Czech University of Life Sciences in Prague

Faculty of Environmental sciences

Department of Ecology

Effect of fertilizer application on yield of potatoes, size and number of tubers and concentration of selected macro-, micro- and risk elements

Vliv hnojení na výnosy brambor, velikost a počet hlíz a na obsahy vybraných makro-, mikro- a rizikových prvků

Bachelor thesis

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Bachelor Thesis Assignment

Mariya Musya

Applied Ecology

Thesis title

Effect of fertilizer application on yield of potatoes, size and number of tubers and concentration of selected macro-, micro- and risk elements

Objectives of thesis

The aim of the work is to find out what effect fertilization has on potato yields, size and number of tubers and on the content of macro-, micro- and risk elements.

Methodology

As part of long-term experiments with fertilization, which have been taking place at the Crop Research Institute in Prague since 1955, the student will analyze potato yields and their elemental composition in the 2016 season. fertilizers, mineral fertilizer applications and combinations of organic and mineral fertilizers.

The proposed extent of the thesis

30 pages

Keywords

Solanum tuberosum, nitrogen, phosphorus, potassium

Recommended information sources

1. Šrek P., Hejcman M., Kunzová E. (2010): Multivariate analysis of relationship between potato (Solanum tuberosum L.) yield, number of applied elements, their concentrations in tubers and uptake in a long-term fertilizer experiment. Field Crops Research 118: 183–193.
2. Šrek P., Hejcman M., Kunzová E. (2012): Effect of long-term cattle slurry and mineral N, P and K application on concentration of N, P, K, Ca, Mg, As, Cd, Cr, Cu, Mn, Ni, Pb and Zn in peeled potato tubers and peels. Plant Soil and Environment 58: 167–173.

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DECLARATION

I hereby declare that this Bachelor's thesis is a presentation of my original research work, which was done under the guidance of prof. RNDr. Michal Hejcman, Ph.D. et Ph.D. at the Czech University of Life Sciences Prague. Wherever contributions of others are involved, there is an acknowledgement of collaboration and every effort is made to indicate this clearly, with due reference to the used literature.

In Prague, 22 June 2020 ____________________

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Abstract

The aim of this study was to investigate how potato yield, the concentrations of elements (N, P, K, Ca, Mg, S, As, Cd, Cr, Cu, Fe, Mn, Ni, Pb and Zn) in tubers and their uptake are affected by mineral N, P and K fertilizers and organic fertilizers (organic manure and pig slurry) application. Our experiment took place at the Crop Research Institute in Prague as the long-term fertilizer experiment established. Potatoes were collected in years 2016 and 2017 from the Ruzyne Fertilizer Experiment (RFE, the Czech Republic, 24 fertilizer treatments, 4 replications), which was established on a permanent arable field (Illimerized Luvisol) in 1955. Separate use of organic fertilizers made a significant difference in yield, but not as big as NPK treatment. Application of mineral fertilizers not only significantly affected the number of tubers and yield, but also the chemical composition of potatoes

From the profit, application of farmyard manure and pig slurry, combined with mineral NPK, provided the highest yields and these combinations represent the best fertilization approach when compared with application of organic manures or mineral fertilizers applied alone.

Abstrakt

Cílem této studie bylo zjistit, jak výnos brambor, koncentrace prvků (N, P, K, Ca, Mg, S, *As*, Cd, Cr, Cu, Fe, Mn, Ni, Pb a Zn) v hlízách a jejich příjem je ovlivňován minerálními hnojivy N, P a K a organickými hnojivy (hnůj a prasečí kejda). Náš experiment se uskutečnil ve Výzk umném ústavu rostlinné výroby v Praze, když byl zaveden dlouhodobý experiment s hnojivy. Brambory byly sbírány v letech 2016 *a* 2017 z experimentů s hnojivy Ruzyně (RFE, Česká re publika, 24 ošetření hnojiv, 4 replikace), který byl založen na trvalém orném poli v roce 1955. Samostatné využívání organických hnojiv významný rozdíl ve výnosu, ale ne tak velký jako ošetření NPK. Aplikace minerálních hnojiv významně ovlivnila nejen počet hlíz a výnos, ale také chemické složení brambor.

Ze zisku je použití statkových hnojiv a prasečí kejdy v kombinaci s minerální NPK za předpo kladu nejvyššího výnosu a tyto kombinace představují nejlepší přístup k hnojení ve srovnání aplikací organických hnojiv nebo minerálních hnojiv aplikovaných samostatně.

Contents

Introduction
History

Potato, (Solanum tuberosum L.) is an annual plant from the nightshade family (Solanaceae). The potato is native to the Peruvian-Bolivian Andes and was grown for its starchy edible tubers on the territory of Peru, Chile, Bolivia, and Ecuador, where was domesticated approximately 7,000–10,000 years ago. (G. Lisinska, W. Leszczynski,1989) Thousands of distinct kinds had been cultivated since then due to different weather conditions, types of soil and farmers'needs. Containing a high level of proteins and carbohydrates, as well as essential fats, vitamins and minerals potatoes were the perfect food source to fuel the Indian tribes, making it a staple food supply (Horton Douglas, 1987).

The first case of potato introduction in Europe is dated to 1570 when Spain conquistador's ships returned from their journey. At the start, the plant began to spread across the continent rather like a decorative and slightly poisonous garden plant than food, but in a view of the rich yield and cheap cultivation, potatoes have been gradually replacing turnip, which was very common at that time. Many academics argued that the potato's domestication in Nothern Europe put an end to the famine in that area. Moreover, historian William H. McNeill has claimed, the potato led to empire: "By feeding rapidly growing populations, [it] permitted a handful of European nations to assert dominion over most of the world between 1750 and 1950."

However, it took more than three hundred years before the potato caught on as a major food source throughout Europe, tubers consumption had become popular among the working class only from the early 19th century (Zeven, van Harten, 1979). Step by step, the European potato started to be more resilient towards severe climate and could be grown more wildly, but its low genetic diversity led to a low resistance towards late blight, a plant disease that is caused by the fungus pathogen Phytophthora infestans, that plagues mostly species of the nightshade family, especially potatoes and tomatoes. The asexual life cycle of P. infestans proceeds at a rapid pace with the production of extensive numbers of sporangia that are able to spread out easily. But visually, there are generally no symptoms for at least 2 days, after which time small areas of necrosis are noticeable. Contaminated fields, therefore, can be transformed from slightly affected to nearly completely ruined in a very short time (Bourke,1991). Phytophthora infestans is also known as the main reason for the Irish Potato Famine. Since 1590, after the Irish adopted the potato, their population dramatically increased from 1,4 to 8,2 million, as did their dependence on the tuber as a major food staple. From 1845 to 1849 potato blight disease ravaged the vast majority of Ireland's potato crop that led to the Great Hunger (1845 – 1849). The introduction of a new crop into local agriculture system could entail dramatic impacts that change the course of history for the whole country. Over a million Irish citizens starved to death and more than 2 million people emigrated, mainly to the USA (O'Neill, 2009).

Nowadays the potato is still one of the most important crops in the world. The largest producers are China, Russia, India and the USA. Tubers are a source of starch and ethanol production as well. Potatoes were and are one of the most traditional arable crops in the Czech Republic. The sowing area reached almost a half-million ha between

1934-1938, the average potato yield was approximately 15 t ha-1 at that time. As time passed by, the sowing area decreased significantly. In the 1960s, the sowing area decreased below 400 000 ha and the tendency has been continuing (Hlisnikovský&Kunzová, 2017). Nowadays, consumable potatoes are grown on approximately 20 000 ha in the Czech Republic, and the average annual yield per hectare is around 26 t (Figure 1).

