------	
0-30	7.7	2.1	41.8	497
30-60	7.9	1.6	11.9	319
60-90	8.2	1.4	4.9	229

Experimental treatments

Experimental treatments consisted of different K fertilization rates (concentration) and a number of foliar applications (two or three times) for a given planting density (D_1, D_2 or D_3). Two sources of K (soluble mineral fertilizers) were tested: KNO_3 and K_2SO_4. Application rates of tested foliar fertilizers were 5 percent and 8 percent KNO_3, 2.5 percent and 4 percent for K_2SO_4. The control was sprayed with water alone. Concentrations of KNO_3 applications correspond to those recommended in the literature (Obreza *et al.*, 2008; Abd-Allah, 2006; Erner *et al.*, 2004; Erner and Ya'acov, 2004). The applied rates for K_2SO_4 correspond to a K content equivalent to that contained in KNO_3. The dates of foliar applications were as follows: July 16, August 3 and August 21, 2007. At a given application date, each tree was sprayed with ten liters of the foliar K fertilizer.

Measurements

The measured production parameters in this study were fruit size, weight and yield. Monitored fruit quality parameters were skin thickness, firmness, color index, maturity index, juice content, acidity and total soluble sugars. Skin thickness was measured on ten fruit skins using a caliper. Fruit firmness was measured with a penetrometer (Koehler, France). Color measurements were determined using a colorimeter (Minolta CR-400; Konica Minolta Sensing, Inc) from which maturity index was derived. Juice content was extracted from ten fruits, acidity was determined by Sodium hydroxide (NaOH) titration and total soluble sugars were measured using a digital refractometer (PAL-1, Atago Co., Japan).

Results and discussion

Effects of foliar K fertilization on mineral elements content in leaves

The levels of K in leaves of clementine var. *Cadoux* increased two weeks after the last foliar K application. This increase was observed in all treatments except in the control where a slight decrease in leaf K content was noticed (Table 2).

The increase of K concentration in the leaves of fertilized trees was independent of the source of K (KNO_3, K_2SO_4) and the number of foliar applications. The increase in K after foliar K applications reached 40 percent, while in the control that content dropped 15 percent from its level before foliar fertilizer applications.

This marked increase in K content of citrus leaves indicates the effectiveness and speed of absorption of K when applied as a foliar fertilizer to leaves (Opazo and Razeto, 2001) as compared to conventional soil application.

Levels of P and magnesium (Mg) were not affected by foliar K applications. In all treatments, Mg concentrations were below optimum before and after foliar applications of K, while calcium (Ca) content was at optimal levels.

Effects of foliar K fertilization on citrus fruit parameters

Fruit weight

The highest average weight, about 96 g per fruit, was recorded in the medium planting density (D_2: 6 x 5 m) while the lowest average weight, about 91 g, was obtained with the highest density (D_3: 6 x 3.5 m). Regardless of planting density, the control treatment had the lowest values of fruit weight (Fig. 1).

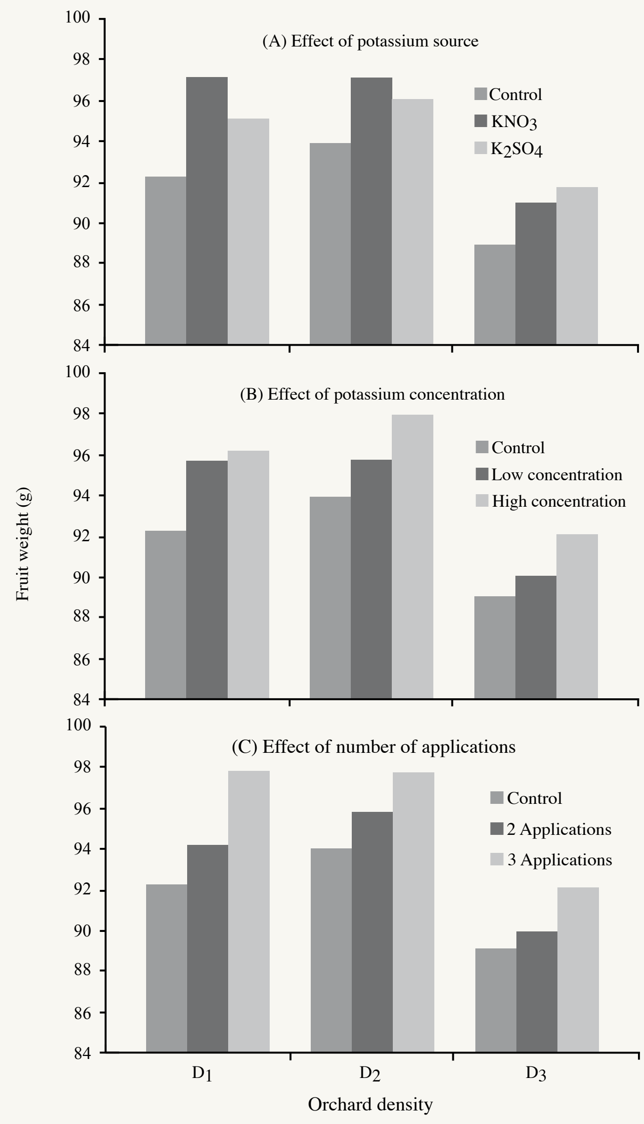

Fig. 1. Effects of foliar K fertilization on fruit weight of clementine var. *Cadoux*: (A) Effect of K source, (B) effect of application rate, and (C) effect of number of applications.

At the low density D_1, treatment with 8 percent KNO_3 in two or three foliar applications, proved most effective in improving average fruit weight. These treatments had respective weights of 98.2 and 98.6 g (Fig. 1). Two foliar applications recorded the lowest average fruit weight compared to other treatments.

In terms of efficacy, treatments with high concentrations of K (8 percentKNO_3 or 4 percent K_2SO_4) in three foliar applications are to be recommended to increase weight and size of clementine fruit.

Table 2. P, K, Ca and Mg levels (percent dry matter) in leaves of clementine var. *Cadoux* before and two weeks after the last foliar K application.

Treatments	P		K		Ca		Mg	
	Before	After	Before	After	Before	After	Before	After
	--% of DM--							
Control	0.16	0.14	1.88	1.60	4.04	4.76	0.28	0.23
5%-KNO_3 x 2	0.15	0.16	1.84	2.32	4.12	4.16	0.25	0.26
5%-KNO_3 x 3	0.18	0.15	1.88	2.48	4.00	3.60	0.22	0.23
8%-KNO_3 x 2	0.13	0.16	1.76	2.20	5.32	4.24	0.27	0.26
8%-KNO_3 x 3	0.12	0.16	1.72	2.08	4.44	3.96	0.26	0.26
2.5%-K_2SO_4 x 2	0.18	0.17	1.88	2.64	3.56	3.92	0.25	0.25
2.5%-K_2SO_4 x 3	0.19	0.15	2.04	2.28	4.24	4.32	0.38	0.27
4%-K_2SO_4 x 2	0.13	0.17	1.80	2.48	4.28	3.24	0.25	0.23
4%-K_2SO_4 x 3	0.16	0.15	1.76	2.24	3.68	3.88	0.23	0.23

Table 3. Distribution of fruit number (%) of clementine by size class in response to foliar K fertilization for the low (D_1), medium (D_2) and high (D_3) planting density.

Treatments	Cal 1-3 57 to 63 mm			Cal 4 51 to 56 mm			Cal 5 44 to 50 mm			Cal 6 41 to 43 mm			Out of range <40 mm		
	D_1	D_2	D_3	D_1	D_2	D_3	D_1	D_2	D_3	D_1	D_2	D_3	D_1	D_2	D_3
	%														
Control	7.8	9.2	7.6	68.9	52.8	30.5	23.3	11.5	24.2	0	15.3	24.6	0	11.2	13.2
5%-KNO_3 x 2	22.2	17.3	14.4	67.8	72.2	63.3	10.0	7.1	4.3	0	3.3	3.2	0	0	14.7
5%-KNO_3 x 3	63.3	60.8	54.2	36.7	37.4	30.2	0	1.3	3.2	0	0.5	11.5	0	0	1.0
8%-KNO_3 x 2	21.1	16.2	12.6	64.4	66.2	64.2	14.4	15.2	13.4	0	2.3	3.3	0	0	6.6
8%-KNO_3 x 3	73.3	62.9	57.3	26.7	28.4	32.6	0	7.8	7.2	0	0.8	2.8	0	0	0
2.5%-K_2SO_4 x 2	20.0	22.4	16.2	71.1	58.7	61.4	8.9	9.2	6.5	0	7.2	8.2	0	2.5	7.7
2.5%-K_2SO_4 x 3	62.2	55.3	48.7	37.8	31.5	36.6	0	5.2	7.2	0	4.3	5.3	0	3.7	2.2
4%-K_2SO_4 x 2	24.4	19.3	14.6	67.8	65.2	51.4	7.8	8.2	5.2	0	5.2	16.2	0	2.1	12.6
4%-K_2SO_4 x 3	63.4	56.2	47.5	36.7	38.7	42.2	0	3.4	5.2	0	1.7	3.2	0	0	1.9

Control
5%-KNO_3 x 2
5%-KNO_3 x 3
8%-KNO_3 x 2
8%-KNO_3 x 3
2.5%-K_2SO_4 x 2
2.5%-K_2SO_4 x 2
4%-K_2SO_4 x 2
4%-K_2SO_4 x 3

Photo 1. Effect of foliar K fertilization on fruit size and color of citrus clementine var. *Cadoux* (densitiy D_1, 6 x 3.5 m). Photo by the authors.

Fruit size

K fertilization treatments in three foliar applications showed the best percentages of extra size class (Cal 1-3), whatever the source of K (KNO_3 or K_2SO_4) or plant density (Table 3). The treatment 8 percent KNO_3 x 3 gave the highest percentage of fruit in the extra size class in all planting densities. For the three planting densities (D_1, D_2 and D_3), the 8 percent KNO_3 x 3 treatments, respectively, produced 73, 63 and 57 percent of fruits in the larger Cal 1-3 class, compared to the 7.8, 9.2 and 7.6 percent recorded in the control.

