10.17951/c.2016.71.1.57

ANNALES
UNIVERSITATIS MARIAE CURIE-SKŁODOWSKA
LUBLIN – POLONIA

VOL. LXX, 2 SECTIO C 2015

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Responses of potato (*Solanum tuberosum* L.) var. Agria to application of bio, bulk and nano-fertilizers

ABSTRACT

Potato (*Solanum tuberosum* L.), is one of the important crops grown in the world which is important as food and nutritional security option at the global level. The experiment was laid out as randomized complete block design in three replications with six nutrition treatments consisted of control, NPK, Mog bio-fertilizer, Nano-Ca, Nano-Zn+B and Nano-Com. The treatment-by-trait (TT) biplot analysis was applied to data to examine its usefulness in visualizing relationships among trait as well as treatments and showed that the first two principal components accounted 80% of total variation. Tuber yield, mean tuber diameter, mean tuber weight, tuber weight per plant, starch content of initial fresh, number of tubers per plant, number of leaves and dry matter content were in the same sector, with Nano-Com fertilizer treatment as the best treatment. Based on ideal entry biplot, the Nano-Com treatment is closest to the position of an ideal treatment and it is ranked the highest in term of morphological performance. Also, the best fertilizer treatment for obtaining of high tuber yield could be found as Nano-Com treatment following Nano-Zn+B treatment. The studied nano-fertilizers showed a good potential compared to the commercial bulk and bio fertilizers.

Keywords: nano-fertilizer, nanotechnology, micronutrients, macronutrients

INTRODUCTION

The potato (*Solanum tuberosum* L.) is one of the important field crops in the world and in Iran, its average annual consumption of 50 kg tubers *per capita* in 2010–2015 (SCI, 2015), and a cropping area of 190,000 ha representing 0.2% of total agricultural land in 2013 and the average potato yield increased substantially to 29.3 t ha^{-1} (FAOSTAT, 2013). It is a very important crop in the Mediterranean region, occupying an overall cultivated area of about one million ha and producing 18 million tonnes of tubers (FAOSTAT, 2013), and in several countries of this region, potatoes are not grown in the usual cycle owing to high temperatures and considerable demand for irrigation water (11). The increase in potato yield was substantially lower in Iran than in New Zealand, United States and Belgium (maximum global yield with average 46 t ha^{-1}) due to the lower macro and micro nutrients application rates (17). Potato yield is affected by nutrient availability, thus, several researches on fertilizers' application have received much attention worldwide (9, 10).

Three main macronutrients (NPK) are the predominant fertilizers which have been used to improve yield and quality of potato where soil supplies are limited (28). Phosphorus application increases the tuber yield (21) and tuber number (14) while inadequate nitrogen application leads to poor potato yield (6, 25, 32). Also, previous studies have shown that most crops like potato are responding to K fertilizer in the suitable levels of available nitrogen (1). The crop growth is greatly influenced by a wide range of nutrients while zinc is an essential micronutrient to increase the production potential and is taken up by the crops in ionic form zinc fertilizer application. Boron is an essential micronutrient and its insufficient quantity causes the decrease of yield performance (23). Calcium fertilization is frequently confused because its role in crop nutrition is often eclipsed by interest in macronutrients while it is a multifunctional nutrient which in playing an important role in plant physiology which in solvable form can influence its uptake and availability (7). However, commercial application of the above mentioned micronutrients (Zn, Ca, B) must deal with the difficulty of equally distributing small amounts of fertilizer and recently, nano fertilization with micronutrients is successful because deliverable amounts are enough to meet most crops requirements (22).

Nanotechnology is a new opportunity for improving fertilizers' application, due to the increased surface area off nano-materials which can lead to increased reactivity and faster dissolution kinetics (19). Micronutrients have been incorporated into different nanoparticles for a high impact to improve their uptake like zinc and calcium. They are micronutrients that can be effectively provided to humans via micronutrient fertilization of crops (4). Some investigations have studied the use of ZnO nanoparticles on some crops such as cucumber (33), peanuts (20), sweet basil (8), cabbage, cauliflower, tomato (26), and chickpea (19). In another study, foliar application of ZnO led to enhanced yield (8) while another study examining some crops noted that nano-ZnO increased seed germination while a bulk form of ZnO used for comparison had a negative impact on germination (26). This study aimed to assess the general behavior of one potato variety (Agria Potatoes were developed by Kartoffelzucht Bohm in Luneburg, Germany) under different bulk, bio, and nano fertilizers. The objectives of this research were to determine the optimal fertilizer treatment and to identify the traits that best responded to fertilizers. Thus, the following assumption was made: the use of nano-fertilizer increases crop yields.

