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Impact of different organic fertilizers on soil available nutrient contents, potato yield, tuber nitrate contents

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Abstract

In this study, field experiment was conducted to assess the effect of different organic fertilizer and mineral fertilizer on mineral and different organic fertilizer treatments effect on available N, P, K contents, the yield of potato (*Solanum tubevosum* L.), cultivar Astana, nitrate contents of tuber under dark chestnut soil conditions in southeast of Kazakhstan during the spring and summer of 2022. The experiment was carried out in the field and laid out as complete randomized block design with four replicates. Thirteen treatments that are, control without fertilizer treatment, mineral fertilizer with recommended dose ($N_{150}P_{90}K_{120}$) and eleven different organic fertilizers treatment were used. The results showed that available nutrient (N, P and K) contents of the post-harvest soil were affected by mineral and different organic fertilizers compared to the control. And, the available N, P and K contents in the soils taken from the biohumus (10 t ha^{-1}) and cattle manure (40 t ha^{-1}) treated plots were found to be higher than all of the other treatments and control. Similarly, plots treated recommended mineral fertilizer and different organic fertilizers had a significantly higher yield of potato tuber compared with control. When all applications were compared with each other, it was determined that the treatments that increased the potato yield the highest was the treatment of Biohumus (10 t ha^{-1}) + BioZZ (5 L ha^{-1}, 3 times). The highest nitrate content of tubers was obtained in mineral fertilizer with recommended dose ($N_{150}P_{90}K_{120}$). Hence, these results suggest that organic production of potato (Biohumus, 10 t ha^{-1} + BioZZ 5 L ha^{-1}, 3 times) could be an alternative to conventional production in Kazakhstan without reduction in yield, and with low nitrate content of tuber and high available nutrient contents in soil.

Keywords: Potato, organic fertilizer, biohumus, soil, nutrient, tuber nitrate.

Introduction

Potato (*Solanum tubevosum* L.) is one of the world's major staple crops after wheat, maize and rice to the world's food security (Waqas et al., 2021). Also, potatoes are an important crop in the Central Asian Republics (Loebenstein and Manadilova, 2003). They are the second most important crop in Kazakhstan, after wheat, grown on about 205.000 ha and its yields average 19.5 t ha^{-1} (Alimkhanov et al., 2021).

Potato adapts to many environmental conditions and is of short life cycle when compared with other tropical tuber crops (Horton, 1988, Esan et al., 2021). The importance of potato is increasing in Kazakhstan's farming and food systems because it is easy to plant, matures easily and has enormous industrial and economic potentials. Potato planting is done using conventional methods using chemical fertilizers, organic potato production is not done today in Kazakhstan. Organically grown food is attractive to both scientific and non-scientific communities (Hajšlová et al., 2005). Considering Kazakhstan's agricultural land capacity, farmer habits and increases in potato consumption in Kazakhstan and other countries, organic potato production

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could be important for Kazakhstan and make Kazakhstan a brand for organic potato production. Because, health benefits associated with organic food remains a focal point for research and production (Holden, 2001).

Several research results indicated that potatoes produced with organic practices are healthier than potatoes produced using conventional methods (Michaelidou and Hassan, 2008; Baudry et al., 2017). Potatoes produced with organic agricultural inputs contain less nitrate than potatoes produced with conventional methods using chemical fertilizers (Erhart et al., 2005; Lairon, 2009; Kazimierczak et al., 2019). Likewise, increases in dry matter, vitamin C, total amino acids, total protein, total sugars, and mineral plant nutrients were noted for potatoes produced with organic inputs when compared to potatoes produced by conventional methods (Wszelaki et al., 2005; Hajšlová et al., 2005; Rembialkowska, 2007; El-Sayed et al., 2015; Djaman et al., 2021; Esan et al., 2021; Li et al., 2022). And also, in principle, organic fertilizers are more environmental friendly and less expensive than mineral fertilizers.

