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EVALUATION OF THE LONG-TERM FERTILIZER EXPERIMENT: HOW ORGANIC MANURES, MINERAL FERTILIZERS AND POTATO VARIETIES AFFECTED TUBER YIELDS

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Abstract

We evaluated how organic manures (farmyard manure, dung water and poultry slurry), different doses of mineral fertilizers (three treatments), combinations of manures with mineral fertilizers (three treatments), and potato varieties (four varieties) influenced potato tuber yields in our long-term fertilizer experiment in Prague, established in 1954.

According to our crop rotation, potatoes were planted every ninth year, starting in 1962. Four potato varieties were used since then (Krasava, Radka, Korela, Dita), all of them were medium-maturing and consumable.

The average potato yield was 19.1 Mg ha^{-1} at the beginning of our experiment (1962, var. Krasava) and 37.5 Mg ha^{-1} in 2007 (var. Dita), showing low suitability of the experimental site for potato production. The mean tuber yield of varieties Krasava, Radka, Korela and Dita was 18.5, 17.1, 30.2 and 37.5 Mg ha^{-1}, respectively. The effect of organic manures was principally comparable with mineral fertilizers. Increasing doses of mineral fertilizers were not related to appropriate increase in tuber yield. Therefore, application of N, P and K around 50, 50 and 144 kg ha^{-1}, respectively, gives fair yields in such non-optimal production area, as is our experimental site. In the case of warm and dry seasons, even high doses of the mineral fertilizers can't ensure usual potato production.

Keywords: *Solanum tuberosum*, farmyard manure, dung water, poultry slurry, long-term experiment, mineral NPK

INTRODUCTION

Potatoes were and are one of the most traditional arable crops in the Czech Republic. The sowing area reached almost a half million of ha between 1934-1938, the average potato yield was approximately 15 Mg ha^{-1} at that time. As the time passed by, the sowing area decreased significantly. In 1960, the sowing area decreased below 400 kha and the tendency has been continuing. Nowadays, consumable potatoes are grown on 20 kha in the Czech Republic and share approximately the same area as sunflower or poppy seed. Together with decreasing production area, the potatoes yield increased systematically during the second half of the 20th century. This increase was achieved by several factors, mainly by better availability of mineral fertilizers and organic manures during the socialistic era, by genetic breakthroughs resulting in stronger varieties and by advances in plant protection. While the average yield oscillated around 13.2 Mg ha^{-1} in 1950s, fifty years later reached the average yield 22 Mg ha^{-1}.

Fertilizers, especially N and P fertilizers, are perhaps one of the most important factors from both a production and environmental standpoint. Insufficient amount of nitrogen can limit yield, while excessive doses can leach to groundwater or negatively affect yield of marketable tubers. Potatoes are also traditionally fertilized with organic manures, if the livestock production is part of the farm, or exists in the near vicinity.

In his research, Errebhi *et al.* (1998) tested four different doses (ranging from 0 to 135 kg ha^{-1}) of N applied at planting in two consecutive years. In both years, the yield of marketable tubers was not affected by any treatment. Moreover, increasing doses of N negatively affected larger tubers, while positively affected smaller, non-marketable tubers. Waddell *et al.* (1999) experimented with different sources of nutrients and concluded, that using of organic manure is a viable alternative for potato production, if managed properly. Kanal and Kuldkepp (1993) studied the effect of eight different organic fertilizers on potatoes, combined with or without mineral fertilizers. In his research, the best results were obtained by cattle dung with litter, in both treatments with or without the NPK. Combination of mineral fertilizers and organic manure was the best treatment in the research from Agbede (2010), where the application of poultry manure with NPK provided 83% higher yields of sweet potatoes, than unfertilized Control and 44% and 38% higher yields, than NPK and poultry manure, respectively, applied alone. Similar results with standard potatoes fertilized by farmyard manure and NPK published Caliskan *et al.* (2004), or by Balemi (2012).

The source of the nutrients plays an important role in today's agriculture, especially if consumers are concerned about the association between agricultural practices and human health, mainly from the contamination of food with pesticides and nitrates. The rising demand of organically produced agricultural products opens the question, if organic manures can supplement mineral fertilizers. That's the reason why we analyzed the effect of different doses of mineral fertilizers, the effect of organic manures and the combination of mineral fertilizers with organic manures on potatoes yield in our long-term fertilizer experiment.