MATERIALS AND METHODS

The experiment was carried out in northwest of Iran during 2014–2015 growing season. Its climate is considered to be a local steppe climate and has mean annual minimum and maximum temperatures of 2.2°C and 17.1°C, respectively. The soil type of the trial field was silty clay loam, consists of 46% silt, 36% clay and 18% sand, with pH of 7.8 and EC 1.3 dS m^{-1} in the topsoil. Chemical analysis of field soil indicated 0.66% organic matter, 0.07 % nitrogen, 324 mg kg^{-1} available potassium, and 11.3 mg kg^{-1} available phosphorus. Seed tubers of variety Agria were machine cut and allowed to suberize for at least one week prior to planting. 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 irrigation system was used for water supply during the growing season.

The experiment was laid out as randomized complete block design in three replications with six nutrition treatments. Fertilizer treatments consisted of control (no fertilizer application), NPK bulk chemical fertilizer, Mog enzymatic bio-fertilizer (2 lit ha^{-1}), Nano-Ca; nano-chelated calcium (2 kg ha^{-1}), Nano-Zn+B: nano-chelated zinc + boron (1 kg ha^{-1}) and Nano-Com: complete nano-chelated fertilizer (1 kg ha^{-1}). The NPK fertilizer (20:10:5) applied at rate of 200 kg ha^{-1}in two split applications, i.e. half as pre-planted half as post-emergence side dress application during tuber initiation stage. Other fertilizers were applied through irrigation during planting and tuber initiation stages. Nano chelated fertilizers were obtained from the Sepehr Parmis Company, Iran, which contained Calcium oxide, zinc oxide and boron trioxide nanoparticles and they had been characterized morphologically by a scanning electron microscope (Fig. 1). The number of leaves per plant (NL) was evaluated at tuber bulking stage. At the end of the growth season, when majority of plants were

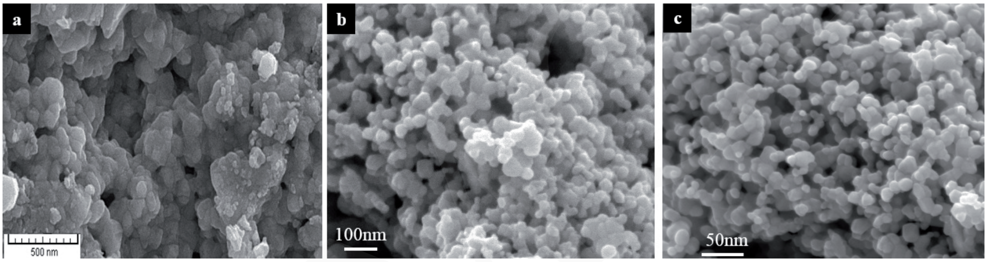

Fig.1. Scanning Electron Microscope (SEM) image of (a) calcium oxide, (b) boron trioxide, and (c) zinc oxide used in nano-fertilizers composition

supposed to ripe, MTD, mean tuber diameter; MTW, mean tuber weight (g); TWP, tuber weight per plant (g); TY, tuber yield (t ha^{-1}); NTP, number of tubers per plant; DIT, day to initiation of tuberization; DRC, number of the days to row closure; DF, number of days to flowering; DM, dry matter content (%); and NS, number of stems were measured. The percent of starch content (ST,) of initial fresh was measured according to Noda et al. (18). The two-way matrix of treatment × trait (TT) biplot model (31) is generated via this equation by GGEbiplot software (29):

$$\frac{\theta_{ij} - \phi_j}{\sigma_j} = \sum_{n=1}^{2} \lambda_n \psi_{in} \varphi_{jn} + \varepsilon_j = \sum_{n=1}^{2} \psi_{in}^{*} \varphi_{jn}^{*} + \varepsilon_j$$

where θ_{ij} is the mean value of treatment i for trait j, ϕ_j is the mean value of all treatments in trait j, σ_{ij} is the standard deviation of trait j among the treatment means, λ_n is the singular value for principal component n (PCn), ψ_{in} and φ_{jn} are scores for treatment i and trait j on PCn, respectively, and ε_{ij} is the residual associated with treatment i in trait j. TT biplot analysis was performed using GGEbiplot software (29).

