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EFFECTS OF BIO-ORGANIC, CONVENTIONAL AND NANOFERTILIZERS ON GROWTH, YIELD AND QUALITY OF POTATO IN COLD STEPPE

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Abstract

Janmohammadi M., Pornour N., Javanmard A., Sabaghnia N., 2016: Effects of bio-organic, conventional and nanofertilizers on growth, yield and quality of potato in cold steppe [Bioorganinių, tradicinių ir nanotrąšų poveikis bulvių augimui, derliui ir kokybei šaltojoje stepėje]. – Bot. Lith., 22(2): 133–144.

The potato (*Solanum tuberosum* L.) is an important crop in moderate to cold regions, producing high yields of nutritionally valuable food in the form of tubers. In the cold steppe of the North West of Iran, nutrient management is a crucial component for successful potato production. This study was conducted to determine the effect of different fertilizers on growth, phenological development, tuber yield and tuber qualitative characteristics in two potato cultivars (‘Agria’ and ‘Spirit’). Specific objectives were to assess the effects of nanofertilizers on potato. Fertilizer treatments included: T_1 – control (no fertilizer application), T_2 – N-P-K chemical bulk fertilizer, T_3 – MOG enzymatic bio-fertilizer, T_4 – nano-chelated calcium, T_5 – nano-chelated zinc+boron and T_6 – nano-chelated complete fertilizer. The results indicated that application of nano-chelated Zn+B, complete nanofertilizer and chemical bulk N-P-K significantly increased plant height, the number of stems, main stem diameter and the number of leaves, and also accelerated the row closure (canopy closure). Application of nanofertilizer noticeably decreased the number of days to the initiation of tuberization. The evaluation of tuber yield components revealed that the highest numbers of tuber per plant, mean tuber weight, tuber weight per plant and harvest index were obtained by application of complete nanofertilizer. Comparisons of the cultivars indicated that ‘Agria’ was more responsive than ‘Spirit’ to nutrient managements and showed a more acceptable performance. Nutrient managements significantly affected the qualitative characteristics of tuber; so that the highest dry matter, starch and protein content was recorded for plant grown by complete nanofertilizer. The results of the present experiment agreed with the conclusion that balanced plant nutrition through the efficient nanofertilizers can improve potato productivity. Maintaining soil fertility through an adequate, suitable and balanced nutrient supply is one of the key components for increasing potato production under irrigated condition in cold steppe.

Keywords: CaO *nano*particles, chemical fertilizer, *nano-sized* B_2O_3, nutrient, stand establishment.

INTRODUCTION

The potato (*Solanum tuberosum* L.) is one of humanity’s most important food and leading vegetable crop. Its volume of production ranks fourth in the world after rice, wheat, and maize with the production of 368 million tons from 19.4 million hectares (Faostat, 2013). Iran is the twelfth producer of potato in the world and the third biggest in Asia, after China and India. The annual production of potato in Iran is near to 5.56 million tons, which is achieved from 190.000 ha (Faostat, 2013). Although Iran is clearly one of the largest potato growers in the Central Asia, nutritional management of this plant has been one of the most challenging. Considerable part of nutrients is accumulated in the top soils and is removed from the field in the harvested tubers (Mikkelsen, 2006). Therefore, careful nutritional management is very important in the potato fields. In semiarid cold steppes, the loss of organic matter and low fertility are of great concern. In these regions, low yield is partly due to the following factors: a) high nutrient turnover in soil-plant system coupled with low and imbalanced fertilizer use, b) deficiencies of micro and secondary nutrients, c) soil degradation due to salinization and alkalization as well as erosion, d) wide nutrient gap between nutrient demand and supply, and e) low fertilizer use efficiency (Rao & Reddy, 2010; Rayan et al., 2012). Soils of these areas often have low to medium available phosphorus (P), medium to high potassium (K), low iron (Fe), manganese (Mn) and zinc (Zn). Therefore, nutrient management is one of the important approaches in achieving high productivity of potato in this region.

However, over the last years, increased use of high-yielding crop varieties in intensive cropping systems has led to a substantially higher demand for nutrients (Zhang et al., 2012), and need for a new generation of high-performance fertilizers is apparent. On the other hand, the low amount of locally available nutrient sources (farmyard manure, compost and biological fixed nitrogen) highlighted the need for application of more efficient fertilizer.

Nanotechnology is a new area of technology in agricultural fields that recently has emerged and could be very useful in designing the new generation of fertilizers with higher efficiency of nutrient use. Nano-fertilizer technology is very innovative and has the potential to revolutionize the agricultural systems. Nanofertilizers are nano-structured formulation of fertilizers that release nutrients into the soil gradually and in a controlled way (DeRosa et al., 2010; Naderi & Danesh-Shahraki, 2013; Rameshaiah & Jpallavi, 2015). Nano-structured fertilizer exhibits novel physico-chemical properties, so that they can satisfy plant root demand more efficiently in comparison with conventional fertilizers (in the form of salts). The controlled release of the nutrient could be through the process of dissolution and ion exchange reactions (DeRosa et al., 2010). Nano-sized active ingredients in nano-structured fertilizer may help to improve nutrient use efficiency and it may be due to their small size (between 1 to 100 nm) and more surface area, which facilitates adsorption of the nutrients by plant roots (Kumar & Pandey, 2014).