MATERIALS AND METHODS

Site description

Our long-term experiment is located in the western part of Prague (Central Europe, temperate climate zone) and was established in 1954. The annual average temperature and precipitation were 8.5°C and 495.8 mm, respectively (1954-2015, Prague-Ruzyně weather station). The altitude of the experiment is 338 m a.s.l. The soil type is classified as Luvisol-LV (World Reference Base for Soil Resources, 2015). The initial soil pH at the beginning of the experiment was 6.5 in the top 20 cm layer.

Experimental design

The long-term experiment is made up of five fields (I, II, III, IV, V). Each field comprises 96 plots (12 x 12 m), where we are testing 24 different fertilizer treatments, each treatment replicated four times, arranged in a completely randomized design. The subject of this study is field number II. Its crop rotation consists of alfalfa, alfalfa, winter wheat, sugar beet, spring barley, potatoes, winter wheat, sugar beet and spring barley. Out of 24 fertilizer treatments, we analyzed ten treatments for the purpose of this paper. The treatments are unfertilized control (Control), farmyard manure (FYM), dung water (DW), poultry slurry (PS), three treatments with different doses of mineral NPK (NPK1, NPK2 and NPK3), farmyard manure with NPK3 (FYM+NPK3), dung water with NPK (DW+NPK3), and poultry slurry with NPK (PS+NPK3). Mineral nitrogen, phosphorus, and potassium were applied as calcium ammonium nitrate (27 % N), superphosphate (8.3 % P) and potassium chloride (49.8 % K), respectively. The doses of N, P and K were: 50, 50 and 144 kg ha^{-1} (NPK1), 90, 50 and 144 kg ha^{-1} (NPK2) and 110, 70 and 224 kg ha^{-1} (NPK3), respectively. Organic manures were applied at doses: 15 Mg ha^{-1} (FYM), 30 Mg ha^{-1} (DW) and 43 Mg ha^{-1} (PS).

Four potato varieties have been used from the beginning of the experiment: Krasava (1962, 1971), Radka (1980, 1989), Korela (1998) and Dita (2007). Weather information describing mean temperature and precipitation shows Figure 1.

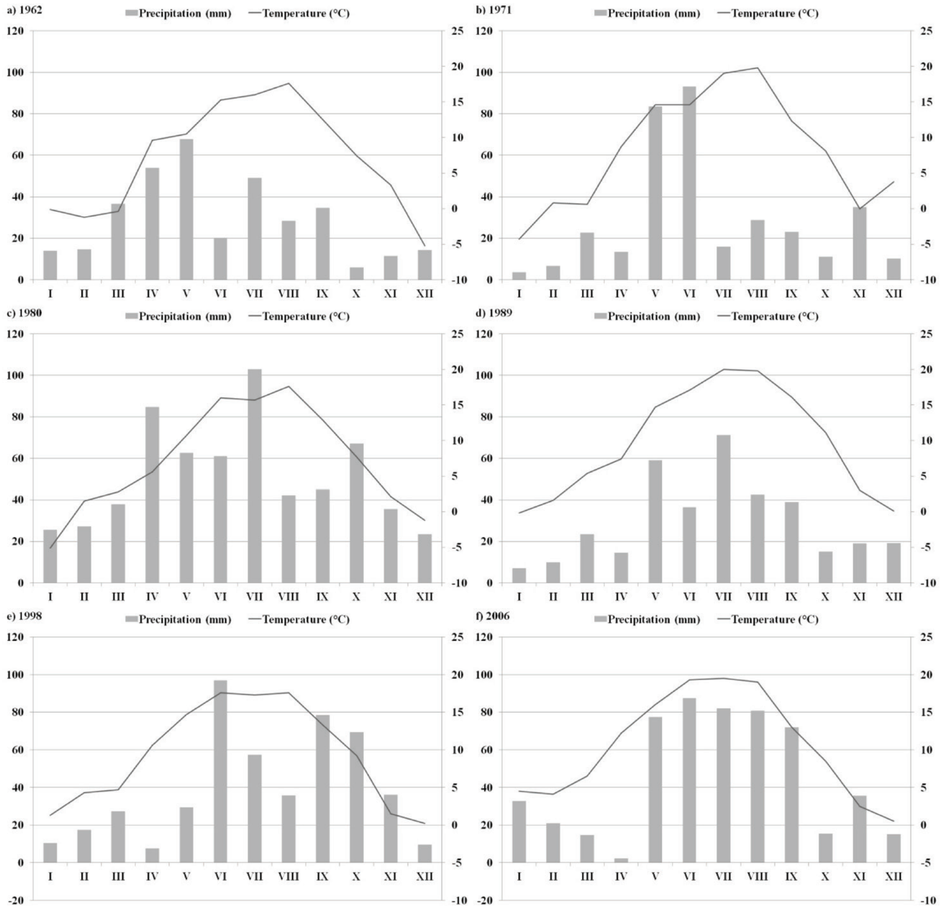

Figure 1. The sum of precipitation (mm) and mean temperature (°C) in the years a) 1962, b) 1971, c) 1980, d) 1989, e) 1998 and f) 2006.