RESULTS AND DISCUSSION

The principle components analysis (PC1 and PC2) based on TT biplot method together explained 80% of the observed variation for the measured traits of potato across fertilizer treatments (Fig. 2). Biplots effectively identify TT interaction and which-won-where information (30) and using this method, fertilizer treatments can be evaluated for their performance in individual traits and across traits. Figure 2 indicates which fertilizer treatment gave the highest potato tuber yield. Tuber yield (TY), mean tuber diameter (MTD), mean tuber weight (MTW), tuber weight per plant (TWP), starch content of initial fresh (ST), number of tubers per plant (NTP), number of leaves (NL), and dry matter content (DM) were in the same sector, with Nano-Com fertilizer treatment as the best treatment (Fig. 2). Day to initiation of tuberization (DIT) and number of the days to row closure (DRC) were in the same sector, with Control as the best fertilizer treatment while the number of days to flowering (DF) and number of stems (NS) were in the same sector, with NPK as the best fertilizer treatment (Fig. 2). The other vertex fertilizer treatment (Nano-Zn+B) and its related treatments (Nano-Ca and Mog treatments) were not the best in any of the measured traits (Fig. 2). Therefore, for obtaining the best performance in the measured traits like tuber yield as well as yield components, application of Nano-Com treatment (contains 5% N, 3% P, 3% K, 4.5% Fe, 8% Zn, 6% Ca, 6% Mg, 0.7% Mn, 0.65% Cu, 0.1% B, and 0.65% Mo) would be useful, it demonstrated that all of above nutrients are essential for potato production.

Figure 3 is a vector view of TT biplot showing the interrelationship among all the traits measured using the lines connecting each trait marker to the origin of the biplot or the trait vector. From Figure 3, TY, MTW, TWP, ST, NTP, NL and DM were highly positively correlated and it shows they all gave similar information about variability among the treatments. These results were in agreement

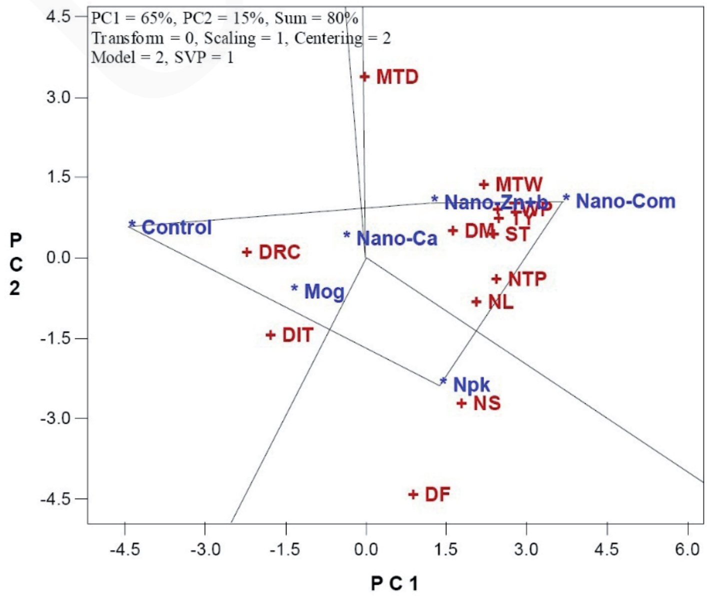

Fig. 2. Polygon-view of treatment by trait (TT)biplot showing which nano, bio and bulk fertilizer treatment had the highest values for which traits of potato. For traits' abbreviations, refer to the text