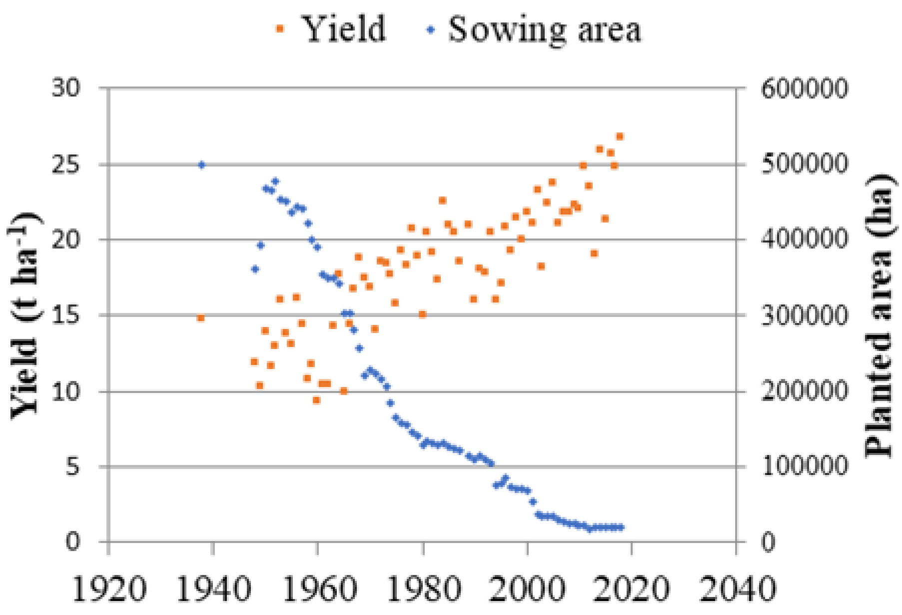


Figure 1. The mean annual yield and total planted area in the Czech Republic (1938 – 2018).

Fertilizers

In 1840, Justus von Liebig formulated this law: "The success of an organism in a given environment is limited by factors whose value is the least favourable to him. " Liebig's law of minima can express the fact that the development of plants in the production ecosystem can be slowed down or even suppressed due to an element that will not be present in sufficient quantities in the ecosystem. By supplying fertilizers to the environment, this problem can be prevented and it is possible to grow plants on less fertile soils. Law No. 156/1998 Coll. defines fertilizers as substances providing an effective amount of nutrients for the nutrition of cultivated plants and forest trees, for maintaining or improving soil fertility and for favourably influencing yield or quality of production.

Three basic systems of agricultural management are distinguished in practice, each of which takes a different approach to the use of fertilizers. Conventional agriculture is designed so that the yield of the crop is maximum even at the cost of increased application rates of fertilizers, this method is very effective, but not very environmentally friendly (Zitta, 1998). The counterweight of conventional agriculture is the organic economic system. Organic farming standards prohibit the use of industrial fertilizers and pesticides, with mainly livestock waste products and green manure in the form of ploughed pre-crops or old straw being used as fertilizers (Cooper et al., 2011). Both approaches are then combined by the so-called "low input", which is an agricultural system that seeks to use the smallest possible amount of mineral fertilizers and pesticides based on carefully planned decisions and knowledge of the crop

(Zitta,1998).

Fertilizers can be classified according to several criteria. Depending on the effectiveness of direct fertilizers, which supply plants with one or more nutrients in either organic or mineral form, and indirect fertilizers, which have the effect of improving the physical and chemical properties of the soil, thereby improving nutrient availability to plants (Tlustoš et al., 2007). Indirect fertilization can be considered as the modification of the soil reaction by liming, or the addition of phosphorus, potassium, and magnesium to the soil environment (Vaněk et al., 2012). Furthermore, fertilizers can be divided according to their state into solid and liquid, according to their chemical composition into one-component, which contain one main nutrient and accompanying ions or microelements (e.g. nitrogen or phosphorus) and multi-component (e.g. NPK), or they can be divided according to origin into organic and mineral fertilizers (Tlustoš et al., 2007).

Mineral fertilizers

Mineral fertilizers are mostly products of the chemical industry. Although produced from natural raw materials, but the content of secondary components is limited and the main nutrient is modified so that the plant as easily acceptable (Vanek et al., 2012). In agriculture, it is essential to commit to maintaining the biochemical cycle. As we know, intensive farming requires a continuous supplement of mineral fertilizers which are inorganic chemical compounds containing essential nutrients for plants and crops in a form of various mineral salts. Application of these treatments is the main feature of intensive agriculture that requires a continuous supplement of mineral fertilizers that substituting the lack of soil nutrients, washed out or exported during harvests. When crops are harvested, the nutrients follow the crop. Important nutrients are therefore removed from the soil. Often the soil is not able to replenish all the nutrients by itself, that is where fertilizers supply the nutrients that are lacking. Drained soil should be properly repaired because the release of nutrients from the primary minerals or humus is not enough to provide the future harvest with an adequate amount of necessary elements. Fertilization is certainly an important practice which however has an impact of the soil microbiota that should be taking into account. Among single-component fertilizers that are applied in large doses include nitrogen, phosphate and potassium fertilizers.

N

Nitrogen is an essential component of amino acids, proteins and enzymes and coenzymes, chlorophyll, nucleic acids, and other substances in plants. It mainly supports the growth of sprouts and the formation of green leaf mass. When protein synthesis is disrupted, N accumulates in plants in the form of nitrates (Baier and Baierová, 1985). Although nitrogen is the most common element in the atmosphere, the bond in the N2 molecule is so strong that only a few photosynthetic organisms can break it. Nitrogen is supplied to the soil in the form of NO3- in the form of nitrates (calcium nitrate, ammonium nitrate), as well as ammonium cation NH4+, which is contained in the already mentioned ammonium nitrate or as amide nitrogen NH2+, which is part of urea CO(NH2)2 (Vaňek et al., 2012). Contamination of drinking water sources with NO3 ions, which have a negative effect on human health and soil acidification, especially when ammonium sulphate is used, can be a risk factor for excessive or incorrect use of nitrogen fertilizers (Isherwood, 1998).

P

Plants receive phosphorus from the soil in the form of anions $H_2PO_4^-$ and HPO_4^-. Phosphatase is the primary enzyme responsible for mineralizing organic phosphates and making phosphorus available to plants. However, in soils that have a low pH, there is a risk that soluble phosphate ions will precipitate into less available plant forms (Vaněk et al., 2012). Minerals that are a source of phosphorus can also contain small amounts of hazardous elements such as cadmium and, if not sufficiently purified, can contaminate soils with these elements (Isherwood, 1998). The results of the research show that root phosphatase activity is closely correlated with the concentration of CO_2 in the atmosphere. Barrett et al. (1998) found in their experiment that a two-fold concentration of CO_2 increased wheat phosphatase activity by 30-40% on soils with insufficient phosphorus supply, thereby increasing the rate of phosphorus available from the soil. An increase in activity was also observed for crops grown in a sterile environment. The importance of phosphorus in the plant is mainly in the energy cycles (ATP, ADP, and AMP) and for construction purposes. Phosphoric acid reacts with organic substances to form organophosphates. Nucleotides that act as nucleic acid building blocks and activate intermediates in several biochemical reactions are very important in this regard (Klement et al., 2012). Furthermore, phosphorus increases resistance to low temperatures and supports the development of the root system and the intake of other nutrients and moisture.