Data analysis

Tuber yield differences between particular fertilizer treatments were analyzed by one-way and multivariate analysis of variance (ANOVA, MANOVA) in STATISTICA 12.0 (www.statsoft.com). In the case of a finding of statistically significant differences, we applied the Tukey HSD post hoc test to determine differences between individual treatments.

RESULTS

The average tuber yield ranged from 14.7 Mg ha^{-1} (Control) to 22.7 Mg ha^{-1} (DW+NPK3) in the beginning of the experiment (1962), and the effect of the fertilizer treatment on tuber yield was significant (d.f. = 9, F = 13.45, $p < 0.0001$). All organic manures provided yields comparable to Control treatment. Application of mineral fertilizers and combination of NPK with organic manures increased tuber yield significantly, when compared with Control (Fig. 2a). A similar pattern was recorded nine years later, with the same potato variety, Krasava (d.f. = 9, F = 13.43, $p < 0.0001$). In 1971, the average yield ranged from 12.6 Mg ha^{-1} (Control) to 19.5 Mg ha^{-1} (DW+NPK3)(Fig. 2b). The summary average yield of the Krasava potato variety was 18.05 Mg ha^{-1}.

In 1980, a new potato variety Radka was introduced. The summary average tuber yield was similar to its predecessor, 17.1 Mg ha^{-1} (Fig. 3). The mean tuber yield ranged from 9.0 Mg ha^{-1} (DW) to 25.9 Mg ha^{-1} (NPK3) in 1980 (d.f. = 9, F = 10.63, $p < 0.0001$)(Fig. 2c), and from 14.0 Mg ha^{-1} (PS+NPK3) to 22.2 Mg ha^{-1} (FYM) in 1989 (d.f. =9, F = 1.32, $p < 0.271$)(Fig. 2d).

The potato variety Korela was introduced in 1998, almost doubling previous potato yields with mean yield 30.2 Mg ha^{-1} (Fig. 3). The effect of the fertilizer treatment was significant (d.f. = 9, F = 15.86, $p < 0.0001$) and yields ranged from 21.8 Mg ha^{-1} (Control) to 34.2 Mg ha^{-1} (DW+NPK3)(Fig. 2e). Nine years later our former colleagues changed potato variety again. New variety Dita provided higher average yield, 37.5 Mg ha^{-1} (Fig. 3). The effect of the fertilizer treatment was significant (d.f. = 9, F = 19.17, $p < 0.0001$) and yields ranged from 23.8 Mg ha^{-1} (Control) to 42.6 Mg ha^{-1} (NPK2)(Fig. 2f).

Evaluation of the experiment over the whole time by MANOVA method showed, that the "fertilizer treatment" influenced tubers yield only by about 5% ($p<0.001$), while the factor "year-potato variety" by 94% ($p<0.001$).