with those reported by Maity and Chattarzee (15), Bhagowati and Saikia (5) and Tuncturk and ÇiftÇi (27). Also, Day to initiation of tuberization (DIT) and number of the days to row closure (DRC) were positively correlated (Fig. 3) and the taking any one of the two will give the same information with less effort. These results were in agreement with those reported by Asghari-Zakaria et al. (2). Traits TY, MTW, TWP, ST, NTP, NL and DM had approximately negative correlation with day to initiation of tuberization (DIT) and the number of days to row closure (DRC). Also, mean tuber diameter (MTD) had approximately negative correlation with the number of days to flowering (DF). A near zero correlation between DF with DRC and DIT, between MTD with DRC and DIT, and between DF with TY, MTW, TWP, ST, NTP, NL and DM, and MTD with TY, MTW, TWP, ST, NTP, NL and DM as indicated by the near perpendicular vectors (Fig. 3).

Ideal test trait effectively discriminate treatments and represent their grouping (31) which can be classified into two types: (i) traits with high treatment discrimination and representative of their grouping that are close to ideal and should be chosen for superior treatment selection, when few treatment can be evaluated due to budget constraints as NTP following NL, SL, TY, TWP, MTW and DM traits (i); and traits with low treatments discrimination that should not be selected as test trait as DRC and DIT (Fig. 4). In this analysis, since there was TT interaction, treatments changed rank for agronomic traits, and single trait was ideal for

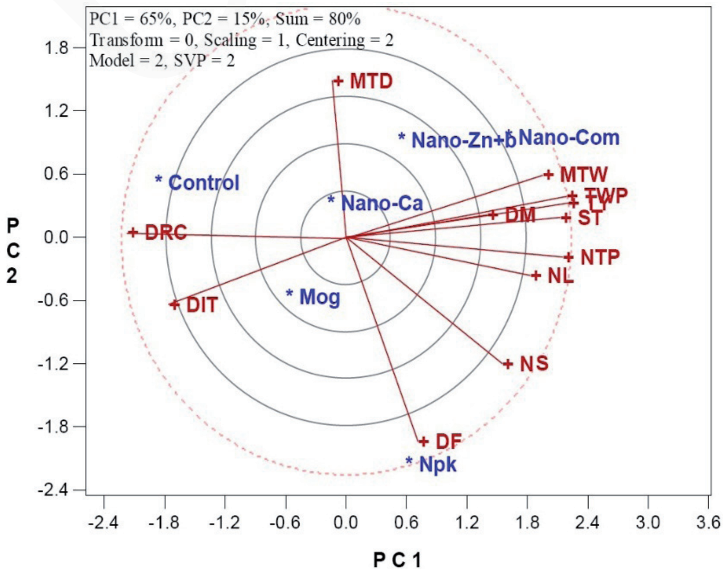

Fig. 3. Vector view of treatment by trait (TT)biplot showing the interrelationship among measured traits of potato under different nano, bio and bulk fertilizer treatments. For traits' abbreviations, refer to the text

yield and its components (NTP, NL, SL, TY, TWP, MTW and DM). But, if we are only interested in tuber yield, DRC, DIT, MTD, NS and DF could be dropped, because they did not provide much unique information.

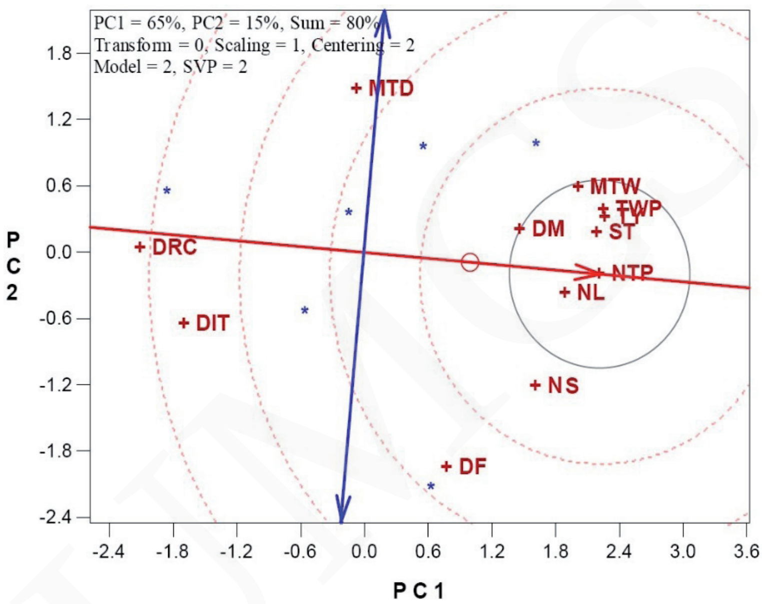

Fig. 4. Ideal tester view of treatment by trait (TT)biplot, showing the relationships of different traits with ideal tester (trait) in potato. For traits' abbreviations, refer to the text

