EVALUATION OF SOME NANO-FERTILIZERS, BIOFERTILIZERS AND CHEMICAL FERTILIZERS ON POTATO VARIETY SPRIT

Naser Sabaghnia* and Mohsen Janmohammadi

ABSTRACT: Potato is one of the most important crops grown worldwide. Current research was performed to identify the influences of various types of nano-fertilizers, biofertilizer and bulk fertilizers on tuber yield and some other traits of the Sprit potato variety. The trial was arranged in a randomized complete block design with three replicates with six nutritional treating; control, NPK in bulk form, MOG biofertilizer, nano-calcium, nano-zinc plus nano boron and complete nano-fertilizer and various twelve traits of potato were measured. They were number of leaves (NL), number day to initiation of tuberization (DIT), days to row closure (DRC), days to flowering (DF), number of tubers per plant (NTP), number of stems (NS), tuber yield (TY), mean tuber diameter (MTD), mean tuber weight (MTW), tuber weight per plant (TWP), dry matter content (DM) and starch total (ST). The factor analysis indicated that the first two factors, accounted 92% of variability and revealed that MOG biofertilizer was related to days to row closure and mean tuber diameter, while NPK produced the high numbers of stems. Also, no fertilizer usage (control) caused delay to initiation of tuberization, while complete nano-fertilizer had the higher amounts of the other traits like tuber yield. For obtaining the more number of leaves per plant, using complete nano-fertilizer following to nano-zinc plus nano boron is advise while for more numbers of tubers per plant, application of all tested nano-fertilizers is useful. The nano-fertilizers have beneficial ability in comparison to bulk-form and biologic fertilizers, thus nano-fertilizers especially the complete nano-fertilizer should be used to minimize the harmful influences of nutrient shortage and reaching targets of sustainable and low-input agricultural systems in production of potato under semi-arid environments.

KEYWORDS: Factor analysis, Cluster analysis, Sustainable agriculture, Nanoparticles

INTRODUCTION

The potato holds a significant position as a crucial food source for humanity. Its global production stands as the fourth highest, following cereals, amounting to 370 million tons whereas Iran, ranking twelfth globally and third in Asia (after China and India) (FAOSTAT, 2022). Despite Iran's notable standing as a major potato producer, managing the nutritional needs of this crop has proven to be a considerable challenge. A portion of nutrients accumulates in the topsoil and is subsequently extracted from the field during tuber harvesting (Job *et al.,* 2019). Several factors contribute to the low yields experienced in cold semiarid areas, including: the soil-plant system experiences high nutrient turnover, shortage of nutrients, a substantial nutrient shortage, and inefficiency in nutrients utilization further compounds the challenges (Mukhopadhyay *et al.,* 2021). The fields of cold semiarid areas exhibit low levels of potassium, phosphorus, iron, manganese, and zinc, so effective nutrient management emerges as a crucial strategy to enhance potato productivity in this region (Janmohammadi *et al.,* 2016).

The limited availability of local nutrient sources such as farmyard manure, compost, and biologically nitrogen fixation emphasizes the urgent requirement for the using fertilizers in a more efficiently system. Nanotechnology has emerged the development of a new fertilizers that boast enhanced nutrient utilization efficiency (Janmohammadi & Sabaghnia, 2023). Distinguished by unique

*Corresponding author; email: sabaghnia@yahoo.com
University of Maragheh, Agriculture College, Department of Plant Production and Genetics, Iran

physico-chemical properties, nano-structured fertilizers efficiently meet plant root demands in comparison to routine fertilizers in salt form. The gradual release of nutrients occurs through processes like ion exchange activities (Vejan *et al.,* 2021). Nano-fertilizers exhibit controlled release properties, ensuring a gradual supply of nutrients over time, which is achieved through processes like dissolution and ion exchange reactions. These fertilizers are formulated at the nanoscale, imparting unique physico-chemical properties which allow for efficient nutrient delivery to plant roots (Das *et al.,* 2021). Nano-fertilizers possess novel physico-chemical properties that set them apart from conventional fertilizers, which contribute to their ability to satisfy plant root demands more efficiently. The advent of nanotechnology in agriculture, particularly in the form of nano-fertilizers, has the potential to revolutionize traditional agricultural practices (Sabaghnia & Janmohammadi, 2023). Given the increased demand for nutrients in intensive cropping systems, nano-fertilizers offer a promising solution to meet these demands more effectively.