However, alongside the new generation of fertilizers, biological fertilizers are also the centre of consideration. One of the recently introduced organic fertilizers is MOG, which is manufactured by using fruit juice and crop residues, and contains 18 types of enzymes (such as alkaline protease, glucamylase, lipase, lipoxigenas, nitrogenase, etc.), natural form of micro and macro nutrients and vegetable based vitamins. They are extremely advantageous in enriching soil fertility and fulfilling plant nutrient requirements by supplying the organic nutrients (Janmohammadi et al., 2014a, b; Vessey, 2003). However, information about the effect of enzymatic fertilizer on potato production systems is meagre.

In potato production, positive response of conventional N-P-K fertilizer has been observed particularly in texturally poor soils (Mahmood et al., 2003). Also adequate calcium (Ca) is a critical aspect of the mineral nutrition of potatoes. Calcium is involved in both the structure and function of all plant cell walls and membranes. Micronutrient availability generally decreases as soil pH increases. Boron is one of the micronutrients needed in cell wall synthesis and it affects calcium absorption (Marschner, 2011). Therefore, it seems that boron can affect tuber storage quality characteristics. Moreover, zinc is a necessary component of various enzyme systems for energy production, protein synthesis, energy production, maintains the structural integrity of bio-membranes and growth regulation (Hänsch & Mendel, 2009). In the north-western part of Iran, micronutrient deficiencies are nutritional disorders in potato production systems. Despite the some researches about nutrient managements in potato, there is little information about the effect of biological and nano fertilizers on yield and quality of potato. The objective of the present study was to investigate the potential for in-season supplemental fertilizers (biological, nano and conventional chemical) to improve potato production.

MATERIALS AND METHODS

The experiment was carried out at the experimental farm in Sarab, East Azarbaijan Province, Iran (47°53′ E, 37°93′ N; 1682 m above sea level) during the growing seasons in 2014. Sarab is a cold steppe located in the middle section of the Great Plains of Azarbaijan at the northwest of Iran. This region is under the aquifer realm of Oroumiyeh Lake and the Adji-Chai River. The climate of Sarab according to the KÖPPEN-GEIGER classification is BSk (KOTTEK et al., 2006). Cold semiarid climates (BSk) have cold winters and relatively temperate summer. Eleven-year (2003–2014) meteorological data of the area indicated that the area had mean annual minimum and maximum temperatures of 2.2°C and 17.1°C, respectively. The average relative humidity in mid-afternoon during the growing season was 57%. The total annual amount of precipitation was 240 mm and about 43% of the total rainfall occurred during the growing season. The soil type of the trial field was sandy loam, consisted of sand (56%), silt (31%) and clay (13%); pH 7.77 and EC 1.29 dS m^{-1} in the topsoil (0–0.3 m depth). Soil chemical analyses showed that the organic matter content (OM) made up 0.66%, nitrogen (N) – 0.071%, available potassium – 324 mg kg^{-1}, available phosphorus – 11.25 mg kg^{-1} and total neutralizing value (TNV) – 43.6%. The soil characteristics were determined according to TANDON (1995). In the previous year, the field was abandoned as bare fallow.

The potato (*Solanum tuberosum* L.) cultivars 'Agria' and 'Spirit' procured from Sarab Agricultural Research Station were used for the current study. Both potato cultivars have been classified as late medium maturity (PARVIZI, 2008). Seed tubers were machine cut and allowed to suberize for at least one week prior to planting. The field was mouldboard-ploughed in November and twice disked before seed planting. Seed bed types in experimental plots were ridge and furrow. After primary and secondary tillage, the seeds were hand planted about 20 cm deep on 10 May, 2014. Each plot was 36 m^2 consisting of eight rows, 6 m in length with 0.75 m between rows and 0.25 m between seed pieces within rows. The free-flow surface irrigation system was used for water supply during growing season and plants were grown under straight furrow irrigation. The outer ridge per plot was used as a guard row to avoid horizontal soil water movement. The experiment was laid out as a split plot in a randomized complete block design with three replications. The main plots were assigned to six nutrition treatments. Fertilizer treatments consisted of: T_1 – control (no fertilizer application), T_2 – conventional N-P-K fertilizer, T_3 – MOG enzymatic bio-fertilizer (2 L ha^{-1}), T_4 – nano-chelated calcium (2 kg ha^{-1}), T_5 – nano-chelated Zn+B (1 kg ha^{-1}) and T_6 – nano-chelated complete fertilizer (1 kg ha^{-1}). The subplots included varieties of 'Agria' (A) and 'Spirit' (S). N-P-K (20:10:5) fertilizer was applied at the rate of 200 kg ha^{-1} in two split applications, i.e. a half as a pre-plant (starter fertilizer) and a half as a post-emergence side dress application during tuber initiation stage (prior to hilling). Other fertilizers were applied as fertigation through irrigation water during planting and tuber initiation stages. Fertigation permits application of a nutrient directly at the site of a high concentration of active roots and as needed by the crop. Nano-chelated fertilizers were obtained from the Sepehr Parmis Company, Iran, which contained calcium oxide, zinc oxide and boron trioxide nanoparticles. Synthesized nanoparticles were characterized morphologically using a scanning electron microscope (Fig. 1). Nano-chelated complete fertilizer contained 11 essential elements (N = 5%, P = 3%, K = 3%, Fe = 4.5%, Zn = 8%, Ca = 6%, Mg = 6%, Mn = 0.7%, Cu = 0.65%, B = 0.1%, Mo = 0.65%). MOG enzymatic bio-fertilizer was provided from Azarabadegan Company (West Azarbaijan, Iran). The MOG enzymatic bio-fertilizer contained

