Effects of Nanofertilizers (Mg and Fe) and Planting Data on Productivity and Quality of Potato Tubers in Cold Desert Climate

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Abstract

Interaction among nanofertilizers supply and planting data may yield synergistic outputs that could influence nutrient use efficiency. To provide insight on this phenomenon, a double split plot based on RCBD with 3 replications were laid out to evaluate the effects spraying solution of nanoparticles magnesium (Mg) and iron (Fe); 0.0 %, 1.0 %, and 2.0 % at flowering and tuber filling stages) and planting data (October 5, 2019 and October 25, 2019) on bioelements, protein nitrogen, and nitrates contents of Sante potato tubers in a cold desert climate (Kerman, Iran). Considering the control group, the use of different dosages of nanofertilizers resulted in a significant increase in the bioelements and pH contents. Besides effects of area and time of planting, their two and three effects on tuber chlorophyll contents were reported significant. The highest protein and nitrogen portion of the potato tubers were related to spraying solution of Mg (1.0 %) + Fe (2.0 %) nanofertilizers. Increasing nanofertilizers supplementation reduced the nitrate content of potato tubers. The results indicated that the application of nanofertilizers significantly increased the carotenoid portion of the potato tubers. The interaction effects of nanofertilizers and planting data on chlorophyll index and calcium levels of potato tubers were completely significant. Our analysis corroborated that application nanofertilizers by spraying during flowering and tuber filling stages enhances potato productivity and quality by improving bioelements or resulting in favorable physiological outcomes and is recommended to farmers.

Keywords: Bioelements. Sante potato tubers. Nanofertilizers. Nitrate. Planting data. Iran.

Introduction

The world population continues to grow rapidly. Likewise, in recent years the growth rates of world agricultural production and crop yields have slowed. This has raised fears that the world may not be able to grow enough food and other commodities to ensure that future populations are adequately fed (FAO, 2015). To overcome this phenomenon and to achieve food security, the research has aimed to clarify the effect of fertilization with nanofertilizers on efficient agronomic production.

Nowadays, how nanofertilizers affect crop yields and physiological outcomes in crop species under varying area conditions remain particularly interesting questions to be addressed. Nanotechnology helps to improve agricultural production by increasing the efficiency of inputs and minimizing relevant losses.

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Also, nanomaterials as unique carriers of agrochemicals facilitate the site-targeted controlled delivery of nutrients with increased crop protection (SHANG *et al.,* 2019; TABARRAEI *et al.,* 2019).

Potato (Solanum tuberosum L.) is widely used for many food and industrial applications and is considered one of the most significant crops in moderate to cold regions (BIRCH *et al*., 2012). Some previous studies reported that the application of nanofertilizers plays a dominant role in the course of growth and development processes, shaping the volume and quality of potato yields (especially at flowering and tuber filling stages) (ZENGIN *et al.,* 2008; POBEREZNY; WSZELACZYNSKA, 2011; WANG *et al.,* 2020), which are safe to consumers' health.

Magnesium (Mg) and iron (Fe) are involved in metabolic processes and these are considered activators of important key enzymes (MENGAL; KIRKBY, 2001; EMAMI and OLFATI, 2017). Mg plays a part in energy transfer, in the absorbing of water by the way of organizing of osmotic pressure in the cell and cell growing (ZENGIN *et al.,* 2008). Generally, Mg fertilization improves crop yield in most production systems. The deficiency of which affects photosynthesis and carbohydrate partitioning in crops (NEJIA *et al.,* 2016) reduces the sustainability of agricultural production and development (JEROEN *et al.,* 2015). The conflicting response of yield and quality traits of potato to increasing Mg supply may serve as an example (GERENDAS; FUHRS, 2013). Also, it has been estimated that more than 60 % of the world's population is Fe dietary deficient (WHITE; BROADLEY, 2009). Fe is an essential element for crop yields. Fe deficiency is a common nutritional disorder in many crop plants, causing chlorosis, poor yields, and reduced nutritional quality (AL-JOBORI; AL-HADITHY, 2014).

Potato tubers have a low tendency to accumulate nitrates (WRONIAK, 2006; HMELAK *et al.,* 2014). Nitrates content in consumable plant organs is small and should not raise concern provided that the recommended fertilization and harvest terms of the original plants are observed (POBEREZNY *et al.,* 2014).