Trees sprayed with only two foliar applications were markedly less effective in improving clementine fruit size when compared with those that received three applications (Fig. 2).

These results show the effectiveness of foliar K fertilization in improving fruit size of clementine (Photo 1).

It should be noted that an increase in planting density also induces a decrease in fruit size. It is therefore wise to choose a low planting density (D_1 = 6 x 6 m) to reach a level of profitable, commercial grade fruit (Cal 1-3 and 4).

Our results confirm those in the literature (Embleton *et al.*, 1975, Wei *et al.* 2002; Obreza *et al.*, 2008) which show that increasing the rate and frequency of foliar applications of K is accompanied by an increase in citrus fruit size.

The coloration of the fruit rind

In general, whatever the planting density, all treatments of foliar K fertilization induced a redder color of the fruit rind than the control (Photos 1 and 2).

The Color Index (CI), measured with a colorimeter (Model CR-400, Konica Minolta Sensing, Japan) and whose value reflects

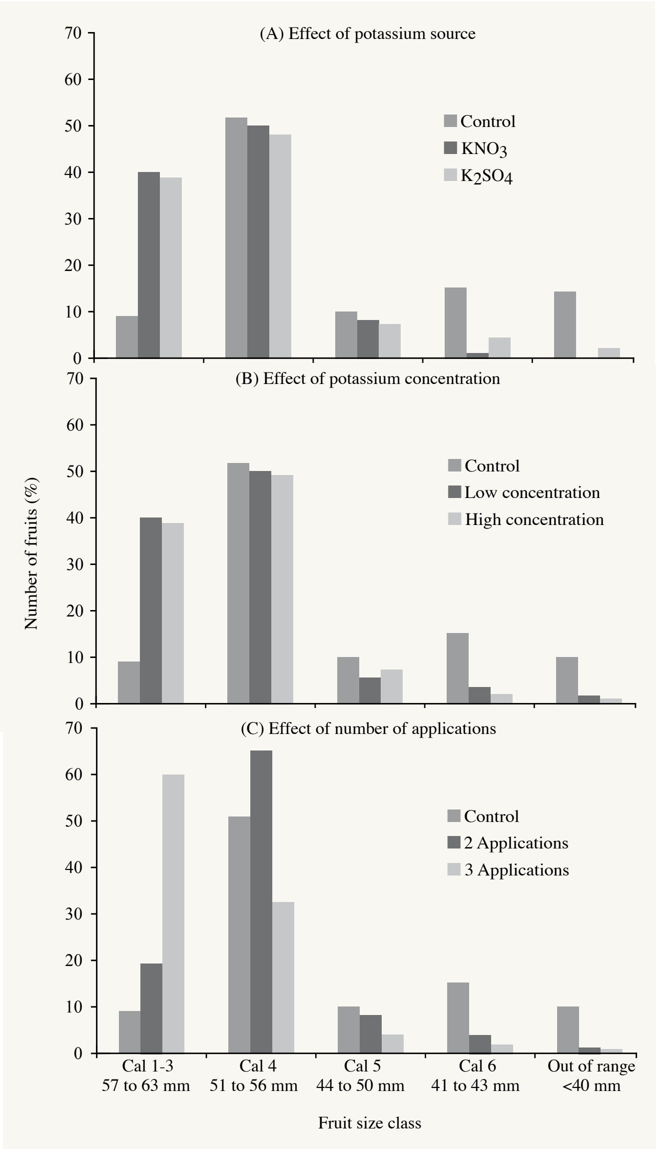

Fig. 2. Effects of foliar K fertilization on fruit size of clementine var. *Cadoux*: (A) Effect of K source, (B) effect of K concentration, and (C) effect of number of applications.

the intensity of the orange-red, was significantly reduced as plant density increases. The recorded values are respectively 5.52, 4.80 and 3.99 for D_1, D_2 and D_3.

All foliar K fertilization treatments have a greater average value of CI than that of the control, indicating that foliar applications of K had a positive impact on improving fruit color of clementine var. *Cadoux*. Generally, foliar applications of KNO_3 were more effective in improving fruit color than K_2SO_4 (Photo 1).

In the low density D_1, treatments 5 percent KNO_3 x 3 and 2.5 percent K_2SO_4 x 2 had the greatest CI values, with 6.3 and 6.4 respectively.

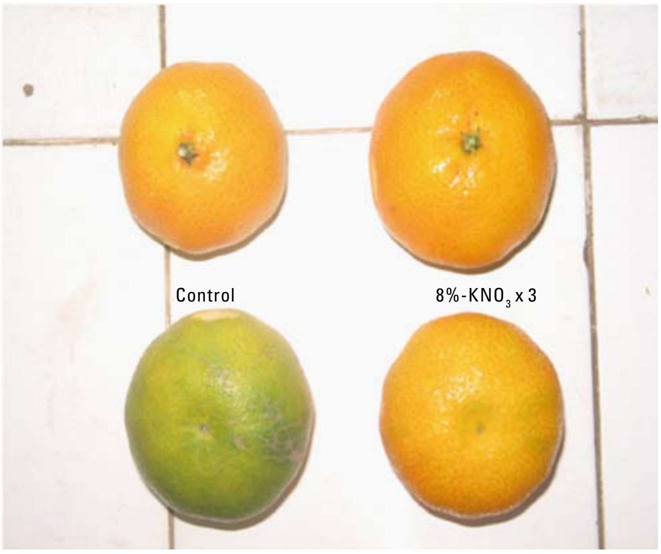

Photo 2. Improvement of fruit color by foliar K fertilization and persistence of green color in the control (left). Photo by the authors.

For the medium density D_2, treatment 8 percent KNO_3 x 2 was superior in terms of fruit color improvement when compared to other treatments. Its color index (CI = 5.5) was significantly higher than that of treatment 2.5 percent K_2SO_4 x 3 (CI = 4.2).

For the high density D_3, treatment 5 percent KNO_3 x 3 induced the highest value of color index (CI = 4.6) whereas treatments 8 percent KNO_3 x 2 and 2.5 percent K_2SO_4 x 3 had the lowest values.

A positive effect of foliar K fertilization on citrus fruit color is reported in the literature (Hellali, 2002; Erner *et al.*, 2004; Obreza *et al.*, 2008). It is also reported that high concentrations of K applied to citrus induced green fruits compared to the application of low concentrations (Koo, 1988). This latter effect was observed in the present experiment with the 4 percent K_2SO_4 treatment in two applications which gave the lowest values of color index and caused a delay in fruit coloration (Photo 1).

It can be concluded that foliar fertilization of KNO_3, at 5 and 8 percent in three foliar applications, and those based on K_2SO_4 at 2.5 and 4 percent respectively, in two and three foliar applications, are most effective in improving fruit color of clementine var. *Cadoux*.

Fruit firmness

Whatever the planting density, the control treatment had higher values of fruit firmness, with 405, 366 and 402 g/0.5 cm^2 for densities D_1, D_2 and D_3 respectively. In addition, all treatments of foliar K fertilization had acceptable fruit firmness, which varied between 300 and 415 g/0.5 cm^2.

Thickness of the fruit rind

The average fruit rind thickness of all treatments is 11.5 mm. Foliar K fertilization slightly increased rind thickness as K concentration, or the number of foliar applications, increased.

Our results are consistent with those reported in the literature, which indicate that increasing K, applied as foliar fertilization, induces an increase in the citrus fruit rind thickness (California Fertilizer Association, 1998; Obreza *et al.*, 2008).

This increase in thickness of the skin of the fruit is of importance as it provides resistance to insects.

Fruit juice content

In all treatments, the fruit juice content met the standards for export of the fruits of Moroccan clementine (a minimum of 40 percent).

In the low density D_1, the increase in the number of foliar applications, for a given concentration of either KNO_3 or K_2SO_4, is accompanied by an increase in fruit juice content. This increase was 0.5 percent between treatments 5 percent KNO_3 x 3 and 5 percent KNO_3 x 2; and 1.8 percent between 8 percent KNO_3 x 3 and 8 percent KNO_3 x 2. A slight decrease in fruit juice content of 0.92 percent is recorded between treatments 4 percent K_2SO_4 x 3 and 4 percent K_2SO_4 x 2.

For the medium density D_2, the juice content decreased with the increasing number of foliar applications for low K concentrations but increased with the number of foliar applications for high concentrations of K.

For the density D_3, the juice content is highest in the 4 percent K_2SO_4 x 2 treatments with a value of 45 percent.

Acidity (A) of the juice

The acidity of the juice of clementine var. *Cadoux* for all foliar K fertilization treatments meets the export standards of between 0.8 and 1.5 percent. In all treatments, acidity was less than 1.1 percent. Increasing the number of foliar K applications, however, causes a slight increase in acidity in the fruit juice.

These results are consistent with those of the literature which indicates that increased levels of K in leaves, due to an increase in concentration and/or number of foliar applications, induces an increase in acidity of citrus fruit (Erner *et al.*, 2004; Obreza *et al.*, 2008).

Fruit total soluble sugar content (TSS)

The export market for Moroccan clementine citrus requires a minimum content of total soluble sugars (TSS) of nine percent. In all foliar K fertilization treatments, and in the control, TSS contents were much higher than stated standards for exports of clementine.