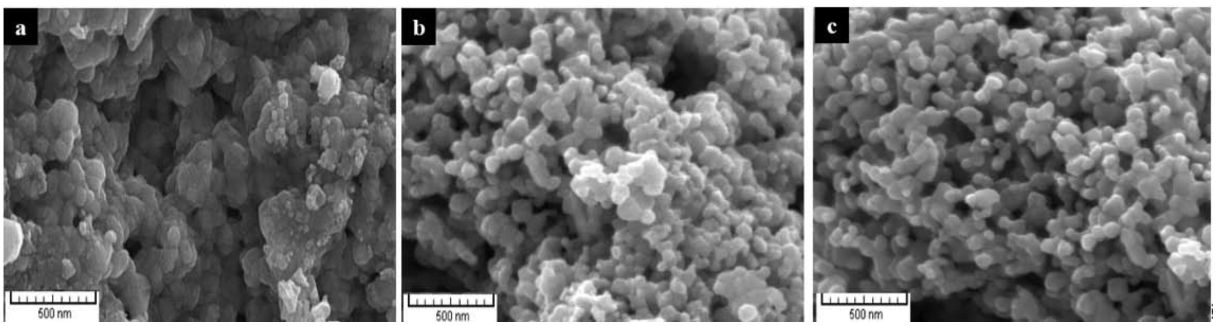

Fig. 1. Scanning Electron Microscope (SEM) image of synthesized nanoparticles of calcium oxide (a), boron trioxide (b) and zinc oxide (c) utilized for nano-structured fertilizer

organic carbon (25%), nitrogen (4%), K_2O (4%), Fe (0.42%), Cu (0.16%) and enzymes (13%).

Irrigation was applied every week to replace soil water lost due to evapotranspiration. Low weed, disease and insect pest pressure were maintained by using cultivation and recommended amounts of agrochemicals common to commercial practices in Sarab region. Phenological growth phase, e.g. day to initiation of tuberization, days to flowering, days to row closure, days to maturity were monitored at 1–2–day intervals throughout the season according to the method described by Hack et al. (1993). Days to row closure were considered as when plants in adjacent rows touched each other between the rows across the furrows and foliage completely covered the distance of two adjacent rows.

The number of leaves per plant was evaluated at tuber bulking stage. At the end of the growth season, when most plants were supposed to ripe, plant height, the main stem diameter, the number of stems and biological yield were measured on 10 randomly selected bushes. Two weeks after chemical vine desiccation (on October 5), tubers were mechanically harvested from two inner rows of each experimental plot. Then, tuber weight per plant, mean tuber weight and tuber number per plant were recorded. The starch percentage was measured at the laboratory according to Noda et al. (2004). Fresh tubers were washed, peeled, and diced. These dices were dipped in ice water containing 100 ppm $Na_2S_2O_5$ to minimize browning and was wet milled at low speed in a laboratory scale blender with 1:2 w/v of tap water for 2 min and filtered through a gauze cloth. Residue was repeatedly wet milled and filtered for thrice and suspension was kept overnight for settling of starch. The supernatant was decanted and the settled residue was further purified with repeated suspension in tap water (1:2 v/v) followed by the settling process for 3 h. The purified starch was dried at 35°C, sifted through a 300 μm sieve, sealed, and packed for analysis. Measurement of protein and nitrate was conducted in accordance with the methods described by Darvishi et al. (2012) and Lachman et al. (2005). Crude protein content was determined as nitrogen in dry matter of potato tubers multiplied by coefficient 6.25. Total nitrogen content was analyzed using microkejeldal. Nitrates were extracted by aluminium potassium sulfate and determination of nitrate content in tubers was carried out through ion selective electrode. Dried tissue was ground to pass through a 20-mesh sieve; 50 mL 1% of $KAl(SO_4)_2$ extracting solution was added and shaken for 1 h. Next 10 mL aluminium sulfate was added and shaken immediately before the test. The data were tested for the Skewness and Kurtosis normality of distribution by SPSS Statistics 17.0 (*SPSS* Inc., Chicago, IL, USA). The experimental data were statistically analyzed for variance using the SPSS and MINITAB version 14 (*Minitab* Inc., Harrisburg, PA, USA). Differences in character means were also measured using the Least Significant Difference (LSD).

RESULTS

The results of variance analysis showed that the effect of fertilizer treatments and cultivars on plant height was statistically significant at 99% confidence level. The tallest plant recorded under application of nano-chelated Zn+B, complete nanofertilizer and chemical N-P-K, whereas the shortest plant was observed for control and MOG bio-fertilizer (Table 1). Also, plant height in cultivar 'Agria' was approximately 10% higher than 'Spirit'. Evaluation of the number of stems showed that the effect of both cultivars and nutrient managements were significant ($p < 0.01$) on this trait. The plant grown by complete nanofertilizer and conventional N-P-K had the highest number of stems per plant. Also the number of stems in cultivar 'Agria' was higher than 'Spirit' (Table 1). A significant variety × fertilizer interaction was obtained for mean stem diameter (Table 1). Means comparison indicated that the thickest stems were recorded for cultivar 'Agria' grown by complete nanofertilizer, which followed by 'Agria' plants under nano-chelated Zn+B condition, while the thinnest stems were observed for cultivar 'Agria' and 'Spirit' grown under no fertilizer application (Fig. 2).