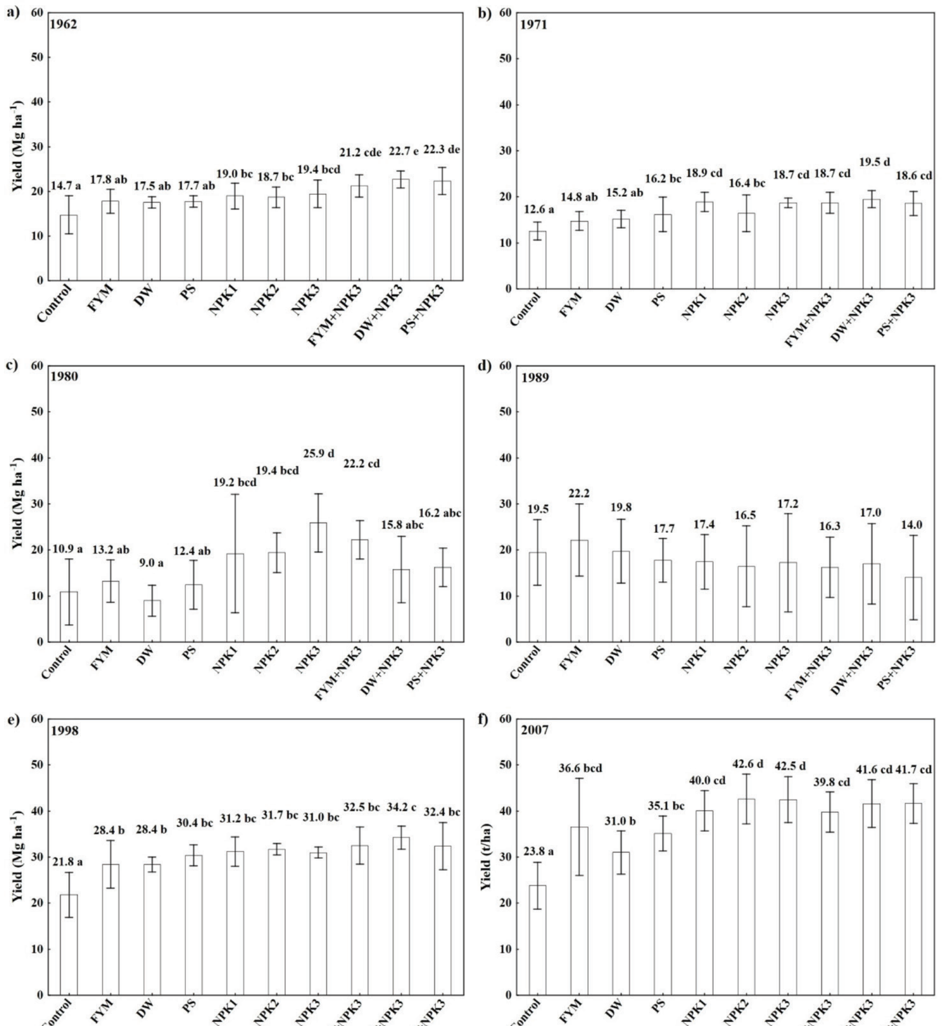

Figure 2. Mean tuber yield (Mg ha[-1]) as affected by fertilizer treatment (Control, FYM-farmyard manure, DW-dung water, PS-poultry slurry, NPK1, NPK2, NPK3, FYM+NPK3, DW+NPK3, PS+NPK3) and by year, variety – a) 1962 (Krasava), b) 1971 (Krasava), c) 1980 (Radka), d) 1989 (Radka), e) 1998 (Korela), f) 2007 (Dita). Means followed by the same letter were not significantly different at 0.05 probability level.

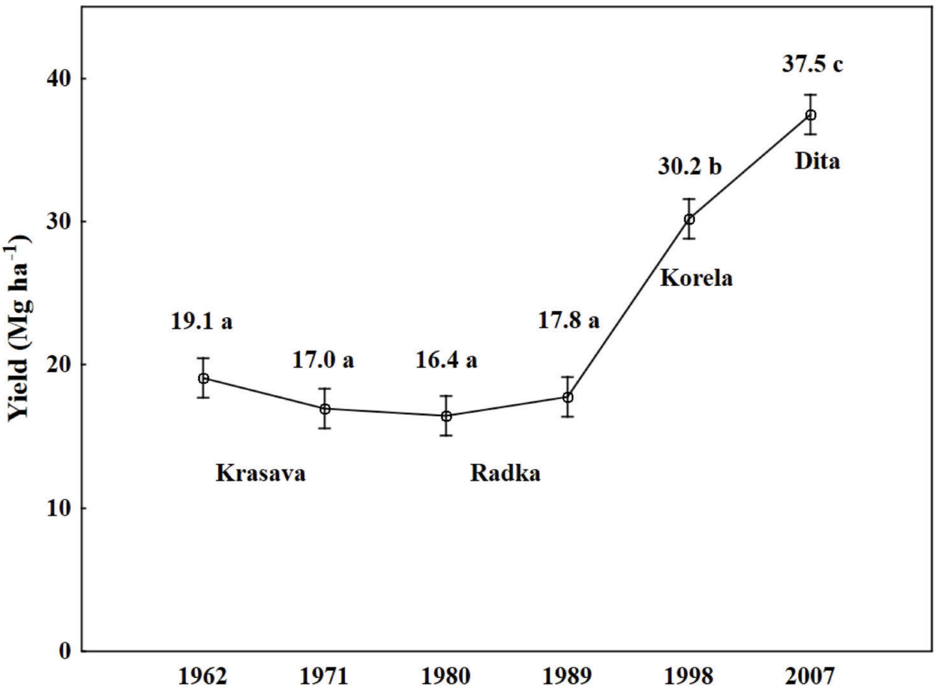

Figure 3. Mean potato yield (Mg ha^{-1}) as affected by potato variety and year over the all time of the experiment (1962-2007). Means followed by the same letter were not significantly different at 0.05 probability level.