K

Potassium affects stalk strength, drought resistance, and fungal resistance diseases. It is applied as a fertilizer either in the form of chloride, which is produced mainly from sylvinite or carnality or as a sulphate type (Tlustoš et al., 2007; Ryant et al., 2003). As potassium plays an important role in the water regime of the plant, the deficiency in the soil leads to reduced growth and yields. Its accumulation in cells leads to osmotic water intake and generates the cellular turgor required for growth and stomas opening. It is also important in influencing the osmotic water absorption of plant roots and in control leaf transpiration (Fournier et al., 2005). The root hydraulic conductivity can be affected by various forms of abiotic stress, such as salinity, anaerobiosis, drought, and Ca, P, and N deficiency. A slight K deficiency, however, can promote and may have conductivity positive effect on plant transpiration (Quintero et al., 1998). In addition to potassium, it supports intake water plant roots also abscisic acid - a phytohormone whose function is influenced by the concentration of K ions in the roots (Fournier et al., 2005, Quintero et al., 1998). Potassium is in the plant a mobile element and its deficiency is primarily reflected in older leaves - the edges of the leaves change colour to light green, yellow, and finally white. In serious cases, the leaves die but remain attached to the stem. In some cases, there may be a shortage To show small white dots on the leaves (Šrojtová et. al, 2003).

Fertilization with mineral fertilizers is one of the key factors in the potato growing system. Both in terms of agriculture focused on yields and quality, and in terms of environmental protection. While malnutrition leads to low yields, applying excess nutrients in fertilizers can negatively affect the environment, especially the pool of the groundwater.

Organic manures

Potatoes are traditionally fertilized in the Czech Republic with organic manures. Organic manures are mostly the by-products of animal husbandry, and their composition and nutrient content reflects the way nutrients are handled on the farm (Vaněk et al., 2012). In addition to supplying macroelements to the soil, they are important for humus production. Disadvantages in the use of organic manures appear to be the low concentration of nutrients they contain, and therefore it is necessary to apply much more per unit than mineral fertilizers, which would provide equivalent amounts of nutrients (Ryant et al., 2003). Organic manures refer to farmyard manure, slurry, and straw. Sewage sludge, a by-product from the wastewater treatments, and composts can also be considered as fertilizers (organic fertilizers) but must be carefully analyzed before the use for the possible pathogens, organic pollutants, and risk elements content (Balík et al., 1999).

The farmyard manure consists of faeces, litter and feed residues produced by livestock. Nutrient contents are highly variable and depend on the type of animals, their feeding, the type of housing and many other factors. The effects after the application of manure are visible only five years after the treatment, the plots treated with manure show higher fertility, which they maintain for a long period (Vaněk et al., 2012). Since the composition of manure is highly dependent on animal nutrition, there is a risk of contamination of manure by adding nutritional supplements to their diet, especially zinc and copper (Petersen et al., 2007). Urea is a liquid fertilizer consisting of fermented urine of livestock diluted with water. It can be used as valuable nitrogen-potassium fertilizer, but the amount of its application must follow the demands of the cultivated crop (Ryant et al., 2003). The slurry is a mixture of solid and liquid faeces of livestock diluted with water, which is formed during the grate or free housing of animals without litter (Vaněk et al., 2012). In recent years, the importance of straw as a fertilizer has increased. By ploughing straw, the humus content in the soil increases, the soils are airier. They mainly supply potassium to soils, their disadvantage is that they do not provide such a concentration of nutrients as previous organic manures, and therefore straw should be used in combination with mineral fertilizers (Ryant et al., 2003). Several researchers studied the effect of organic manures on potatoes yield. Kanal&Kuldkepp (1993) analyzed eight different fertilizer treatments, including organic manures, mineral fertilizers, and their combinations. The best results were obtained with cattle dung applied with or without mineral NPK. Agbede (2010) also concluded that combination of poultry manure, applied with mineral NPK, increased potatoes yield by 83%, when compared with the unfertilized Control, by 44%, when compared with NPK, and by 38%, when compared with poultry manure. Other researchers, such as Caliskan et al. (2004), or Balemi (2012), recorded comparable results.

Risk elements

In all kinds of contaminated locations, we will surely find inorganic elements such as Pb, Hg, Cd, Cr, Cu, etc. The tendency to be actively involved in biochemical processes with environmental components is the main feature of the behaviour of inorganic pollutants, for example during the transport of risk elements from soil to plants (Němeček et al. 2010). Heavy metals are a specific group of inorganic contaminating elements, non-ferrous metals that do not contain iron (ferrite) in appreciable amounts. For example, lead, copper, zinc, nickel, chromium, cadmium, cobalt, mercury. In small quantities, they are necessary for plants. But a significant excess of their allowable number leads to serious diseases. Their presence in the soil may pose an environmental threat to the resulting product. Accumulation of the main part of pollutants is observed mainly in the humus-accumulative soil horizon, where they are bound by aluminosilicates, non-silicate minerals, and organic substances due to various interaction reactions.

A high concentration of these metals combined with adverse physicochemical conditions can have a significant impact on environmental components, soil, and groundwater (Kabata-Pendias 2011). These heavy metals that have been released into the ecosystem due to human activities will interact with soil and rock sooner or later. Every type of soil has a certain level of absorbing capacity which is naturally saturated mostly with alkaline elements. The vast majority of important heavy metals have a significantly bigger absorbing capacity, thereby displacing from the soil the naturally stored elements (Tlustoš et al. 2007). In this stage, soil holds the pollutants off and reduces hazard towards the environment. However, at the moment when there is an excess of heavy metals, protective processes of soil are no longer in force and cannot prevent the diffusion of the heavy metal into the groundwater. Thus, the concentrated and polluting heavy metals lead to a discharge and present a drastic change for the ecosystem, as a change of the soil pH balance (Hon 2013). The pH value of soil has a crucial role in the risk elements of mobility in the soil-groundwater system. The high content of heavy metals in the soil doesn't necessarily mean an urgent danger at the moment when the soil interacts with underground water. Despite the high level of risk elements, the pH of water can be neutral and will not let the contaminating metals dissolve. At the moment of consideration of heavy metals pollution, it is also important to know concentrations of water infusions and conditions for pH in a certain area (Kunzová et al. 2015).

Heavy metal contamination represents a serious risk for crop production, their quality and human health due to the contaminants high toxicity and mobility on the long term basis. Even though scientists dedicate special attention to the chemical properties of heavy metals, our knowledge about these elements are still not comprehensive. The ability of hazardous chemicals to affect soil condition is much stronger than affecting any other part of the biosphere. Furthermore, heavy metal contamination of soil is assumed to be permanent. They are, however, removed from the environment through the leaching, erosion or harvesting plants from the soil, but very slowly (Panwar et al. 1999). The half-life of risk elements in soil was calculated depending on soil type. The elements, such as Zn, the half-life of which is from 70 to 3000 years, Cd – from 75 to 1100 years, Cu – from 310 to 3000 years and Pb - from 740 to 5900 years respectively. These data suggest that the complete elimination of heavy metals from the soil is very challenging or even impossible. Usually in the areas with low or medium pollution, containing heavy metals is not high enough to lead to acute poisoning, but in a long-term perspective, it is better to be aware that they tend to pass through the food chain and may lead to the harmful consequences and severe effects to human health (Adriano 2001). It is necessary to minimalize the metal transfer in the agricultural domain for the reason of already existing heavy metal excess in human nutrition (Puschenreiter et al. 2005).

Long-term use of mineral fertilizers and even organic manures can negatively affect the environment and growing arable crops (Muhammad et al., 2020). The fertilizer application can increase the concentration of some potentially hazardous elements, such as Cd, Zn, Cr, and Cu (Zhen et al., 2020). The effect of applied fertilizers is direct, which means that applied fertilizers contain these substances, or they affect the soil properties, influencing the mobility of hazardous substances (Keller &Schulin, 2003, Hejcman et al., 2009).

The aim of the thesis

This thesis aims to analyze the effect of different fertilizer treatments (unfertilized Control, mineral NPK, farmyard manure, pig slurry, combinations of farmyard manure and pig slurry with NPK) on potatoes tuber yields, yielding parameters, and concentration of nutrients and risk elements.