It is well known that organic fertilizers improved the soil physical, chemical and biological properties and this consequently encourage the plant to have a good growth (Kızılkaya and Hepşen, 2007; Courtney and Mullen, 2008; Kızılkaya et al., 2012; Gülser et al., 2015; Bayadilova et al., 2022). Moreover, the slow released nutrients contained in organic fertilizers permit the plants to beneficial of it. All these reasons resulted in improve plant growth. The value of organic fertilizers as a source of nutrients for potato plants has been revived by several investigators (Hamouz et al., 2005; Singh and Kushwah, 2006; Maggio et al., 2008; Blecharczyk et al., 2023).

Mineral fertilizers are usually applied below the recommended rate ($N_{150}P_{90}K_{12}$) for potato production in Southern Kazakhstan. However, the effects of organic fertilizers on yield of potato on dark chestnut is unknown in Kazakhstan. For potato cropping, nutrients' primary source is the mineral fertilizer. Therefore, this study was aimed to determine different organic fertilizers and mineral fertilizer with recommended dose treatments effect on available N, P, K contents, the yield of potato, nitrate contents of tuber under dark chestnut soil conditions in South-east Kazakhstan.

Material and Methods

Study site and Soil Properties

During the spring and summer of 2022, the current research was conducted at the Regional Branch "Kainar" of the LLP "Kazakh Research Institute of Fruit and Vegetable Growing", foothill zone of the southeast of Kazakhstan (1050-1100m above sea level) on a dark chestnut soil. The commercial potato (*Solanum tuberosum* L.) cultivar Astana which are generally planted in April and harvested in September was used.

The locations of the evaluations were characterized by the continental climate (large daily and annual fluctuations in air temperature, characterized by cold winters and long hot summers), the air temperature reaches minimum values in January (-32,-35^{0}C), and maximum values in July (37-43^{0}C). The warm period lasts 240-275 days, the frost-free period is 140-170 days and an annual amount of precipitation is 250 – 600 mm.

A soil sample was collected from the experimental field at the beginning of the experiment. Physical and chemical properties of the experimental soil were determined Kazakh National Agrarian Research University according to the Rowell (1996). The soil belongs to the general soil type of dark chestnut. The land was medium high with loamy. The soil was characteristically slightly alkaline (pH 7.3-7.4), soil organic matter 2.9-3.0% (moderate), total N 0.18-0.20% (high), available P_2O_5 35-40 mg kg^{-1} (moderate), available K_2O 360-390 mg kg^{-1} (low), cation exchange capacity 20-21 meq 100g^{-1} soil, bulk density 1.1-1.2 gr cm^3, field capacity 26.6%.

Soil Preparation, Experimental design and Cultivation

As per standard commercial cultural practice for chestnut soil. The field was plowed using a chisel plow. Thereafter, the experimental field was divided into 180 cm wide strips. For each fertilizer treatment described below, two 1.80 m strips were divided into 50 m long sections. Total plot area was 180 m^2 (3.6 m by 50 m) to which organic and mineral fertilizers. Organic and mineral fertilizers were then incorporated into the soil using a rotavator. Fertilizer treatments were arranged in a complete randomized block design with four replicates.

Potato (*Solanum tuberosum* L.) cultivar Astana seeds were cut (approximately 35 g pieces) and left for a week for curing before planting. Potato tubers were mechanically planted on 28 April 2022, using a four-row-planter leaving 25 cm between hills and 90 cm between rows in all plots. Therefore, each plot was 50 m by 3.6 m with four rows of 0.90 m.

Treatments, Fertilizer application and Harvest

The experiment consisted of thirteen treatments as follows:

T1	Control (without fertilizer)
T2	Mineral fertilizer ($N_{150}P_{90}K_{120}$)
T3	Biohumus (10 t ha^{-1})
T4	Biohumus (10 t ha^{-1})+BioZZ (5 L ha^{-1}, 3 times)
T5	Cattle manure (40 t ha^{-1})
T6	Bird manure (30 t ha^{-1})
T7	Bird manure (10 t ha^{-1}) + Terra Sorb Foliar (3 L ha^{-1}, 3 times)
T8	Wheat straw (3 t ha^{-1}) + Megavit, (5 L ha^{-1}, 3 times)
T9	Baraebong Organic Fertilizer (10 t ha^{-1})
T10	Megavit, (5 L ha^{-1}, 3 times)
T11	WORMic, (5 L ha^{-1}, 3 times)
T12	BioEkoGum, (3 L ha^{-1}, 3 times)
T13	ZhGU (3 L ha^{-1}, 3 times)