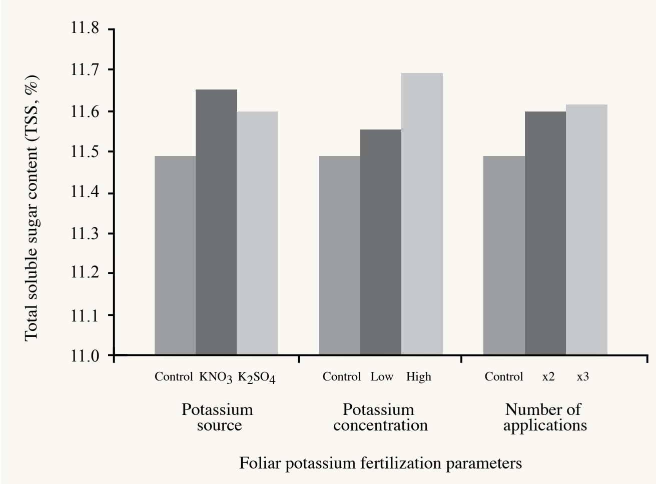

Fig. 3. Effects of foliar K fertilization on fruit TSS of clementine var. *Cadoux*: Effect of K source, concentration and number of applications.

Foliar K fertilization slightly improved total soluble sugar content of the fruit with better efficiency for KNO_3 in comparison to K_2SO_4 (Fig. 3).

Index of fruit maturity (TSS/A)

According to export standards, a minimum maturity index of 7 is required for Moroccan clementine although some importing countries require a value between 7 and 7.5.

In all foliar K fertilization treatments, the fruit maturity index exceeded 10.6. This index was lower in treatments which received KNO_3, and higher in treatments that received K_2SO_4 as a source of K for foliar application.

Effect of foliar K fertilization on fruit yield

The fruit production of the different planting densities were respectively 174, 160 and 116 kg per tree for the low (D_1), medium (D_2) and high density (D_3). In terms of fruit production per hectare, yields of densities D_1, D_2 and D_3 were 48.1, 53.7 and 55.3 mt ha^{-1} respectively.

Concerning the effect of foliar K fertilization, our results clearly indicate that raising the K concentration and the number of foliar applications increased tree fruit yield (Fig. 4B and 4C; Photo 3).

For treatments that received two foliar applications, raising K concentration did not induce any significant increase in production.

These results are consistent with the literature that indicates that increasing frequency or concentration of K foliar application on citrus, three to five weeks after the fruit size reached a diameter of 20 to 25 mm, leads to increased production (Erner *et al.*, 2004; Obreza *et al.*, 2008).

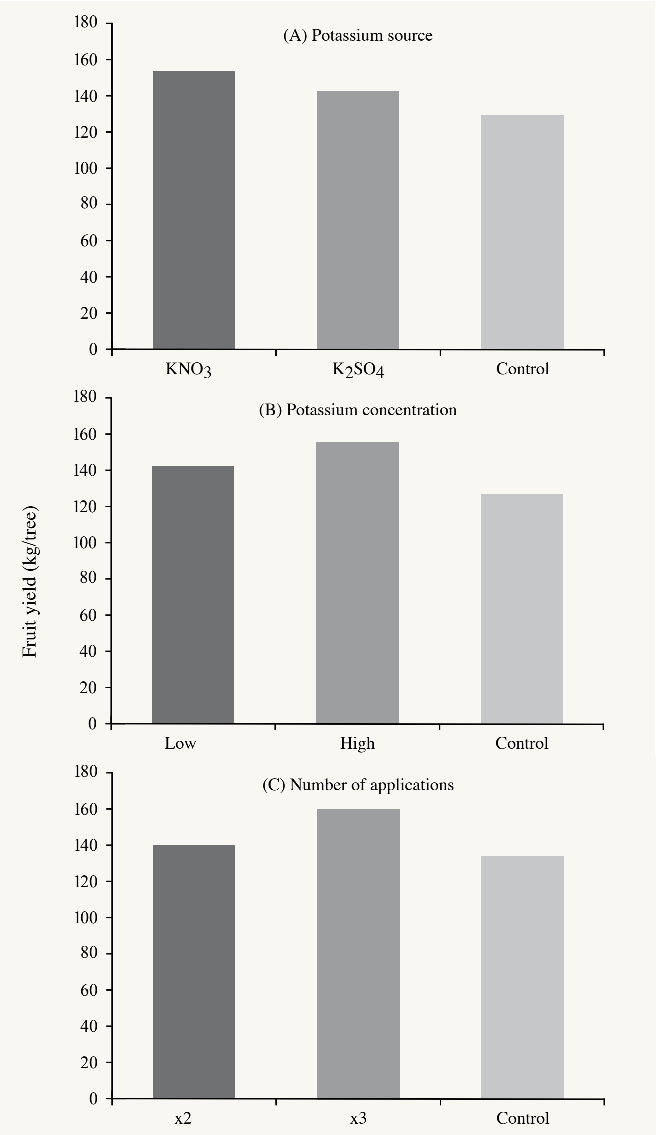

Fig. 4. Effects of foliar K fertilization on fruit yield (kg tree^{-1}) of clementine var. *Cadoux*: Effect of (A) K source, (B) K concentration, and (C) number of applications.

Within the planting densities D_1 and D_2, 8 percent KNO_3 and 4 percent K_2SO_4 treatments with three foliar applications were the most effective in improving fruit yield of clementine var. *Cadoux*. The recorded yields for these treatments in D_1 were 204 and 195 kg/tree respectively, while the control produced only 160 kg/tree. This increase in production was 21.5 percent and 17.6 percent respectively for treatments 8 percent KNO_3 x 3 and 4 percent K_2SO_4 x 3 over the control.

For the medium density D_2, the treatment 8 percent KNO_3 x 3 was the most effective as it increased fruit yield by 21.2 percent over the control (184 kg/tree versus 145 kg/tree). The 5% KNO_3 x 3 and 4 percent K_2SO_4 x 3 treatments have generated a marked production increase of 16.5 percent (173 and 175 kg/tree respectively) when compared to the control.

For the high density D_3, treatment 5 percent KNO_3, 8 percent KNO_3 and 4 percent K_2SO_4 in three foliar applications appear to be the most effective in improving fruit production of clementine var. *Cadoux*. There was no significant difference between these two treatments and the recorded average production was 130 kg/tree, an improvement of 18 percent when compared to the control.

Production gains and efficiency of KNO_3 and K_2SO_4 foliar application on clementine var. *Cadoux*

Treatments 5 percent KNO_3, 8 percent KNO_3, 2.5 percent K_2SO_4 and 4 percent K_2SO_4, with three foliar applications, were selected for an evaluation of their efficiencies because of their positive effects on fruit production and quality parameters of clementine var. *Cadoux*.

Treatment 8 percent KNO_3 with three foliar applications had an average production gain of 12-13 mt ha^{-1} over the control in the three planting densities (Table 4), while the treatment 2.5 percent K_2SO_4, with three foliar applications, gave the lowest fruit production gains.

Control — 5%-KNO_3 x 3 — 4%-K_2SO_4 x 3

Photo 3. Trees representative of the effects of foliar K fertilization on fruit yield of clementine var. *Cadoux* (density D_1, 6 x 3.5 m). Photos by the authors.

Table 4. Production gain and marginal productivity of citrus clementine var. *Cadoux* with three foliar K applications of KNO_3 and K_2SO_4.

K source and concentration	Planting density	Yield	Applied fertilizer	Production gain	Efficiency
		mt ha^{-1}	*kg ha^{-1}*	*mt ha^{-1}*	*kg fruit per kg fertilizer*
	D_1	44.4	-	-	-
Control	D_2	48.4	-	-	-
	D_3	50.5	-	-	-
	D_1	50.5	415.5	6.1	14.7
5%-KNO_3 x 3	D_2	57.7	499.5	9.4	18.7
	D_3	59.4	714.0	8.9	12.4
	D_1	56.5	664.8	12.1	18.2
8%-KNO_3 x 3	D_2	61.4	799.2	13.1	16.4
	D_3	63.6	1,142.4	13.0	11.4
	D_1	47.0	207.7	2.7	12.7
2.5%-K_2SO_4 x 3	D_2	53.2	249.7	4.8	19.3
	D_3	54.6	357.0	4.1	11.4
	D_1	53.9	332.4	9.5	28.6
4%-K_2SO_4 x 3	D_2	58.2	399.6	9.9	24.7
	D_3	60.9	571.2	104	18.2

In terms of efficiency of foliar K fertilizers, the treatment 4 percent K_2SO_4 in three applications resulted in a maximum gain of about 28 and 24 kg of fruits per kg of foliar fertilizer, respectively for densities D_1 and D_2 (Table 4).

Conclusion

Foliar application of K, either as KNO_3 or K_2SO_4, increased fruit production and quality parameters (weight, size, color, rind thickness, juice content and maturity index) of clementine citrus var. *Cadoux*.

On the basis of yield gain, fertilizer efficiency and profitability, the combination of D_1 spacing (6 x 6 m) sprayed with 4 percent K_2SO_4 three times, gave the best return and is recommended for foliar fertilization of clementine var. *Cadoux*.

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The paper "Response of Clementine-Citrus var. *Cadoux* to Foliar Potassium Fertilization: Effects on Fruit Production and Quality" also appears at:

Regional Activities/WANA

Research Findings

Experimental plot with pigeon pea crop at the Fertilizer Research Station Uttari Pura, Univ. of Agric. & Tech., Kanpur. Photo by E. Sokolowski.

Effect of Potassium Application on Yield and Quality Characteristics of Pigeon Pea *(Cajanus cajan)* and Mustard *(Brassica juncea* L. *Czern)* Crops in Central Plain Zone of Uttar Pradesh

Tiwari, D.D.[(1)(2)], S.B. Pandey[(2)], and M.K. Dubey[(2)]

Abstract

To investigate the effect of five levels of potassium at 0 (control), 20, 40, 60 and 80 K_2O kg ha^{-1} applied as muriate of potash on pigeon pea and mustard, as pulse and oil seed crops respectively, field experiments were conducted at the Fertilizer Research Station Uttari Pura, of C.S.A. University of Agriculture & Technology, Kanpur during 2007 to 2011. The experimental field had available 195 kg ha^{-1} K_2O and was sandy loam in nature. Nitrogen, phosphorus, sulphur and zinc were also applied in amounts determined by soil analysis to provide adequate supply.

