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INFLUENCES OF NANO AND NON-NANOFERTILIZERS ON POTATO QUALITY AND PRODUCTIVITY

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ABSTRACT

Today, to achieve sustainable agriculture with maximum yield and minimum environmental risks, the use of nanofertilizers has riveted ample consideration. Field experiments were conducted during binary season of 2016 and 2017 at Research Farm, Faculty of Agriculture, Minia University, Egypt to estimate whether NPK nanofertilizers applied in equivalent or lower rates could replace recommended levels of NPK chemical fertilizers in potato farming systems without retrograde effects upon yield production or quality. Impacts of recommended rates of NPK chemical fertilizers (control treatments) compared to NPK nanofertilizers in equivalent or lower rates (100%, 50% and 25%), foliar or soil applied on potato productivity and quality were studied.

Compared with control treatments, plots receiving foliar application of NPK nanofertilizers at 50% or 25% of recommended level showed higher values of economic yield (23.59-ton ha^{-1}), starch rates (79.62%), NPK nutrient use efficiency (67.74, 278.92, 118.54 kg potato/kg nutrient), harvest index (59.24%) and only lower potato nitrate content (1.15 g/kg) as a harmful indicator. Among all treatments, foliar application of NPK nanofertilizers at 50% rate was found to be the most economical treatment as it gave highest potato yield and quality plus highest profit: cost ratio of potato production. This research recommends foliar application of nanofertilizers in potato production to increase production and quality compared to soil applications. As yet, using lower rates of nanofertilizers as foliar application in the present study proved to be an eco-friendly environmental and economic alternative to recommended rates of chemical fertilizers with significant increase in potato productivity and quality.

Keywords: Nanofertilizers, Foliar Application, Potato Harvest Index.

INTRODUCTION

Potato (*Solanum tuberosum* L.) is widely used for many industrial and food applications and considered one of the most important vegetable crops in Egypt, and the second most economically valuable vegetable crop, after tomato (Birch *et al.*, 2012). Potato is cultivated in about 20% of the total area for vegetable production in Egypt and worldwide and Egypt is one of the largest producers and exporters of potatoes in Africa and ranks 14th in the world in terms of ware potato production. Egypt is considered a major exporter of potatoes and produces about 5 million metric tons of potatoes destined for human consumption in potato form. In calendar year 2018, Egypt has exported over 759, 200MT of potatoes, supplying primarily the Russian Federation (367,000MT or 48 percent) and to a lesser extent the EU-18 (190,400MT or 25 percent) and United Arab Emirates (UAE) (53,100MT or 7 percent) markets.

Presently around the world, nanotechnology is one of the most significant tools used in contemporary agroecosystem to increase food production in an attempt to supply enough food for mushrooming population. This increase in food production in Egypt mainly counted on using short-lived high yielding varieties which are highly responsive to NPK chemical fertilizers, thereby securing food demand for up to 104 million people in 2018 (Abd El-Azeim *et al.*, 2016). The agriculture in Egypt is mainly dependent on high consumption of chemical fertilizers with much imported causing rising of fertilizers cost on daily basis with concurrent subsidy termination by the Government on domestic fertilizers for farmers. On the other hand, excessive use of chemical fertilizers has adverse effects on agroecosystem and soil health and consequent human welfare by dropping productivity issues and rising environmental problems (Ranjan *et al.*, 2016; El-Ramady *et al.*, 2018). In addition, excessive application of NPK chemical fertilizers have been found to be highly inefficient used up ranging from 20 to 50% for nitrogen, from 10 to 25% for phosphorus and from 70 to 80% for potassium (Chinnamuthu and Boopati, 2009, Thul *et al.*, 2013). These lower fertilizers use efficiency are mainly attributable to leaching, decomposition, hydrolysis, volatilization or denitrification losses contributing to gas emission, health hazards such as blue baby syndrome and waterbodies eutrophication.

In addition, the agricultural sector in Egypt is captivated by shortage of arable land, limited water resources and soil infertility. Thereby, the agricultural scientists are facing great challenges to produce sufficient food for the ever-increasing population without degrading the agroecosystem (Abd El-Azeim *et al.,* 2016; Brown, 2017; El-Ramady, 2018). Henceforth, nanotechnology has emerged as a technological approach to overcome all these challenges by increasing resource use efficiency and consequent production with minimum harm to the environment (Kashyap, 2015; Servin *et al.,* 2017). Nanomaterials under 100 nm in size could be used as fertilizer for effective nutrient management as well as the advantages of slow release and stress tolerance (Pan and Xing, 2012; Bottero, 2016). Nanofertilizers as a superior product of nanotechnology, can go afar in guaranteeing fertilizers use efficiency and ensuring sustainable agriculture, soil health and crop production (Lal, 2008, Abdel-Aziz *et al.,* 2016; Patil *et al.*, 2016). Nanofertilizers are elements encapsulated inside nano-porous substances, covered with thin polymer films and delivered as a particle or emulsions of nanoscale polymer fertilizers (Rai *et al.,* 2012, Abdelsalam *et al.*, 2019).

These nanofertilizers are eco-friendly products synthesised from traditional fertilizers by chemical, physical or biological processes and have been considered to resemble or to be more efficient than conventional chemical fertilizers in terms of nutrients contents and application rates (Liu and Lal, 2015, Meena *et al.,* 2017; Abdel-Aziz *et al.*, 2018). The use of nanofertilizers may (1) reduce soil toxicity, (2) increase nutrients use efficiency, (3) minimize the potential negative effects associated with over dosage and (4) reduce the frequency of the application (El-Ramady *et al.,* 2018). Hence, nanotechnology has a high potential for achieving sustainable agriculture, especially in developing countries (Mani and Mondal 2016). In fact, nano-fertilizers have opened up new opportunities to improve inputs use efficiency, minimize costs and environmental deterioration. Therefore, the scope for application of nanofertilizers in agricultural system needs to be prioritized in 21st century to accelerate the productivity of crops and sustains soil health and environmental quality through promoting use of nanoparticles in fertilizers and nano-sensors in soil microbial activity (Belal and El-Ramady 2016; Chhipa 2017; Sarlak and Taherifar, 2017).

Today, the usage of nanofertilizers in crop nourishment is one of the main functions of nanotechnology in the agriculture. Therefore, the application of nanofertilizers in agricultural sector may lead to sustainable development through lower inputs and lower wastes generation, diminishing nutrient losses, and increasing nutrient use efficiency by releasing nutrients at a suitable rate for plant demand comparing with conventional chemical fertilizers. There is a difference between non-nanofertilizers and nano-fertilizers depending on their mechanisms in the soil and plant ecosystem, application methods, effective rates of addition as well as their impact on the environment. However, both non nano-fertilizers and nano-fertilizers in comparison and their interaction under field conditions are required further studies. Therefore, this research was conducted to evaluate effects of soil or foliar applied recommended levels of conventional non-nano-NPK chemical fertilizers compared to eco-friendly nano-NPK fertilizers in equivalent or lower rates on potato quality, productivity, nutrients use efficiency under field conditions. This high performance and efficient nanofertilizers are expected to enhance crop production while protecting the environment compared to traditional chemical NPK fertilizers. So that a viable and economically feasible options can be made to the Egyptian farmers for maintaining sustainable agriculture through improved crop production and quality and increased fertilizer use efficiency in potatoes crop farming systems.

MATERIALS AND METHODS

Two field experiments were conducted for two *nili* seasons (2016 and 2017) in order to study effects of NPK nanofertilizers compared to NPK non-nanofertilizers on yield and yield components of potato crop (*Solanum tuberosum* L.) at Research Farm facilities, Faculty of Agriculture, Minia University, Egypt. Experiments were laid out in a factorial design based on complete randomized block design (CRBD) with eight treatments and three replicates. Treatments of this research comprised of four application rates, two fertilizers (NPK non-nanofertilizers and NPK nanofertilizers in equivalent and lower rates) and two methods of application (soil addition and foliar application). Under field conditions, potato crop yield and quality as well as fate and use efficiency of total NPK from non-nanofertilizers (conventional chemical fertilizers) and NPK nanofertilizers applied to clay soil were studied. The specifics materials and methods used and experimental procedures followed during the course of this research was as following:

Experimental Site and Soil Characteristics.