There is a growing focus on biological fertilizers like biofertilizer of MOG via various plants residues by enriching of different enzymes, nutrients and vitamins. This organic fertilizer offers significant advantages in generating fertile field and nutrients needs through the supply of natural elements (Shokouh *et al.,* 2018). However, there is limited information available regarding the impact of enzymatic fertilizers on potato production systems. In the context of potato production, there has been a positive response to conventional NPK fertilizer, especially in soils with poor texture. There are some nutrient deficiencies in potato production systems of Iran and in spite of some research on nutrient management in potato, there is limited information about the effects of biologic and nanoform fertilizers on potato tuber yield. Therefore, the target of the investigation is to explore the effect of biofertilizer, nano-fertilizers, and bulk fertilizers, in improving potato production.

MATERIAL AND METHODS

Materials

The research took place at the experiment farm in Sarab, Iran (37°56′N 47°32′E), with climate as cold semi-arid (BSk), indicative of semiarid conditions characterized by cold winters. Meteorological data spanning last decade for the region revealed min 2°C and max 17°C, with mean temperature 9/26°C day/night during growing season. The farm is identified as sandy loam, composed of 56% sand, 31% silt, and 13% clay. The soil analysis indicated a low organic matter (0.7%), N (0.07%), K (324 mg kg^{-1}), and P (11.3 mg kg^{-1}). For this study, the potato variety Spirit fall into the category of late-medium maturity. The field preparation was performed in November, followed by two disking sessions before seed planting. The seeds were sown at a depth of approximately 20 cm on May 10, 2014. Each plot covered an area of 36 m^2, comprising eight 6-meters rows, with of 75 cm between rows space and 25 cm within rows space. A surface irrigation is applied and plants received furrow irrigation. The employed design was a randomized complete block design with three replicates.

Treatments

The six nutritional treating, each representing a specific fertilizer treatment: Control (no fertilizer application), NPK (chemical nitrogen, potassium and phosphorus fertilizers in 20:10:5 rate), MOG (2 L ha^{-1} biofertilizer), Nano-Ca (2 kg ha^{-1} nano-calcium), Nano-Zn+B (2 kg ha^{-1} nano-zinc plus nano-boron), and Nano-C (1 kg ha^{-1} nano-complete fertilizer). The NPK was used at a rate of kg ha^{-1}; 100 kg ha^{-1} served as a pre-sowing and the remained amount was applied on the tuber initiation. The remined treatments were administered through fertigation, a method where nutrients are applied directly via irrigation on sowing and tuber initiation. Fertigation allows for the targeted application of nutrients directly to areas of root zone, meeting the crop's needs. The nano-nutritional treating sources were received from the SepehrParmis Co., Iran, which contain nanoparticles of CaO, ZnO and B_2O_3. Morphological characterization of the synthesized nanoparticles was conducted using a SEM (**Fig. 1**). The MOG enzymatic biofertilizer utilized in the study was provided from the Azarabadegan Co., Iran. Irrigation was administered on a weekly and to manage weeds, disease, and pests, cultivation practices and recommended amounts of agrochemicals commonly used in the Sarab region were applied.

Traits Measurement

The number of leaves (NL) was recorded in the tuber bulking. Some phenological traits like DIT, number day to initiation of tuberization (No.); DRC, days to row closure (No.) and DF, days to flowering (No.) were recoded. At the harvesting stage; NTP, number of tubers per plant (No.); NS, number of stems and TY, tuber yield (t ha^{-1}) were measured. Also, some yield components like MTD, mean tuber diameter (cm); MTW, mean tuber weight (g); TWP, tuber weight per plant (g) were registered. The dry matter content (DM, %) and the starch total (ST, %) from newly cut tubers was evaluated based on Noda *et al.* (2004).

Data analysis

The normal distribution of data was evaluated by the Ryan-Joiner goodness of fit test. The factor analysis was used for the decrease of associated traits to a small number of factors and the extracted factor loadings were rotated via varimax orthogonal method. For graphic presentation of traits' associations, the scores of first two factors were plotted each other. Also, for simultaneous presentation of treatments and traits in a single graph, a scatter plot that benefits both signs of treatments and traits which is known as biplot was generated to show data pattern. Finally, treatments and traits were clustered by their distance from each other using Squared Euclidean Distance and clustered by Ward's minimum variance procedure. The cutoff point for determine the number of final clusters was verified using λ statistic of MANOVA. The data analysis was performed via STATISTICA version 10.0 application.