Mineral fertilizers were applied at a rate of $N_{150}P_{90}K_{120}$. All amounts of phosphorus and potassium were applied manually during soil preparation in the form of double superphosphate (46%P_2O_5) and potassium sulfate (56% K_2O), while nitrogen was divided into two equal portions, and applied during soil preparation and 6 weeks after planting in the form of ammonium nitrate (34.5% N). Biohumus (in many countries of the former Soviet Union such as Azerbaijan, Kazakhstan and Russian Federation, vermicompost is called biohumus) consisted of 40% organic matter, 3% N, 5% P_2O_5, 1.2% K_2O, 5% Ca, 5% Mg, Cattle manure (0.6% N, 0.3% P_2O_5, 0.7% K_2O, 0.7% Ca, 0.15% Mg, 0.1% S), Bird manure (1.5% N, 1.8% P_2O_5, 1.0% K_2O), Wheat straw (0.5% N, 0.25% P_2O_5, 0.8% K_2O) and Baraebong Organic Fertilizer (3.5 % organic matter, 2.50 % N, 2.05% P_2O_5, 1.56 % K_2O) were applied during the planting. On the other hand, Terra Sorb Foliar (20% Organic matter, 6% Total N, 1% Organic N and 6% free amino acid), Megavit (contains amber, oxalic, citric, orthophosphoric acids, extract from biohumus, extract from unripe coals, nano-carbon, N,P,K,B, Ca, S, enriched with chelated form of 3 g Mg L^{-1}, 2 g B L^{-1}, 2 g Fe L^{-1}, 1 g Zn L^{-1}, 1 g Cu L^{-1}, 1 g Mn L^{-1}), WORMic (contains N, P, Ca, S, Zn, Cu, Mn, Zam-Zam water, phytohormones, amino acids, fulvates, gibberellins, auxins, peptides, humins, soil bactericides), BioEkoGum (contents: 189 N mg mL^{-1}, 31 mg P mL^{-1}, 310 mg K mL^{-1}, 1.2 g total C L^{-1}, 2.1 g humic acid L^{-1}, 0.28 g fulvic acid L^{-1}, 0.14 mg Cu mL^{-1}, 135.2 mg Zn mL^{-1}, 170, 4 mg Mn mL^{-1}, 748.5 mg Mo mL^{-1}, 11.2 mg Fe mL^{-1}, 4.4 mg B mL^{-1}), and ZhGU (liquid humic fertilizer contains all components of biohumus in dissolved state: humic acids, fulvic acids, vitamins, natural phytohormones, micro- and macroelements in the form of bioavailable organic compounds; 1500 mg N $100g^{-1}$, 1600 mg P $100g^{-1}$, 2500 mg K $100g^{-1}$), were applied just after planting, and 3, 6, and 9 weeks after planting. These foliar fertilizers were applied in the form of liquid using knapsack pesticide sprayer.

Harvesting of the crop was done treatment-wise on 30 September 2022. Firstly one border row from both sides and two plants from both ends were harvested to eliminate the border effect from each plot. Harvesting was done by digging of plants with the help of sickle axe.

Data collection

Soil Sampling and Analyses

After harvest, the soil samples collected from depth of 20 cm were naturally air-dried, milled and passed through 2.0 mm sieve. Available nitrogen (NH_4+NO_3) by the modified Kjeldahl method, available Phosphorus was determined by the 0.5M $NaHCO_3$ extraction method, available Potassium content were determined by the 1N NH_4OAc extraction method according to the Rowell (1996) and Jones (2001)

Plant Sampling and Analyses

After harvesting, tubers were separated according to the treatment and weighed on double pan balance for each treatment separately. After this, total tuber yield was calculated as the sum of the weights of marketable and unmarketable tubers from the net plot area and transformed to ton per hectare.