However, the assessment of the number of leaves per plant showed that cultivar 'Spirit' grown by complete nanofertilizer and nano-chelated Zn+B possessed the highest number of leaves, whereas in both cultivars the plants grown under no fertilizer application had the lowest number of leaves. Monitoring of the phenological development between the treatments and cultivars revealed that the number of days to initiation of tuberization was noticeably af-

Table 1. Effect of different fertilizers on some morphological traits of potato (*Solanum tuberosum* L.) cultivars

Fertilizers (F)	PH	NS	MSD	NL	DTI	DF	DRC	NDM	BY
control	52.16^{c}	3.57^{c}	4.16^{e}	42.68^{c}	45.08^{a}	34.08^{d}	45.11^{a}	110.33^{ab}	37.61^{b}
Chemical N-P-K	61.96^{a}	4.33^{a}	5.07^{bc}	51.92^{ab}	41.83^{ab}	37.58^{b}	38.00^{cd}	117.41^{a}	40.22^{a}
MOG bio-fertilizer	52.25^{bc}	3.85^{bc}	4.53^{d}	51.04^{b}	42.16^{ab}	35.75^{c}	42.00^{b}	97.33^{b}	39.71^{a}
Nano-chelated Ca	56.33^{b}	3.91^{b}	4.90^{c}	51.04^{b}	39.66^{bc}	36.50^{bc}	39.00^{c}	116.33^{ab}	39.97^{a}
Nano-chelated Zn+B	64.78^{a}	3.77^{bc}	5.24^{b}	53.23^{ab}	37.83^{c}	37.08^{bc}	39.00^{c}	118.33^{a}	39.71^{a}
Complete nanofertilizer	64.35^{a}	4.50^{a}	5.47^{a}	54.34^{a}	39.50^{c}	39.16^{a}	36.83^{d}	112.66^{a}	40.56^{a}
Irrigation (I)									
‘Agria’	61.95^{a}	4.23^{a}	5.11^{a}	47.15^{b}	41.22^{a}	32.83^{b}	40.0^{a}	114.77^{a}	40.15^{a}
‘Spirit’	56.32^{b}	3.74^{b}	4.67^{b}	54.26^{a}	40.80^{a}	40.55^{a}	39.98^{a}	112.69^{a}	39.13^{b}
Significance Level									
F	**	**	**	**	**	**	**	NS	**
C	**	**	**	**	NS	**	NS	NS	**
F×C	NS	NS	*	*	NS	**	NS	NS	NS
CV%	5.41	6.09	3.22	4.57	7.01	3.09	3.16	14.55	8.48

PH = plant height (cm), NS = number of stems, MSD = main stem diameter (mm), NL = number of leaves, DTI = day to initiation of tuberization, DF = number of days to flowering, DRC = number of days to row closure, NDM = number of days to maturity, BY = biological yield (t ha^{-1}). Mean values of the same category followed by different letters are significant at $p \leq 0.05$ level.

fected by fertilizer treatments. So that application of complete nanofertilizer, nano-chelated Zn+B and nano-chelated Ca considerably accelerated the tuber initiation compared to control condition (Table 1). A significant variety × fertilizer interaction was recorded for the days to flowering ($p < 0.01$). Although the consumption of fertilizers in cultivar ‘Agria’ had little effect on initiation of the flowering, fertilizer application in cultivar ‘Spirit’ considerably delayed the flowering. So that the latest flowering time was recorded for plant grown by application of complete nanofertilizer and nano-chelated Zn+B in cultivar ‘Spirit’ (Fig. 3).

Evaluation of the number of days to row closure (ground cover rate) revealed that the effect of fertilizer treatment on this trait was significant ($p < 0.01$). Mean comparison for rate of ground cover showed that fertilizer application accelerated row closure compared to control (Table 1). The quickest row closure was recorded for plants grown by application

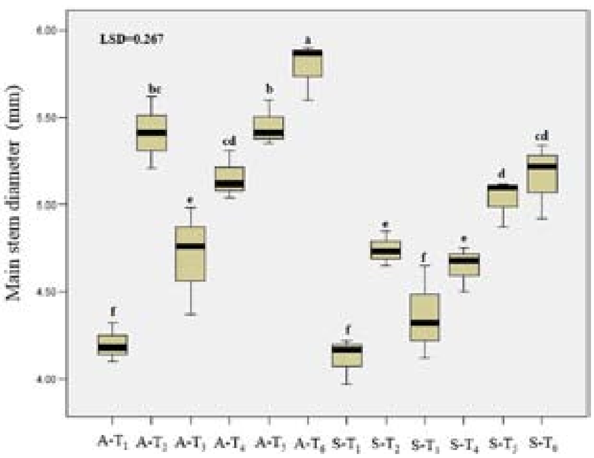

Fig. 2. Effects of different fertilizers on the main stem diameter of potato cultivars in cold steppe of Sarab. A: cultivar ‘Agria’, S: cultivar ‘Spirit’, T_1: no fertilizer application (control), T_2: conventional N-P-K fertilizer, T_3: MOG-enzymatic biofertilizer, T_4: nano-chelated Ca, T_5; nano-chelated Zn+B, T_6: complete nanofertilizer

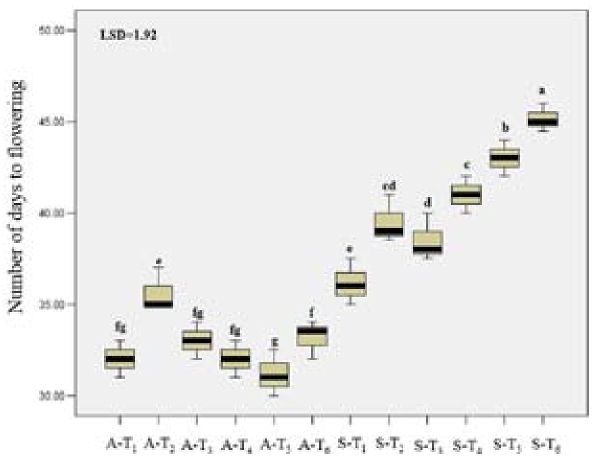

Fig. 3. Effects of nutrient management on the number of days to flowering of two potato cultivars. A: cultivar ‘Agria’, S: cultivar ‘Spirit’, T_1: no fertilizer application (control), T_2: conventional N-P-K fertilizer, T_3: MOG-enzymatic bio-fertilizer, T_4: nano-chelated Ca, T_5; nano-chelated Zn+B, T_6: complete nanofertilizer

of complete nanofertilizer and conventional N-P-K. Application of these fertilizers noticeably increased the growth of the foliage. However, neither fertilizer nor cultivar affected the days to maturity. Investigation of biological yield showed that both factors significantly affected this trait ($p < 0.01$). The lowest biological yield was recorded for plant grown under no fertilizer application, while there was no significant difference between different fertilizer treatments (Table 1).