The present study aimed to determine the effects of nanofertilizers (Mg and Fe from spraying solution) and planting date on the bioelements compounds and the protein nitrogen and nitrates content in potato tubers in a local cold desert climate that higher nutritional demand.

Materials and methods

Soil analysis

Soil samples in 0-30 cm deep were collected, air-dried, crushed, and sieved through a 2 mm sieve, and analyzed for the physicochemical properties with Ostrowska, Gawliñski, and Szczubiaka methods (1991).

Table 1 – Some physicochemical properties of the soil used (2019): Electrical conductivity (EC) in ds m^{-1}, pH, percentage of silt, sand, and clay, soil texture, organic matter (OM) in percentage (%). Nitrogen (N), Phosphorus (P), Potassium (K), Iron (Fe), Magnesium (Mg) in g kg^{-1}. Kerman, Iran (2019).

Area	EC (ds m^{-1})	pH	Soil property (%)			*Soil texture*	OM (%)	Elements (g kg^{-1})				
			Silt	Clay	Sand			N	P	K	Fe	Mg
Zeh-e Kalut	1.8	7.7	29	33	38	Sandy soil	0.59	0.06	12	135	2.6	3.2
Islamabad	1.8	7.9	39	28	33	Sandy soil	0.59	0.06	13	140	2.2	3.1

Source: Central Agriculture Laboratory, Bam Islamic Azad University (2019).

A double split plot based on randomized complete block design with 3 replications were laid out to determine the effects of spraying a solution of nanoparticles Mg and Fe (0, 1, and 2 % at flowering and tuber filling stages) and planting data (October 5, 2019 and 25 October 25, 2019) on bioelements (Nitrogen (N), Potassium (K), Calcium (Ca), Sodium (Na), Phosphorus (P) and Iron (Fe)) and protein nitrogen and nitrates contents of Sante potato tubers in a cold desert climate (Kerman, Iran). Field experiments were carried out at the farms of Islamabad and Zeh-e Kalut Station (TABLE 2).

Table 2 – Geographical condition of areas (Kerman, Iran; 2019)

Area	Longitude	Latitude	Sea level
Zeh-e Kalut	27"14"51	56"35"56	22751
Islamabad	27"47"27	58"35"34	386

Source: Meteorological Organization, Tehran, Iran (2019)

The first spraying solution of nanoparticles was performed after the rows became compact and potato plants formed first floral buds, and the following treatments took place at 7-day intervals. Once the potato had completed their vegetative growth, potato tubers were collected and samples were fragmented, dried at 70 °C, and stored in sealed containers.

The concentration of bioelements was measured with a mix of Hydrochloric acid and Nitric acid solutions using standard methods derived from Westerman (1990). P concentration was measured with Spectrophotometric methods (RYAN; STEFAN; RASHID, 2001), and other elements were measured by atomic absorption methods (JONES, 2001).

Total and protein nitrogen contents were determined with Kjeldhal's methods. In brief, 24 % solution of trichloroacetic acid was used for titration of proteins to determine protein nitrogen. The content of nitrates was measured using the ion-selective methods (multi-purpose computer device CX-721, Elmetron).

Statistical analysis

Statistical analysis was performed using SPSS 17.0 software (2008). The results were expressed as mean ± standard deviation (SD) and performed with one-way analysis of variance (ANOVA) followed by Dunnett's new multiple range test and values of $p < 0.05$ were considered as statistically significant.

Results and discussion

The bioelements content in potato tubers was significantly affected by the experimental factors and their interaction (TABLES 3 and 4). The lowest concentration of bioelements was determined in the potato tubers harvested in the control group (in which only distilled water had been applied). Considering the control group, the use of different dosages of nanofertilizers resulted in a significant increase in the bioelements concentration (including K, Ca, and Fe) ($p<0.05$). In this study, the highest Fe and Ca contents were recorded in the potato tubers treated with Mg (1.0 %) + Fe (2.0 %) spraying solution.

Two and three effects of area and time of planting on tuber chlorophyll contents were reported significant (TABLES 5 and 6, $p<0.01$). Likewise, the interaction effects of nanofertilizers and planting data on chlorophyll index and Ca levels of potato tubers were completely significant ($p<0.05$).