Material and methods

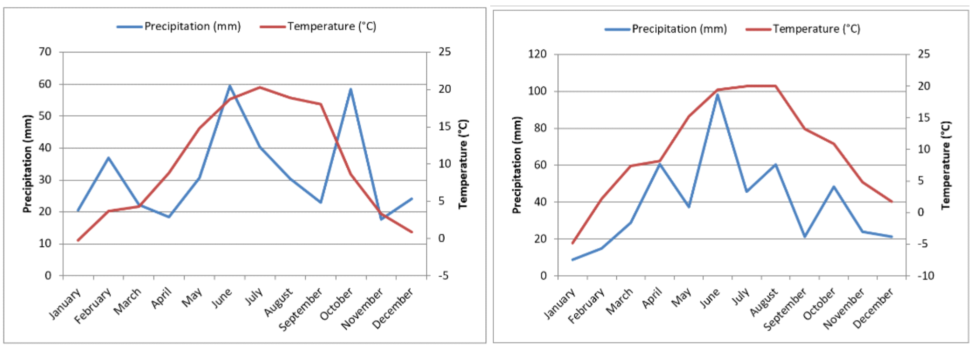
Area description

Our experiment took place on the western edge of Prague (50°05′15″N; 14°17′28″E), the capital of the Czech Republic (Central Europe, temperate climate zone), in years 2016 and 2017. The experiment is running in the Crop Research Institute in Prague as the long-term fertilizer experiment, established in 1954. The aims of the experiment are: 1) to study the effect of different mineral and organic fertilizers and organic manures on yield and quality of arable crops, 2) to study the effect of different crop rotations on yield and quality of arable crops

The altitude of the experiment is 345 m a.s.l. The mean annual temperature was 10.0°C and 9.8°C in 2016 and 2017, respectively. The annual sum of precipitation was 382.1 mm in 2016, and 470.0 mm in 2017. The development of weather and precipitation in analyzed years is shown in Figure 2. The soil type is classified as illimerized luvisol (illimerized grey-brown soil). The cultivated topsoil contains 27% of clay, increasing to 40% of clay at the depth of 30–40 cm, and 49% at the depth of 40 – 50 cm. The pH of the soil was 6.5 in the top 20 cm before the establishment of the experiment in 1954 (Šrek et al., 2012).

Figure 2. Average temperature and percipitation amount for the years:

a) 2016 b) 2017



Experimental design

The long-term field experiment consists of five fields (I., II., III., IV., and B). Each field is divided into 96 experimental plots, where 24 fertilizer treatments in four replications is analyzed (24 treatments x 4 replications = 96 plots), arranged in a completely randomized block design. The size of the field is 13 824 m^2. The size of the experimental plot is 12 x 12 m^2 (144 m^2), but only the 5 x 5 central area is used for obtaining the samples for analyses (ellimination of the edge effect).

For the purpouse of this thesis, we analyzed the yield and yielding parameters of potatoes harvested from the field II. (2016), and I. (2017). Out of 24 fertilizer treatments, we have analyzed four: 1) the unfertilized Control treatment (unfertilized since the establishment in 1954), 2) organic manure (farmyard manure in 2016 (FYM) and pig slurry in 2017 (PS)), 3) mineral nitrogen, phosphorus, and potassium (NPK), and 4) combination of organic manure with mineral NPK (NPK+OM). To obtain and analyze results from more than one seasson, and from selected years of the student's time of study, we were forced to combine the results from two different organic manure treatments. For that reason, we have analyzed the effect of farmyard manure in 2016, and the effect of pig slurry in 2017. The pig slurry (2016) and farmyard manure (2017) were applied during the August (first half of the August for the pig slurry). Both fertilizers were spreaded on the surface and immediately incorporated into the soil via ploughing. The farmyard manure was applied at a dose of 15 t ha^{-1}, while pig slurry was applied at a dose of 49 t ha^{-1}. The mineral nitrogen was applied as a lime ammonium nitrate (27% N), mineral phosphorus as superphosphate (8.3%), and potassium as potassium chloride (49.8% K). The rates of mineral N, applied to potatoes in 2016 was 110 kg ha^{-1}, the dose of mineral P was 70 kg ha^{-1}, and the dose of K was 224 kg ha^{-1}. In 2017, the doses of mineral N, P, and K, applied directly to potatoes, were 140, 144, and 224 kg ha^{-1}, respectively. The reason why different doses of mineral fertilizers were used in the experiment was that both results come from different crop rotations (the preceding crop was identical in both years: *Hordeum vulgare* L.).

Potato tubers sampling and chemical analysis

The medium-early ware salad medium-sized tuber variety Ditta was used in this study. Tubers were excavated using a potato-digger and collected manually from the soil surface. Two kilograms of fresh potatoes were collected from each plot during the harvest on 10th September 2008. The tubers were washed carefully in deionized water, cut into strips and dried at 80 °C to determine their dry matter content and dry matter yield. The concentrations of elements in the potato tubers were determined by wet ashing with increased pressure. Exactly 1 g of powdered tubers was decomposed in a mixture of HNO3 and H2O2. The ash was then decomposed using the microwave ashing device CEM 2000 (CEM Corporation, USA) and diluted in aqua regia. Aliquots of the certified reference material RM NCS DC 73350 poplar leaves (purchased from Analytika) were mineralized under the same conditions for quality assurance. As, Ca, Cd, Cr, Cu, K, Mg, Mn, Ni, Pb, S and Zn were measured by optical emission spectrometry with inductively coupled plasma (ICP-OES Thermo Jarrell Ash, Trace Scan, Franklin, USA), To determine the N concentration, tubers were mineralized in concentrated (98%) H2SO4. N and P in potato tubers were measured by flow colourimeter (SAN plus SYSTEM, SKALAR, DE Breda, The Netherlands) (Šrek et al., 2010).

Statistical analysis

Statistical analysis of the data was performed using STATISTICA 13.3 software (Statistica 13.3, TIBCO Software, Palo Alto, USA). One-way analysis of variance (ANOVA) was carried out to compare the means of different treatments. Differences between the individual means were tested using the Tukey-HSD test at 0.05 significant level. To compare the results from both seasons and between the same fertilizer treatments (Control – Control, NPK – NPK, FYM – PS, NPK+FYM – NPK+PS), we have used MANOVA, followed by post hoc analysis (Tukey-HSD test).

Results

Yielding parameters and yield in 2016

Potato length

According to ANOVA results, the length of potatoes was not significantly affected by the fertilizer treatment in 2016 (d.f. = 3, F = 2.5, p = 0.107). The average length of potatoes was lowest in the Control (63.83 mm), while highest in the NPK+FYM treatment (70.47 mm)(Table 1).

Potato width

The mean width of the potatoes was not significantly affected by fertilizer treatment (d.f. = 3, F = 2.5, p = 0.112). The lowest widths were recorded in the Control and FYM treatments (45.5 mm), while the highest width was recorded in the NPK treatment (48.48 mm)(Table 1).

Potato weight

The average weight of one potato was not significantly affected by the fertilizer treatment (d.f. = 3, F = 1.3, p = 0.329). The lowest average weight was recorded in the Control treatment (85.10 g), while the heaviest potatoes were recorded in the NPK treatment (98.98 g)(Table 1).

Number of potatoes per ha

The average number of tubers per ha was significantly affected by fertilizer treatment (d.f. = 3, F = 17.05, p < 0.001). The lowest average number of tubers provided the Control treatment (111 643), followed by NPK, FYM, and NPK+FYM treatments (Table 1).

Potatoes yield

The mean yield of potatoes was significantly affected by the fertilizer treatment (d.f. = 3, F = 61.99, p < 0.001). The lowest yield was recorded in the Control treatment (9.53 t ha-1), followed by the FYM, NPK, and NPK+FYM treatments (Table 1). The tuber yield in the NPK+FYM treatment was significantly higher when compared with FYM and NPK treatments.