The variance analysis and mean comparison of yield components were presented in Table 2. A significant variety × fertilizer interaction was observed for the number of tubers per plant at 99% confidence level. The highest number of tubers was recorded for cultivar 'Agria' grown under application of complete nanofertilizer, conventional N-P-K and nano-chelated Zn+B, whereas the lowest number of tuber was related to plants under no fertilizer application (Fig. 4). Overall, this yield component strongly responded to the use of fertilizers. So that in both cultivars, regardless of the type of fertilizer, nutrient application significantly increased the number of tube over control. Evaluation of mean tuber weight indicated that fertilizer application considerably influenced this component ($p < 0.01$). Application of complete nanofertilizer, nano-chelated Zn+B and conventional N-P-K increased mean tuber weight up to 25%, 16% and 13% over control, respectively. The main effects of fertilizer and cultivar were significant, and a significant fertilizer × cultivar interaction was obtained for mean tuber diameter (Table 2). The largest tuber was related to cultivar 'Agria', which was obtained by application of complete nanofertilizer, while the lowest tuber diameter was obtained by application of N-P-K in both cultivars (Fig. 5). In the case of tuber weight per plant and tuber yield per hectare, the results showed that all investigated factors significantly affected this trait (Table 2). Averagely, tuber weight per plant in cultivar 'Agria' was 9% higher than cultivar 'Spirit'. Overall, the nutrient application increased the tuber yield. So that the greatest impact was related to complete nanofertilizer (18%), while the application of enzymatic MOG bio-fertilizer increased the tuber yield up to 7%. A similar trend was also observed for the harvest index (Table 2). Thus, the highest harvest index (HI) was recorded for plants grown by complete nanofertilizer, nano-chelated Zn+B and conventional N-P-K, respectively. Evaluation of tuber dry matter content (MDT) showed that application of complete nanofertilizer increased the HI up to 12% over the control.

Table 2. Comparison of yield and yield components of *potato* (*Solanum tuberosum* L.) cultivars under application of different fertilizers

Potato traits	NTP	MTW	MTD	TWP	TY	HI	DMT	NI	ST	PRO
Fertilizers (F)										
Control	8.07^{d}	48.79^{c}	4.56^{b}	512.33^{d}	21.56^{d}	57.21^{e}	18.12^{c}	52.00^{d}	13.02^{e}	3.91^{d}
Chemical N-P-K	10.62^{b}	55.26^{b}	4.27^{cd}	577.00^{b}	24.38^{b}	60.62^{b}	19.72^{b}	88.16^{a}	15.08^{b}	5.23^{ab}
MOG bio-fertilizer	8.96^{c}	48.49^{c}	4.19^{cd}	555.00^{c}	23.16^{c}	60.21^{c}	20.71^{b}	50.83^{d}	13.77^{d}	4.54^{c}
Nano-chelated Ca	10.38^{b}	51.12^{c}	4.45^{bc}	577.83^{b}	24.06^{b}	58.31^{d}	20.29^{b}	50.51^{d}	14.36^{cd}	4.90^{bc}
Nano-chelated Zn+B	10.92^{ab}	56.63^{b}	4.27^{cd}	584.83^{b}	24.40^{b}	61.42^{b}	20.31^{b}	62.00^{c}	14.89^{bc}	5.43^{a}
Complete nanofertilizer	11.32^{a}	61.17^{a}	4.65^{b}	619.83^{a}	25.33^{a}	62.45^{a}	22.63^{a}	70.83^{b}	16.89^{a}	5.56^{a}
Cultivar (C)										
'Agria'	10.45^{a}	52.80^{a}	4.50^{a}	588.05^{a}	24.51^{a}	61.09^{a}	19.36^{b}	69.72^{a}	14.90^{a}	5.01^{a}
'Spirit'	9.64^{b}	54.35^{a}	4.32^{b}	554.22^{b}	23.09^{b}	58.98^{b}	21.22^{a}	55.05^{b}	14.43^{b}	4.85^{a}
Significance Level										
F	**	**	**	**	**	**	**	**	**	**
C	**	NS	*	**	**	**	**	**	*	NS
F×C	*	NS	**	NS	NS	NS	NS	NS	NS	NS
CV%	5.30	5.56	4.33	2.79	2.28	1.17	5.80	10.98	3.54	7.70

NTP = number of tubers per plant, MTW = mean tuber weight (g), MTD = mean tuber diameter (cm), TWP = tuber weight per plant (g), TY = tuber yield (t ha^{-1}), HI = harvest index, DMT = dry matter content (%), NI = nitrate content (mg kg^{-1}), ST = starch content (%) of initial fresh, PRO = protein content (% dry matter). Mean values of the same category followed by different letters are significant at $p \leq 0.05$ level.