The experimental site under investigation was located at arid region (28º18'16"N latitude and 30º34'38"E longitude) categorized with an evaporation rate more than 5000 mm/year, annual rainfall ranges from 2 – 23 mm/year and temperatures in winter varied from 5 to 20^{o}C with extreme summer temperature 47 ^{o}C in July as stated by data recorded by the Egyptian Meteorological Agency. The soil of the experimental site has a clay texture, pH 7.7, with an electrical conductivity 1.35 dS m^{-1}, CEC 37.87 (cmol$_c$ kg^{-1}), soil organic carbon (SOC) 18.48 g kg^{-1} and classified as Alluvial soil according to Abd El-Azeim *et al.*, (2016). Prior to the initiation of the field trials, clay soil detailed in Table 1 was collected, air dried, sieved to < 2.0 mm, and composite sub-samples were used to determine the basic soil physicochemical properties using standard methods derived from Jackson (1973), Black (1965), Avery and Bascomb (1982), Page *et al.*, (1982).

Table 1. Physicochemical properties of the soil investigated.

Soil Property			
pH (1:2.5 water)	7.7 (7.4)[a]	$CaCO_3$ (g kg^{-1})	17.9
EC (dS m^{-1} at 25°C)	1.35	F.C %	42.45
CEC ($cmol_c$ kg^{-1})	37.87	PWP %	13.78
O.M (g kg^{-1})	28.61[b]	WHC %	48.76
Total N (g kg^{-1})	1.29	A.V (F.C – PWP) %	28.67
Total C/N Ratio	22.18	A.V (WHC – PWP) %	34.98
S.O.C g kg^{-1}	18.48	Bulk Density (BD) g/cm^3	1.31
Organic N (g kg^{-1})	0.76	Particle Density (PD) g/cm^3	2.22
Organic C/N Ratio	24.31	Clay (%)	56.45
Mineral N (mg kg^{-1})	78.46	Sand (%)	17.76
Total P (g kg^{-1})	0.56	Silt (%)	25.79
Available P (mg kg^{-1})	13.11	Soil texture	Clay
Total K (g kg^{-1})	4.37		

[a] Figures in parentheses are pH values obtained for soil by $CaCl_2$ extraction ratio of 1:2.5.

[b] Organic matter determined by loss on ignition.

Experimental procedures and methods

In this experiment, nitrate ammonium (33%N), triple super phosphate (15% P_2O_5) and potassium sulphate (48% K_2O) were used as resources for chemical fertilizers at the recommended level for potato crop at rates of 350 nitrogen, 85 phosphorus, and 200 potassium kg ha^{-1} as recommended by the Egyptian Ministry of Agriculture, Egypt (Selim *et al.,* 2009). Individual nano-N, nano-P and nano-K fertilizers in liquid formulations were imported from India containing 19% of each nutrient of NPK. These fertilizers are eco-friendly made through biological process, and have been designed to match chemical fertilizers in terms of nutrient content and application rates. These revolutionary nutritional agricultural inputs of nano-N, nano-P and nano-K fertilizers are developed by private company (Pratishtha) in India in association with Indian Council of Agricultural Research as complete nutritional nanofertilizer of NPK for crops. The experimental actions followed during the course of this research have been conducted two methods of application (soil addition and foliar application) and comprised of four application rates in accordance with treatments described below. Agricultural activities other than abovementioned treatments were conducted according to potato cultivation recommendations of Agricultural Research Centre in Egypt. The experimental treatments included therefore were as following:

1- (T_1) = 100% NPK non-nano fertilizers, soil added at recommended level (control).

2- (T_2) = 100% NPK nanofertilizers, soil added equal to recommended levels.
3- (T_3) = 50% NPK nanofertilizers, soil added at half recommended level.
4- (T_4) = 25% NPK nanofertilizers, soil added at quarter recommended level.
5- (T_5) = 100% NPK non-nano fertilizers, foliar added at recommended level (control).
6- (T6) = 100% NPK nanofertilizers, foliar added equal to recommended levels.
7- (T_7) = 50% NPK nanofertilizers, foliar added at half recommended level.
8- (T_8) = 25% NPK nanofertilizers, foliar added at quarter recommended level.

Field preparation, potato sowing and harvest

Soil plot area was 8 m^2, prepared manually after the experimental field was deeply turn over using Chesil plow and then levelled accurately to break soil clods and bring soil to desired tilth. Nile compost was added during soil preparation before ploughing as organic fertilizer at the rate of 40 m^3 ha^{-1}. Factorial design of eight treatments in a randomized complete block design was used with three replicates. Field plots were irrigated fifteen days prior to sowing then potato tubers sowing was done at 10 cm depth at the tuber rates of 1500 kg ha^{-1} by opening furrows in lines at a distance of 50 cm among rows and the distance between hills was 25 cm apart. Potato tubers; cv Cara were obtained from Mallawy Agricultural Research Centre (ARC), Ministry of Agriculture, Egypt. Tubers were divided into pieces, averaging approximately 35 g weight, then potato tuber pieces were sterilized with Kapetan 1% at the rate of 1.25 kg/ton for 5 min. The sterilized potato tuber pieces were sown 10 cm depth on September 15th and 19th in both *nili* seasons respectively. Nitrogen nano or chemical fertilizer was soil or foliar applied in three equal portions, the 1st was applied after emergence, then two and four weeks later at the rate of 350 Kg N ha^{-1}. Phosphorous and potassium was applied during soil preparation at a rate of 85 kg P ha^{-1} and 200 kg K ha^{-1}, respectively.

At the maturity stage, dated after active growth period (after 100 days from planting), a random sample of four plants was taken from each experimental unit to determine the growth parameters, i.e. vegetative fresh and dry weights in plant vegetative aboveground and root parts. At harvesting time (115 days from planting), the tuber yield per plant and plots were determined. At maturity potato tubers were harvested manually using hand digger and individual plots were harvested separately to eliminate the border effects, then tubers were allowed for sun drying and cleaning for net plot marketable tuber weights after excluding unmarketable tubers using spring balance in the field.

Potato total biological, economical and vegetative Yield (ton ha^{-1})

The biological and economical crop yield of potato was quantified in ton per hectare (ton ha^{-1}) after excluding unmarketable tubers. The total biological yield (potato tubers + potato vegetative aboveground and root parts) from net plots was recorded and vegetative yield was worked out by subtracting potato tubers yield (economical yield) from biological yield.