Table 1. The yielding parameters as affected by fertilizer treatment in 2016.

	Length (mm)	Width (mm)	Weight (g)	Number	Yield (t ha^{-1})
Control	63.83±1.42 A	45.48±0.69 A	85.10±4.59 A	111 643 A	9.53±0.82 A
FYM	65.29±2.11 A	45.47±1.00 A	87.30±6.61 A	192 406 B	16.52±0.49 B
NPK	68.32±2.32 A	48.48±1.13 A	98.98±5.95 A	189 218 B	18.63±0.70 B
NPK+FYM	70.47±1.52 A	46.71±0.73 A	98.78±8.44 A	231 685 B	22.50±0.71 C

The means, followed by the same letter, were not significantly different.

Potato nutrient concentration

Nitrogen

The average nitrogen concentration was significantly affected by fertilizer treatment ($p < 0.05$). The lowest N concentration was recorded in the Control treatment (12.78 g kg-1). Application of the FYM and NPK resulted in the same concentrations (13.89 g kg-1), while the combination of FYM+NPK provided the average concentration of N 15.33 g kg-1)(Table 2).

Phosphorus

Application of different fertilizers significantly affected the mean concentration of P in potato tubers ($p < 0.05$). While no differences were recorded between Control, FYM, and NPK treatments, the P concentration significantly increased followed the application of FYM+NPK (2.80 g kg-1)(Table 2).

Potassium

The increased K concentration in potato tubers was connected with the application of mineral NPK. The differences between the Control and FYM treatments were negligible (13.40 and 14.14 g kg-1, respectively). Following the application of NPK, the mean K concentration increased to 19.44 g kg-1 (NPK) and 20.56 g kg-1 (NPK+FYM)(Table 2). No statistically significant differences were recorded between NPK and NPK+FYM treatments.

Calcium

No effect of fertilizer treatment on Ca concentration was recorded. The average values ranged from 0.93 g kg-1 (Control) to 1.00 g kg-1 (NPK)(Table 2).

Magnesium

Similar to K, the increased concentration of Mg was connected with the NPK. While no significant differences were recorded between the Control (0.81 g kg-1) and FYM (0.79 g kg-1) treatments, application of NPK (0.94 g kg-1) and NPK+FYM (0.93 g kg-1) increased the average Mg concentration significantly (Table 2).

Sulphur

Similar to Ca, the concentration of S in potato tubers was not affected by fertilizer treatment. The average S concentration ranged from 1.42 g kg-1 (NPK) to 1.54 g kg-1 (Control) (Table 2).

Table 2. The concentration of macronutrients as affected by fertilizer treatment in 2016.

	N (g kg^{-1})	P (g kg^{-1})	K (g kg^{-1})	Ca (g kg^{-1})	Mg (g kg^{-1})	S (g kg^{-1})
Control	12.79±0.60 A	2.08±0.12 A	13.40±0.61 A	0.93±0.04 A	0.81±0.01 A	1.54±0.07 A
FYM	13.89±0.59 AB	2.31±0.07 A	14.14±0.41 A	0.94±0.04 A	0.79±0.02 A	1.46±0.05 A
NPK	13.89±0.35 AB	2.11±0.06 A	19.44±0.64 B	1.00±0.03 A	0.94±0.03 B	1.42±0.04 A
NPK+FYM	15.53±0.61 B	2.80±0.14 B	20.56±1.04 B	0.95±0.04 A	0.93±0.02 B	1.47±0.02 A

The means, followed by the same letter, were not significantly different.

Potato risk elements concentration

Arsenic

The concentration of As was not affected by fertilizer treatment. The mean As concentration in potato tubers ranged from 0.05 mg kg-1 (NPK) to 0.11 mg kg-1 (NPK+FYM)(Table 3).

Cadmium

The concentration of Cd was not affected by fertilizer treatment. The mean Cd concentration in potato tubers was 0.01 mg kg-1 for all fertilizer treatments (Table 3).

Chrome

The mean concentration of Cr was variable, significantly affected by the fertilizer treatment (Table 3). The significant difference was recorded between the Control + FYM+NPK and NPK treatments. The lowest concentration was recorded in NPK treatment (0.82 mg kg-1), while the highest in the Control treatment (1.33 mg kg-1).

Copper

The concentration of Cu was significantly affected by fertilizer treatment (Table 3). The ANOVA separated three groups of fertilizers. The lowest concentration was recorded in the NPK treatment (5.27 mg kg-1), the middle group is formed of Control (5.93 mg kg-1) and NPK+FYM (5.73 mg kg-1), while the highest concentration was recorded in the FYM treatment (6.39 mg kg-1).

Iron

The concentration of Fe was significantly affected by fertilizer treatment. The highest concentration was recorded in the NPK+FYM treatment (23.55 mg kg-1), while the lowest in the Control (16.06 mg kg-1). The significant difference was recorded between Control + FYM and NPK+FYM treatments Table X. The concentration of As, Cd, Cr, Cu, and Fe (mg kg^{-1}) as affected by fertilizer treatment in 2016 (Table 3)

	As	Cd	Cr	Cu	Fe
Control	0.09±0.03 A	0.01±0.001 A	1.33±0.13 B	5.93±0.09 B	16.06±0.57 A
FYM	0.07±0.03 A	0.01±0.001 A	1.13±0.05 AB	6.39±0.07 C	17.16±0.99 A
NPK	0.05±0.02 A	0.01±0.001 A	0.82±0.12 A	5.27±0.10 A	19.52±0.39 AB
NPK+FYM	0.11±0.01 A	0.01±0.001 A	1.26±0.09 B	5.73±0.11 B	23.55±1.86 B

Table 3. The concentration of heavy metals as affected by fertilizer treatment in 2016

The means, followed by the same letter, were not significantly different.

Manganese

The concentration of Mn significantly affected by fertilizer treatment (Table 4) and ranged from 4.05 mg kg-1 (FYM) to 5.13 mg kg-1 (NPK+FYM). A significant difference was recorded between the FYM and NPK+FYM treatments.

Nickel

The mean Ni concentration in potato tubers ranged from 0.71 mg kg-1 (Control) to 1.79 mg kg-1 (NPK+FYM). The NPK+FYM treatment was the only one with significantly higher mean values (Table 4).

Lead

No differences in Pb concentrations were found between the fertilizer treatments (Table 4). The mean values ranged from 0.03 mg kg-1 (Control) to 0.05 mg kg-1 (NPK+FYM).

Zinc

Similar to Ni, the concentration of Zn was not significantly different between Control, FYM, and NPK treatments (Table 4). Application of NPK+FYM significantly increased its concentration in tubers, with the mean value of 21.90 mg kg-1. Table X. The concentration of Mn, Ni, Pb, and Zn (mg kg^{-1}) as affected by fertilizer treatment in 2016.

	Mn	Ni	Pb	Zn
Control	4.67±0.28 AB	0.71±0.18 A	0.03±0.01 A	16.60±0.46 A
FYM	4.05±0.20 A	1.07±0.06 A	0.04±0.01 A	17.13±0.58 A
NPK	4.19±0.29 AB	1.07±0.13 A	0.03±0.01 A	15.64±0.37 A
NPK+FYM	5.13±0.19 B	1.79±0.15 B	0.05±0.02 A	21.90±1.46 B

Table 4. The concentration of heavy metals as affected by fertilizer treatment in 2016.

The means, followed by the same letter, were not significantly different.

Yielding parameters and yield in 2017

Potato Length

The tubers length was variable, significantly affected by fertilizer treatment ($p < 0.05$). The biggest difference was recorded between the Control and NPK treatments. The average length of potatoes was lowest in the Control (70.85 mm), while the highest in the NPK (83.30 mm) (Table5).