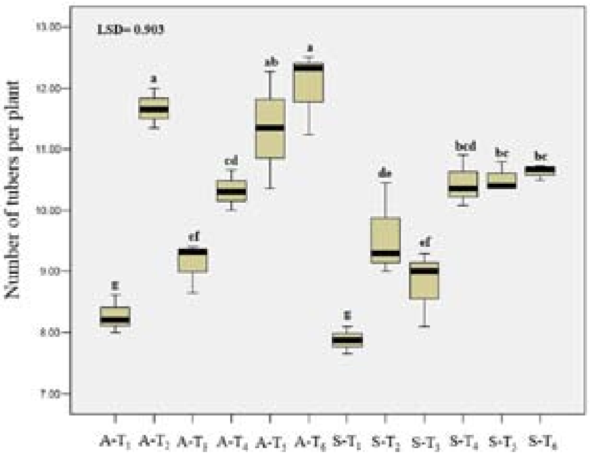

Fig. 4. Influence of fertilizer application on the number of tubers in two potato cultivars. A: cultivar 'Agria', S: cultivar 'Spirit'; T_1: no fertilizer application (control), T_2: conventional N-P-K fertilizer, T_3: MOG-enzymatic bio-fertilizer, T_4: nano-chelated Ca, T_5; nano-chelated Zn+B, T_6: complete nanofertilizer

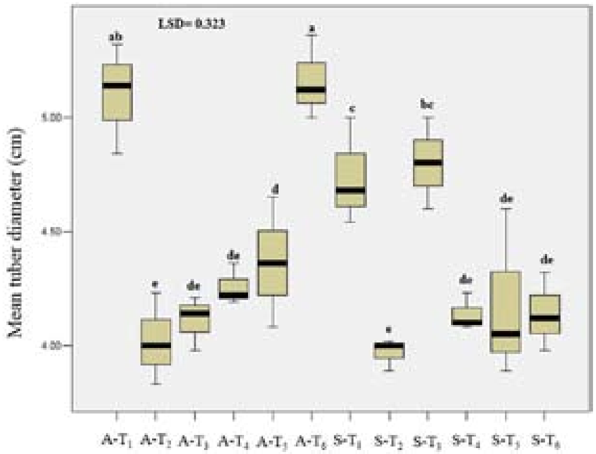

Fig. 5. Effects of nutrient management on mean tuber diameter of two potato cultivars. A: cultivar 'Agria', S: cultivar 'Spirit'; T_1: no fertilizer application (control), T_2: conventional N-P-K fertilizer, T_3: MOG-enzymatic bio-fertilizer, T_4: nano-chelated Ca, T_5; nano-chelated Zn+B, T_6: complete nanofertilizer

The harvest index of cultivar 'Agria' was significantly higher than cultivar 'Spirit'. However, there was no difference between conventional N-P-K, MOG bio-fertilizer, nano-chelated Ca and nano-chelated Zn+B. Mean comparison of DMT between the cultivars showed that the amount of this component was significantly higher in cultivar 'Spirit' (Table 2). Assessment of the nitrate content showed that its concentration in cultivar 'Agria' was significantly higher than cultivar 'Spirit'. Nitrate content in consumable plant organs should be small and not to be raised by fertilizer management. However, the results revealed that application of conventional N-P-K substantially increased the nitrate content (Table 2). Starch content (ST) in tuber was significantly affected by fertilizer treatments, so that the application of complete nanofertilizer increased this qualitative parameter up to 29% compared to control. In terms of ST, cultivar 'Agria' was richer than the cultivar 'Spirit'. Considerable influence of complete nanofertilizer on protein content was also recognizable (Table 2).

The correlations between different traits were presented in Table 3. Tuber yield was observed to be noticeably and positively correlated at 1% significance level with plant height, the number of stems, main stem diameter, biological yield and the number of tubers per plant. One of the most interesting findings was a significant negative correlation of yield components with days to row closure and days to tuber initiation, so that these can be introduced as a suitable descriptor for the evaluation of potato performance in semiarid cold region. A similar trend was observed between phenological traits and starch content as well as protein content. Also, a positive correlation was observed between the traits associated with plant size (plant height, the number of stems, main stem diameter and biological yield) and nitrate content (Table 3).

DISCUSSION

This study showed that application of conventional N-P-K, complete nanofertilizer and nano-chelated Zn+B considerably induced the vegetative growth. It may suggest that the soil of the studied area has both micro and macronutrient deficiencies. Although in the investigated region the soil contains relatively high water soluble potassium, nitrogen and phosphorus, these elements have always been the main limiting nutrients for growth. At high soil pH, most phosphorus is in the form of calcium compounds and is unavailable for plant (Troeh & Thompson, 2005). In terms of effectiveness, calcium ranks fourth. The soil test recommendation for Ca for potato production is around 300 ppm. Although calcium deficiency can be observed in sandy soils, the necessity of calcium application becomes more evident with the increasing soil salinity in semiarid region. In this context, it was revealed

Table 3. Pearson's correlation coefficients for morphophysiological traits of potato