Potato Harvest Index (%)

Harvest Index (HI %) was calculated by calculating the ratio of potato economical yield to biological yield using formula as supposed by (Beukema and Zaag, 1990) as following:

$$\text{Potato Harvest Index (\%)} = \frac{\text{Economic yield (ton ha}^{-1}\text{)}}{\text{Biological yield (ton ha}^{-1}\text{)}} \text{ x } 100$$

Potato Quality and Nutrients Uptake

A representative sample of 10 tubers from each experimental plot was selected from average tuber sizes to obtain quality standards of tuber as follows: potato starch was determined in dry tubers according to Luff-Schoorl (AOAC 1990) by acid hydrolysis of starch and titration by sodium-f-sulphate. Tubers nitrate concentration was determined in dry tuber using Auto analyzer (Kampshake *et al.*, 1967). Potato plant samples and tubers were taken at the time of harvesting for estimation of N, P and K concentration as described by Peterburgski (1968) and Cottenie (1982). The samples were oven dried, then finely ground with electric grinder and analyzed for nitrogen, phosphorus and potassium concentrations. N, P, K uptake in tubers and plant samples were calculated by multiplying percentage of nutrient content with their respective dry matter accumulation as following:

$$\text{Nutrient uptake (kg ha}^{-1}\text{)} = \frac{\text{Nutrient content (\%) x Dry matter accumulation (kg ha}^{1}\text{)}}{100}$$

Nutrient Use Efficiency (kg of tuber/kg of nutrient)

Nutrient use efficiency is the return in potato tubers yield per unit of fertilizer nutrient applied and was calculated by the following formula (Devasenapathy *et al.*, 2008).

$$\text{Nutrient Use Efficiency} = \frac{\text{Tuber yield (kg ha}^{-1}\text{)}}{\text{Quantity of N, P or K fertilizer applied (kg ha}^{-1}\text{)}}$$

Potato Relative Economic Studies

Cultivation Cost and Total Income

Cost of different operations was calculated for different treatments on the basis of existing market prices of inputs and operations and the total cost was calculated by adding the expenditure involved in all kinds of operations as per treatment on per hectare basis. Total income was calculated by multiplying the total potato yield with currently dominant market prices of potato and then presented on per hectare basis as per treatments. Market price of potato was 6000 EGP/ton.

Net revenue and Profit to Cost Ratio (B: C ratio)

Net revenue was computed by deducting the total cost of cultivation from the total income as per treatments. Profit cost ratio was calculated by dividing net revenue by cost of cultivation for each treatment.

$$\text{Benefit: Cost (B:C) Ratio} = \frac{\text{Net Revenue (EGP /ha)}}{\text{Cost of cultivation (EGP /ha)}}$$

Statistical Analysis

Data presented are mean values and statistically were subjected to variance analysis. Significance of the differences was estimated and compared using Duncan test at 5% level of probability ($p < 0.05$). Simple linear correlation analysis was done to show the relationship between experimental factors. Finally, all statistical analyses were carried out using "SAS" computer software package (2013).

RESULTS AND DISCUSSIONS

Responses of potato plants productivity and quality as affected by NPK nano and non-nanofertilizers was investigated as follows:

Potato yield and yield parameters

Effects of NPK nano and non-nanofertilizers (chemical fertilizers) on potato crop yield and yield parameters viz biological yield, economic yield, and fresh and dry weights of tubers and vegetative parts are presented in Table (2). In general, a perusal of data depicted in Table (2), a significant use impact of nano and non-nanofertilizers was observed on potato yield and yield quality parameters for fertilizer foliar application compared to soil addition. Potato crop yield in terms of fresh and dry weights of tuber revealed that yield characteristics of potato exposed obvious improvements at all treatments with nano or non-nanofertilizers. Among different treatments of NPK nano or non nano-fertilizers, treatment T7 (50% of NPK nanofertilizers, foliar applied at half recommended level) resulted in significant increases in all potato crop yield parameters compared to other soil addition fertilizer treatments. However, treatment T_8 (25% of NPK nanofertilizers, foliar applied at quarter recommended level) and treatment T_6 (100% of NPK nanofertilizers, foliar applied equal to recommended levels) were found to be statistically paralleled with T_7 in affecting potato yield components improvements. Treatment (T_7) gave rise to significantly higher fresh potato yield (23.71-ton ha^{-1}) than T_3, T_4 and T_5 treatments in comparison. However, it was found to be almost at parity with treatment (T_1), (T_2), (T_8) and (T_6) treatments. The lowest fresh yield (14.22-ton ha^{-1}) was observed in treatment T_4 (soil applied of 25% of NPK nanofertilizers).

Tubers fresh and dry yield is an important index indicating the photosynthetic efficiency of the crop which ultimately influences the crop yield, quality and economic value. Analysis of variance relating to fresh and dry matter of potato crop showed that all treatments significantly increased assimilation flow from potato biological yield into potato fresh and dry matter accumulation per hectare at all application rates. Two plausible reasons to explain the significant increases in fresh and dry tubers yield with foliar application of NPK nanofertilizers over foliar or soil application of recommended levels of NPK chemical fertilizers even at lower rates. Firstly, due to the fact that nanofertilizers foliar applied are associated with increased plant vegetative growth and leaf area helping in better utilization of solar radiation and essential available nutrients for increasing plant productivity and quality. Secondly, these increases in turn force more photosynthetic surface, chlorophyll formation, biomass and more nutrient uptake which resulted in cumulative vigorous growth. These results were in accordance with the findings of Benzon *et al.,* (2015); Hafeez *et al.,* (2015); Abdel-Aziz *et al.,* (2016) and Singh *et al.,* (2017).

Results clearly revealed that foliar application of NPK fertilizers whether in the form of conventional chemical fertilizers (non-nano-fertilizers) or nanofertilizers, significantly affected all potato yield parameters compared to fertilizers soil addition in both potato seasons. Precisely, plots treated with foliage applied NPK nanofertilizers had a significant higher yield and yield components compared with soil addition of nanofertilizers or conventional chemical fertilizers. In addition, biological or economic yield and yield components from plots treated with soil addition of nanofertilizers were insignificantly different from plots treated with conventional NPK chemical fertilizers (control) in both seasons. The superiority of potato crop yield parameters following foliar application of nanofertilizers or non-nanofertilizers compared with soil addition might be attributed to increased availability of nutrients by foliar application due to quick absorption of NPK nanofertilizers by stomatal tissues. Also, nutrients uptake may have increased as a result of increased photosynthesis rate, fresh and dry weights of potato and consequently improved overall growth parameters of potato plants (Drostkar, *et al.,* 2016; El-Sharkawy *et al.,* 2017; Burhan and Hassan, 2019).

The experiential results showed that among treatments, treatment T_7 (foliar applied of 50% of NPK nanofertilizers) and T_8 (foliar applied of 25% of NPK nanofertilizers) though statistically at par with treatment T_6 (foliar applied of 100% of NPK nanofertilizers) recorded significant higher yield and better yield traits over all other treatments in comparison. Based on variance analyses, the effect of nano or chemical fertilizers rate is significant on potato yield and yield components indicating the importance of fertilizer amount applied in potato cultivation, which should be selected with considerations of economic and environmental factors. Based on these results, the use of nanofertilizers over chemical fertilizers are recommended as the priority of equal or lower rates of nanofertilizers in terms of preferred potato yield and yield traits was significant in foliar application treatments at 50% or 25% percent of recommended level (El-Sharkawy *et al.,* 2017; Sohair EED *et al.,* 2018; Burhan and Hassan, 2019).

Yield parameters of potato was measured in terms of biological yield, economical yield, tuber dry yield, vegetative fresh and dry yield and tuber and vegetative concentrations and uptakes of NPK. A significant use effect of nano and non-nano fertilizers was observed on the biological yield index of potato at all application rates regardless method of application except for T_4 (soil added of 25% of NPK nanofertilizers). Among treatments, application of T_8 however at par with T_7 resulted in significantly higher biological yield of potato i.e. (41.56-ton ha^{-1} in second season) than recommended dose of NPK chemical fertilizers (control) and other treatments in comparison. However, T_4 (soil added of 25% of NPK nanofertilizers) recorded minimum biological yield (29.79-ton ha^{-1} first season).

Biological yield is an important index of plant growth and plant accomplishment representing the infrastructure build-up over a period of time to produce good quality tubers yield with better accumulated dry matter. The total biological yield (potato tubers + potato vegetative aboveground and root parts) is a reliable plant index which determines the crop yield and capacity of plants to trap solar energy for photosynthesis and in turn increase assimilation flow into yield. In general, a significant effect of nano and non-nanofertilizers was obtained on potato biological yield at all application rates with fertilizer foliar application. Therefore, the vertical expansion of agricultural land in Egypt is only feasible by increasing use efficiency of available fertilizers with minimum impairment to the environment through current uses of nanotechnology in agriculture. Application of nanofertilizers will have in the future greater potential role in enhancing potato crop yield production and quality by reducing fertilization costs and ecosystem pollution hazards. From this study, foliar application of nano-NPK 50% was at par with control treatments of foliar or soil applied recommended levels of chemical NPK fertilizers and in most cases studied, nano 25% also recorded statistically at par with control treatments (NPK chemical fertilizers at recommended levels). This indicates and confirms that the use of nanofertilizers can be enhanced and improve potato yield productivity and quality up to optimum application methods and rates.