Increasing doses of potassium up to 60 kg K_2O ha^{-1} significantly increased grain and stover yields of pigeon pea and mustard crops. Mean yields of pigeon pea grain and stover were raised from 1,358 to 1,764 and 5,647 to 6,594 kg ha^{-1} respectively, and that of mustard grain and stover from 1,645 to 2,257 and 4,041 to 5,077 kg ha^{-1} respectively.

Likewise, protein and oil content were also increased significantly by K application to pigeon pea and mustard respectively. Protein content in pigeon pea grain increased from 21.01 percent in the control to 21.95 percent at the highest K treatment, K_{80}. Mean oil content in mustard seed was raised from 37.01 percent (control) to a maximum of 40.98 percent in the K_{60} treatment.

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Experimental plot with mustard crop at the Fertilizer Research Station Uttari Pura, Univ. of Agric. & Tech., Kanpur. Photo by E. Sokolowski.

Table 1. Area, production and productivity of pigeon pea and mustard crops in India and the state of Uttar Pradesh (2009-2010).

Crop		India	Uttar Pradesh
Pigeon pea	Area (million ha)	3.86	0.31
	Production (million mt)	2.9	0.20
	Productivity (kg ha^{-1})	751	662
Mustard	Area (million ha)	6.51	0.61
	Production (million mt)	7.67	0.68
	Productivity (kg ha^{-1})	1,179	1,113

Source: Directorate of Economics and Statistics, Department of Agricultur and Cooperation, Ministry of Agriculture, Government of India.

K content increased from 1.53 to 1.58 and 2.51 to 2.56 percent in grain and stover of pigeon pea, and 0.88 to 0.99 percent in mustard seed. No clear increase in K concentration due to K application was found in mustard stover.

Increasing levels of K application lowered the negative balance of K in the soil. Removal of K from the soil by pigeon pea and mustard crops progressively increased from 163 to 194 and 143 to 184 kg K_2O ha^{-1} respectively between the 0 to 80 kg K_2O ha^{-1} levels. For the same levels of increasing rates of K_2O application the negative balance of K_2O kg ha^{-1} was lowered from 163 to 114 under pigeon pea, and 143 to 104 under mustard.

Introduction

A substantial proportion of the Indian population has a vegetarian diet in which plant oil and protein make up the principal sources of dietary lipid and protein. The major sources of oil and protein are oilseeds and pulses respectively. Pulses are grown for proteins as a target product and oilseeds provide both oil and protein because oils are stored and synthesized in protein rich tissues. Of the pulses and oilseeds, pigeon pea *(Cajanus cajan)* and mustard *(Brassica juncea* L. *Czern)* are the major crops of the state of Uttar Pradesh in terms of area of cultivation, as well as production and productivity (Table 1). The nutrient requirements of these two crops are similar to rice and wheat and they thrive under varied edaphic regimes. In general, farmers apply low rates of nitrogen (N) and phosphorus (P), but potassium (K) is frequently absent from their fertilizer schedule. This lack of K is responsible for low yields and poor crop quality because, apart from other major physiological and biochemical requirements in plant growth, K is a key nutrient element in the biosynthesis of oil in oilseeds and protein in pulse crops.

For the work reported in this paper, we tested in a field experiment over four growing seasons, the effect of increasing rates of K fertilization on yield and quality of pigeon pea and mustard adequately fertilized with other plant nutrients. The yield and K content was measured for the seed and stover of both crops. Protein content is used as a measure of quality of pigeon pea and oil for mustard seeds. The K uptake by the crops and K balance between the crop and soil is also reported.

Materials and methods

The field experiments were carried out at the Fertilizer Research Station, Uttaripura, of the Chandra Shekhar Azad (CSA) University of Agriculture & Technology, Kanpur, during 2007 to 2011. Pigeon pea in Kharif and mustard in Rabi seasons were used as test crops. Five levels of potassium at 0, 20, 40, 60 and 80 kg K_2O ha^{-1} were applied to both the crops as a basal dressing in the form of muriate of potash. N, P, sulphur (S) and zinc (Zn) in the forms of urea, diammonium phosphate (DAP), gypsum and zinc sulphate were applied uniformly in required amounts based on soil chemical analysis. Plot size of the experimental field was 40 m^2. The experimental soils were neutral in reaction (pH 7.3), low in organic carbon (0.41), and deficient in S (16.3 kg ha^{-1}) and available Zn (0.51 mg kg^{-1}). The available N, P_2O_5 and K_2O of the experimental fields were 180, 12.5 and 195 kg ha^{-1}, respectively.

All necessary agronomic practices were followed, when and where required. At maturity, the crops were harvested and grain and stover yields were recorded as per treatments.

Soil pH, EC, organic carbon and available NPK were analyzed using standard procedures (Jackson, 1973).

Available soil S was determined by the turbidimetric procedure (Chesnin and Yein, 1951) after extraction with Morgan's reagent, and available soil Zn was determined by AAS after extraction with DTPA (Lindsay and Norvell, 1978).

Grain N content was determined by the micro Kjeldahl method and protein in pigeon pea was estimated by multiplying the N content by 6.25. Oil in mustard seed was extracted by the soxhlet method. Grain and straw K contents were estimated by flame photometry following nitric and perchloric acid digestion of the samples (Jackson, 1973).

Table 2. Effect of treatments on grain and stover yield (kg ha^{-1}) of pigeon pea.

Treatments	Kharif 2007		Kharif 2008		Kharif 2009		Kharif 2010		Mean		Response over control (grain)	AE_K * (grain)
	Grain	Stover	Grain	Stover	Grain	Stover	Grain	Stover	Grain	Stover		
kg K_2O ha^{-1}	-------	-------	-------	-------	*kg ha^{-1}*	-------	-------	-------	-------	-------	*%*	*kg kg^{-1}*
K_0	1,206	5,462	1,395	5,875	1,380	5,547	1,450	5,810	1,358	5,674	-	-
K_{20}	1,400	5,906	1,480	6,095	1,450	5,756	1,530	6,120	1,465	5,969	7.9	5.35
K_{40}	1,575	6,269	1,585	6,290	1,520	5,897	1,620	6,310	1,575	6,192	15.9	5.42
K_{60}	1,744	6,500	1,750	6,750	1,710	6,207	1,810	6,570	1,754	6,507	29.2	6.60
K_{80}	1,750	6,631	1,765	6,745	1,720	6,398	1,820	6,600	1,764	6,594	29.8	5.07
CD (p = 0.05)	87	308	120	320	65	175	78	170	-	-	-	-

*AE_K = Agronomic efficiency of potassium

Table 3. Effect of treatments on grain and stover yield (kg ha^{-1}) of mustard.

Treatments	Rabi 2007/8		Rabi 2008/9		Rabi 2009/10		Rabi 2010/11		Mean		Response over control (grain)	AE_K* (grain)
	Grain	Stover	Grain	Stover	Grain	Stover	Grain	Stover	Grain	Stover		
kg K_2O ha^{-1}	-------	-------	-------	-------	*kg ha^{-1}*	-------	-------	-------	-------	-------	*%*	*kg kg^{-1}*
K_0	1,763	4,040	1,650	3,940	1,675	3,983	1,490	4,200	1,645	4,041	-	-
K_{20}	2,100	5,403	1,735	4,120	1,890	4,200	1,670	4,310	1,849	4,508	12.4	10.2
K_{40}	2,315	6,045	1,890	4,340	2,035	4,440	1,820	4,490	2,015	4,828	22.5	9.3
K_{60}	2,467	6,458	2,185	4,520	2,250	4,650	2,100	4,680	2,251	5,077	36.8	10.1
K_{80}	2,468	6,461	2,190	4,515	2,260	4,630	2,110	4,700	2,257	5,077	37.2	7.7
CD (p = 0.05)	133	375	125	170	140	180	135	109	-	-	-	-

*AE_K = Agronomic efficiency of potassium

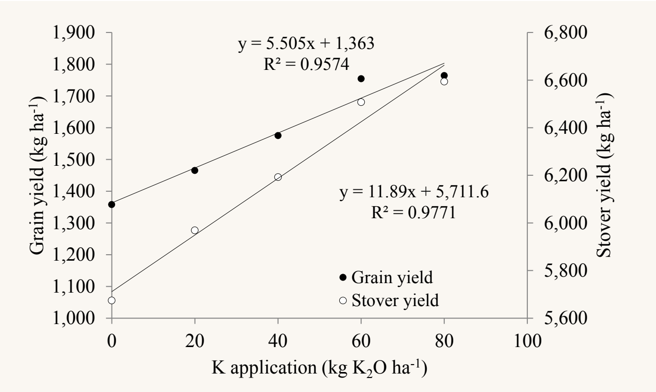

Fig. 1. Effect of treatments on grain and stover yields of pigeon pea (average of four years, 2007-2010).

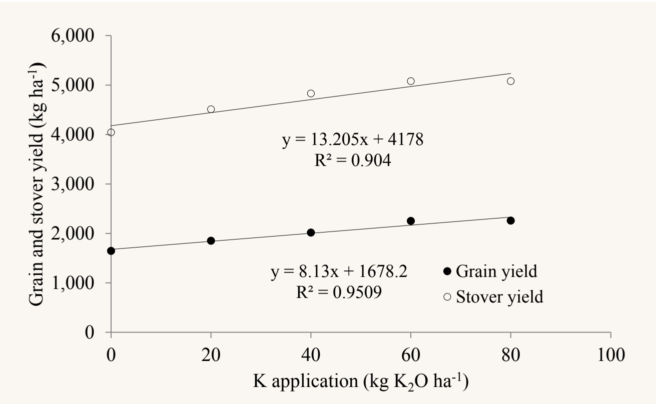

Fig. 2. Effect of K-doses on grain and stover yields of mustard (average of four years, 2007/08-2010/11) .