	PH	NS	MSD	NL	DTI	DF	DRC	NDM	BY	HI	NTP	MTW	MTD	TWP	TY	DMT	NI	ST
NS	0.74																	
MSD	0.93	0.79																
NL	0.15	–0.05	0.22															
DTI	–0.61	–0.22	–0.71	–0.61														
DF	–0.17	–0.32	–0.11	0.86	–0.30													
DRC	–0.70	–0.64	–0.85	–0.59	0.77	–0.28												
NDM	0.56	0.38	0.54	0.22	–0.38	0.17	–0.48											
BY	0.69	0.77	0.78	0.29	–0.56	–0.10	–0.74	0.38										
HI	0.88	0.80	0.95	0.16	–0.66	–0.20	–0.81	0.53	0.81									
NTP	0.85	0.69	0.96	0.32	–0.77	0.03	–0.89	0.54	0.79	0.91								
MTW	0.67	0.47	0.69	0.62	–0.63	0.47	–0.77	0.63	0.46	0.68	0.69							
MTD	–0.26	–0.05	–0.18	–0.53	0.37	–0.41	0.36	–0.38	–0.34	–0.07	–0.25	–0.19						
TWP	0.85	0.83	0.95	0.25	–0.69	–0.13	–0.84	0.47	0.89	0.96	0.92	0.66	–0.14					
TY	0.84	0.83	0.93	0.22	–0.64	–0.17	–0.82	0.49	0.93	0.97	0.90	0.62	–0.18	0.98				
DMT	0.13	0.08	0.26	0.89	–0.51	0.79	–0.54	0.20	0.29	0.19	0.29	0.63	–0.27	0.32	0.24			
NI	0.73	0.80	0.68	–0.07	–0.11	–0.22	–0.55	0.42	0.58	0.65	0.64	0.46	–0.19	0.59	0.66	–0.14		
ST	0.78	0.77	0.88	0.40	–0.62	0.16	–0.85	0.59	0.76	0.86	0.87	0.85	–0.11	0.91	0.86	0.50	0.62	
PRO	0.89	0.64	0.90	0.55	–0.81	0.21	–0.89	0.59	0.74	0.84	0.88	0.82	–0.48	0.86	0.84	0.50	0.57	0.85

Critical values of correlation $p < 0.05$ and $p < 0.01$ are 0.50 and 0.75, respectively. Abbreviations: PH = plant height, NS = number of stems, MSD = main stem diameter, NL = number of leaves, DTI = day to initiation of tuberization, DF = number of days to flowering, DRC = number of days to row closure, NDM = number of days to maturity, BY = biological yield, NTP = number of tubers per plant, MTW = mean tuber weight, MTD = mean tuber diameter, TWP = tuber weight per plant, TY = tuber yield, HI = harvest index, DMT = dry matter content, NI = nitrate content, ST = starch content of initial fresh, PRO = protein content.

that adequate levels of calcium assist in K^+/Na^+ selectivity. This beneficial effect of calcium is mediated through a signalling pathway that regulates activity of potassium and sodium transporters (Malvi, 2011). However, it seems that utilization of calcium alone is not so beneficial, so that the application of complete nanofertilizer had the best effect on both vegetative growth and tuber production. This may be the result of synergistic relationships between the calcium and other beneficial elements. For instance, optimal levels of calcium and zinc improve the uptake of phosphorus and potassium (Marschner, 2011). This suggests that management of calcium fertility is very important in the potato fields. In this regard, it has been indicated that even if calcium uptake is adequate, calcium deficiencies can arise in the tubers due to the pattern of allocation of calcium within the plant (Palta, 2010). With regards to specific situation of the region, where the plant may suffer early cold at the end of growing season, the application of calcium is very necessary. There is evidence that the impact of frost on potato plant can be mitigated by calcium nutrition (Kang & Banga, 2013).

Our finding revealed that conventional N-P-K improved the growth and tuber yield; nevertheless, it was associated with impressive increase in nitrate content in tubers. These findings further support the idea of Pobereżny et al. (2015), who have suggested that the content of nitrates in potato tubers depends on the organic matter, soil fertilizer and cultivation. Nitrates are not harmful; however, when affected by digestive enzymes, they get transformed into nitrites, which, in turn, get changed into toxic N-nitro compounds. Proper N management is one of the most important factors required to obtain high yields of excellent quality potatoes. Nitrogen should normally be applied to achieve acceptable potato yields. Its efficiency may be substantially increased if it is applied as close as possible to actual plant growth requirements. Nitrogen in the form of conventional fertilizer is highly mobile and can readily move below the crop rooting zone. Therefore, it seems that supplying the nitrogen as nano-structured fertilizers can solve this problem. Nanofertilizers can improve the nutrient use efficiency through mechanisms such as targeted delivery, slow or controlled release. They could exactly release their active ingredients in responding to environmental triggers and biological demands (Solanki et al., 2015). Likewise, application of excessive amounts of conventional nitrogen fertilizer in potato production system can reduce the uptake of phosphorus, potassium, iron and almost all secondary and micronutrients like calcium and magnesium iron, manganese, zinc and copper.

Over the last few decades, consumer demand for healthier food and government policies focused on environmentally sustainable agricultural systems have both promoted a rapid expansion of organic farming (Rigby & Cáceres, 2001). Although the beneficial effect of MOG bio-fertilizer has been reported on some plants (Janmohammadi et al., 2014a, b), it seems that in semiarid regions application of bio-fertilizers alone will not be sufficient and simultaneous application of other nutrient resources is unavoidable. This finding corroborates the ideas of Rayan et al. (2012), who have suggested that in dry land West Asia–North Africa region bio-fertilizers are not so efficient. Lack of effectiveness of bio-fertilizers might be due to soil conditions in this region. The best bio-fertilizers are those containing multiple-stress tolerances to microorganisms and enzymes.