Procedure for Nitrate Determination

Immediately after the harvest, potato tuber samples were placed in a storeroom at a temperature of 10^{0}C and RH of 80%. After three days of storage, the part of potato tubers were washed. Raw tubers were cut into 1 x 1 x 1 cm cubes and frozen in liquid nitrogen. Frozen potato samples were stored at a temperature of -18^{0}C. The samples were then lyophilised and ground (particle size of 0.3–0.5 mm) using a laboratory mill Ultra-Centrifuge. The ground samples were stored in the dark in tightly sealed bags in a desiccator until laboratory testing. In this way, the nitrates and nitrites content were determined in the prepared material. Two grams of freeze-dried potatoes were mixed with 50 mL of 1% $KAl(SO_4)_2$ solution and well extracted. The extraction was carried out for 1 h using a shaker. The samples were filtered through Whatman No. 4 filter paper. Ten millilitres of 60% $Al_2(SO_4)_3$ solution was added to the filtrate and mixed immediately before the assay. The nitrate content was determined based on the KNO_3 standard curves. At each stage of the analytical testing, deionised water was used. Nitrate concentration in samples determined by the ion-selective potentiometric method according to Baker and Thompson (1992).

Results and Discussion

Nutrient contents of post-harvest soil

The effect of mineral and different organic fertilizers on available nutrient contents of post-harvest soil are presented in Figure 1. The soils from every plot after harvest of potato (*Solanum tuberosum* L.) cultivar Astana were analyzed for available nitrogen, phosphorus and potassium contents. The result from this study indicated that the available nutrient contents of the soil were affected by mineral and different organic fertilizers compared to the control. Available nitrogen content in soil was the highest (67.60 mg kg^{-1}) in T3 treated plot which was similar to the all treatments i.e. T5, T6, T7, T8, T2 and T9 treatments with the values of 64.4, 60.4, 58.3, 53.2, 50.4 and 47.6 mg kg^{-1}, respectively. Available phosphorus contents in soil had increased in all treated soils including control plot. The T5 treatment showed the highest value (134 mg kg^{-1}) which was different from all other treatments. Next to T3, the other three treatments (T6, T9 and T7) were differ. But, other treatments were identical. All treatments except T8 treatment increased the available potassium content of soils compared the control, the values being 300-520 mg kg^{-1}. The highest K content was noted with the T3 treatment which was significantly higher over all other treatments. The T3 treatment (Biohumus, 10 t ha^{-1}) showed the best positive effect on available soil nutrients (N, K and P) which was presumably due to higher mineralization. Thus, it is likely that the residual effects of organic amendment would have positive contribution to the next crop(s).). Sultana et al. (2021) stated that organic and inorganic integrated treatment gave the higher values for soil N, P and K contents whereas the inorganic treatment gave significantly lower values for those nutrients. Thomas et al. (2019) reported that application of anaerobic digestate (AD), compost, farmyard manure (FYM), straw, and mixes of amendment + straw applications can increase available N, P and K contents in the soil. Previous studies (Whalen and Chang, 2002; Diacono et al., 2010. Sürücü et al., 2014; Gülser et al., 2015) have reported that organic fertilizers were able to effectively improve the content of these nutrient elements in newly reclaimed land. Similarly, the results from this study indicated that the effect of organic fertilizers was dependent on the kind of organic fertilizers as well as the nutrient elements compared the mineral fertilizer.