Potato width

The average weight of one potato was not significantly affected by the fertilizer treatment. The lowest widths were recorded in the Control (48.01 mm), while the highest width was recorded in the NPK+PS treatment (50.18 mm) (Table 5).

Potato weight

The average weight of one potato was significantly affected by fertilizer treatment ($p < 0.05$). The lowest average weight was recorded in the Control treatment (85.10 g), while the heaviest potatoes were recorded in the NPK treatment (98.98 g)(Table 5).

Number of potatoes per ha

The average number of tubers per ha was significantly affected by fertilizer treatment ($p < 0.05$). The lowest average number of tubers provided the Control treatment (180 298), followed by NPK, PS, and NPK+PS treatments (353 301) (Table 5).

Potatoes yield

The mean yield of potatoes was significantly affected by fertilizer treatment ($p < 0.05$). The lowest yield was recorded in the Control treatment (21.01 t ha-1), followed by the PS, NPK, and NPK+PS treatments (Table 5). The tuber yield in the NPK+PS treatment was significantly higher (50.18 t ha-1) when compared with PS and NPK treatments.

	Length (mm)	**Width (mm)**	**Weight (g)**	**Number**	**Yield (t ha^{-1})**
Control	70.85±2.46 A	48.01±0.35 A	117.07±4.94 A	180 298 A	21.01±0.36 A
PS	77.90±1.27 AB	49.55±0.47 A	134.25±4.55 AB	246 478 B	32.92±1.19 B
NPK	83.30±1.62 B	49.33±0.48 A	145.42±4.25 B	302 057 BC	43.86±0.64 C
NPK+PS	82.95±2.52 B	50.18±1.18 A	143.19±6.96 B	353 301 C	50.18±0.87 D

Table 5. The yielding parameters as affected by fertilizer treatment in 2017.

Potato nutrient concentration

Nitrogen

The average nitrogen concentration was significantly affected by fertilizer treatment ($p < 0.05$). The lowest N concentration was recorded in the Control treatment (14.42 g kg-1). Application of the PS and NPK didn't cause a significant difference (16.15 and 17.42 g kg-1 respectively), while the combination of NPK+PS provided the average concentration of N 19.51 g kg-1)(Table 6).

Phosphorus

Application of different fertilizers significantly affected the mean concentration of P in potato tubers ($p < 0.05$). The lowest P concentration was recorded in the Control treatment (1.95 g kg-1). While no differences were recorded between PS and NPK treatments, the P concentration significantly increased followed the application of PS+NPK (2.80 g kg-1) (Table 6).

Potassium

The increased K concentration in potato tubers was connected with the application of different fertilizers.). The lowest K concentration was recorded in the Control treatment (11.87 g kg-1). Following the application of NPK, the mean K concentration increased to 20.85 g kg-1 (NPK) and 22.16 g kg-1 (NPK+PS) (Table 6). No statistically significant differences were recorded between NPK and NPK+PS treatments.

Calcium

No effect of fertilizer treatment on Ca concentration was recorded. The average values ranged from 0.92 g kg-1 (Control) to 1.07 g kg-1 (NPK+PS)(Table 6).

Magnesium

The increased Mg concentration in potato tubers was connected with the application of mineral NPK fertilizers. While no significant differences were recorded between the Control (0.95 g kg-1) and PS (1.08 g kg-1) treatments, application of NPK and NPK+PS increased the average Mg concentration significantly. There was no difference between NPK and NPK+PS treatment (1.24 g kg-1)(Table 6).

Sulphur

The concentration of S was significantly affected by the fertilizer treatment ($p < 0.05$) (Table 6). The ANOVA separated three groups of fertilizers. The lowest concentration was recorded in the NPK treatment (1.34 g kg-1), the middle group is formed of PS (1.49 g kg-1) and NPK+PS (1.51 g kg-1), while the highest concentration was recorded in the Control treatment (1.54 g kg-1).Table X. The concentration of macronutrients as affected by fertilizer treatment in 2017.

	N (g kg^{-1})	P (g kg^{-1})	K (g kg^{-1})	Ca (g kg^{-1})	Mg (g kg^{-1})	S (g kg^{-1})
Control	14.42±0.84 A	1.95±0.03 A	11.87±0.11 A	0.92±0.03 A	0.95±0.03 A	1.54±0.06 B
PS	16.15±1.10 AB	2.02±0.08 AB	15.27±0.85 B	0.98±0.06 A	1.08±0.04 A	1.49±0.05 AB
NPK	17.42±0.60 AB	2.13±0.10 AB	20.85±0.47 C	1.04±0.08 A	1.24±0.03 B	1.34±0.02 A
NPK+PS	19.51±0.88 B	2.82±0.36 B	22.16±1.16 C	1.07±0.06 A	1.24±0.04 B	1.51±0.03 AB

Table 6. The concentration of macronutrients as affected by fertilizer treatment in 2017

Potato risk elements concentration

Arsenic

The concentration of As was not affected by fertilizer treatment. The mean As concentration in potato tubers ranged from 0.08 mg kg-1 (PS) to 0.17 mg kg-1 (NPK)(Table 7).

Cadmium

The concentration of Cd was significantly affected by fertilizer treatment ($p < 0.05$). The highest concentration was recorded in the NPK treatment (0.12 mg kg-1), while the lowest in the PS (0.06 mg kg-1). The significant difference was recorded between Control + PS and NPK treatments (Table 7).

Chrome

The concentration of Cr was not affected by fertilizer treatment. The mean Cr concentration in potato tubers ranged from 0.22 mg kg-1 (PS) to 0.31 mg kg-1 (NPK) (Table 7).

Copper

The concentration of Cu was significantly affected by fertilizer treatment ($p < 0.05$) (Table 7). The ANOVA separated three groups of fertilizers. The lowest concentration was recorded in the NPK+PS treatment (5.02 mg kg-1), the middle group is formed of PS (6.20 mg kg-1) and NPK (5.51 mg kg-1), while the highest concentration was recorded in the Control treatment (6.54 mg kg-1).

	As (mg kg^{-1})	Cd (mg kg^{-1})	Cr (mg kg^{-1})	Cu (mg kg^{-1})
Control	0.13±0.03 A	0.08±0.01 A	0.26±0.06 A	6.54±0.21 C
PS	0.08±0.04 A	0.06±0.01 A	0.22±0.03 A	6.20±0.18 AB
NPK	0.17±0.06 A	0.12±0.01 B	0.23±0.02 A	5.51±0.48 AB
NPK+PS	0.13±0.03 A	0.09±0.01 AB	0.31±0.10 A	5.02±0.40 A

Table 7. The concentration of heavy metals as affected by fertilizer treatment in 2017.

Iron

The concentration of Fe was significantly affected by fertilizer treatment ($p < 0.05$). The highest concentration was recorded in the NPK+PS treatment (33.17 mg kg-1), while the lowest in the PS treatment (22.38 mg kg-1). The significant difference was recorded between Control + PS and NPK+PS treatments (Table 8).

Manganese

No effect of fertilizer treatment on Mn concentration was recorded. The average values ranged from 5.49 mg kg-1 (Control) to 6.65 mg kg-1 (NPK+PS)(Table 8).

Nickel

Concentration of Ni significantly affected by fertilizer treatment ($p < 0.05$) (Table 8) and ranged from 1.23 mg kg-1 (PS) to 2.36 mg kg-1 (NPK). A significant difference was recorded between the PS and NPK treatments.

Lead

No differences in Pb concentrations were found between the fertilizer treatments (Table 8). The mean values ranged from 0.012 mg kg-1 (PS) to 0.16 mg kg-1 (NPK).