Results and discussion

Yield

Application of K up to 80 kg K_2O ha^{-1} significantly increased grain and stover yield of pigeon pea during each year of the experiment (Table 2). On average, with the high K application (80 kg K_2O ha^{-1}), a 29.8 percent increase in grain yield over the control was achieved. With stable yields through the four years of the experiment, the response to K was significant in every year.

The response to K application was significant to both grain and stover (R_2 >0.95; Fig. 1), implying that higher levels of K might have increased yields further. This increase in yield is in accordance with essential requirement for K in plant biochemistry and physiology, in processes including photosynthesis, water relationships, protein synthesis and the requirement for K in at least 60 different enzyme systems within the plant. Similar results showing the benefit of K on crop yield have also been reported by Prasad *et al.* (1993).

Agronomic Efficiency of Potassium (AE_K) varied from 5.07-6.60 kg/kg of K in pigeon pea with the maximum at K application of 60 kg ha^{-1}.

Application of K up to 60 kg K_2O ha^{-1} also significantly increased grain and stover yields of mustard during each year of the experiment (Table 3). On average, with the high K application (80 kg ha^{-1}), a 37.2 percent increase in grain yield was achieved. As with the yield of pigeon pea, with mustard yields stable through the four years of the experiment, the response to K was significant in every year.

Table 4. Effect of treatments on percent K content in pigeon pea (Kharif 2007-2010) and removal of K by the crop (kg K_2O ha^{-1}).

Treatments	Kharif 2007		Kharif 2008		Kharif 2009		Kharif 2010		Mean				
	K concentration										Removal of K		
	Grain	Stover	Grain	Stover	Grain	Stover	Grain	Stover	Grain	Stover	Grain	Stover	Total
kg K_2O ha^{-1}	---%										---kg K_2O ha^{-1}---		
K_0	1.42	2.17	1.72	2.64	1.44	2.34	1.56	2.87	1.53	2.51	20.8	142.4	163.2
K_{20}	1.50	2.15	1.74	2.72	1.51	2.47	1.65	3.00	1.55	2.56	22.7	152.8	175.5
K_{40}	1.57	2.21	1.73	2.70	1.48	2.40	1.67	2.98	1.56	2.54	24.6	157.3	181.8
K_{60}	1.56	2.32	1.80	2.68	1.55	2.41	1.73	2.84	1.58	2.55	27.7	165.9	193.8
K_{80}	1.51	2.33	1.79	2.68	1.51	2.45	1.75	2.84	1.57	2.52	27.7	166.2	193.9

Table 5. Effect of treatments on percent K content in mustard (Rabi 2007/08-2010/11) and removal of K by the crop (kg K_2O ha^{-1}).

Treatments	Rabi 2007/08		Rabi 2008/09		Rabi 2009/10		Rabi 2010/11		Mean				
	K concentration										Removal of K		
	Grain	Stover	Grain	Stover	Grain	Stover	Grain	Stover	Grain	Stover	Grain	Stover	Total
kg K_2O ha^{-1}	---%										---kg K_2O ha^{-1}---		
K_0	1.04	3.05	1.04	3.15	1.04	3.14	1.00	3.07	0.88	3.18	14.5	128.5	143.0
K_{20}	1.05	3.19	1.03	3.20	1.04	3.25	1.01	3.12	0.91	3.11	16.8	140.2	157.0
K_{40}	1.05	3.34	1.09	3.23	1.09	3.25	1.02	3.09	0.91	3.15	18.3	152.1	170.4
K_{60}	1.05	3.46	1.20	3.22	1.22	3.17	1.09	3.10	0.99	3.18	22.3	161.4	183.7
K_{80}	1.06	3.31	1.20	3.24	1.20	3.18	1.08	3.13	0.98	3.19	22.1	162.0	184.1

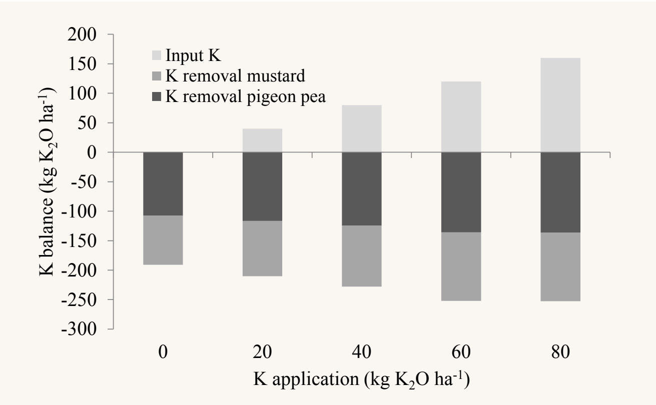

Fig. 3. K balance in pigeon pea - mustard crop rotation (average of four years, 2007-2010).

The response to K application was significant for both grain and stover (R_2 >0.9; Fig. 2), implying that higher levels of K might have increased yields further.

AE_K was high and varied from 7.7-10.2 kg/kg of K in mustard seeds, with a maximum at K application of 20 kg ha^{-1}.

Potassium content

K content in grain and stover of pigeon pea increased with the use of K over the control. K content ranged from 1.53 to 1.58 percent in the grain but only from 2.51 to 2.56 percent in the stover (Table 4). The removal of K increased as yield increased, up to 194 kg K_2O ha^{-1} (Table 4). Similarly, in the mustard crop, K content increased in grain (from 0.88 to 0.99 percent) but not for stover (Table 5). The removal of K increased mainly by the increased yield, up to a level of 184 kg K_2O ha^{-1} (Table 5).

K balance calculation for pigeon pea – mustard crop rotation system was based on the removal of K in grain (seeds) and stover (fully removed from the field) using the average annual removal rates of four years (Fig. 3, based on data of Tables 4 and 5). Removal rates of the two crops in this cropping system are very similar, at approximately 100 kg K_2O ha^{-1} year^{-1}, for each crop (Tables 4 and 5). However, the mustard crop is unique in that the removal of K by the seeds is larger than that by the stover (Table 5). K fertilizer was calculated as the only K input, and K output with regard to removal by crop (Fig. 3). Results show that K balance in all treatments was negative, ranging from almost 200 (K=0) to 100 (K=80) kg K_2O year^{-1}. It also indicates that even at the high rate of K application, there is still significant K mining from soil.

Protein content in pigeon pea and oil in mustard

Protein levels in pigeon pea grain increased significantly over the control in all years of the experiment, reaching approximately 22 percent (Table 6). The protein content varied from 21 to 22.15 percent, with a minimum in the control and a maximum at 80 kg K_2O ha^{-1}. This increase in grain protein content might be due to enhanced N use efficiency as a consequence of increased K application. Pathak *et al.* (1999) and Tiwari *et al.* (2009) also reported similar results.

Oil content in mustard grain increased significantly with the application of K up to 60 kg K_2O ha^{-1} in each year of the experiment (Table 6). The highest oil content (40.98 percent) was obtained at

Table 6. Concentration of protein and oil in pigeon pea and mustard seeds respectively.

Treatments	Pigeon pea					Mustard				
	2007	2008	2009	2010	Mean	2007/8	2008/9	2009/10	2010/11	Mean
	----------------*Protein (%)*----------------					------------------------*Oil (%)*------------------------				
K_0	21.20	20.90	20.95	21.00	21.01	37.52	36.90	37.55	36.10	37.01
K_{20}	21.57	21.15	21.20	21.25	21.29	38.82	38.10	38.70	37.75	38.34
K_{40}	21.74	21.20	21.55	22.00	21.62	40.26	39.15	39.85	38.40	39.41
K_{60}	21.75	21.75	22.05	22.10	21.91	41.00	41.25	41.20	40.50	40.98
K_{80}	21.85	21.70	22.10	22.15	21.95	41.18	41.10	41.15	40.30	40.93
CD (p = 0.05)	0.19	0.20	0.24	0.21		0.67	0.75	0.80	0.85	

60 kg K_2O ha^{-1} which was about 16 percent higher than the control, without any K application. This finding is in agreement with the observations of Kushwaha and Ali (1999).

Conclusions

Grain yield and quality of pigeon pea and mustard seed increased significantly with the application of K up to 60 kg K_2O ha^{-1}. At this rate of application, yield of pigeon pea increased 29 percent, while that of mustard seed 37 percent. The agronomic efficiency of potash applied to pigeon pea and mustard (6.6 and 10.2 respectively) provides a stable economic return.

Removal rates of K were increased with K application mostly from higher yield, but also as K concentration in grain and stover increased with increasing K application. The applied K in this experiment was insufficient to prevent a significant K negative balance for the cropping system of approximately 100 kg K_2O year^{-1}.

K application significantly increased protein content in pigeon pea and oil content in mustard seeds, bringing higher economic value to the harvested crop.

Based on the results of this four year experiment in which we produced stable responses year after year, we conclude that 60 kg K_2O ha^{-1} is the recommended amount of K for achieving high yield of pigeon pea and mustard in medium K-soils of Uttar Pradesh. However, based on the data shown in Fig. 1 and 2, the nature of response implies that there is still scope for higher inputs of K which may generate additional yield, as well as reduce the calculated negative K balance.

Farmers' meeting at the Fertilizer Research Station Uttari Pura, Univ. of Agric. & Tech., Kanpur. Photo by E. Sokolowski.

Acknowledgement

The financial support provided by IPI, Switzerland for conducting the research is gratefully acknowledged. We place on record our thanks to Dr. S.K. Bansal, Director, Potash Research Institute of India (PRII), Gurgaon, for guiding and monitoring the research experiments during the course of this study.

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Tiwari, D.D., R.C. Nigam, and S.B. Pandey. 2009. Effect of Potassium Application on Yield and Quality of Linseed in Central Plain Zone of U.P. *In:* Proceeding of IPI-OUAT-IPNI International Symposium, Bhubneshwar, India. p. 232-233.