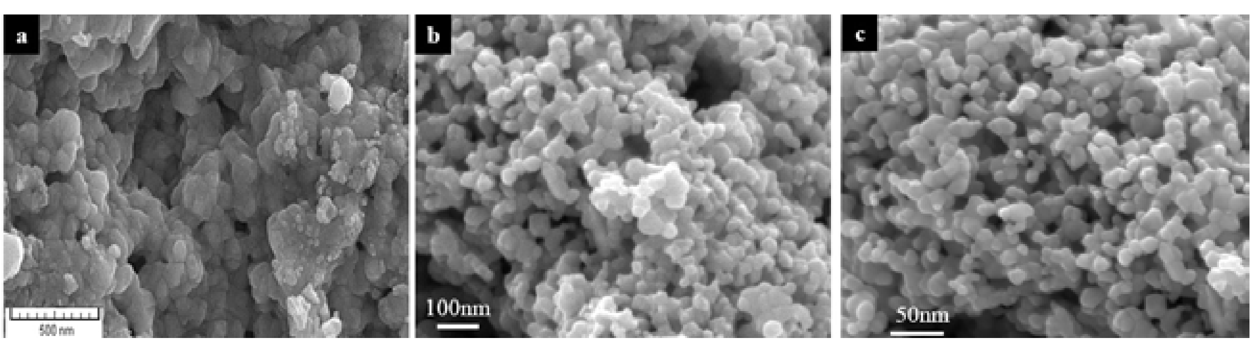

Fig. 1. SEM of nanoparticles which are used in nano-fertilizer treatments (a) CaO, (b) B_2O_3, and (c) ZnO.

RESULTS AND DISCUSSION

Phenotypic Traits

The first two factors explained 92% of the variability for the potato characteristics under various treating (**Fig. 2**), and the associations among them can be understand via the vectors of each characteristic to the center of the plot. The longitude of each line indicates the bias of association and the cosine of the lines' angle indicates the magnitude of association between the traits. The right lines' angle representative of no association (cos 90°=0), the opposite lines' angle representative of negative association (cos 180°= -1), and closed lines' angle representative of positive association (cos 0°= +1). From **Fig. 2**, DM, NTP, DF, NL, TWP, ST, TY and MTW were positively associated and showed relatively the same information about response of potato to the fertilizers. Most of the above traits were related to tuber properties like NTP, TWP, TY and ST, so improving one of them can increase the other related traits results in higher yield performance. Our findings were in good compromise with those mentioned by Zelalem *et al.* (2009), who reported tuber yield had positive association with tuber number and tuber weight and increasing of number and weight of tubers by appreciate fertilizer application cause to increase in tuber yield. Also, DRC and MTD were positively correlated and gave the similar information about the fertilizers impacts on potato (**Fig. 2**). Similarly, Blauer *et al.* (2013) reported that number of the days to row closure had positive association to mean tuber diameter. Regarding the right lines' angle of DIT and NS, there is not any significant association between these traits (**Fig. 2**). Also, NS did not show any significant association with DM, NTP, DF, NL, TWP, ST, TY and MTW due to relatively right angles (**Fig. 2**). Although, according to Knowles & Knowles (2006), number of stems has positive association with number of tubers and positive association with tuber size, but we could not identify such association. The DIT showed significant negative association with DM, NTP, DF, NL, TWP, ST, TY and MTW (**Fig. 2**), so early tuberization can be regarded for obtaining the high magnitudes of above traits specially yield and its components.

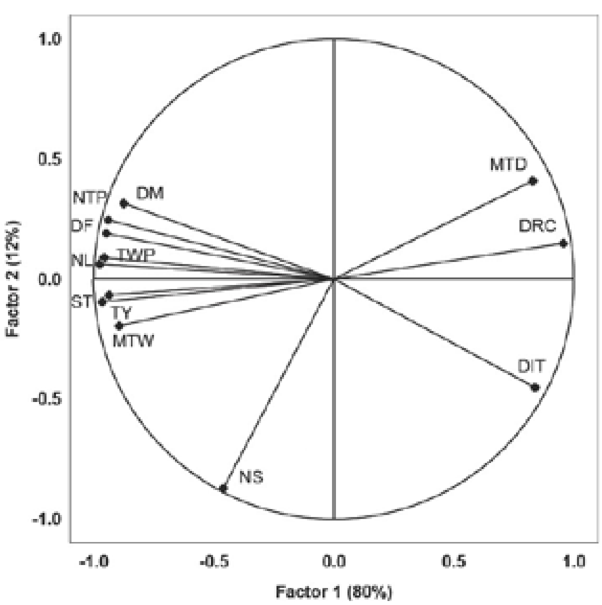

Fig. 2. Plot of first two factors showing the interrelationships among traits of potato.