Zinc

The concentration of Zn was not affected by fertilizer treatment. The mean Zn concentration in potato tubers ranged from 16.27 mg kg-1 (NPK) to 19.00 mg kg-1 (NPK+PS) (Table 8).

	Fe (mg kg^{-1})	Mn (mg kg^{-1})	Ni (mg kg^{-1})	Pb (mg kg^{-1})	Zn (mg kg^{-1})
Control	24.20±2.14 A	5.49±0.24 A	1.64±0.21 AB	0.13±0.01 A	17.05±0.14 A
PS	22.38±2.19 A	5.51±0.22 A	1.23±0.12 A	0.12±0.02 A	18.56±2.05 A
NPK	27.56±1.38 AB	6.10±0.15 A	2.36±0.32 B	0.16±0.02 A	16.27±0.86 A
NPK+PS	33.17±2.48 B	6.65±0.52 A	2.17±0.29 AB	0.14±0.03 A	19.00±1.49 A

Table 8. The concentration of heavy metals as affected by fertilizer treatment in 2017.

	Control		FYM	PS
	2016	2017	2016	2017
Lenght (mm)	63.83 A	70.85 B	65.29 A	77.90 B
Width (mm)	45.48 A	48.01 B	45.47 A	49.55 B
Weight (g)	85.10 A	117.07 B	87.30 A	134.25 B
Number	111 643 A	180 297 B	192 406 A	246 478 B
Yield (t ha^{-1})	9.53 A	21.01 B	16.52 A	32.92 B
N (g kg^{-1})	12.79 A	14.42 A	13.89 A	16.15 A
P (g kg^{-1})	1.95 A	2.08 A	2.02 A	2.31 B
K (g kg^{-1})	11.87 A	13.40 B	14.14 A	15.27 A
Ca (g kg^{-1})	0.92 A	0.93 A	0.94 A	0.98 A
Mg (g kg^{-1})	0.81 A	0.95 B	0.79 A	1.08 B
S (g kg^{-1})	1.54 A	1.54 A	1.46 A	1.49 A
As (mg kg^{-1})	0.08 A	0.13 A	0.07 A	0.08 A
Cd (mg kg^{-1})	0.006 A	0.08 B	0.007 A	0.06 B
Cr (mg kg^{-1})	0.26 A	1.33 B	0.22 A	1.13 B
Cu (mg kg^{-1})	5.93 A	6.54 B	6.20 A	6.39 A
Fe (mg kg^{-1})	16.06 A	24.20 B	17.16 A	22.38 A
Mn (mg kg^{-1})	4.67 A	5.49 A	4.05 A	5.51 B
Ni (mg kg^{-1})	0.70 A	1.64 B	1.07 A	1.23 A
Pb (mg kg^{-1})	0.03 A	0.13 B	0.04 A	0.12 B
Zn (mg kg^{-1})	16.60 A	17.05 A	17.13 A	18.56 A

Table 9. Yielding parameters and chemical composition of potatoes as affected by year, and fertilizer treatment.

	NPK		NPK+FYM	NPK+PS
	2016	2017	2016	2017
Lenght (mm)	68.32 A	83.30 B	70.47 A	82.95 B
Width (mm)	48.48 A	49.33 A	46.71 A	50.18 B
Weight (g)	98.98 A	145.42 B	98.78 A	143.19 B
Number	189 218 A	302 057 B	231 685 A	353 301 B
Yield (t ha^{-1})	18.63 A	43.86 B	22.50 A	50.18 B
N (g kg^{-1})	13.89 A	17.42 B	15.53 A	19.51 B
P (g kg^{-1})	2.11 A	2.13 A	2.80 A	2.82 A
K (g kg^{-1})	19.44 A	20.85 A	20.56 A	22.16 A
Ca (g kg^{-1})	1.00 A	1.04 A	0.95 A	1.07 A
Mg (g kg^{-1})	0.94 A	1.24 B	0.93 A	1.24 B
S (g kg^{-1})	1.34 A	1.42 B	1.47 A	1.51 A
As (mg kg^{-1})	0.05 A	0.17 A	0.11 A	0.13 B
Cd (mg kg^{-1})	0.01 A	0.12 B	0.01 A	0.09 B
Cr (mg kg^{-1})	0.23 A	0.82 B	0.31 A	1.26 B
Cu (mg kg^{-1})	5.27 A	5.51 A	5.02 A	5.73 A
Fe (mg kg^{-1})	19.52 A	27.56 B	23.55 A	33.17 B
Mn (mg kg^{-1})	4.18 A	6.10 B	5.13 A	6.65 B
Ni (mg kg^{-1})	1.07 A	2.36 B	1.79 A	2.17 A
Pb (mg kg^{-1})	0.03 A	0.16 B	0.05 A	0.14 B
Zn (mg kg^{-1})	15.64 A	16.27 B	19.00 A	21.90 A

Table 10. Yielding parameters and chemical composition of potatoes as affected by year, and fertilizer treatment.

Discussion

In 2016, we have analysed how mineral NPK fertilizers, the FYM, and combination of NPK+FYM affected potato yielding parameters, tuber yield, and potato chemical composition. According to our result, the application of FYM, NPK, and NPK+FYM slightly increased the length, width, and the weight of potatoes. However, the differences were not statistically different when compared with the unfertilized Control. Application of all three fertilizer treatments significantly affected the number of tubers harvested from the field. Comparing the tuber yield, the lowest yield was recorded in the Control, followed by FYM, NPK, and NPK+FYM. From this point of view, application of fertilizers does not affect the size or the weight of potatoes, but a higher yield in fertilized treatments was achieved by gathering a higher number of tubers from the field. Focusing on the yield, the combined application of NPK+FYM resulted in the highest yield and out of all four tested fertilizer treatments can be recommended as the approach securing best results.

Application of mineral fertilizers not only significantly affected the number of tubers and yield, but also the chemical composition of potatoes. This is visible in the case of N, P, K, and Mg. A higher concentration of nutrients is connected mainly with NPK and NPK+FYM treatments. From this point of view, properly fertilized potatoes not only offer higher yields, but also slightly higher protein content, and a higher concentration of minerals. On the other hand, we have also recorded a higher concentration of several risks and potential risk elements in the fertilized treatments.

For example, the concentration of As was slightly higher in the NPK+FYM treatment, when compared with other treatments, but still wasn't critical. The concentration of As ranged from 0.05 to 0.13 mg kg−1 and was well below the Czech limit of 1.24 mg kg−1 in all investigated treatments. The concentration of As was comparable with values for cabbage (0.083 mg kg−1), beet bulb (0.033 mg kg−1), tamarind (0.045 mg kg−1) and sugar cane (0.05 mg kg−1) published by Stalikas et al. (1997) and Zarcinas et al. (2004). Even though the application the NPK+FYM treatment affected arsenic concentration, the difference was not significant. The same pattern was recorded in the case of Fe, Mn, Ni, Pb, and Zn. On the other hand, the concentration of Cr was highest in the unfertilized Control treatment, while the concentration of Cu was highest in the FYM treatment. Thus, the pattern of how fertilizers affect the chemical composition of potatoes is specific for each element and can't be generalized.

In 2017, the effect of different organic manure - the pig slurry, and the effect of higher doses of mineral NPK were analyzed. In 2017 we can see larger differences between potato parameters. In contrast with the year 2016, the application of fertilizer treatments significantly affected the length of potatoes, especially the application of NPK and NPK+PS. A similar pattern was visible in the case of the width of potatoes, but no statistical differences were recorded here. Application of NPK was also connected with gathering slightly, but significantly heavier potatoes in 2017. Finally, the differences between the number of harvested potatoes were significant. In the end, the application of PS, NPK, and PS+NPK resulted in significantly higher yields of potatoes, especially in the case of PS+NPK. Comparing the concentration of nutrients, application of PS+NPK positively increased the N, P, K, and Mg concentrations in potato tubers. The fluctuation of risk and potential risk elements was lower. A statistically higher concentration of Cd and Ni was recorded in the NPK treatment. The concentration of Cu was significantly higher in the Control treatment. No differences between As, Cr, Mn, Pb, and Zn were recorded in 2017.