Table 3 – Effects of nanoparticles and planting data on bioelements contents (%) of Sante potato tubers (Kerman, Iran; 2019): Nitrogen (N), Phosphorus (P), Potassium (K), Iron (Fe), Magnesium (Mg) in g kg^{-1}. Kerman, Iran (2019); $p<0.05$.

Treatments	K	Na	Ca	P	Fe
Area					
Zeh-e Kalut	1.9 [a]	1.64[a]	0.09 [a]	0.072[a]	33.35 [a]
Islamabad	1.84 [a]	1.50[a]	0.09 [a]	0.070[a]	33.22 [a]
Cultivar time					
5 October	1.88 [a]	1.98[a]	0.09 [a]	0.070[a]	33.17 [a]
25 October	1.85 [a]	1.93[a]	0.09 [a]	0.070[a]	33.4 [a]
Spraying solution					
Control	1.75 [b]	1.66[a]	0.07 [e]	0.056[a]	29.38 [c]
1 % Fe	1.84 [ab]	1.69[a]	0.08 [d]	0.058[a]	32.8 [b]
2 % Fe	2.01 [a]	1.74[a]	0.09 [c]	0.060[a]	32.6 [b]
1 % Mg	1.84 [ab]	1.71[a]	0.07 [b]	0.073[a]	32.18 [b]
2 % Mg	1.79 [b]	1.69[a]	0.09 [a]	0.077[a]	32.24 [b]
1 % Fe * 1 % Mg	1.9 [ab]	1.75[a]	0.10 [b]	0.091[a]	33.71 [b]
1 % Fe * 2 % Mg	1.76 [b]	1.72[a]	0.11 [a]	0.096[a]	32.6 [b]
2 % Fe * 1 % Mg	1.93 [ab]	1.70[a]	0.10 [a]	0.093[a]	37.03 [a]
2 % Fe * 2 % Mg	1.99 [a]	1.78[a]	0.11 [a]	0.099[a]	36.89 [a]

ns: non-significant; The letters (a-d) show a significant difference between groups

Source: Elaborated by the authors (2021).

Table 4 – Interaction between area * time cultivar * spraying solution applications on bioelements content of Sante potato tubers (Kerman, Iran; 2019);): Nitrogen (N), Phosphorus (P), Potassium (K), Iron (Fe), Magnesium (Mg) in g kg^{-1}. Kerman, Iran (2019); $p<0.05$.

Source of changes	Df	Average of squares				
		K	Na	Ca	P	Fe
Area	1	0.09 ns	2447/6 ns	0.000003 ns	0.004 ns	0.46 ns
Original error	4	0.33	6619/4	0.003	0.003	50.42
Time cultivar	1	0.03 ns	120.05 ns	0.0002 *	0.001 ns	1.43 ns
Area * Time cultivar	1	0.001 ns	220.6 ns	0.00001 ns	0.004 ns	1.64 ns
Minor error	4	0.02	2970.6	0.0004	0.002	9.36
Spraying solution	8	0.11 **	1121/1 ns	0.002 **	0.005 ns	68.63 **
Area * Spraying solution	8	0.01 ns	1092/7 ns	0.0001 *	0.0007 ns	9.1 ns
Time cultivar * Spraying solution	8	0.01 ns	773.5 ns	0.0001 *	0.001 ns	19.25 ns
Area * Time cultivar * Spraying solution	8	0.01 ns	741.2 ns	0.00005 ns	0.003 ns	6.31 ns
Minor error error	64	0.03	940.4	0.00005	0.002	9.9
CV%	-	10.01	18.5	8.2	17.4	9.4

* : $p<0.05$, ** : $p<0.01$, ns : non-significant

Source: Elaborated by the authors (2021).

Table 5 – Effects of nanoparticles and planting data on chlorophyll index and photosynthetic pigments (mg g^{-1} fresh leaves) of Sante potato tubers (Kerman, Iran; 2019); $p<0.05$.