Factorial Analysis

For simultaneous evaluation of treatments and traits, biplot, a scatter plot that benefits both signs of treatments and traits to show data pattern, was generated (**Fig. 3**). It indicates the scores of the individuals and variables of the principal components analysis in a single plot, so using this plot, fertilizers can be studied for their influence in measured traits. **Fig. 3** shows Nano-C treatment produced high amounts of DM, NTP, DF, NL, TWP, ST, TY and MTW traits in potato while MOG treatment caused high magnitudes of DRC and MTD traits (**Fig. 3**). So, it seems using complete nano-fertilizer can help potato grow better and produce more tuber yield. It has 11 important nutrients in it, consist on

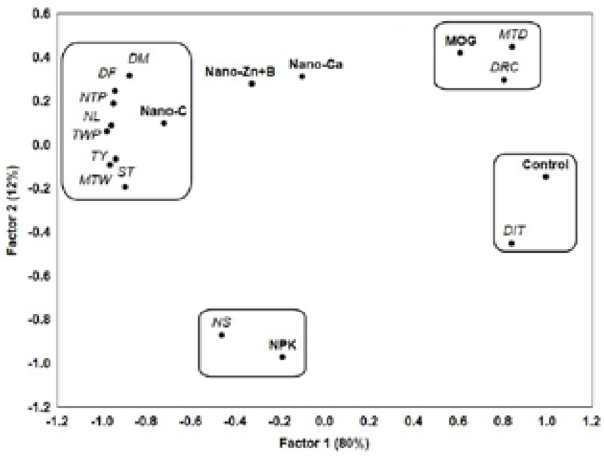

Fig. 3. Biplot of first two factors showing the interrelationships among fertilizer treatments and traits in potato.

nitrogen, phosphorus, potassium, iron, zinc, calcium, manganese, magnesium, copper, boron and molybdenum, that are all needed for potato growth and production. There is a lot of documented information about how potato responds to various nutrients especially about nitrogen, phosphorus and potassium, as well as some information about magnesium, zinc, and manganese (Zarzecka *et al.,* 2016; Baranowska *et al.,* 2017). But there is less information about how potato's response to iron and molybdenum as well as limited information reaction of potato to calcium, boron, and copper (Singh & Maiti, 2022). The reaction of potato to macronutrient fertilizers application changes with micronutrient fertilizer regarding to the field circumstances, variety type whereas most micronutrients like iron, zinc, manganese, copper and molybdenum influence potato yield performance (Lal *et al.,* 2020). Also, high DIT (day to initiation of tuberization) is seen in no-fertilizer treatment which emphasize the role of fertilization in early tuberization. The NPK treatment generated a greater number of stems (NS) while both other nano-fertilizers (zinc plus boron and calcium) were not the best treatment for any of characteristics in potato. It was shown that using fertilizers in nanoform enhanced chickpea to grow better and faster with aiding chickpea grow better and survive in the stress of climate change problem (Bala *et al.,* 2014).

Cluster Analysis

For verification discussed results of factor analysis, the cluster analysis as an agglomerative hierarchical tool was used to grouping traits (**Fig. 4**) as well as treatments (**Fig. 5**). The measured twelve traits of potato could be agglomerated into four clusters and this number of clusters was confirmed by λ statistic of Wilks which is obtained from MANOVA (λ=0.0051, p<0.01). In dendrogram of **Fig. 4**, Cluster-I consist on DM, NTP, DF, NL, TWP, ST, TY and MTW traits which is verified the obtained results of **Fig. 3**. Also, Cluster-II contains NS; Cluster-III consist on DIT and Cluster-IV contains DRC and MTD traits (**Fig. 4**). While it is expected that most results of factor analysis and clustering can be verified from each other, but some results were not consistent because the factor analysis usually describes less than 100% of the total variability. In this research, two first factors explained 92% of total variance and only 8% was remined for the other factors, but the overall results were in good agreement with