In this study, the best performance was observed for plants grown by complete nanofertilizer and nano-chelated Zn+B. Complete nanofertilizer contains appropriate and balanced rate of approximately all the elements needed for plant growth. Growing healthy potatoes for maximum yield and quality requires that all the essential nutrients be supplied at the right rate, the right time, and the right place. For potatoes, either deficient or excessive plant nutrition can reduce tuber bulking and quality. There is significant evidence showing that micronutrient deficiency is a critical nutritional problem in the cultivated areas of the semiarid zones where the climate is similar to that of the Mediterranean region (Çakmak, 2000; Kinaci & Kinaci, 2005). It seems that nanofertilizers by gradual and controlled release of micronutrients such as Zn, Fe, Mn and B, largely eliminate this deficiency. Nutrient source in nanofertilizers is a chelated structure and this is one of the reasons for their superiority compared to conventional inorganic salts. Formulation of the fertilizer also influences the application method and rate for micronutrients. Application rates can generally be lower, when the chelated form is applied compared to the inorganic salt (conventional fertilizer). The nutrient should also be available for a longer time interval after application and the chelated form of nanofertilizers resolves this problem. On the other hand, the utilization of nanofertilizers as fertigation increases its advantages. It has been revealed that pre-plant application of conventional fertilizers of Mn and Fe increase the possibility of oxidation to unavailable forms before plant uptake, particularly on the high pH, calcareous soils (Marschner, 2011).

Application of the complete nanofertilizer significantly decreased the number of the days to tuber initiation. Acceleration of the tuberization is very important in the short season environment, because in potato plants after tuberization a shift is rather typical from sink to source limitation. Supplying the nanofertilizer improves the synchronization of the source and sink activity and can lead to an increase in tuber yield. Current results showed that cultivar 'Agria' noticeably responded to the application of fertilizers and showed a better performance. This finding is in agreement with Tiemens-Hulscher et al. (2009) findings, which have showed that there are significant differences between 'Agria' and 'Spirit' for yield, leaf area index, period of maximum soil cover in response to nutrient management. The difference between the cultivars has resulted from the discrepancies in their genetic background. However, genetic variation contributes to differences in the root length, root density, efficiency of nutrient uptake, assimilation efficiency and net production efficiency.

CONCLUSIONS

The results of the investigation suggest that the most effective fertilizer to improve tuber yield and quality appears to be the mid-season application of complete nanofertilizer through the irrigation system. Although conventional N-P-K fertilizer improved the vegetative growth and tuber yield, it also tends to increase nitrate levels in the tubers. We found evidence that the impact of MOG enzymatic bio-fertilizer on tuber yield components in the investigated cold steppe was not so defined. Although Ca fertilizer treatments slightly alter yields, its consumption is a necessity for potato production system. We found genotypic variation for tuber yield, days to row closure, phenological development and tuber quality. Furthermore, in the current experiment, varieties differed in their strategies to maximize tuber production by fertilizer application. Taking into account this fact and the previous literature data showing the more beneficial effects of nanofertilizers compared to conventional and biological fertilizers, more studies should be carried out to determine the right rate and the right time of nano-fertilizer application, and the interactions between nanofertilizers and soil factor need to be more evaluated.

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BIOORGANINIŲ, TRADICINIŲ IR NANOTRĄŠŲ POVEIKIS BULVIŲ AUGIMUI, DERLIUI IR KOKYBEI ŠALTOJOJE STEPĖJE

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Santrauka

Vidutinio ir šalto klimato rajonuose bulvės (*Solanum tuberosum* L.) yra svarbus žemės ūkio augalas, gumbavaisių pavidalu tiekiantis daug vertingo maisto. Šaltoje Šiaurės vakarų Irano stepėje, siekiant sėkmingo bulvių derliaus, ypač svarbus yra augalų mitybos valdymas. Tyrimas buvo atliktas siekiant nustatyti skirtingų trąšų poveikį dviejų bulvių veislių (‘Agria’ ir ‘Spirit’) augimui, fenologiniam vystymuisi, derliui ir gumbavaisių kokybinėms charakteristikoms. Darbo tikslas buvo įvertinti nanotrąšų poveikį bulvėms. Tręšimo schema: T1 – kontrolė (nepaveikta trąšomis), T2 – NPK birios cheminės trąšos, T3 – MOG fermentinės biologinės trąšos, T4 – nanochelatinės kalcio, T5 – nanochelatinės cinko + boro ir T6 – pilnos sudėties nanochelatinės trąšos. Rezultatai parodė, kad nanochelatinės Zn+B, pilnos sudėties nanotrąšos ir birios cheminės NPK trąšos gerokai padidino augalų aukštį, stiebų skaičių, pagrindinio stiebo skersmenį ir lapų skaičių, o taip pat paspartino lapijos susivėrimą. Nanotrąšų panaudojimas pastebimai sumažino dienų skaičių iki gumbavaisių formavimosi pradžios. Įvairiapusiškai įvertinus gumbavaisių derlių parodyta, kad didžiausias vieno augalo gumbavaisių skaičius, vidutinis gumbavaisio svoris, vieno augalo visų gumbavaisių svoris ir derliaus indeksas buvo gautas panaudojus pilnos sudėties nanotrąšas. Skirtingų veislių palyginimas parodė, kad ‘Agria’ labiau nei ‘Spirit’ reaguoja į mitybinę terpę ir yra efektyvesnė. Augalų mitybos pokyčiai gerokai paveikė kokybines gumbavaisių savybes: didžiausias sausos medžiagos, krakmolo ir baltymų kiekis buvo gautas auginant augalus su pilnos sudėties nanotrąšomis. Šio eksperimento rezultatai patvirtino išvadą, kad efektyvių nanotrąšų pagalba subalansuota augalų mityba gali pagerinti bulvių produktyvumą. Dirvožemio derlingumo palaikymas tinkamai papildant reikalingomis, tinkamomis ir subalansuotomis mitybinėmis medžiagomis yra viena iš svarbiausių plano sudedamųjų dalių didinant bulvių produktyvumą šaltoje stepėje drėgnomis sąlygomis.