Comparison of all analysed parameters between 2016 and 2017 wouldn't be methodologically correct, as we can't differentiate the effect of the year, crop rotation, use of different organic manures, and different doses of mineral nutrients. However, according to our results, several things are visible and general conclusions can be stated.

Comparing the results from the Control treatment, the year 2017 offered significantly higher length, width, weight, number of potatoes, and yield. This points to more favourable climatic conditions for potato growing in 2017. With higher yields, there is also a connection with different concentrations of nutrients and risk elements. Comparing the Control treatments between 2016 and 2017, we have recorded higher K, Mg, Cd, Cr, Cu, Fe, Ni, and Pb concentrations in 2017. This can be related to higher nutrient uptake in 2017.

Comparing the effect of different organic manures (FYM - 2016, PS - 2017), all yielding parameters and potato yields were significantly different between 2016 and 2017. According to our results, the application of PS provided longer, wider, and heavier potatoes. Together with the higher number of potatoes harvested from the field it resulted in significantly higher yields. As mentioned above, the year 2017 provided more favourable climate conditions, so the role of the year significantly increased all analyzed parameters. The second factor, affecting the yielding parameters and yield of potatoes, was the organic manure used in 2016 and 2017. The difference between the FYM and PS is crucial here. First, both manures have different content of nutrients and organic matter content (different C:N ratio). The C:N ratio is a parameter influencing the speed of mineralization of manures in the soil. While the speed of mineralization of FYM is slower, it releases its nutrients in a longer period but a lower amount. On the other, manures with lower C:N ratio (slurries) release a higher amount of nutrients during the first year following its application (Vaněk, 2002). This fact partially contributed to the differences we have recorded between the effect of FYM and PS. The speed of mineralization, together with different concentrations of nutrients and risk elements, contributed to the differences between nutrients concentration (P, Mg), and risk elements concentration (Cd, Cr, Mn, and Pb). But again, different climate conditions also affected the uptake from the soil and we can't distinguish what contributed more, treatment or the year.

A similar situation occurred in the case of NPK treatment. As mentioned in the Methodology, both crop rotations use different doses of mineral nutrients. From this point of view, longer and heavier potatoes, a higher number of potatoes harvested from the field and thus higher yields in 2017 are a result of both, favourable conditions in 2017, and higher doses of mineral nutrients applied in 2017. This is visible especially in the case of N. Comparing the results, concentrations of all elements were higher in 2017, some of them significantly. This can be related with higher uptake of nutrients from the soil, with favourable conditions in 2017, with Fertilizer treatment*Year interaction, and with higher amount of chemical elements applied into the soil. This is visible in the case of Cd. In 2016, no differences between the fertilizer treatment were recorded. In 2017, the concentration in tubers ranged from 0.06 to 0.12 mg kg-1. These concentrations were above the limits set by Czech legislation (0.05 mg kg-1). However, it was substantially lower than in results published by other scientists. For example, Dudka et al. (2015) recorded concentrations ranging from 0.3 to 1.0 mg kg-1, and from 0.15 to 3.88 mg kg-1 (Dudka et al., 1996). Piotrowska and Kabata-Pendias (1997) recorded concentrations ranging from 0.11 to 3.72 mg kg-1, and McLaughlin et al. (1997) recorded concentrations ranging from 0.24 to 1.12 mg kg-1. The possible reason for the lower concentrations in 2016 is the application of low amounts of Cd in the fertilizers (lower dose), as well as the neutral soil pH, resulting in low Cd mobility at the study site (Uprety et al., 2009). According to the Hejcman and Šrek (2010), despite the low concentration of Cd in the tubers, that ranged from 0.02 to 0.07 mg kg−1 in their research, the concentration of total Cd in the soil was above the limits set by Czech legislation (0.050 mg kg-1). This fact points at the lack of connection between the total content of Cd in the soil and the Cd concentration in tubers.

In the article "Occurrence of trace elements in potatoes" published by the magazine Úroda (2002) is reported that if soils are excessively contaminated with a trace element, this can cause a reduced or increased intake of other nutrients or other trace elements. Translocation of substances in tubers and aboveground parts can also occur. Cadmium, arsenic, lead and beryllium, in particular, can have a very significant effect on this. Increased amounts of cadmium in the environment and potatoes increases the content of manganese and iron in tubers. On the contrary, the iron content decreases in the above-ground parts. The cadmium limits set of Czech legislation is 0,050 mg kg-1, for manganese is 4.5 mg kg-1. The results that we obtained say that increasing manganese concentration doesn't correlate with the increase in Cd. However, Mn increasing links with applying of mineral fertilizers. (Table 11)

The concentrations of Cu, Mn and Zn ranged from 5.02 to 6.54 mg kg−1, 4.05 to 6,65 mg kg−1 and 15.64 to 19.00 mg kg−1 respectively and were comparable with values published by Mansour et al. (2009) and by Hejcman and Šrek (2010). Although pig slurry supplied the soil with considerable amounts of Cu, Mn and Zn, there was no significant effect of pig slurry application on Cu and Zn concentrations in tubers, only the rate of Mn has shown a significant difference with the PS treatment.

	2016		2017	
	Cd (mg kg^{-1})	Mn(mg kg^{-1})	Cd(mg kg^{-1})	Mn(mg kg^{-1})
Control	0.006	4.67	0.08	5.49
FYM/PS	0.007	4.05	0.06	5.51
NPK	0.01	4.18	0.12	6.10
NPK+FYM/PS	0.01	5.13	0.09	6.65

Table 11. Concentrations of Cd and Mn of potatoes as affected by year, and fertilizer treatment.

The concentration of Pb in 2016 ranged from 0.03 (Control) to 0.05 mg kg-1 (NPK+FYM). In 2017, it ranged from 0.12 to 0.16 mg kg-1, which was already above the limit set by Czech legislation (0.10 mg kg-1). The concentration of Pb in tubers was higher in all fertilizer treatments in 2017, even in the Control treatment, when compared with 2016. From this point of view, the external factors, such as close vicinity of the international airport and a high way surrounding the field are out of the question, and the cause ought to be in the climate conditions in 2016 and 2017. It seems that beneficial conditions in 2017 increased the uptake of all elements in 2017 because all analysed parameters were higher in 2017 in the Control treatment, most differences were statistically significant.

Conclusions

According to our results, the application of organic manures and mineral fertilizers significantly affected yields of potato tubers in 2016 and 2017. Both manures have manifested itself in different ways.

In 2016, the yielding parameters, such as the length, width, and weight of potatoes, were not affected by any fertilizer treatment. The potatoes yield was significantly affected by the fertilizer treatment, mainly due to the significantly higher number of potatoes harvested from the plots treated with FYM, NPK, and NPK+FYM. Applying of NPK+FYM also significantly affected the concentration of N and K in the tubers, and application of NPK and NPK+FYM significantly increased the content of P in the tubers.

In 2017, the application of PS and NPK significantly increased weight and length of potatoes, and also the number of potatoes harvested from the experimental plots. Therefore, the differences between yields were not achieved only by the higher number of potatoes, but also by the fact that tubers were bigger and heavier. The chemical composition of potatoes was also significantly affected by the fertilization treatment, especially in the case of some heavy metals. These higher concentrations in 2017 were achieved due to the higher uptake, caused by better climate conditions this year.

From the profit, application of farmyard manure and pig slurry, combined with mineral NPK, provided the highest yields and these combinations represent the best fertilization approach when compared with application of organic manures or mineral fertilizers applied alone.

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