Treatments	Chlorophyll index	Chlorophyll a	Chlorophyll b
Area			
Zeh-e Kalut	42.9 ^{a}	30.28 ^{a}	20.4 ^{a}
Islamabad	40.9 ^{a}	27.3 ^{a}	17.85 ^{a}
Cultivar time			
5 October	42.36 ^{a}	29.33 ^{a}	19.79 ^{a}
25 October	41.44 ^{b}	28.2 ^{b}	18.46 ^{a}
Spraying solution			
Control	35.93 ^{g}	22.24 ^{e}	13.42 ^{d}
1 % Fe	39.4 ^{e}	25.7 ^{d}	15 ^{d}
2 % Fe	41.87 ^{d}	28.18 ^{c}	17.64 ^{c}
1 % Mg	38.04 ^{f}	24.35 ^{d}	14.5 ^{d}
2 % Mg	41.11 ^{d}	27.61 ^{c}	17.86 ^{c}
1 % Fe * 1 % Mg	43.85 ^{c}	30.35 ^{b}	20.85 ^{b}
1 % Fe * 2 % Mg	41.76 ^{d}	34.1 ^{a}	26.47 ^{a}
2 % Fe * 1 % Mg	46.51 ^{b}	32.66 ^{a}	23.16 ^{b}
2 % Fe * 2 % Mg	48.51 ^{a}	34.08 ^{a}	23.2 ^{b}

ns: non-significant; The letters (a-d) show a significant difference between groups

Source: Elaborated by the authors (2021).

Table 6 – Interaction between area * time cultivar * spraying solution application on chlorophyll index and photosynthetic pigments of Sante potato tubers (Kerman, Iran; 2019).

Source of Changes	Df	Average of squares			
		Chlorophyll index	Chlorophyll a	Chlorophyll b	Carotenoid
Area	1	108.6 **	234.9 **	0.78 ^{ns}	176.5 **
Original error	4	284.84	270.6	4.16	300.5
Time cultivar	1	22.87 **	29.14 *	0.82 ^{ns}	47.9 *
Area * Time cultivar	1	1.84 ^{ns}	0.26 ^{ns}	1.04 ^{ns}	0.52 ^{ns}
Minor error	4	2.38	2.17	24.03	6.79
Spraying solution	8	189.42 *	221.3 **	6.73 ^{ns}	246.8 **
Area* Spraying solution	8	7.89 **	11.36 *	3.47 ^{ns}	9.19 ^{ns}
Time cultivar * Spraying solution	8	10.23 **	15.24 **	3.45 ^{ns}	13.68 ^{ns}
Area * Time cultivar * Spraying solution	8	11.72 **	7.09 ^{ns}	5.48 ^{ns}	6.1 ^{ns}
Minor error	64	2.16	5.08	4.5	8.84
CV%	-	3.51	7.82	21.6	15.54

ns: non-significant; The letters (a-d) show a significant difference between groups.

Source: Elaborated by the authors (2021).

In this study, the dosage of nanofertilizers (0.0 %, 1.0 %, and 2.0 % at flowering and tuber filling stages) used significantly decreased the content of nitrates in potato tubers (TABLES 7 and 8, $p<0.05$). The highest decrease in nitrate content was obtained at the 2.0 % and 1.0 % nanofertilizers treatments. These groups were divided into a single statistical group and showed difference with other groups. Increasing nanofertilizers supplementation amplification of pH contents of potato tubers (p>0.05). The results indicated that the application of nanofertilizers significantly increased the carotenoid portion of the potato tubers (p<0.05).

Table 7 – Effects of nanoparticles and planting data on Fe (mg/kg), nitrogen (%), nitrates (mg/kg) and pH of Sante potato tubers (Kerman, Iran; 2019); p<0.05

Treatments	Protein	Nitrogen	Nitrates	pH
Area				
Zeh-e Kalut	210.7 [a]	0.7 [a]	210.7 [a]	4.39 [a]
Islamabad	203.11 [a]	0.67 [a]	203.11 [a]	3.84 [a]
Cultivar time				
5 October	201.96 [a]	0.69 [a]	201.96 [a]	4.15 [a]
25 October	211.85 [a]	0.68 [a]	211.85 [a]	4.07 [a]
Spraying solution				
Control	237.5 [a]	0.55 [f]	237.5 [a]	3.48 [g]
1 % Fe	224.2 [ab]	0.61 [de]	224.2 [ab]	3.83 [ef]
2 % Fe	207.3 [bcd]	0.66 [cd]	207.3 [bcd]	4.06 [de]
1 % Mg	206.7 [bcd]	0.59 [ef]	206.7 [bcd]	3.69 [fg]
2 % Mg	194.9 [cd]	0.74 [b]	194.9 [cd]	4.43 [bc]
1 % Fe * 1 % Mg	204.1 [bcd]	0.71 [bc]	204.1 [bcd]	4.21 [cd]
1 % Fe * 2 % Mg	213.7 [abc]	0.67 [cd]	213.7 [abc]	4.07 [de]
2 % Fe * 1 % Mg	187.34 [cd]	0.84 [a]	187.34 [cd]	4.52 [ab]
2 % Fe * 2 % Mg	186.3 [d]	0.8 [a]	186.3 [d]	4.72 [a]

ns: non-significant; The letters (a-d) show a significant difference between groups