The paper "Effect of Potassium Application on Yield and Quality Characteristics of Pigeon Pea *(Cajanus cajan)* and Mustard *(Brassica juncea* L. *Czern)* Crops in Central Plain Zone of Uttar Pradesh" also appears at:

Regional Activities/India

IPI Events

July 2012

International Symposium on "Management of Potassium in Plant and Soil Systems in China", Chengdu, Sichuan, China, 24-27 July 2012. The symposium will be jointly organized by the International Potash Institute, Soil Science Institute, Nanjing, China, Chinese Academy of Sciences and the China Agriculture University. Details are available on the IPI website, or contact Mr. Eldad Sokolowski, IPI Coordinator China.

Papers and speakers:

1. **Role of K fertilizers in sustaining food security in China**
   Zhang Fusuo and Weifeng Zhang (China Agricultural University, Beijing, China)
2. **Simulating the effect of potassium fertilization on CO_2 sequestration in soil**
   Benayahu Bar-Yosef and Jiftah Ben Asher (AgriEcology, The Katif Research Center, Israel)
3. **Field-scale K and P fluxes in bioenergy crops: theoretical energy yield and management implications**
   Sylvie Brouder (Purdue university, USA)
4. **Precision Nutrient Management: Applications and Future Needs**
   Raj Khosla (Colorado State University, USA)
5. **K balance and fertilizer demand in China**
   Weifeng Zhang (China Agricultural University, China)
6. **Changes in nutrient efficiencies in cereal crops in China 1990-2010**
   Zhenling Cui (China Agricultural University, Beijing, China)
7. **Factors affecting NEK release and the method for quantification of soil NEK with various bioavailability**
   Jianmin Zhou (Institute of Soil Science, Chinese Academy of Science, Nanjing, China)
8. **Pools and fluxes of potassium in the soil: Field balances and mineralogical studies in long-term agricultural experiments**
   Magnus Simonsson (Swedish University of Agricultural Sciences, Sweden)
9. **Comparing methods for evaluating soil K availability to rice and wheat in various soils in China**
   Huoyan Wang (Institute of Soil Science, Chinese Academy of Science, Nanjing, China)
10. **Characteristics of soil K evolution in grain producing areas in China in the last 20 years**
    Huimin Zhang and Minggang Xu (Chinese Academy of Agricultural Sciences, Beijing, China)
11. **Influence of crop residue return on crop yields and soil nutrient status**
    Shihua Tu (IPNI; Sichuan Academy of Agricultural Sciences, Chengdu, China)
12. **Current situation of potassium soil reserves and needs in typical cropping systems in Central European countries**
    Pavel Čermák (Crop Research Institute, Prague, Czech Rep.)
13. **Potassium-Sodium interactions in soil and plant under saline conditions**
    Abdul Wakeel (Agricultural University, Faisalabad, Pakistan)
14. **Salinity management with potassium in horticultural crops in irrigated areas of Argentina**
    Ricardo Melgar (INTA, Argentina)
15. **The positive impacts of S-ABA on potassium absorption and the effect on potash fertilizer utilization in China**
    Speaker from SINOCHEM
16. **Potassium and stress alleviation: physiological functions and management**
    Derrick Oosterhuis (University of Arkansas, USA)
17. **Genotypic differences in potassium uptake and utilisation efficiency**
    Zed Rengel (The University of Western Australia)
18. **Improving potassium acquisition and utilization by crop plants**
    Philip White (The James Hutton Institute, UK)
19. **Research progress on the mechanism of plant K efficient use in agriculture - a China perspective**
    Fang Chen (IPNI; Wuhan Botanical Garden, Chinese Academy of Sciences, Wuhan, China)
20. **Adaptation of rice to potassium deficiency**
    Guohua Xu (Janjing Agricultural University, Nanjing, China)
21. **Effect of crop plants fertilizing with potassium on water use efficiency**
    Vitold Grzebisz (Poznan Agricultural University, Poland)
22. **A critical evaluation of citrus leaf mineral status guidelines for optimal yield in Israel**
    Eran Raveh (Agricultural Research Organization ARO Volcani Center, Israel)
23. **Potassium Management in Mechanized Conservation Tillage Systems in North America**
    Xinhua (Frank) Yin (University of Tennessee, USA)
24. **Potassium management in rice-maize systems in South Asia**
    J. Timsina (Consultant, IRRI, Australia)
25. **K source in fertigation systems in China: a comparison between KCl and K_2SO_4**
    Zhang Chenglin (South China Agricultural University, Guangzhou, China)

26. **K and Mg nutritional status of greenhouse tomatoes: lessons for better K and Mg management of vegetables and fruit trees**
Volker Römheld (University of Hohenheim, Germany) and Chen Qing (China Agricultural University, Beijing, China)
27. **Potassium fertilizer management in winter oilseed rape in China**
Jianwei Lu (Huazhong Agricultural University, Wuhan, China)
28. **K management in maize in China**
Xinping Chen (China Agricultural University, Beijing, China)
29. **Effects of potassium application on yields, nutrient composition of tea leaves and changes in soil K status**
Jianyun Ruan (Tea Research Institute, Chinese Academy of Agricultural Science, Hangzhou, China)
30. **Crop responses to K application and K budget**
Ping He (IPNI; Institute of Agricultural Resources and Regional Planning, Chinese Academy of Agricultural Sciences, Beijing, China)
31. **Web and mobile phone applications for providing farmers with field-specific nutrient management**
Roland Buresh (International Rice Research Institute, Philippines)
32. **Potassium and irrigation management in Xinjiang; soil K changes during 1990s-2010s**
Changzhou Wei (Shihezi University, Xinjiang, China)
33. **The influence of foliar application and potassium level on the plant nutrition condition and yield of Pummelo [*Citrus maxima* (Burm. ex Rumph.) Merr.]**
Alminda M. Fernandez (University of Southeastern Philippines - Tagum-Mabini)
34. **Improving crop yield and resource use efficiency through innovative extension systems**
Hongyan Zhang and Xiaolin Li (China Agricultural University, Beijing, China)

July 2012

IPI-FAI Training Program for Industry Dealers on "Balanced Fertilization and Integrated Nutrient Management", Patna, Bihar, India, 13 July 2012. For details contact Dr. S.K. Bansal.

Other Events

July 2012

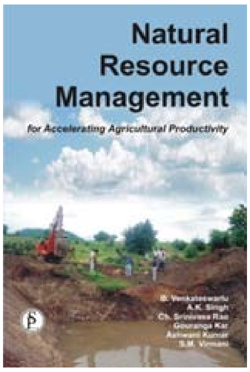
China International Water Soluble Fertilizer Conference & Exhibition, Beijing, China, 3-5 July 2012. Organizer: China National Chemical Information Center (CNCIC); co-organizer: New Ag International. Detailed information is available on the conference website.

11th International Conference on Precision Agriculture, Indianapolis, Indiana, USA, 15-18 July 2012. For more details go to the conference website.

November 2012

The 1st World Congress on Biostimulants in Agriculture, Strasbourg, France, 26-29 November 2012. Agricultural biostimulants include diverse formulations of compounds, substances and other products that are applied to plants or soils to regulate and enhance the crop's physiological processes, thus making them more productive. Organized by New Ag International (see conference website).

Publications



Natural Resource Management for Accelerating Agricultural Productivity.

Venkateswarlu, B., A.K. Singh, Ch. Srinivasarao, G. Kar, A. Kumar, and S.M. Virmani. 2012. ISBN: 978-93-80012-36-0.

Natural resources like land, water and biodiversity are the key to sustaining agricultural productivity. Growing pressure of intensive agriculture and other non-farm enterprises on natural resources like soil and water is leading to their degradation, threatening the food security and ecosystem stability. Studium Press (India) Pvt. Ltd, New Delhi 110002, e-mail: studiumpress@gmail.com, website: http://www.studiumpress.in.

From the IPI project "Disease Supression by Potash Application in Rice" in Brazil:

Adubação potássica e a supressão da brusone de arroz em várzeas tropicais no Brasil. Maria da Conceicao Santana Carvalho, CNPAF; Jaison Pereira de Oliveiry, CNPAF; Pedro Luiz Oliveira de a Machado, CNPAF; Alexey Naumov, International Potash Institute. *In:* CONGRESSO BRASILEIRO DE CIÊNCIA DO SOLO, 33., 2011, Uberlândia. Solos nos biomas brasileiros: sustentabilidade e mudanças climáticas: anais. [Uberlândia]: SBCS: UFU, ICIAG, 2011. Download the paper.

Publication by the PDA

Soil Potassium and Nitrogen Interactions in Crops.

Johnston, A.E., and G.F.J. Milford. 2012. Download a pdf file from 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. *Note*: Hardcopies of PDA's publications are available only in the UK and Ireland.

K in the Literature

Recent Developments in Potato Storage in Europe.

Gottschalk, K. 2011. Potato J. 38(2):85-99.

Abstract: Recent development trends and perspectives are to find alternative methods and materials like breeding new varieties, finding biological sprout suppressants, or investing in innovative storage facilities and technologies to meet consumer demands, climatic changes, and regulations. Paper discusses applicability of controlled atmosphere or modified atmosphere storage to potatoes. Forced application of ethylene in sealed store-rooms has been proved to control dormancy. Ozone is used to suppress bacteria in order to reduce the risk of spreading diseases. The use of volatile oil as sprout suppressant is of high interest to small scale organic growers. Main advantages of bin boxes compared to bulk storage are high variability and transportability, gentle handling, and ability to smaller partitioning of varieties. The free convective ventilation of big bin box stores needs special strategies to obtain homogeneous temperature. Absorption refrigerator can be used as cooling system for potato stores. The heat may be provided by a biogas generator plant. Modern climate controllers can be equipped with modules to control CO_2 and air humidity. They can be extended with algorithms for potato surface drying and anti-condensing control. Newer control systems have options for weather forecast and online control or monitoring via mobile telephone.

Growth Rates for Potato in India and their Implications for Industry.

