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Research Findings

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

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

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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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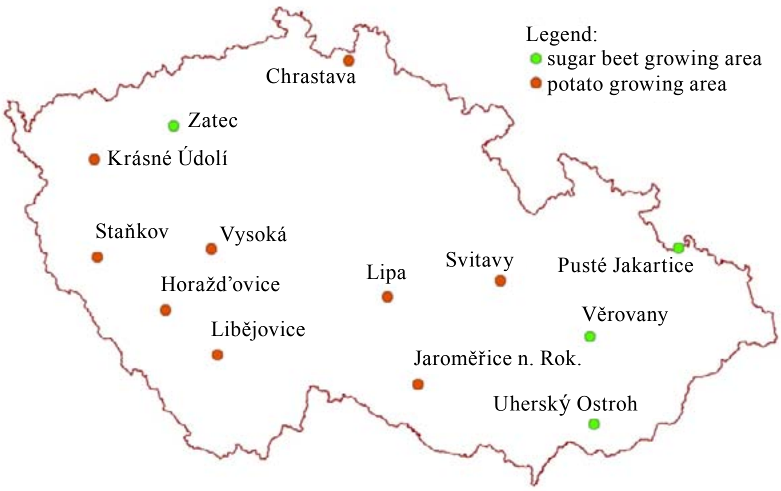

Map of LTFE experimental locations in the Czech Republic (Table 1).

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.

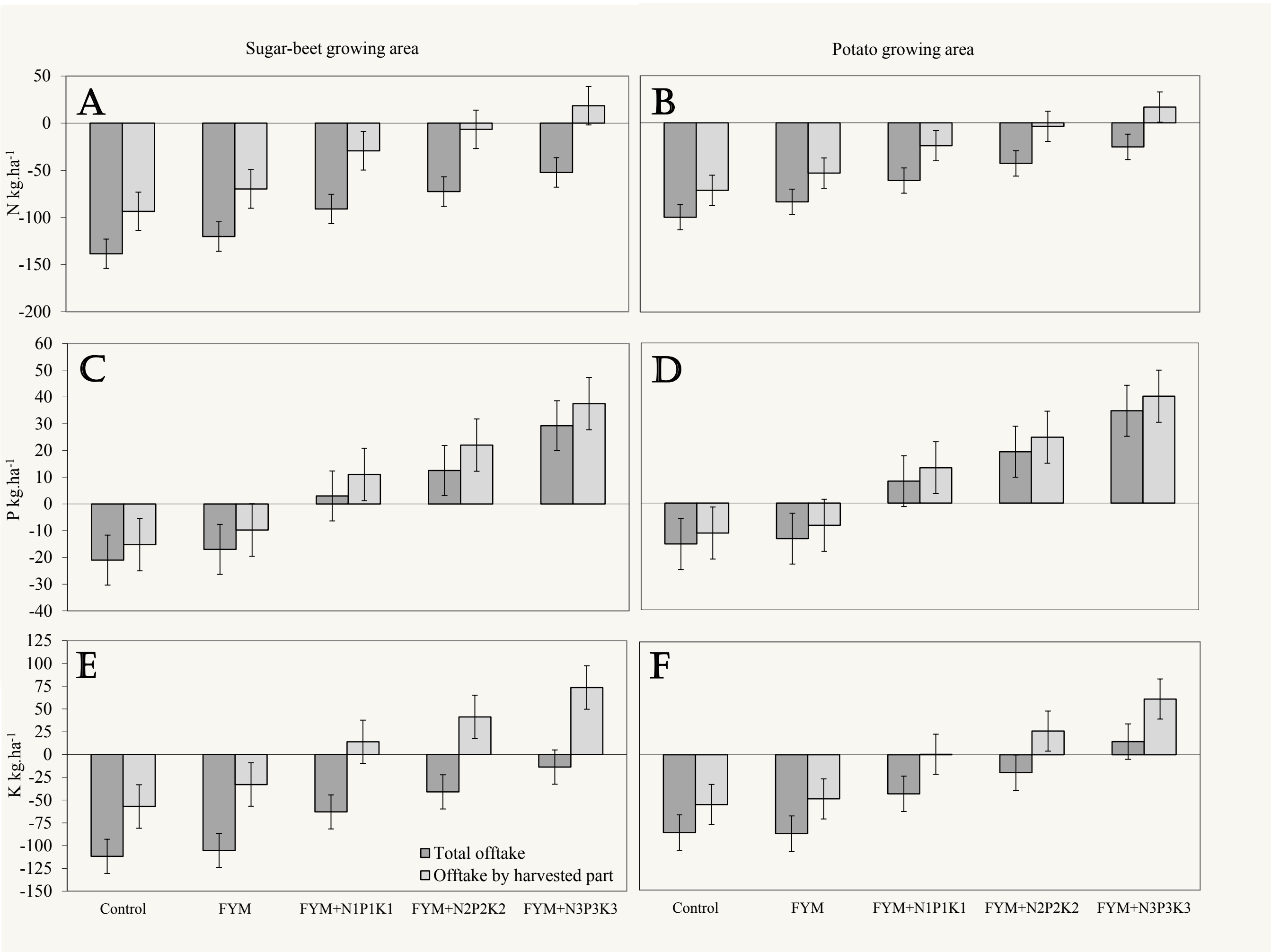

Fig. 1. (A-F): Average nitrogen (A & B), phosphorus (C & D) and potassium (E & F) balance in SBGA (left column) and PGA (right column). Data represents the average over 37 years; kg of nutrient ha^{-1} in four locations; bars represent standard error (SE).

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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