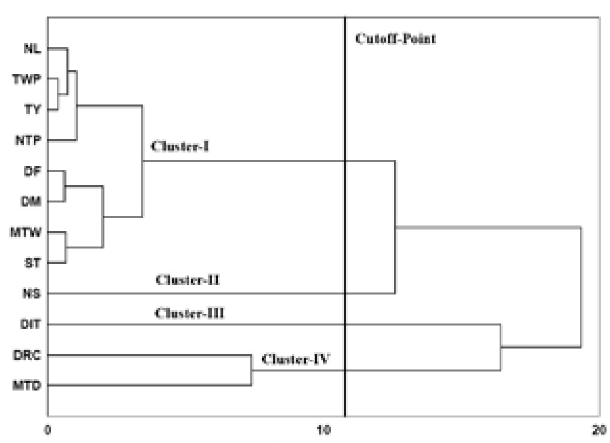

Fig. 4. Dendrogram of cluster analysis showing the grouping of measured traits of potato.

the clustering method which used 100% of observed variance. Finally, both methods give visual understanding on the data pattern, which is more practical and reliable than the univariate statistics. The six fertilizer treatments could be categorized into five clusters via confirmation of λ statistic of Wilks in MANOVA (λ=0.0064, p<0.01). In dendrogram of **Fig. 5**, Group-I was Control, Group-II was MOG, Group-III was NPK, Group-IV was two nano-fertilizers (Nano-Zn+B and Nano-Ca) and Group-V was Nano-C. Similar to traits, clustering of fertilizer treatments verified the results of factor analysis in **Fig. 3**.

Means of Clusters

The mean values of traits for fertilizer treatments were compared, and it can be indicated that Nano-C treatment was the best for DM, NTP, DF, NL, TWP, ST, TY and MTW traits while for NTP and NL traits, the other treatments can be regarded as the same with Nano-C. In other word, for obtaining the grater NL, we can use both Nano-C and Nano-Zn+B while for reach to the higher NTP, we can use Nano-C, Nano-Zn+B and Nano-Ca (Results are not shown). Such details are missed in multivariate analysis and they gave general grasp from data pattern. However, for obtaining the grater NS, using NPK is suitable while for reach to the higher DIT, DRC and MTD, no using any fertilizer is advised. However, using MOG treatment result is same results of Control treatment in MTD trait.

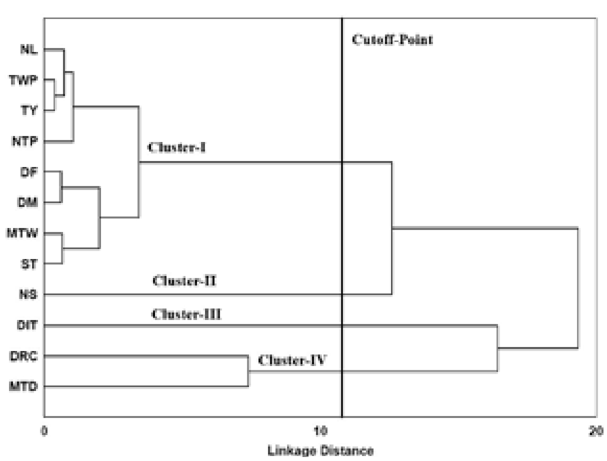

Fig. 5. Dendrogram of cluster analysis showing the grouping of fertilizer treatments.

Importance of Nano-fertilizers

The current investigation indicated that application of complete nano-fertilizer positively induced the potato growth in comparison to the other fertilizer, so the field soil has some nutritional deficiencies. The need of calcium is essential in saline fields of semiarid conditions for control the balance of potassium and sodium ions while using only calcium is less useful and the applying of Nano-C had the best impact on potato in comparison to Nano-Zn+B. This may be the result of synergy phenomena between the calcium and other macro and micro nutrients, like the positive effect of zinc on calcium for next uptake of P and K from the soil (Lambers *et al.,* 2019). Thus, calcium fertilizer is important in the potato and it has been shown that even if calcium application is sufficient, its deficiency can be compensated and calcium is allocated in tubers allocation of calcium within the plant (Naumann *et al.,* 2020).