An ideal treatment has been defined as the treatment that combines several good traits in its performance and it should be close to the ideal treatment represented by the innermost concentric circle with an arrow pointing to it (22). Such ideal treatment can be used as a reference in subsequent trials where the same traits will be measured. In the biplot displayed in Figure 5, the single-arrow line that passes through the biplot origin is referred to as ATC and on this line is ranked the cultivars in terms of their morphological performance. Based on this biplot, the treatments that performed above average were Nano-Com, Nano-Zn+B and NPK; while Control, Mog and Nano-Ca performed below average in terms of morphological parameters (Fig. 5). Nano-Com treatment is closest to the position of an ideal treatment and it is ranked the highest in terms of morphological performance because it is desirable in terms of most of the morphological traits. This treatment could serve as a good fertilizer treatment among other treatments.

The best fertilizer treatment for obtaining high tuber yield (TY) could be found in the TT biplot of Figure 6 which is a vector-view function and shows fertilizer treatments that have close association with a target trait. According to this biplot, Nano-Com treatment following Nano-Zn+B treatment were the best

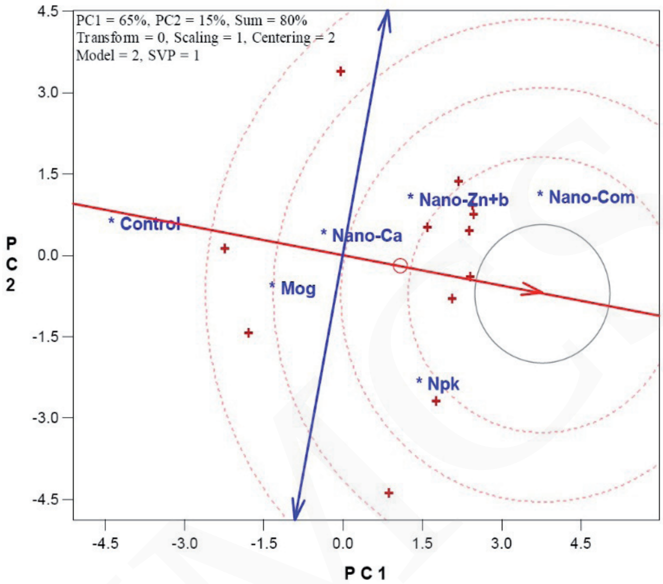

Fig. 5. Ideal entry view of treatment by trait (TT)biplot, showing the relationships of different nano, bio and bulk fertilizer treatments with ideal entry (treatment) in potato. For traits' abbreviations, refer to the text

fertilizer treatmens suitable for obtaining high tuber yield. Thus, application of these treatments is expected to lead to improved target trait and this suggests that using 11 macronutrients and micronutrients (N, P, K, Fe, Zn, Ca, Mg, Mn, Cu, B, and Mo) as well as application of zinc and boron will not only result in the development of high tuber yield but also cause to obtain other desirable agronomic traits which are associated to tuber yield. There are wide ranges of known documented field response data in potato and known responses are well documented for N, P, and K, while those for Mg, Zn, and Mn are intermediate, and essentially none are available for Fe, and Mo while limited information is available for Ca, B, and Cu (28). According to Bala et al. (3), the beneficial role of nano-fertilizer application in germination and growth of chickpea is demonstrated. Liu et al. (13) reported that nano-particles' application was safe for wheat production and has some economic benefits and Kharol et al. (12) indicated that application of increasing levels of zinc increased the yield of chickpea. Substantial growth in fertilizer use efficiency can be achieved by nano-scale fertilizers in the wake of global warming while the other advantages include increase in chances of plant survival, higher yield at lower input price and given the demand and economic importance, the nano-fertilizer development has immense potential (16).