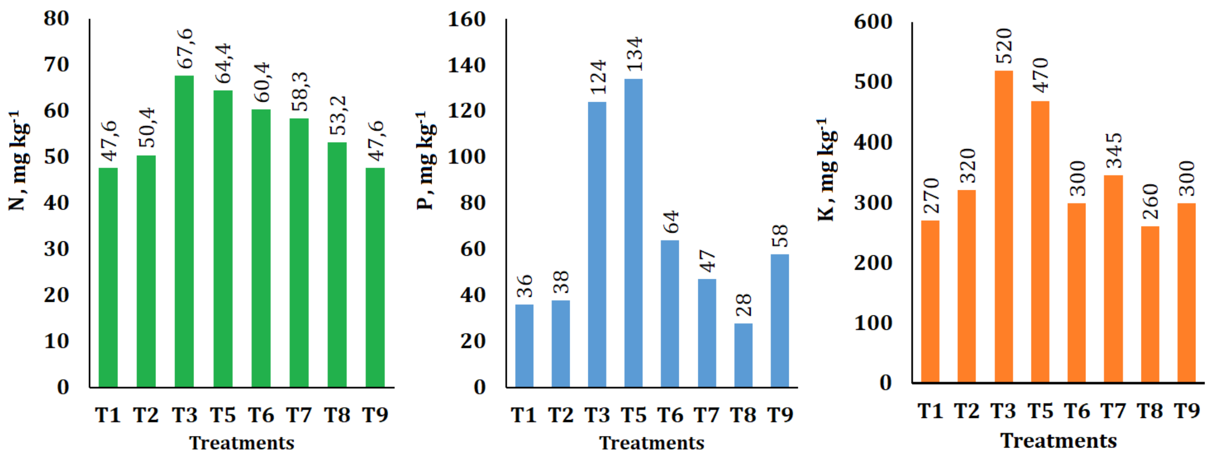

Figure 1. Effect of mineral and different organic fertilizer treatments on available N, P and K content in dark chestnut soil T1: Control (without fertilizer), T2: Mineral fertilizer ($N_{150}P_{90}K_{120}$), T3: Biohumus (10 t ha^{-1}), T5: Cattle manure (40 t ha^{-1}), T6: Bird manure (30 t ha^{-1}), T7: Bird manure (10 t ha^{-1}) + Terra Sorb Foliar (3 L ha^{-1}, 3 times), T8: Wheat straw (3 t ha^{-1}) + Megavit, (5 L ha^{-1}, 3 times), T9: Baraebong Organic Fertilizer (10 t ha^{-1}).

Potato yield

The effect of mineral and different organic fertilizers on total yield of potato tuber is presented in Figure 2. Plots treated recommended mineral fertilizer rate ($N_{150}P_{90}K_{120}$) in conventional systems and plots treated with different organic fertilizers had a significantly higher yield of potato tuber compared with control plots. In this study, the yield of potato tuber in the control treatment (T1) without NPK was determined as 18.4 t ha^{-1}, while the potato yield in the recommended treatment of mineral fertilizers (T2) was determined as 26.9 t ha^{-1}. The result from this study indicated that Potato yield was significantly affected by fertilizer treatments, and mineral/organic fertilizers exhibited a significant increase (17.4% in T13 treatment–87.5% in T4 treatment) in yield of potato tuber compared to the control. T4 increased potato yield by 87.5%, followed by T3 which increased by 72.3%.

Some of the organic fertilizers used in this experiment were applied to the plant only as foliar spraying (T10, T11, T12 and T13), some of them were applied only from the soil (T3, T5, T6 and T9) and some of them were applied both from the soil and from the leaves (T4, T7 and T8). According to the results, it was determined that the application of organic fertilizer applied to the potato with only foliar spraying in 3 times increased the yield of potato tuber compared to the control, but this increase was lower than the mineral fertilizer. However, it was determined that only the application of organic fertilizer from the soil increased the yield of potato tuber compared to the control. It was determined that the increase in T3, T5 and T9 treatments were higher than the mineral fertilizer application. However, the increase in T6 treatment was found to be lower than the application of mineral fertilizers. It was determined that the effect of both soil and foliar spraying treatments (T4, T7 and T8) on yield of potato tuber, the increase in all applications was higher than both control and mineral fertilizer application. These treatments, T4 treatments (Biohumus, 10 t ha^{-1} + BioZZ, 5 L ha^{-1}, 3 times) were highest in yield of potato tuber compared with the all of other treatments. It was determined that the effects of organic fertilizers on yield of potato tuber were also different. The various effects of organic fertilizers on yield of potato tuber may be mainly attributed to the difference in their composition. In agreement with the result of this study, some previous studies (Butler and Muir, 2006; Zhao et al., 2020; Li et al., 2022) have also reported the use of organic fertilizers in the yield of potato tuber. For example, Liu et al. (2014) reported the effects of biochar treatments on rapeseed and potato yields and water stable aggregate in upland red soil.