Potato yield quality parameters

potato quality parameters were measured in terms of tuber and vegetative concentrations and uptakes of NPK nutrients and potato starch and nitrate contents. Data on potato NPK uptake and concentration as influenced by usage of nano and non-nano fertilizers foliar or soil applied at different application rates were recorded and presented in Tables 3, 4 and Figures 1, 2. Through a perusal of data depicted in Tables (3 and 4), usage impact of nano and non-nanofertilizers failed to show straight significant outcomes with respect to the mean concentration and uptake values of NPK recording a fluctuating insignificant trend at all application rates except for treatments (T_4) (soil application of 25% nanofertilizers). Irrespective of the fertilizer treatment type and rate, high positive correlation between tubers yield and N uptake (0.676**), P uptake (0.589**) and K uptake (0.440**), was observed indicating difficulty of predicting the availability differences between treatments under these conditions.

Table (2). Effects of NPK chemical or nano-fertilizers on potato biological, economical, fresh and dry yield for both seasons.

Treatment		**Potato vegetative and tuber fresh and dry yield (ton ha^{-1}) ***									
		Biological yield		Economical yield		Tubers dry yield		Vegetative fresh yield		Vegetative dry yield	
		2016	2017	2016	2017	2016	2017	2016	2017	2016	2017
Soil Addition	T1	39.33^{abc}	39.69^{abc}	21.15^{abc}	21.41^{abc}	7.05^{abc}	7.14^{abc}	18.18^{b}	18.28^{abc}	3.64^{b}	3.66^{abc}
	T2	38.60^{abc}	39.05^{abc}	20.41^{abc}	20.68^{abc}	6.80^{abc}	6.89^{abc}	18.19^{b}	18.37^{ab}	3.64^{b}	3.67^{ab}
	T3	36.13^{bc}	36.74^{bc}	18.11^{c}	18.88^{c}	6.04^{c}	6.29^{c}	18.03^{b}	17.86^{bc}	3.61^{b}	3.57^{bc}
	T4	29.79^{d}	30.55^{d}	14.22^{d}	14.44^{d}	4.74^{d}	4.81^{d}	15.57^{e}	16.11^{e}	3.11^{e}	3.22^{e}
Foliar Application	T5	35.96^{c}	36.51^{c}	18.42^{bc}	18.86^{c}	6.14^{bc}	6.29^{c}	17.54^{bc}	17.65^{bcd}	3.51^{bc}	3.53^{bcd}
	T6	36.95^{bc}	37.46^{bc}	20.07^{abc}	20.29^{bc}	6.69^{abc}	6.76^{bc}	16.88^{cd}	17.17^{cde}	3.38^{cd}	3.43^{cde}
	T7	39.81^{ab}	40.31^{ab}	23.59^{a}	23.71^{a}	7.86^{a}	7.90^{a}	16.23^{ed}	16.61^{de}	3.25^{ed}	3.32^{de}
	T8	41.11^{a}	41.56^{a}	21.86^{ab}	22.21^{ab}	7.29^{ab}	7.40^{ab}	19.25^{a}	19.35^{a}	3.85^{a}	3.87^{a}
L.S.D $_{0.05}$ for rates		3.74	3.64	3.57	3.04	1.19	1.016	0.80	1.17	0.16	0.23
Applications		1.87	1.82	1.78	1.52	0.595	0.508	0.40	0.58	0.08	0.11

*Figures in columns followed by the same letters are insignificantly different at $P \leq 0.05$ and represent means of three replicates.

Increases in certain amounts of nutrients are continually associated with attainable fresh and dry yields of any crop where nutrient uptake is a function of fresh and dry matter production. It is apparent from this study that there was a close relationship between total uptake of nutrients with tuber yield and vegetative growth of potato crop albeit using lower application rates of NPK nanofertilizers. highest total uptake of N, P and K was recorded in treatment T_7 and lowest total uptake of N, P and K was recorded in treatment T_8. This was due to increased availability of the nutrients *viz*. N, P & K in readily available form for quick absorption by the crop. The foliar application of NPK nanofertilizers boosted nutrients uptake by potato due to the fact that nano-fertilizers combine nano devices in order to synchronize the release of fertilizer-N, P and K with their uptake by crops, so stopping unwanted nutrient losses to soil and water via direct adoption by crops, and avoiding the interaction of nutrients with soil, microorganisms and water (DeRosa *et al.,* 2010). These findings are in accordance with the results of Adhikari et al. (2014), and Jhanzab *et al*. (2015).

Starch and nitrate contents are important standard determinants of tuber quality in potato crop production. Data depicted in Table 5 revealed that use of nano and non-nanofertilizers had no significant effect on starch content (%) of potato except for T_4 treatment. Among the applied treatments, treatment T_6 even though paralleled with T_7 and T_2 treatments recorded significantly higher potato starch content (81.34%) while, treatment T4 recorded minimum starch content (74.15%). By contrast, the usage impact of nano and non-nanofertilizers showed significant results with respect to mean concentrations of nitrate in potato tubers recording adverse significant trends at all application rates (Table 5). Soil addition of NPK nano and non-nanofertilizer treatments (T_2) and (T_1) recorded maximum nitrate contents of potato tubers (3.41 and 3.20 g kg^{-1}) whereas the minimum nitrate contents i.e. 0.96 and 1.13 g kg^{-1} was recorded in nanofertilizers foliar applied treatments (T_8) and (T_4). In the case of chemical fertilizers soil application, the higher nitrate uptake and assimilation was attributed to increased movement in soil as negative charged anion facilitating nitrate soil absorption.

Table (3). Effects of NPK nano and non-nanofertilizers on potato vegetative and tuber concentrations of NPK (%) for both seasons.

Treatment		Potato vegetative and tuber concentrations of NPK%											
		N%				P%				K%			
		Vegetative		Tuber		Vegetative		Tuber		Vegetative		Tuber	
		2016	2017	2016	2017	2016	2017	2016	2017	2016	2017	2016	2017
Soil Addition	T1	2.22^{a}	2.22^{a}	2.65abc	2.66^{ab}	0.63^{a}	0.63^{a}	0.83^{a}	0.84^{a}	1.64^{ab}	1.66^{ab}	1.98^{ab}	1.97^{ab}
	T2	2.21^{ab}	2.21^{a}	2.64abc	2.65^{ab}	0.63^{a}	0.63^{a}	0.83^{a}	0.83^{ab}	1.59^{ab}	1.60^{bc}	1.90^{b}	1.90^{b}
	T3	2.17^{ab}	2.18^{ab}	2.58c	2.60^{b}	0.62^{a}	0.61^{abc}	0.82^{a}	0.81^{b}	1.57^{ab}	1.58^{bc}	1.86^{bc}	1.87^{bc}
	T4	2.04^{c}	2.05^{c}	2.48d	2.48^{d}	0.58^{b}	0.57^{c}	0.78^{b}	0.78^{c}	1.49^{ab}	1.50^{c}	1.75^{c}	1.76^{c}
Foliar Application	T5	2.16^{ab}	2.17^{ab}	2.59bc	2.60^{b}	0.61^{a}	0.61^{abc}	0.82^{a}	0.82^{ab}	1.57^{ab}	1.59^{bc}	1.86^{bc}	1.88^{bc}
	T6	2.21^{ab}	2.21^{a}	2.62bc	2.62^{ab}	0.61^{a}	0.60^{abc}	0.82^{a}	0.82^{ab}	1.74^{a}	1.75^{a}	1.91^{b}	1.94^{b}
	T7	2.12^{bc}	2.11^{bc}	2.69a	2.69^{a}	0.58^{b}	0.58^{bc}	0.83^{a}	0.83^{ab}	1.36^{b}	1.61^{b}	2.07^{a}	2.10^{a}
	T8	2.22^{a}	2.22^{a}	2.66ab	2.66^{ab}	0.61^{a}	0.62^{ab}	0.83^{a}	0.83^{ab}	1.75^{a}	1.76^{a}	1.97^{ab}	1.98^{ab}
L.S.D $_{0.05}$ for rate		0.0941	0.0943	0.072	0.081	0.0278	0.0395	0.022	0.024	0.2767	0.1043	0.127	0.124
For Application		0.047	0.0471	0.036	0.040	0.0139	0.0198	0.011	0.012	0.1383	0.0522	0.063	0.062

*Figures in columns followed by the same letters are insignificantly different at $P \leq 0.05$ and represent means of three replicates.