Source: Elaborated by the authors (2021).

Table 8 – Interaction between area * time cultivar * spraying solution application on nitrogen, nitrates and pH contents of Sante potato tubers (Kerman, Iran; 2019).

Source of Changes			Average of squares		
	Df	**Protein**	**Nitrogen**	**Nitrates**	**pH**
Area	1	1.06 *	0.02 *	1557.3 [ns]	8.16 **
Original error	4	2.28	0.05	12631.7	5.66
Time cultivar	1	0.1 [ns]	0.001 [ns]	2640.4 *	0.16 [ns]
Area * Time cultivar	1	0.06 [ns]	0.001 [ns]	3.68 [ns]	0.02 [ns]
Minor error	4	0.09	0.002	2734.5	0.01
Spraying solution	8	4.35 **	0.11 **	3370.1 **	1.95 **
Area * Spraying solution	8	0.13 [ns]	0.003 [ns]	992.9 [ns]	0.09 [ns]
Time cultivar * Spraying solution	8	0.16 [ns]	0.004 [ns]	379.22 [ns]	0.11 [ns]
Area * Time cultivar * Spraying solution	8	0.19 [ns]	0.005 [ns]	457.9 [ns]	0.09 [ns]
Minor error	64	0.17	0.004	829.7	0.08
CV%	-	9.62	9.68	13.9	7.26

ns: non-significant; The letters (a-d) show a significant difference between groups.

Source: Elaborated by the authors (2021).

As reported, due to the metabolic processes role of Mg and Fe elements in the synthesis of proteins and activators of important enzymes (MENGEL; KIRKBY, 2001), thus utilization of nanofertilizers containing these elements could increase potato productivity and quality. Our findings are well coordinated by the current literature on nanofertilizers productivity, indicating that these nanofertilizers (Mg and Fe) can cause an improvement of the nutritional values of the Sante cultivar. In this study, the management of nanofertilizers is a critical component of potato tubers production systems as potato has a relatively high Mg and Fe requirement and inefficiently uses soil these elements in the cold desert climate of Iran. It is the main component of chlorophyll and activates metabolic reactions of plants (GERENDAS; FUHRS, 2013). Also, the application of nanofertilizers resulted in higher concentrations of bioelements including N, K, Ca, Na, P, and Fe ions in the harvested potato tubers improving their nutritional values. In this study, the bioelements contents of the potato tubers were appropriate. This improvement was obtained because of the positive effect of nanofertilizers on bioelements compounds and the protein nitrogen and nitrates portions of potato tubers. In agreement with the present result, some authors observed application of micronutrients mixture (like K, Fe, Mg, Cu, Zn) during flowering improved the nutritional values of potato tubers (ZENGIN *et al.,* 2008; AL-JOBORI; AL-HADITHY 2014). The nutritional quality of potato tubers is cultivar-specific and depends on climate-soil conditions and agro-technical practices, as well as the conditions during long-term storage (WSZELACZYNSKA *et al.,* 2020). Kohnaward, Jalilian, and Pirzad (2012) showed that micronutrients increase photosynthesis rate and improve leaf area duration. Also, adequate micronutrients are essential for optimizing tuber yield, solids content, nutritional quality, and resistance to some diseases (ROSEN *et al.* 2014).

Zenggin *et al.* (2008) reported that every two years in all locations effects of fertilizers used on tuber yields, tuber size distribution, dry matter content of tuber and K, Mg, and S contents of leaves were significantly changed depending on the locations. Similarly, based on our results the chemical composition of potato tubers, affecting their quality can be improved by the location (Islamabad and Zeh-e Kalut) both during flowering and tuber filling stages (TABLES 3 and 4).