Biplot analysis provides proper summary information because it is a very powerful tool for drawing from experimental data. It is great for visualizing inter-

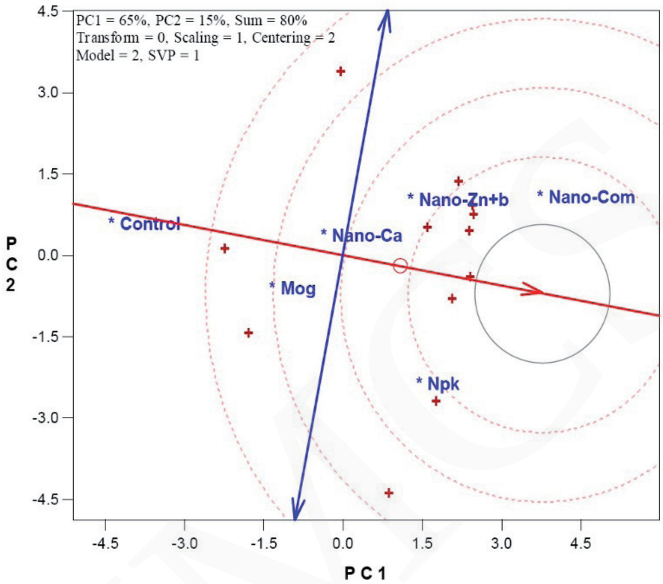

Fig. 6. Vector view of treatment by trait (TT)biplot, showing the relationships of different nano, bio and bulk fertilizer treatments with tuber yield (TY) of potato. For traits' abbreviations, refer to the text

action patterns among very different characteristics as well as various treatments; something that is quite difficult to do without the biplot tool. Biplot method can visualize a two-way, row by column data table and explore characteristics in trait by treatment. This study demonstrated that the TT biplot is an excellent tool for visualizing treatment by trait data, because it reveals the interrelationships among traits, provides a visual tool for comparison among treatments, and independent culling based on multiple traits (31).

CONCLUSIONS

This study demonstrated that application of complete nano-fertilizer (which contains nano particles of N, P, K, Fe, Zn, Ca, Mg, Mn, Cu, B, and Mo) as well as nano-Zn+B increase potato's tuber yield, primarily due to an increase in the yield components, and secondary due to an increase in the other measured traits. Also, this study demonstrated that the TT biplot is an excellent visual tool for interpreting treatment by trait data due to detection of the interrelationships among traits and treatments.

Table 1. Simple correlation coefficients among potato traits

	NL	DIT	DF	DRC	NTP	MTW	MTD	TWP	TY	DM	NC
DIT	-0.72										
DF	0.28	0.20									
DRC	-0.77	0.78	-0.32								
NTP	0.70	-0.79	0.36	-0.97							
MTW	0.46	-0.70	0.11	-0.82	0.88						
MTD	-0.45	0.23	-0.32	0.10	-0.11	0.33					
TWP	0.81	-0.84	0.14	-0.95	0.92	0.87	0.02				
TY	0.81	-0.82	0.18	-0.95	0.93	0.89	0.02	1.00			
DM	0.75	-0.33	0.21	-0.59	0.42	0.35	0.06	0.67	0.65		
NC	0.41	-0.29	0.78	-0.66	0.78	0.66	-0.14	0.55	0.59	0.15	
ST	0.68	-0.64	0.33	-0.88	0.89	0.92	0.20	0.94	0.95	0.64	0.71

Traits are: NL, number of leaves per plant; MTD, mean tuber diameter; MTW, mean tuber weight (g); TWP, tuber weight per plant (g); TY, tuber yield (t ha^{-1}); NTP, number of tubers per plant; DIT, day to initiation of tuberization; DRC, number of the days to row closure; DF, number of days to flowering; DM, dry matter content (%); and NS, number of stems; and ST, percent of starch content.

ACKNOWLEDGEMENT

We would like to thank kindly dear Professor Dr. Weikai Yan (Eastern Cereal Oilseed Research Center of Agriculture and Agri-Food Canada) for making available a time-limited version of GGEbiplot software as "Test Biplotxlsx."

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