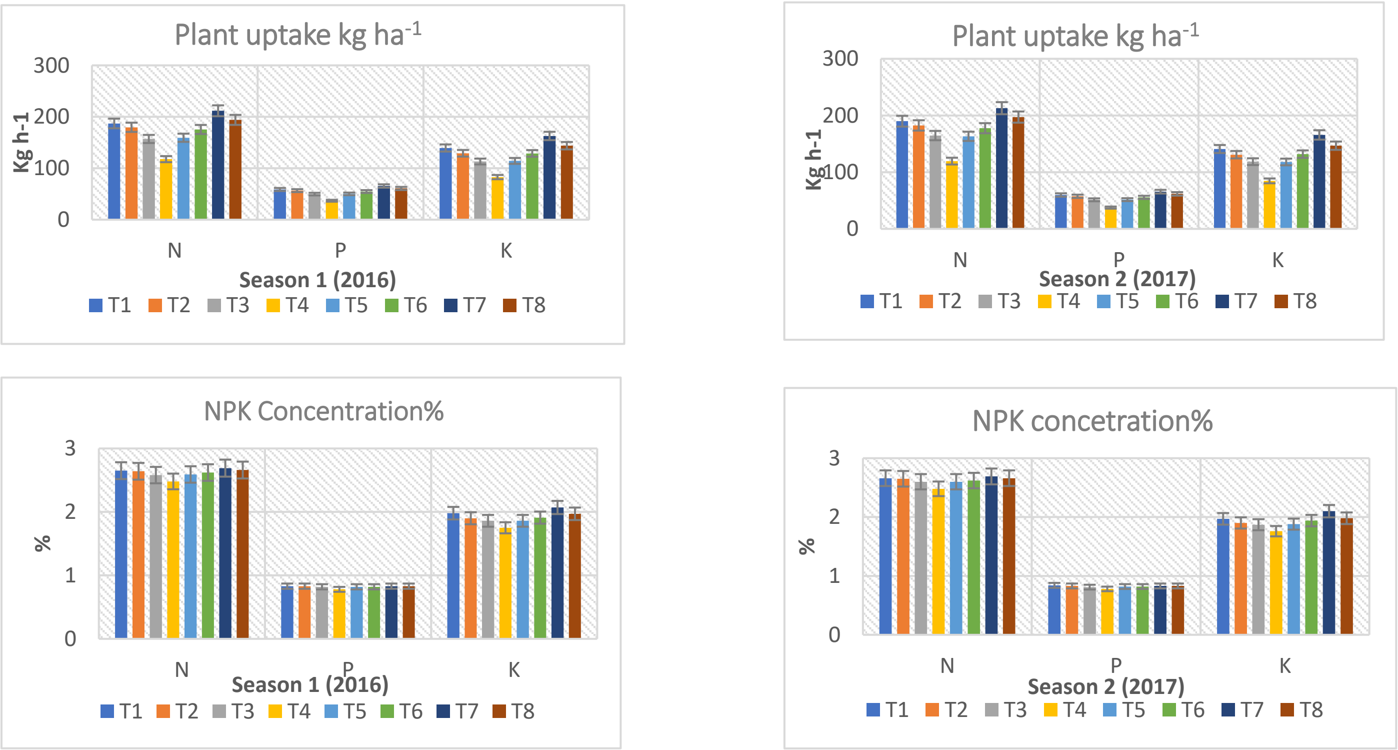

Figure (1). Potato tuber uptake and concentrations of NPK (kg ha^{-1}) as affected by NPK nano and non-nanofertilizers for both seasons. Error pars represent least significant difference at $P \leq 0.05$.

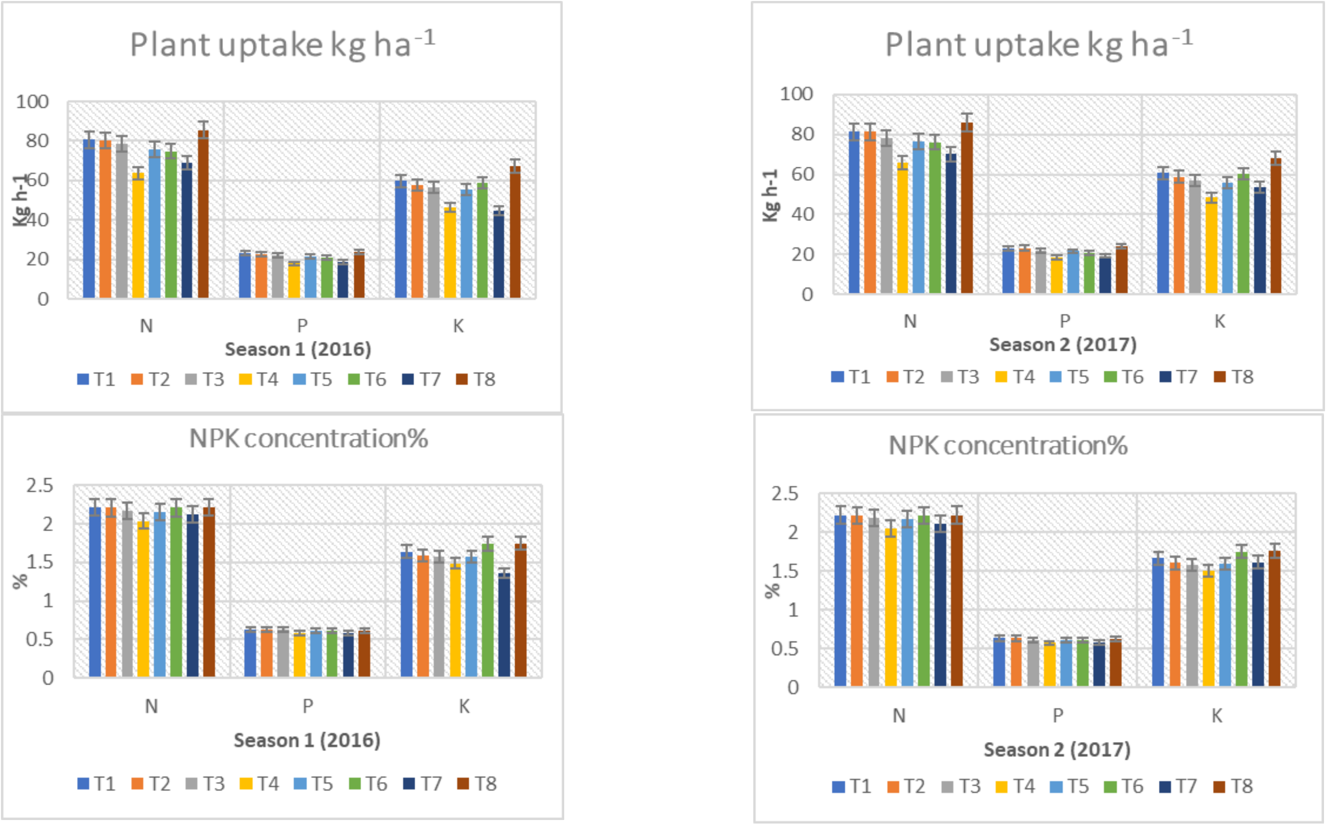

Figure (2). Potato vegetative uptake and concentrations of NPK (kg ha^{-1}) as affected by NPK nano and non-nanofertilizers for both seasons. Error pars represent least significant difference at P≤0.05.