Our results showed that Nano-C followed by NPK increased the tuber yield while application of chemical fertilizers like nitrogen is related with nitrate accumulation in potato tubers, so nitrogen management is one of the important issues needed to achieve good yield performance. Bulk N is very mobile element and can move the root area, so preparing the N as nano-form can eliminate the problem of bulk form. The nutrients use efficiency can be ameliorated by application of nano-fertilizers because they can deliver in exact targets in a slowly release mood. Also, nano-fertilizers can release in dynamic reaction to biologic and non-biologic factors. Using bulk form of macronutrients can decrease the uptake of micronutrients Fe, Ca, Mg, Mn, Zn and Cu.

Importance of Bio-fertilizers

Nowadays, healthier food market is increasing and governmental policy in many countries emphasized on sustainable agriculture, so organic food production is advised in many regions. Although the positive effects of most biofertilizers like MOG has been mentioned in literature (Janmohammadi *et al.,* 2014), but its application in this study could improve only DRC and MTD traits. However, it can be concluded that in cold semiarid areas using biofertilizers will not be adequate for crop growth, so using complementary sources of nutrients is essential. This result is in good agreement with the report of Helmy (2019), who have found the nonefficiency of biofertilizers in semiarid areas due to due to soil properties and humidity. In present investigation, the highest mean values were seen under complete nano-fertilizer which has balance adequate magnitudes of all required elements. Production of high yielding health potato needs all required elements in essential amount, and either deficiency or overdose can decrease tubes. There are several investigations for verification of nutrients' shortage as critical phenomena in the semiarid areas of the Mediterranean regions (Bastida *et al.,* 2019; Brahimi *et al.,* 2022), so nano-fertilizers by slowly release of nutrients can remove this problem. Rate of using for nano-fertilizers can be lower than bulk form because the chelated form is more efficient and available for more time, so their benefits are increase. Our findings indicated that Spirit variety reacted to the fertilizer treatments in compression to Control similar to Jafari-Jood *et al.* (2013), who indicated that this variety has the best performance with application of nitrogen, boron and manganese.

CONCLUSION

We found the best efficient fertilizer application to ameliorate yield performance and yield components of potato is using Nnao-C (complete nano-fertilizer) while the other nano-fertilizers (Nano-Zn+B; nano zinc plus nano boron and Nano-Ca; nano calcium) did not have any considerable impact on potato. Similarly, using chemical NPK fertilizer and MOG biofertilizer did not indicate any considerable effect on potato's traits. We found the useful influence of nano fertilizer compared to bulk and biologic fertilizers, but more investigations are required to evaluate the other aspects of nano-fertilizers, and determining their interactions with soil and other environmental factors.

CONFLICT OF INTEREST

The authors confirm that this manuscript has no conflict of interest.

ETHICAL STATEMENT

This article does not contain any studies with human participants or animals performed by any of the authors.

LITERATURE CITED

Bala, N., Dey, A., Das, S., Basu, R., Nandy, P. (2014). Effect of hydroxyapatite nanorod on chickpea (*Cicer arietinum*) plant growth and its possible use as nano-fertilizer. Iranian *Journal of Plant Physiology,* 4(3), 1061-1069.

Baranowska, A., Zarzecka, K., Gugała, M., Mystkowska, I. (2017). Contents of zinc, copper and manganese in potato tubers depending on the ways of application of the soil fertilizer UGmax. *Journal of Ecological Engineering,* 18(1), 99-106.

Bastida, F., Jehmlich, N., Martínez-Navarro, J., Bayona, V., García, C., Moreno, J.L. (2019). The effects of struvite and sewage sludge on plant yield and the microbial community of a semiarid Mediterranean soil. *Geoderma,* 337, 1051-1057.

Blauer, J.M., Knowles, L.O., Knowles, N.R. (2013). Manipulating stem number, tuber set and size distribution in specialty potato cultivars. *American Journal of Potato Research,* 90, 470-496.

Brahimi, S., Toumatia, O., Drevon, J.J., Zitouni, A., Lazali, M. (2022). Intercropping legumes and cereals increases resource use efficiency and crop productivity in low phosphorus soils under semi-arid Mediterranean conditions. *Agroecology and Sustainable Food Systems,* 46(10), 1482-1501.

Das, P., Gogoi, N., Sarkar, S., Patil, S.A., Hussain, N., Barman, S., ... Bhattacharya, S.S. (2021). Nano-based soil conditioners eradicate micronutrient deficiency: soil physicochemical properties and plant molecular responses. *Environmental Science: Nano,* 8(10), 2824-2843.