Scott, G.J., and V. Suarez. 2011. Potato J. 38(2):100-112.

Abstract: As potato output increased from 1.3 million t to over 34 million t over the last six decades, India became the planet´s second largest potato producer. Nonetheless, this spectacular increase masks a series of less readily apparent tendencies in the growth rates for potato production, area, and yields. While area harvested expanded, the growth for area harvested experienced a series of peaks and valleys; as yields per hectare continuously rose, the growth rate for productivity gradually ground to a halt. This paper analyses the evolution of these and other growth rates for potato in an effort to provide sharper insights into the driving factors behind the increases in production, area harvested, and yields; the most likely future scenario for the potato sector; and, the implications for industry intended to sustain output and utilization in the years ahead. Sub-sector specific recommendations include greater eco-efficiency in cold storage, efforts to explore niches for small-scale processing of French fries to complement industrial scale operations, and renewed promotion of the potato´s nutritional attributes.

Integrated Nutrient Management in Potato Based Cropping Systems in South Bihar Alluvial Plains.

Singh, S.K., and S.S. Lal. 2011. Potato J. 38(2)162-169.

Abstract: A field experiment was conducted at Patna from 2005-06 to 2007-08 on clay loam soil under Trans Gangetic plain to evaluate the effect of four fertility management schedules viz. application of recommended dose of fertilizer to all the crops in the system either alone or in combination with in situ crop residue incorporation in all the crops in the system, in situ green manuring with Sesbania in rice and FYM @ 10 t/ha applied only to winter crop of potato, on productivity and resource use efficiency in three potato based cropping systems viz. potato *(Solanum tuberosum* L.*)*-greengram *(Vigna radiata* L.*)*-rice *(Oryza sativa* L.*)*, potato-maize *(Zea mays* L.*)*-rice and potato-onion *(Allium cepa* L.*)*-rice. Maximum production (60.24 t/ha), net returns (98,990/ha), B:C ratio (1.13), production efficiency (190.99 kg/ha/day) and monetary return efficiency (313.6/ha/day) were recorded in potato-onion-rice cropping system. Potato-greengram-rice cropping system recorded highest value of sustainable yield index, organic C, available N and P in the soil. Green manuring of Sesbania in the cropping system resulted in maximum production, land use efficiency, organic C, available N, P and K in soil, while application

of FYM @ 10 t/ha to potato crop in the system resulted in highest net returns, B:C ratio, production efficiency, monetary return efficiency and sustainable yield index.

Long-Term Effect of Organic Fertilizers on Soil Properties.

Maltas, A., H. Oberholzer, R. Charles, V. Bovet, and S. Sinaj. 2012. French. Recherche Agronomique Suisse 3(3):148-155.

Abstract: Consequences of the use of different organic fertilizers (green manure, cereal straw, manure at 35 and 70 t ha^{-1} every 3 years and cattle slurry at 60 m^3 ha^{-1} every 3 years) and mineral fertilizer (four doses nitrogen) are tested in Changins since 1976. This study analyses their long-term effect on organic, chemical and biological soil properties. After 34 years of trial, when crops receive optimal nitrogen fertilizer, the soil organic matter (SOM) content decreases 0,50 g/100 g of soil for the treatment «mineral fertilizer», 0,20 g/100 g for the treatments «greenmanure» and «straws» and 0,18 g/100 g for the treatments «manure 35 t ha^{-1} every 3 years» and «slurry 60 m^3 ha^{-1} every 3 years». Only the treatment «manure 70 t ha^{-1} every 3 years» shows an increase in the SOM content of 0,15 g/100 g. Organic fertilizers do not significantly affect the main soil chemical properties, except for trace element contents. The treatments receiving manure and cattle slurry present higher amounts of copper, iron, zinc and manganese extractable in ammonium acetate EDTA than the control «mineral fertilizer». Organic fertilizers have also a positive significant effect on the activity and microbial biomass and seems to change the composition of this last.

Long-Term Effect of Organic Fertilizers on Crop Yield and Nitrogen Fertilization.

Maltas, A., R. Charles, V. Bovet, and S. Sinaj. 2012. French. Recherche Agronomique Suisse 3(3):156-163.

Abstract: Consequences of the use of different organic fertilizers (green manure, cereal straw, manure at 35 and 70 t ha^{-1} every 3 years and cattle slurry at 60 m^3 ha^{-1} every 3 years) and mineral fertilizer (four doses nitrogen) are tested in Changins since 1976. This study analyses the long-term effect (34 years) on crop yield, the need for nitrogen fertilizer and the stock of mineral nitrogen (N) in the soil. When N is not limiting, organic fertilizers have different effects on grain yield. The year of organic input and the subsequent years, manure and slurry increase yields compared to the control without organic fertilizer, while green manure and systematic restitution of the cereal straw decrease it. However, on average over the past 34 years, these effects remain weak. On the contrary, when nitrogen is limiting, all forms of organic fertilizers have a positive long term effect on crop yields. The direct effect of organic fertilizer (first year of field application) may be positive or negative. The non fertilized green manure increases the need for nitrogen fertilizer during the year of its destruction but reduces it the following year. When fertilized with 60 kg N ha^{-1}, it decreases the need for nitrogen fertilizer the year of its destruction as well as the following year. The fertilizing value of the cereal straw is negligible. Manure and slurry reduce significantly the need for N fertilizer on the three years following the application. When the fertilizer value of manure is not taken into account, the stock of mineral N in the soil present at harvest was higher in treatments with manure than in the control without organic fertilizer.

Potential for Drip Irrigation in Potato Production Under Changing Climatic Conditions.

Ballmer, T., T. Hebeisen, R. Wüthrich, and F. Gut. 2012. French. Recherche Agronomique Suisse 3(5):244-251.

Abstract: From 2008 to 2010 Agroscope Reckenholz-Tänikon Research Station ART examined the effectiveness of drip irrigation with the potato varieties Agria and Charlotte. Irrigation hoses were laid out between the rows or in each ridge of the furrow with an identical water supply. Only in 2008 there was a tendency for the gross yields produced by the irrigated methods to be higher. In 2008 and 2009, the Agria variety produced 12 to 16 per cent higher marketable yields with the irrigated methods. The percentage yield of oversized tubers (>70 mm) was the lowest in all three years of the trial with ridge irrigation. With irrigation, Agria's yield share in ware size rose by 2 to 9 absolute per cent in all the years of the trial. With the Charlotte variety, no effects of irrigation were noted on the percentage of ware size tubers. In two of the three years, the irrigated tubers of both varieties displayed a higher starch content. Irrigated tubers showed a higher infestation rate with powdery scab, but a lower infestation rate with common scab in netted, deep pitted and raised form respectively than non-irrigated tubers. Drip irrigation is a water- and energy-saving method for future yield and quality assurance in potato production.

Potassium Response and Requirement in Crops Grown in Vertisols: Experiences from Long-Term Fertiliser Experiment.

Muneshwar Singh, and R.H. Wanjari. 2012. Indian J. Fert. 8(3):26-32.

Abstract: Long-term fertilizer experiments (LTFE) were initiated with the aims to monitor the response of crops to nutrient in different soils and cropping systems to sustain productivity and food security of the country. The results generated over the years in LTFE, it indicate the responses to applied K in the soils, which were earlier considered rich in K. So to assess the response of crop to applied K, the data generated over the years were examined for K response. The results revealed that at Jabalpur gradual response to potassium was seen since inception of the experiment in soybean. However, in case of wheat response to

applied K was observed since inception with a magnitude higher than the soybean. At Akola both sorghum and wheat showed responses to applied K, which increased with time in-spite of available K content more than the yard sticks prescribed for K. Analysis of soil K status revealed that absence of K in fertilizer schedule resulted decline in K status at the rate 2.1 to 9.7 kg ha^{-1} and addition of P accelerated the mining of K. Decline in available K status was arrested with the addition of K and some cases led to increase in available K form. Thus results indicate the need to modify or raise the K limits for rating the Vertisols as high and accordingly K recommendation be made in Vertisols.

Economics of Potassium Fertiliser Application in Rice, Wheat and Maize Grown in the Indo-Gangetic Plains.

Majumdar, K., A. Kumar, V. Shahi, T. Satyanarayana, M.L. Jat, D. Kumar, M. Pampolino, N. Gupta, V. Singh, B.S. Dwivedi, M.C. Meena, V.K. Singh, B.R. Kamboj, H.S. Sidhu, and A. Johnston. 2012. Indian J. Fert. 8(5):44-53.

Abstract: Potassium (K) fertilizer cost has increased considerably over the past three years. The sharp increase in price has raised doubts about the profitability of potassium application in cereals where the Minimum Support Prices (MSP) is low. On-farm K response studies in rice, wheat and maize, spread across the Indo-Gangetic Plains, highlighted that grain yield response to fertilizer K is highly variable and is influenced by soil, crop and management factors. Average yield losses in rice, wheat and maize in farmers' fields due to K-omission were 622, 715 and 700 kg/ha, respectively. This suggests that skipping application of K in the three cereal crops will cause variable yield and economic loss to the farmers of the region and will affect overall cereal production in the country. The return on investment of applied potassium in rice, wheat and maize were R.S. 5.5, 4.4 and 3.2 respectively per rupee invested on K. Economic assessment based on projected cost of K fertilizer and projected MSP of the cereals also showed favourable return on investment for K fertilizer. Considering the high variability in K response, blanket K recommendations would most likely lead to economic loss for farmers due to under or over application in most cases. A site specific potassium management strategy, based on the expected crop response to K at a location, would improve yield and profitability of cereal farming.

Flow and Deformation Behavior at the Microscale of Soils from Several Long-Term Potassium Fertilization Trials in Germany.

Holthusen, D., S. Peth, R. Horn, and T. Kühn. 2012. Z. Pflanzenernähr. Bodenk. DOI: 10.1002/jpln.201100073. J. Plant Nutr. Soil Sci.