Table (4). Effects of NPK nano and non-nanofertilizers on potato vegetative and tuber uptake of NPK (kg ha^{-1}) for both seasons.

Treatments		Potato vegetative and tuber uptake of NPK (kg ha^{-1})*											
		N (kg ha^{-1})				P (kg ha^{-1})				K (kg ha^{-1})			
		Vegetative		Tuber		Vegetative		Tuber		Vegetative		Tuber	
		2016	2017	2016	2017	2016	2017	2016	2017	2016	2017	2016	2017
Soil Addition	T1	80.60^{ab}	81.28^{ab}	187.06^{abc}	189.89^{abc}	23.02^{ab}	23.15^{ab}	58.74^{abc}	59.71^{abc}	59.65^{ab}	60.57^{b}	139.40^{abc}	140.89^{abc}
	T2	80.39^{ab}	81.32^{ab}	179.61^{abc}	182.48^{abc}	22.80^{ab}	23.18^{ab}	56.46^{abc}	57.46^{abc}	57.84^{ab}	58.78^{b}	129.13^{bc}	130.84^{bc}
	T3	78.34^{b}	78.12^{ab}	156.98^{c}	164.56^{c}	22.26^{abc}	21.73^{abc}	49.71^{c}	51.28^{c}	56.66^{abc}	56.71^{b}	113.09^{c}	118.56^{c}
	T4	63.64^{d}	66.07^{d}	117.69^{d}	119.50^{d}	17.96^{d}	18.48^{d}	36.81^{d}	37.53^{d}	46.30^{dc}	48.45^{c}	82.78^{d}	84.69^{d}
Foliar Application	T5	75.65^{b}	76.50^{bc}	159.28^{bc}	163.24^{c}	21.51^{bc}	21.54^{abc}	50.16^{bc}	51.55^{c}	55.19^{bc}	56.02^{b}	114.27^{c}	118.00^{c}
	T6	74.68^{bc}	76.09^{bc}	175.40^{bc}	177.59^{bc}	20.73^{c}	20.78^{bcd}	54.70^{abc}	55.56^{bc}	58.88^{ab}	60.25^{b}	128.82^{bc}	131.84^{bc}
	T7	68.80^{cd}	70.07^{cd}	211.76^{a}	212.87^{a}	18.72^{d}	19.26^{cd}	65.51^{a}	65.59^{a}	44.42^{d}	53.58^{bc}	162.77^{a}	165.71^{a}
	T8	85.61^{a}	85.90^{a}	194.05^{ab}	197.18^{ab}	23.61^{a}	23.86^{a}	60.71^{ab}	61.71^{ab}	67.27^{a}	68.11^{a}	143.87^{ab}	146.69^{ab}
L.S.D $_{0.05}$ for rates		6.39	8.14	34.80	31.19	1.79	2.62	10.82	9.65	10.62	7.076	29.08	26.62
For Applications		3.19	4.070	17.40	15.59	0.89	1.31	5.41	4.82	5.31	3.53	14.54	13.31

*Figures followed by the same letters are significantly different at $P \leq 0.05$ and represent means of three replicates.

Table (5). Effects of NPK nano and non-nanofertilizers on potato quality content of starch and nitrates for both seasons.

Treatments		Potato tubers quality*			
		Starch (%)		Nitrate g kg^{-1}	
		2016	2017	2016	2017
Soil Addition	T1	76.42^{ab}	76.47^{ab}	3.05^{ab}	3.20^{a}
	T2	78.19^{ab}	78.75^{ab}	3.41^{a}	3.14^{a}
	T3	75.61^{ab}	74.76^{b}	1.35^{c}	1.64^{b}
	T4	74.15^{b}	74.15^{b}	1.13^{c}	1.17^{b}
Foliar Application	T5	74.37^{b}	74.28^{b}	3.12^{ab}	2.77^{a}
	T6	81.34^{a}	81.34^{a}	2.34^{b}	1.85^{b}
	T7	79.62^{ab}	76.30^{ab}	1.15^{c}	1.60^{b}
	T8	77.33^{ab}	77.33^{ab}	0.96^{c}	0.96^{b}
L.S.D $_{0.05}$ for rates		6.029	5.352	0.849	0.910
For Applications		3.014	2.676	0.424	0.455

*Figures in columns followed by the same letters are insignificantly different at $P \leq 0.05$ and represent means of three replicates.

In the case of soil application of 100% NPK chemical fertilizers, the higher nitrate uptake and assimilation was attributed to increased free movement in soil as negative charged anion facilitating nitrate soil absorption. Several literature reviewers have indicated that potato produced with less nitrate are healthier than potatoes contain high nitrates using high rates of chemical fertilizers (Erhart *et al.,* 2005; Lairon 2009; El-Sayed *et al.,* 2014; Pobereżny *et al.,* 2015). In this study, the content of nitrates in potato tubers in all treatments exceeded the permissible level of 200 mg NO_3^- kg^{-1}. Therefore, the consumption of 300 g potatoes from chemical fertilizers treatments will exceed the acceptable daily intake for nitrates and might trigger the concern about health specially for children. On the other hand, the consumption of 300 g potatoes from lower rates nanofertilizers treatments will not exceed the acceptable daily intake for nitrates, untriggered any concern about health as the use of nanofertilizers decreased it additionally. The application of chemical fertilizers in full dose fertilization increases the consumption of nitrates in potato yield, while using nanofertilizers decreased potato tubers contents of nitrates inconsiderably.

Potato tubers (*Solanum tuberosum* L.) nitrogen content might exist in desired form of amino acids, proteins or harmful nitrates and glycoalkaloids causing the oxidation of hemoglobin to methemoglobin (Hamouz *et al.,* 2005; Pobereżny *et al.,* 2015). Nitrates accumulation in vegetables is very important since vegetables as a source of nitrates in the daily human consumption rate is accounted for 70 to 90% (Ierna, 2009; Rytel, 2010). FAO/WHO Expert Committee on Food Additives (JECFA) (JECFA, 2002) fixed daily intake of an adult of nitrates on the level of 0-3.7 mg and nitrites 0-0.7 mg kg^{-1} body mass. From the fixed values it results that the acceptable daily intake (ADI) by an adult of 70 kg cannot exceed 260 mg of nitrates and 49 mg nitrites. However, the dose of nitrates exceeding 8-11 mg kg^{-1} body weight day is lethal (Burt *et al.*, 1993).

Nutrient use efficiency

Nutrient use efficiency of a treatment was worked out using available data of tuber yield (ton ha^{-1}) and total amount of each NPK nutrient used in each treatment. Data on nutrient use efficiency as influenced by usage of nano and non-nano fertilizers, foliar or soil applied at different application rates, were recorded and presented in Table 6. Treatment (T_7) recorded significant highest nutrient use efficiency of NPK over control (chemical NPK non-nanofertilizers recommended levels) and all other treatments in comparison. In case of nitrogen use efficiency, among the applied treatments, T_7 recorded maximum nitrogen use efficiency (67.74) and the minimum nitrogen use efficiency was recorded in treatment T_4 (40.62). In case of phosphorus use efficiency, among the applied treatments, T_7 recorded maximum phosphorus use efficiency (278.92) and the minimum phosphorus use efficiency was recorded in treatment T_4 (167.27). In case of potassium use efficiency, among the applied treatments, T_7 recorded maximum potassium use efficiency (118.54) and the minimum potassium use efficiency was recorded in treatment T_4 (71.09).