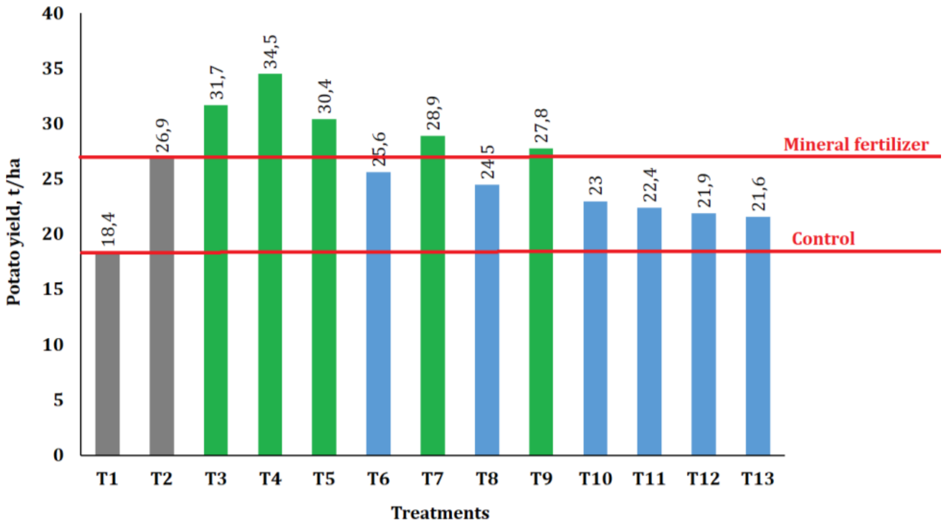

Figure 2. Effect of mineral and different organic fertilizer treatments on yield of potato tuber in dark chestnut soil. T1: Control (without fertilizer), T2: Mineral fertilizer ($N_{150}P_{90}K_{120}$), T3: Biohumus (10 t ha^{-1}), T4: Biohumus (10 t ha^{-1})+BioZZ (5 L ha^{-1}, 3 times), T5: Cattle manure (40 t ha^{-1}), T6: Bird manure (30 t ha^{-1}), T7: Bird manure (10 t ha^{-1}) + Terra Sorb Foliar (3 L ha^{-1}, 3 times), T8: Wheat straw (3 t ha^{-1}) + Megavit, (5 L ha^{-1}, 3 times), T9: Baraebong Organic Fertilizer (10 t ha^{-1}),T10: Megavit, (5 L ha^{-1}, 3 times), T11: WORMic, (5 L ha^{-1}, 3 times), T12: BioEkoGum, (3 L ha^{-1}, 3 times), T13: ZhGU (3 L ha^{-1}, 3 times).

Nitrate contents of potato tuber

In this research, the results indicate a higher nitrate contents in potato tubers produced under mineral fertilizer treatment, as compared to an organic fertilizer treatments. This results from the treatment of recommended mineral fertilizer rate ($N_{150}P_{90}K_{120}$) in conventional systems (Figure 3). This was also confirmed by other researches (Tamme et al., 2006; Wierzbowska et al., 2018; Kazimierczak et al., 2019). In addition, nitrate contents of potato tuber increased in response to mineral fertilizer (T2) and some organic fertilizer treatments (T3, T4, T5, T6, T7, T9, T12, T13) relative to the control (T1) treatment. The nitrates content in the potato tubers, determined immediately after the harvest, ranged from 65 to 223 mg kg^{-1}. Similarly, Wszelaczyńska et al., (2022) reported that the nitrates content in potato tubes ranging from 77.0 to 259.9 mg kg^{-1}. According to Commission Regulation (EC) No. 1822/2005 of 8 November 2005, the nitrates content of potato tubers should not exceed 200 mg kg^{-1}. The higher nitrate contents of potato tuber for the T2 (mineral fertilizer) and T6 (Bird manure, 30 t ha^{-1}) treatments than for any of the other rates of treatments and control (T1). These differences between T6 and other organic fertilizer treatments in these nitrate contents of potato tuber were probably related associated with high application doses and high nitrogen contents of bird manure.