Abstract: The effect of K fertilization on microstructural soil stability is rarely analyzed until now although the ambiguous impact on bulk soil structure was reported quite often, e.g., with regard to higher erodibility on the one hand and higher water storage on the other. Soil material from different long-term fertilization trials in Germany was examined rheologically by means of an amplitude sweep test where the samples were subjected to oscillating shearing with increasing deflection. The resulting shear stress was recorded, and the maximum stress denoted the maximum shear strength of the sample. Results showed an ambiguous influence of K which depends strongly on the soil properties. On the one hand, an increased ion concentration in the soil solution leads to increasing attractive forces as defined by the DLVO theory and therefore higher shear resistance. With increasing desiccation, K^+ like other salts can precipitate at the contact areas between particles and lead to cementation. On the other hand, K^+ as a monovalent ion impedes covalent and ionic bonding between clay minerals which holds true for most of the examined soil types while only sandy soils showed an increase in soil strength due to K fertilization. Potassium depletion further resulted in increased interaction of fertilization with other impact factors, e.g., climate and soil properties. Thus, the destabilizing effect of K^+ was more pronounced under liming as without liming. Subsequent modeling with selected soil parameters confirmed the high influence of matric potential. The modeling also revealed the interactions with other soil parameters, e.g., pH, oxides, texture, exchangeable cations as well as lack or surplus of K in relation to recommended K content. In conclusion, microstructural stability of soil depends on several soil parameters and requires the inclusion of many chemical and physical soil properties.

Critical Carbon Inputs to Maintain Soil Organic Carbon Stocks under Long-Term Finger Millet *(Eleusine coracana* [L.] *Gaertn.)* Cropping on Alfisols in Semiarid Tropical India.

Srinivasarao, C., B. Venkateswarlu, A. Kumar Singh, K. Pandu Ranga Vittal, S. Kundu, G. Ravindra Chary, G. Narayanaiyer Gajanan, and B. Kogganur Ramachandrappa. 2012. Z. Pflanzenernähr. Bodenk.. DOI: 10.1002/jpln.201000429. J. Plant Nutr. Soil Sci.

Abstract: Enrichment of soil organic carbon (SOC) stocks through sequestration of atmospheric CO_2 in agricultural soils is important because of its impacts on adaptation to and mitigation of climate change while also improving crop productivity and sustainability. In a long-term fertility experiment carried out over 27 y under semiarid climatic condition, we evaluated the impact of crop-residue C inputs through rainfed fingermillet *(Eleusine coracana* [L.] *Gaertn.)* cropping, fertilization, and manuring on crop yield sustainability and SOC sequestration in a Alfisol soil profile up to a depth of 1 m and also derived the critical value of C inputs for maintenance of SOC. Five treatments, viz., control, farmyard manure (FYM) 10 Mg ha^{-1}, recommended dose of NPK (50 : 50 : 25 kg N, P_2O_5, K_2O ha^{-1}), FYM 10 Mg ha^{-1} + 50% recommended dose of NPK, and FYM 10 Mg ha^{-1} + 100% recommended dose of NPK imposed in a randomized block design replicated four times. Application of FYM alone or together with mineral fertilizer resulted in a higher C input and consequently built up

a higher C stock. After 27 y, higher profile SOC stock (85.7 Mg ha^{-1}), C build up (35.0%), and C sequestration (15.4 Mg C ha^{-1}) was observed with the application of 10 Mg FYM ha^{-1} along with recommended dose of mineral fertilizer and these were positively correlated with cumulative C input and well reflected in sustainable yield index (SYI). For sustenance of SOC level (zero change due to cropping) a minimum quantity of 1.13 Mg C is required to be added per hectare per annum as inputs. While the control lost C, the application of mineral fertilizer served to maintain the priori C stock. Thus, the application of FYM increased the C stock, an effect which was even enhanced by additional amendment of mineral fertilizer. We conclude that organic amendments contribute to C sequestration counteracting climate change and at the same time improve soil fertility in the semiarid regions of India resulting in higher and more stable yields.

Assessment of Soil Phosphorus and Potassium following Real Time Kinematic-Guided Broadcast and Deep-Band Placement in Strip-Till and No-Till.

Fabián G. Fernández and Daniel Schaefer. 2011. DOI: 10.2136/sssaj2011.0202. Soil Sci. Soc. Am. J. 76(3):1090-1099.

Abstract: Fertilizer placement may cause non-uniform nutrient distribution in the soil, making it difficult to determine whole-field fertility by traditional sampling strategies. Our objectives were to determine P and K distribution after repeated applications in no-till and strip-till soils and to develop improved sampling procedures to estimate soil P and K levels on a corn *(Zea mays* L.*)* and soybean *(Glycine max* [L.] *Merr.)* rotation with crops planted at 76-cm row spacing. Three trials near Pesotum, IL, received blends of 0-0, 22-42, 33-62, 44-83, 55-104, 66-125, and 77-145 kg P-K ha^{-1} in fall 2007 and 2009 before corn planting. Applications were broadcast-applied in no-till (NTBC) and strip-till (STBC) and deep-banded in strip-till (STDB) 15 cm below the surface in the crop row (IR) using real-time kinematic (RTK) satellite navigation. Every year soil P and K was measured at 10-cm increments to a 30-cm depth at 0, 19, 38, and 57 cm from the IR. Subsurface banding reduced P and K levels in the surface and increased them at the point of application, or deeper with the highest rate, while broadcast applications increased surface levels. Soil-surface K levels were greater at IR likely because of K leaching from senescing standing crops. Soil-test results indicated no need to adjust fertilizer rate based on tillage or fertilizer placement. A sampling ratio of 1:3 IR to between the crop rows (BR) seemed adequate to estimate soil fertility across a wide range of P- and K-fertilizer rates and soil test levels where the location of the fertilizer band or planting row is maintained constant.

Distribution of Soybean Roots, Soil Water, Phosphorus and Potassium Concentrations with Broadcast and Subsurface-Band Fertilization.

Bhupinder S. Farmaha, Fabián G. Fernández and Emerson D. Nafziger. 2011. DOI: 10.2136/sssaj2011.0202. Soil Sci. Soc. Am. J. 76(3):1079-1089.

Abstract: In conservation tillage, fertilizer placement is designed to improve nutrient availability. Our objective was to determine the effect of tillage (no-till and strip-till) and P and K rate and placement on the distribution of soybean *(Glycine max* [L.] *Merr.)* roots and on water, P, and K levels in soil. A 3-yr field experiment was conducted near Urbana, IL, with soybean following corn *(Zea mays* L.*)*. Rates of 0-0, 36-0, 0-168, and 36-168 kg P-K ha^{-1} yr^{-1} were applied as no-till/broadcast (NTBC), no-till/deep band (15 cm beneath the planted row) (NTDB), and strip-till/deep band (STDB). Roots and soil water, P, and K levels were measured periodically at in-row (IR) and between-rows (BR) positions at 0- to 5-, 5- to 10-, 10- to 20-, and 20- to 40-cm depths. Deep banding increased P and K soil test levels beneath the row and lowered soil surface test-values compared to broadcast applications, but had no effect on root distribution. Compared to NTBC and NTDB, STDB had a 20% increase in soil water content during the seed-fill period at BR within the top 10 cm of soil where greatest apparent nutrient uptake (estimated by changes in soil-test levels) occurred. Within that zone, NTBC produced and maintained a larger root system than STDB. However, STDB had 23% greater P and 30% greater K accumulation in shoots and also greater apparent nutrient uptake and greater apparent nutrient uptake rate per unit of root surface area. The results indicate that STDB provides overall better soil conditions for P and K uptake compared to the NTBC and NTDB systems.

Alfalfa Yield Components and Soil Potassium Depletion as Affected by Potassium Fertilization.

Lloveras, J., C. Chocarro, L. Torres, D. Viladrich, R. Costafredaand, and F. Santiveri. 2011. DOI: 10.2134/agronj2011.0293. Agron. J. 104(3):729-734.

Abstract: Potassium fertilization recommendations for alfalfa *(Medicago sativa* L.*)* vary depending on the area of production, soil levels, and crop management. The objectives of this study were to determine the impact of K fertilization on irrigated alfalfa yield, yield components, and soil exchangeable K (Ke) values in a Mediterranean climate. A field experiment was conducted during a period of 4 yr (2002-2006) in Spain, on a soil with moderate levels of Ke (161 mg K kg^{-1}). The treatments applied were five annual rates of K (0, 100, 200, 300, and 400 kg K ha^{-1}). Total 4-yr dry matter (DM) yields averaged 74.9 Mg ha^{-1} without differences between K fertilizer rates, although the unfertilized control produced the lowest DM yields. The 4-yr crop uptake of K reached 1738 kg ha^{-1} with the application of 400 kg K ha^{-1} yr^{-1}, and 756 kg K ha^{-1} for the 0 K fertilization. The removal was greater than the K applied. The results suggest that large amounts of K

should not be applied to alfalfa because the crop uses excess K without increasing yield. Soil Ke concentrations decreased every year for all K rates except for the highest treatment of 400 kg K ha^{-1} yr^{1}. Lack of K fertilization did not affect stand density but the shoot weight was the yield component most closely related to K fertilization.

Read on:

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Growth Response of the Salt-Sensitive and the Salt-Tolerant Sugarcane Genotypes to Potassium Nutrition under Salt Stress.
Ashraf, M. *et al.* 2012. DOI: 10.1080/03650340.2010.529609. Archives of Agronomy and Soil Science 58(4-6):385-398.

Long-Term Impacts of Global Food Crisis on Production Decisions: Evidence from Farm Investments in Indonesia.
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Courtesy of Lu Jianwei, Huazhong Agricultural University, Wuhan, China.

Clipboard

Dr. Mohamed Badraoui became a member of the IFDC Board of Directors in 2012 and serves on the board's Africa Committee (see more on the IFDC website). Dr. Badraoui was supporting the IPI program in Morocco for many years.

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