Analysis of variance relating to nutrient use efficiency of NPK by potato crop showed that all treatments significantly increased nutrient use efficiency per hectare (kg ha^{-1} potato/kg ha^{-1}fertilizer) at all application rates. Among the applied treatments, treatment (T_7) gave rise to significantly higher potato yield (kg ha^{-1} potato) for each nutrient unit used (kg ha^{-1}nutrient) of NPK than T_3, T_4, T_5 and T_6 treatments in comparison. However, it was found to be insignificant and almost at parity with treatment (T_1), (T_2) and (T_8) treatments. The lowest potato yield for each nutrient unit used was observed in treatment T_4 (soil applied of 25% of NPK nano fertilizers). Also, the obtained correlation coefficients indicated that total fresh yield was high positively and significantly correlated and almost paralleled with N use efficiency (r=0.954**), P use efficiency (r=0.952**), K use efficiency (r=0.941**) irrespective of the experimental factorsز

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Table (6). Effects of NPK nano and non-nanofertilizers on nutrient use efficiency (kg potato/kg nutrient) for both seasons.

Treatment		Nutrient use efficiency (kg potato/kg nutrient) *					
		N		P		K	
		2016	2017	2016	2017	2016	2017
Soil Addition	T1	60.42^{abc}	61.17^{abc}	248.79^{abc}	251.88^{abc}	105.74^{abc}	107.05^{abc}
	T2	58.31^{abc}	59.09^{abc}	240.09^{abc}	243.32^{abc}	102.04^{abc}	103.41^{abc}
	T3	51.73^{c}	53.95^{c}	213.02^{c}	222.16^{c}	90.54^{c}	94.42^{c}
	T4	40.62^{d}	41.25^{d}	167.27^{d}	169.84^{d}	71.09^{d}	72.18^{d}
Foliar Application	T5	52.64^{bc}	53.88^{c}	216.74^{bc}	221.86^{c}	92.12^{bc}	94.29^{c}
	T6	57.34^{abc}	57.97^{bc}	236.12^{abc}	238.72^{bc}	100.35^{abc}	101.46^{bc}
	T7	67.39^{a}	67.74^{a}	277.48^{a}	278.92^{a}	117.93^{a}	118.54^{a}
	T8	62.45^{ab}	63.46^{ab}	257.16^{ab}	261.31^{ab}	109.30^{ab}	111.06^{ab}
L.S.D $_{0.05}$ for rates		10.19	8.70	42.00	35.85	17.85	15.23
Applications		5.099	4.35	21.00	17.92	8.92	7.61

*Figures in columns followed by the same letters are insignificantly different at $P \leq 0.05$ and represent means of three replicates.

The highest nitrogen, phosphorus and potassium use efficiency were recorded in foliar applied 50% NPK nanofertilizers treatment (T7), this might be due to the fact that nanofertilizers have large surface area and small particle size, less than pore size of potato leaves which can increase penetration into vegetative plant from applied surface and improve uptake and nutrient use efficiency of the NPK nanofertilizer over non-nanofertilizers.

Reduction of particle size results in amplified specific surface area and number of particles per unit area of a fertilizer that provide more opportunity to contact of nanofertilizer which leads to more penetration and uptake of the nutrient and thus results in high nutrient use efficiency (Liscano *et al.,* 2000). Below 100 nm nano-fertilizers makes plant use fertilizers more efficiently, reduces pollution, environmentally friendly, dissolve in water more effectively thus increase its metabolic activities (Joseph and Morrison, 2006). Similar findings were given by Kumar et al. (2014) and Jhanzab et al. (2015). Use efficiency of nutrients NPK in chemical fertilizers hardly exceeded 30-35%N, 18-20%P, 35-40%K as recorded as constant in research for recent years. Nanofertilizers intended to improve these nutrients use efficiencies through unique nanoscale properties by rapid and complete absorbance of nutrients by plants which in turn, save fertilizers consumption and minimize environmental risks (DeRosa *et al.,* 2010; Suppan, 2017; Sohair EED, *et al.,* 2018).

Potato harvest index

Results of this research revealed that significant and highest yield harvest index (59.24%) was attained in foliar applied treatment (T_7) (50% of NPK nanofertilizers, foliar applied at half recommended level) and consequently indicating better yield components of potato compared to all other nano or non-nano fertilizer treatments albeit had no significant differences with T_6 (100%) and T_8 (25%) of foliar applied NPK nanofertilizer treatments (Table 7). The lowest yield harvest index was observed in the soil addition treatment of NPK nanofertilizers equivalent to quarter of recommended level of NPK recommended chemical fertilizers (T_4) i.e. 47.25%.

The drive of this research was to reach the optimal production and quality of potato crop using NPK nanofertilizers in equivalent or lower rates of recommended levels of NPK chemical fertilizers without retrograde effects upon yield production or quality. The production of the crop is determined by many factors including the harvest index indicating the percentage of assimilates portioned to the economic yield of the plant.

Results of this study indicated that foliar application of nanofertilizers increased the assimilation flow from biological yield to potato tubers fresh and dry yields and clearly showed the positive effect on harvest index and all measured potato growth aspects even in lower amounts compared to control (recommended levels of NPK chemical fertilizers). Crop yield potentiality of a plant variety is dependent initially upon genotype but it can be extra improved by practicing suitable agronomic activities in which fertilization management is of prime rank. The increase in potato yield production and quality attributes in foliar nanofertilizer applied treatments might be due to nano-NPK promotes plant to absorb water and nutrients, yet improved photosynthesis, where nano-NPK are considered the biological pump for plants to absorb water and nutrients increasing harvest index which resulted in increased biomass and yield production (Ma *et al.*, 2009; Wu, 2013; Abdel-Aziz *et al.*, 2016; Meena *et al.*, 2017 Sohair EED *et al.*, 2018). The significant increases in potato yield productivity and quality as influenced by foliar application of nano-NPK fertilizers over non-nanofertilizers might be attributed to nanofertilizers features of small sizes and high specific surface areas which facilitate easy absorbance of nutrients through potato leaves stomata and fast translocation in plants (Dhoke *et al.*, 2013; Abdel-Aziz *et al.*, 2016; Meena *et al.*, 2017 Sohair EED *et al.*, 2018).

Table (7). Effects of NPK nano and non-nanofertilizers on potato harvest index (HI %) for both seasons.

Treatments		Harvest Index (HI %)*					
		Biological yield		Economical yield		Harvest index	
		2016	2017	2016	2017	2016	2017
Soil Addition	T1	39.33^{abc}	39.69^{abc}	21.15^{abc}	21.41^{abc}	53.77^{b}	53.94^{b}
	T2	38.60^{abc}	39.05^{abc}	20.41^{abc}	20.68^{abc}	52.86^{b}	52.95^{b}
	T3	36.13^{bc}	36.74^{bc}	18.11^{c}	18.88^{c}	49.45^{bc}	51.07^{b}
	T4	29.79^{d}	30.55^{d}	14.22^{d}	14.44^{d}	47.73^{c}	47.25^{c}
Foliar Application	T5	35.96^{c}	36.51^{c}	18.42^{bc}	18.86^{c}	51.22^{bc}	51.65^{b}
	T6	36.95^{bc}	37.46^{bc}	20.07^{abc}	20.29^{bc}	54.15^{ab}	54.01^{b}
	T7	39.81^{ab}	40.31^{ab}	23.59^{a}	23.71^{a}	59.24^{a}	58.81^{a}
	T8	41.11^{a}	41.56^{a}	21.86^{ab}	22.21^{ab}	53.17^{b}	53.44^{b}
L.S.D $_{0.05}$ for rates		3.74	3.64	3.57	3.04	5.09	3.71
Applications		1.87	1.82	1.78	1.52	2.54	1.86

*Figures in columns followed by the same letters are insignificantly different at $P \leq 0.05$ and represent means of three replicates.