Results of this research revealed that the highest protein and nitrogen portions of the potato tubers were related to spraying solution of nanofertilizers in Zeh-e Kalut area (October 25, 2019). The rate of crop growth is modified by nitrogen application, and its use may depend to a large extent on the supply of Mg and sulfur to plants (POBEREZNY; WSZELACZYNSKA, 2011). This is slightly different from the results reported by Rogozinska *et al.* (2005), who discovered that, besides nitrogen fertilization, applications of larger quantities of Mg also led to lowered total nitrogen contents in potato tubers. Also, Ciecko, Zolnowski, and Mierzejwska (2010) reported that Mg nutrition, either as foliar or soil treatments, did not have any significant influence on the content of total and protein nitrogen in potato tubers. As reported in the Fertilizer Handbook (EAKIN, 1972), more elements supplied by fertilizers may result in different fertilizer applications on the tuber yield and quality. This diversity may be due to the differences in production systems, potato cultivars, locations, and kinds of mineral fertilization (MENGEL; KIRKBY, 2001).

The results suggested to over-accumulation of nitrates substances in Sante potato tubers is depended on the area conditions and agro-technical practices like spraying solution of nanoparticles including Mg and Fe. Application of nanofertilizers sprayed over leaves tended to lower the concentration of nitrates in potato tubers. Also, the experiment found that the content of nitrates in potato tubers ranged from 237 (control) to 186 mg kg^{-1} (2.0 % Fe + 2.0 % Mg). Similar results were stated by Ierna (2009) and Rytel (2012), who found that the content of nitrates is especially affected by fertilization of the mineral and cultivar. On contrary, when nanofertilizers were introduced to soil, they raised the content of nitrates in potato tubers (CIECKO; ZOLNOWSKI; MIERZEJWSKA*,* 2010).

Conclusions

Our analysis corroborated that application nanofertilizers by spraying during flowering and tuber filling stages enhances potato productivity, decreases nitrate contents and quality by improving bioelements or resulting in favorable physiological outcomes, and is recommended to farmers.

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Efeitos de Nanofertilizantes (Mg e Fe) e Dados de Plantio na Produtividade e Qualidade de Tubérculos de Batata em Clima de Deserto Frio

Resumo

A interação entre o suprimento de nanofertilizantes e os dados de plantio podem gerar resultados sinérgicos que podem influenciar a eficiência do uso de nutrientes. Para fornecer uma visão sobre este fenômeno, um gráfico de divisão duplo baseado em Delineamento de Blocos Completos Casualizados (RCBD), com 3 repetições, foi estabelecido para avaliar os efeitos da solução de pulverização de nanopartículas de magnésio (Mg) e ferro (Fe); 0,0 %, 1,0 % e 2,0 % nas fases de floração e enchimento de tubérculos e dados de plantio (5 de outubro de 2019 e 25 de outubro de 2019) em bioelementos, nitrogênio proteico e conteúdo de nitratos de tubérculos de batata Sante em um clima desértico frio (Kerman , Irã). Considerando o grupo controle, o uso de diferentes dosagens de nanofertilizantes resultou em aumento significativo nos teores de bioelementos e pH. Além dos efeitos de área e época de plantio, seus dois e três efeitos sobre os teores de clorofila nos tubérculos foram relatados como significativos. A maior porção de proteína e nitrogênio dos tubérculos de batata foi relacionada à pulverização de solução de nanofertilizantes de Mg (1,0 %) + Fe (2,0 %). O aumento da suplementação de nanofertilizantes reduziu o teor de nitrato dos tubérculos de batata. Os resultados indicaram que a aplicação de nanofertilizantes aumentou significativamente a porção carotenóide dos tubérculos de batata. Os efeitos de interação de nanofertilizantes e dados de plantio sobre o índice de clorofila e os níveis de cálcio dos tubérculos de batata foram completamente significativos. Nossa análise corroborou que a aplicação de nanofertilizantes por pulverização durante os estágios de floração e enchimento de tubérculos aumenta a produtividade e a qualidade da batata, melhorando os bioelementos ou resultando em resultados fisiológicos favoráveis, sendo recomendada para agricultores.
Palavras-chave: Bioelementos. Tubérculos de batata Sante. Nanofertilizantes. Nitrato. Dados de plantio. Iran.

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