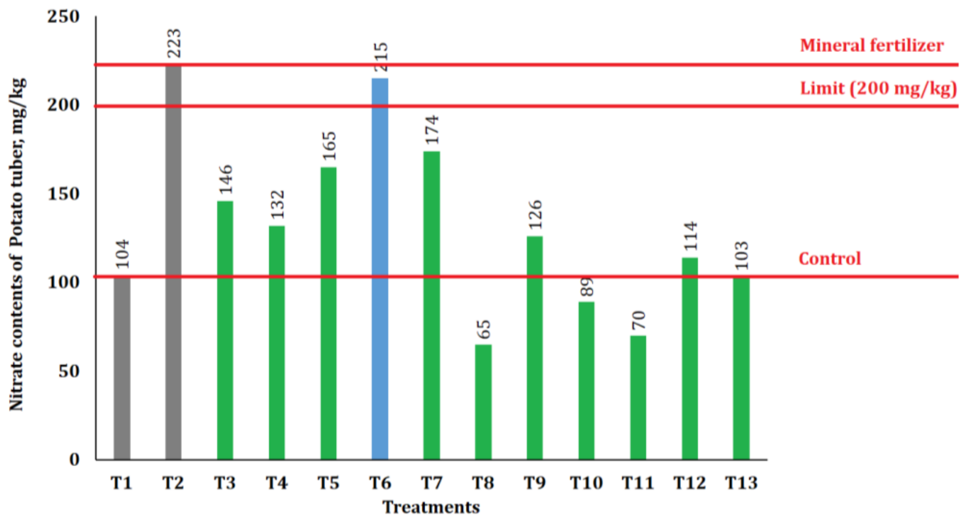

Figure 3. Effect of mineral and different organic fertilizer treatments on nitrate contents of potato tuber in dark chestnut soil. T1: Control (without fertilizer), T2: Mineral fertilizer ($N_{150}P_{90}K_{120}$), T3: Biohumus (10 t ha^{-1}), T4: Biohumus (10 t ha^{-1})+BioZZ (5 L ha^{-1}, 3 times), T5: Cattle manure (40 t ha^{-1}), T6: Bird manure (30 t ha^{-1}), T7: Bird manure (10 t ha^{-1}) + Terra Sorb Foliar (3 L ha^{-1}, 3 times), T8: Wheat straw (3 t ha^{-1}) + Megavit, (5 L ha^{-1}, 3 times), T9: Baraebong Organic Fertilizer (10 t ha^{-1}),T10: Megavit, (5 L ha^{-1}, 3 times), T11: WORMic, (5 L ha^{-1}, 3 times), T12: BioEkoGum, (3 L ha^{-1}, 3 times), T13: ZhGU (3 L ha^{-1}, 3 times).

Conclusion

It can be concluded that integrated use of organic manure and recommended dose of mineral fertilizer and different organic fertilizer resulted in significant improvement in the yield of potato (*Solanum tubevosum* L.), cultivar Astana and available nutrient (N, P and K) contents of the post-harvest soil. Hence, these results suggest that organic production of potato (at the level of 10 t ha^{-1} Biohumus, + BioZZ 5 L ha^{-1}, 3 times) could be an alternative to conventional production (mineral fertilization at a rate of $N_{150}P_{90}K_{120}$) without reduction in potato yield, and with low nitrate content of tuber and soil available nitrogen, phosphorus and potassium contents under dark chestnut soil conditions in South-east Kazakhstan. Therefore, treatment of organic fertilizers that are locally available, eco-friendly, improve soil nutrients can substantially improve potato yield and good returns under better management practices. Thus, we recommend that organic fertilizers should be incorporated into agronomic practices for potatoes which should substitute chemical fertilizers to improve potato productivity. Lastly, the study further recommends additional research to replicate the study in a wider spatial and temporal aspects.

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