DISCUSSION

Up today, the mean tuber yield increased twofold from the first inclusion of potatoes in the crop rotation of our long-term experiment in 1962.

In the beginning of the experiment (1962-1971), application of organic manures slightly increased tuber yield, when compared with unfertilized Control treatment, but the difference was not statistically significant. Our results are in contrast with many short-term experiments, proving a positive effects of organic manures on the yield of arable and industrial crops (Barzegar et al. 2002; Blaise et al. 2005; Ibrahim et al. 2008; Akparobi 2009; Koutroubas et al. 2016). The explanation could be that rapid mineralization of organic manures did not synchronize with nutrition requirements of the potatoes, or the amount of mineralized nutrients was low. While the releasing of nutrients from composted manures is expected low and long, the mineralization of nutrients from swine or poultry manures is expected more rapid (Eghball *et al.* 2002). The availability of nutrients from DW and PS could also be influenced by leaching, because the ratio of manure mineralization decreases during the dry season and increase during the wet season, when the soil moisture is near the field capacity, and winter is the most sensitive time for leaching of elements in Central Europe (Kayser *et al.* 2010). In our case, organic manures were applied in autumn, while the potatoes were sown during following spring. Organic fertilizers can have a beneficial effect on soil characteristics and fertility by increasing soil organic carbon in topsoils (Hati *et al.* 2006; Sradnick *et al.* 2014), water holding capacity, saturated hydraulic conductivity (Zhang *et al.* 2014), microbial biomass (Geisseler and Scow 2014) and by decreasing bulk density (Bandyopadhyay *et al.* 2010; Zhang *et al.* 2014). These facts could explain a beneficial effect of NPK incorporated with organic manures in the beginning of our experiment.

The effect of fertilizer treatment was very low during the eighties, and combinations of NPK with manures were even counterproductive (1980), for which we have no reasonable explanation. The positive effect of fertilizers, especially of organic manures, strongly depends on the weather of a particular year. Conditions during the 1989 were obviously strongly unfavourable for potatoes, as it was above-averagly warm (mean temperature was 9.7°C) and dry year (cumulative precipitation was 356 mm that year with a significant shortage of precipitation during the first quarter of the year). Similar effect of weather, affecting mineralization of fertilizers and grain yields of winter wheat reported Hlisnikovsky *et al.* (2015) during extremely dry and warm year 2012 in Southmoravian region, Czech Republic.

Introduction of new potato varieties during the nineties and first decade of the 21th century significantly increased tuber yields. As all potato varieties in our experiment were medium-maturing and consumable, not for industrial purposes, we believe that the significant increase was achieved by combination of development in plant protection and genetics knowledge. The effect of the NPK application was comparable to organic manures and to the combinations of NPK incorporated with organic manures.

CONCLUSIONS

From the comprehensive view, the long-term and regular application of organic manures, different doses of mineral fertilizers and combination of manures with mineral NPK, resulted in very similar and comparable results. Relatively low yields, even in treatments with high doses of mineral nutrients, are in contrast to results of Hamouz *et al.* (2005), who recorded yields about 45.4 Mg ha^{-1} in conventionally treated fields and 29.1 Mg ha^{-1} in ecologically treated fields in the Czech Republic. This indicates low suitability of the study site for potato production due to lower level of precipitation, when compared with other, more suitable localities. According to Šrek *et al.* (2010) the main potato cropping area starts at altitudes from 400 m a.s.l. in the Czech Republic. Also, the soil in our long-term experiment is naturally highly fertile, directly comparable with chernozems in Central Europe (Hejcman et al. 2012). Combination of naturally highly fertile soil and relatively low suitability of the experimental area for potato production (low precipitation) creates natural barriers, limiting positive effects of mineral fertilizers and upscaling the effects of organic manures. Therefore, application of N, P and K around 50, 50 and 144 kg ha^{-1}, respectively, gives fair yields in non-optimal production areas, while decreasing environmental risks and financial costs, when compared with higher doses of NPK. During the years with abnormal weather conditions, such as dry years with high temperatures, the usual potato production can't be assured even with high doses of mineral fertilizers.

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