FAOSTAT, (2022). Food and Agricultural Organization of the United Nations. http://faostat.fao.org [last accessed 20.2.2024].

Helmy, A.M. (2019). Organic and biofertilization on crop production in semiarid regions. Sustainability of Agricultural Environment in Egypt: Part II. *Soil-Water-Plant Nexus,* 235-263.

Jafari-Jood, S., Shiranirad, A.H., Daneshian, J., Rokhzadi, A. (2013). Effects of nitrogen application and spraying of boron and manganese on growth traits of two potato cultivars. *International Journal of Bioscience,* 3(9), 298-303.

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. Botanica Lithuanica, 22(2), 133-144.

Janmohammadi, M., Zahed S.M., Ahadnezhad, A., Yousefzadeh, S., Sabaghnia, N. (2014). Influence of chemical and organic fertilizer on growth, yield and essential oil of dragonhead (*Dracocephalum moldavica* L.) plant. *Acta Agriculturae Slovenica,* 103(1), 73–81.

Janmohammadi, M., Sabaghnia, N. (2023). Effects of foliar spray of nano-micronutrient and growth regulators on safflower (*Carthamus tinctorius* L.) performance. *Plant Nano Biology,* 5, 100045.

Job, A.L., Soratto, R.P., Fernandes, A.M., Assunção, N.S., Fernandes, F.M., Yagi, R. (2019). Potassium fertilization for fresh market potato production in tropical soils. *Agronomy Journal,* 111(6), 3351-3362.

Knowles, N.R., Knowles, L.O. (2006). Manipulating stem number, tuber set, and yield relationships for northern- and southern-grown potato seed lots. *Crop Science,* 46, 284–296.

Lal, M.K., Kumar, A., Kumar, A., Jena, R., Raigond, P., Kumar, D., ... Singh, B. (2020). Minerals in potato. Potato: nutrition and food security, 87-112.

Lambers, H., Oliveira, R.S., Lambers, H., Oliveira, R.S. (2019). Mineral nutrition. *Plant Physiological Ecology,* 301-384.

Mukhopadhyay, R., Sarkar, B., Jat, H.S., Sharma, P.C., Bolan, N.S. (2021). Soil salinity under climate change: Challenges for sustainable agriculture and food security. *Journal of Environmental Management,* 280, 111736.

Naumann, M., Koch, M., Thiel, H., Gransee, A., Pawelzik, E. (2020). The importance of nutrient management for potato production part II: Plant nutrition and tuber quality. *Potato Research,* 63, 121-137.

Noda T., Tsuda S., Mori M., Takigawa S., Matsuura-Endo C., Saito K., Mangalika W.H.A., Suzuki Y., Yamauchi H. (2004). The effect of harvest dates on the starch properties of various potato cultivars. *Food Chemistry,* 86(1), 119–125.

Sabaghnia, N., Janmohammadi, M. (2023). Influence of some nano-fertilizers on chickpeas under three irrigation strategies. *Plant Nano Biology,* 100037.

Shokouh, A.R., Mehrafarin, A., Abdossi, V., Badi, H.N. (2018). Morpho-physiological and biochemical responses of bladder cherry (*Physalis alkekengi* L.) induced by multienzymatic biostimulant, IBA, and citric acid. *Folia Horticulturae,* 30(1), 79.

Singh, V.P., Maiti, R.K. (2022). A review on mineral nutrition of potato (*Solanum tuberosum* L.). *Farming and Management,* 7(2), 93-109.

Vejan, P., Khadiran, T., Abdullah, R., Ahmad, N. (2021). Controlled release fertilizer: A review on developments, applications and potential in agriculture. *Journal of Controlled Release,* 339, 321-334.

Zarzecka, K., Gugala, M., Baranowska, A., Dolega, H., Sikorska, A. (2016). Concentrations of copper, zinc and manganese in potato tubers under the influence of herbicides. *Journal of Elementology,* 21(1).

Zelalem, A., Tekalign, T., Nigussie, D. (2009). Response of potato (*Solanum tuberosum* L.) to different rates of nitrogen and phosphorus fertilization on vertisols at Debre Berhan, in the central highlands of Ethiopia. *African Journal of Plant Science,* 3(2), 016-024.

MS Received : February 20, 2024; Accepted : January 01, 2025