Potato Relative Economic Returns

Relative economic returns were worked out with operating cultivation cost of individual treatment and the cost of production, the data so obtained are represented in Table 8. Significant variations on total and net income has been originated by foliar or soil application of nano and non-nanofertilizers. The maximum net income (96.848 EGP ha^{-1}) were recorded in treatment T_7 (foliar applied of 50% of NPK nanofertilizers) over control (100% of NPK non-nano fertilizers, soil or foliar application) and other treatments and was followed by treatment T_8 which gave net income of 90.566 EGP per hectare. In general, treatment T_7 over both seasons fetched more total income (141,52 and 142.25 EGP) and net income (96.12 and 96.85 EGP), while treatment T_4 fetched less total income (85.31 and 86.62 EGP) and net incomes (42.61 and 43.92 EGP) over both seasons. Also, means data presented in Table 8 revealed that foliar applied 50% of nanofertilizers treatment (T_7) in both potato crop seasons recorded maximum B: C ratios (2.12 and 2.13 EGP) followed by foliar applied 50% of nanofertilizers treatment (T_8) (2.07 and 2.12 EGP) over recommended chemical fertilizers and all treatments in comparison, while, soil applied of 25% of nanofertilizers (T_4) treatment recorded minimum B: C ratios (1.00 and 1.03 EGP) over both seasons followed by (T_6) treatment.

The economic feasibility and usefulness of a treatment can be effectively adjusted in terms of B: C ratio and net income. The variations in the economics of potato cultivation further led to manifest variations in its relative economics (Table 8). Treatments T_7 recorded numerically higher values for net incomes and B: C ratios followed by treatment T_8 which was eventually due to not only significant differences in potato fresh and dry yields but also by lower cultivation costs incurred at using lower rates of nanofertilizers compared to recommended levels of conventional NPK chemical fertilizers (control). Similar results were also stated by Kumar *et al.*, (2014).

Finally, from this research, it could be concluded that foliar application of NPK nanofertilizers enhanced Egyptian potato yield production and quality, reduced cost of fertilization (approximately, nano 50% and 25% of recommended chemical fertilizers of NPK), and also minimized environmental hazards. Nanofertilizers became a trend to diminish fertilizers loss and consumption as well as minimizing environmental pollution as absorbed by plants rapidly and completely as per requirements in a phased manner. Nanofertilizers are excellent alternatives for soluble conventional chemical fertilizers where the nutrients are released at slower rates throughout the growth cycle in order to plants uptake nutrients before leaching (Sohair EED *et al.,* 2018; Eissa, 2019). These nanoscale polymer fertilizers confirm slow and targeted efficient release at the exact time for crop requirements during growth cycle ensuring fertilizer use efficiency. Tarafdar *et al.,* (2014), stated that nanofertilizers being encapsulated in nanoparticles increased the uptake of nutrients, improved soil physicochemical properties.

CONCLUSIONS

Foliar application of NPK nanofertilizers at equivalent or lower rates of recommended levels of NPK non-nanofertilizers (chemical fertilizers) had produced a beneficial effect on all potato yield and yield parameters compared to control (conventional chemical fertilizers). In general, significant use impact of nano and non-nanofertilizers was observed on potato yield and yield growth quality parameters for fertilizer foliar application compared to soil addition. Potato yield and yield parameters were significantly improved via different rates of NPK nanofertilizers as it was observed that foliar addition of NPK nanofertilizers at lower rates of 25% or 50% was equal or more effective in improving all potato yield and yield parameters than 100% NPK chemical fertilizers under field conditions. In light of obtained and discussed results, it could be concluded that nanofertilizers played a significant role in sustaining potato productivity and quality and can be completely in lower rates substitute chemical fertilizers. This substitution of conventional NPK chemical fertilizers by using nanofertilizers in lower rates plus organic fertilizers can be useful in reducing overall cultivation costs and avoiding chemical fertilizers environmental hazards and harmful impacts on soil and public health.

Table (8). Effects of NPK nano and non-nanofertilizers on potato relative economics for both seasons.

Treatments		Potato Relative Economic Analysis* (EGP)						
		Cultivation Costs	Total Income		Net Income		B/C ratio	
			2016	2017	2016	2017	2016	2017
Soil Addition	T1	45,800	126,882^{abc}	128,460^{abc}	81,082^{abc}	82,660^{abc}	1.77^{ab}	1.80^{ab}
	T2	50,800	122,448^{abc}	124,092^{abc}	71,648^{bc}	73,292^{bc}	1.41^{bc}	1.44^{bc}
	T3	45,400	108,642^{c}	113,304^{c}	63,242^{cd}	67,904^{c}	1.39^{bc}	1.50^{bc}
	T4	42,700	85,308^{d}	86,616^{d}	42,608^{d}	43,916^{d}	1.00^{c}	1.03^{d}
Foliar Application	T5	45,800	110,538^{bc}	113,148^{c}	64,738^{c}	67,348^{c}	1.41^{bc}	1.47^{bc}
	T6	50,800	120,420^{abc}	121,746^{bc}	69,620^{bc}	70,946^{c}	1.37^{bc}	1.40^{cd}
	T7	45,400	141,516^{a}	142,248^{a}	96,116^{a}	96,848^{a}	2.12^{a}	2.13^{a}
	T8	42,700	131,154^{ab}	133,266^{ab}	88,454^{ab}	90,566^{ab}	2.07^{a}	2.12^{a}
L.S.D $_{0.05}$ for rates			21420	18284	21420	18284	0.4596	0.3872
For Applications			10710	9142.2	10710	9142.2	0.2298	0.1936

*Figures in columns followed by the same letters are insignificantly different at $P \leq 0.05$ and represent means of three replicates.

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تأثيرات استخدام الأسمدة النانومترية والتقليدية علي جودة البطاطس وانتاجيتها

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كثير من الدراسات الحديثة اوضحت انه لتحقيق الزراعة المستدامة مع أقصى قدر من الآنتاج والحد الأدنى من المخاطر البيئية لابد من استخدام الأسمدة النانومترية. من أجل ذلك أجريت تجارب حقلية خلال موسمي الزراعة 2016 و 2017 في مزرعة البحوث- كلية الزراعة - جامعة المنيا للاجابة علي التساؤل هل يمكن استعمال الأسمدة النانومترية بكميات مكافئة او أقل من الموصي به من الأسمدة المعدنية التقليدية (NPK) في نظم زراعة البطاطس بدون آثار عكسية علي انتاجية المحصول وجودته.

تمت اجراء دراسة مقارنة بين اسمدة NPKالمعدنية (معاملة الكنترول) بالمعدلات الموصى بها بالأسمدة النانومترية Nano NPK بنسب (100٪ و50٪ و25٪) باستعمال الرش الورقي او الاضافة الي التربة على إنتاجية البطاطس وجودتها.

أظهرت النتائج ان معاملات التسميد النانو NPK رشا بمعدلات 50% و25% من الكميات الموصي بها اعطت قيم اعلي من الانتاج (23.59 طن هكتار في معاملة 50%) ونسبة النشا (79.62٪)، وكفاءة استعمال الاسمدة النانومترية (67.74، 278.92، 118.54 كيلوجرام بطاطس/ كيلوجرام مغذي)، دليل الحصاد (59.24٪) وسجلت أيضا هذه المعاملات أقل كمية من تركيز النترات في البطاطس (1.15 جم / كجم) وذلك كمؤشر ضار في محتوي درنات البطاطس.

أتضح من النتائج ان استخدام الرش الورقي للأسمدة النانومترية NPK بمعدل 50 ٪ أعطى أعلى انتاج وجودة في المحصول مع المحافظة على البيئة.

الكلمات المفتاحية: الأسمدة النانومترية، التسميد الورقي، دليل حصاد البطاطس.