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Impact of Bio- and Organic Fertilizers on Potato Yield, Quality and Tuber Weight Loss After Harvest

Sayed F. El-Sayed · Hassan A. Hassan · Mohamed M. El-Mogy

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Abstract This study was conducted to assess whether organic fertilization alone or with bio-fertilization could replace mineral fertilization in potato production with no adverse effect on quantity or quality. Therefore, two field experiments were conducted at Maba Farm, Cairo—Alexandria Desert Road in Egypt to evaluate the impact of mineral, organic, and bio-fertilizers on a sandy soil on yield, quality, and weight loss after harvest of potato tubers. Control plots were treated with recommended rates of mineral fertilizer + 11.9 t ha^{-1} compost and the other treatments were 23.8 t ha^{-1} compost, 23.8 t ha^{-1} compost + bio-fertilizer, 11.9 t ha^{-1} compost + bio-fertilizer, 50% of mineral fertilizers + 23.8 t ha^{-1} compost, 50% of mineral fertilizers + 23.8 t ha^{-1} compost + bio-fertilizer, 50% of mineral fertilizers + 11.9 t ha^{-1} compost + bio-fertilizer, and 35.7 t ha^{-1} compost. There were significant increases in the total and marketable yield of potato crops from plots treated with 50% of the recommended mineral fertilizers plus 23.8 t ha^{-1} compost with or without bio-fertilizer as well as from plots that received compost at the rate of 35.7 t ha^{-1}, compared with plots treated with full dose of mineral fertilizer plus 11.9 t ha^{-1} compost (control). Compost at 23.8 t ha^{-1} + bio-fertilizer resulted in a significant increase in marketable yield. Nevertheless, total yield obtained from plots treated with compost at 23.8 t ha^{-1} alone or plus bio-fertilizer did not differ significantly from the conventional control treatment. Compared with conventional fertilizer treatment, plots receiving compost at 23.8 t ha^{-1} alone or at 11.9 t ha^{-1} plus 50% mineral fertilizers and bio-fertilizer showed a lower nitrate content in potato tubers. Bio-fertilizer + organic fertilizer at a rate of 11.9 t ha^{-1} reduced marketable yield by 11.8% and total yield by 9.2%, compared with using organic fertilizer at a rate of 23.8 t ha^{-1} compost. So, for export of organic potato, which is characterized by 2–3-fold higher product prices, bio-fertilizer in the present study could not be an alternative to organic fertilizer. The highest nitrate content of tubers was obtained in control plots and plots that received 35.7 t ha^{-1} compost. Conventional fertilizer showed significantly higher weight loss of potato tubers during cold storage

S. F. El-Sayed · H. A. Hassan · M. M. El-Mogy (✉)
Vegetable Crops Department, Faculty of Agriculture, Cairo University, Giza, Egypt
e-mail: elmogymmm75@yahoo.com

than all other treatments. Tuber K content was low in organic potato, whereas no effect was recorded on tuber N, P, or starch content. Hence, these results suggest that organic production of potato (at the level of 23.8 t ha^{-1} compost) could be an alternative to conventional production without significant reduction in yield, and with low nitrate content and better storability.

Keywords Bio-fertilizer · Compost · Organic fertilizer · *Solanum tuberosum*

Introduction

Potato (*Solanum tuberosum* L.) is one of the world's major staple crops after rice, wheat, and maize. Potato crops occupied 19,278,549 ha and produced 365,365,367 tons of tubers in 2012 (FAO 2014). In 2010, potato production in Egypt was 3,643,217 tons with more than 637,434 tons exported at a value of US$250,654 million (FAO, http://www.fao.org).

Organically grown food is attractive to both scientific and non-scientific communities (Hajšlová et al. 2005). Health benefits associated with organic food remains a focal point for research and production (Heaton 2001). For potato, health benefits associated with organic production remains a debatable issue.

Several literature reviews have indicated that potatoes produced with organic practices are healthier than potatoes produced using conventional methods. Organic potatoes contain less nitrate (Boligłowa and Gleń 2003; Erhart et al. 2005; Lairon 2009) than potatoes produced with conventional practices. Likewise, increases in dry matter (Rembialkowska 1999; Moschella et al. 2005), vitamin C (Hajšlová et al. 2005), phenolic compounds (Hamouz et al. 2005), total amino acids (Maggio et al. 2008), total protein (Camin et al. 2007; Maggio et al. 2008), total sugars, and mineral elements (Wszelaki et al. 2005; Hajšlová et al. 2005; Rembialkowska 2007) were noted for organic potatoes when compared to conventional potatoes. In contrast, other research evidences that organically produced potato tubers contained a significantly lower content of total nitrogen, crude protein (Bartova et al. 2013), vitamin C (Warman and Havard 1998), reducing sugars (Hamouz et al. 2005), and dry matter (Pither and Hall 1990) than conventionally produced potatoes. In other reports, significant differences were not detected between organic and conventional potato tubers regarding starch (Makaraviciute 2003; Maggio et al. 2008), essential amino acids, reducing sugars and dry matter (Maggio et al. 2008), phenolic compounds (Woese et al. 1997), or ascorbic acid and dry matter (Camin et al. 2007).

The main challenges for organic production are management of nutrients, diseases, and insects (Finckh et al. 2006). For potatoes, the impact of proper fertility extends beyond harvest to storage where quality loss depends on storage management treatments and fertility management during production (Gottschalk and Ezhekiel 2006). Production practices which improve nutrient use are of interest to farmers. Benefits of compost amendments to soil include correcting Fe deficiency; increasing the uptake of Fe, Zn, Cu, and Mn; pH stabilization; and faster water infiltration rate due to enhanced soil aggregation (Stamatoados et al. 1999). Soils supplied with compost initially had a lower soil pH than those supplied with synthetic fertilizers (Bulluck et al. 2002). The use of organic fertilizers into soil increases yield due to increasing the efficiency of mineral fertilizers (Stamatoados et al. 1999). Many studies showed that yields of potato, pepper, and soybean provided by conventional and organic cultures are comparable (Volterrani et al. 1996; Delate et al. 2003; Lang 2005).

However, organic fertilizers increase the nitrogen levels in some crops such as potatoes, to a point where nitrogen levels exceed thresholds allowed for exportation (170 kg N ha^{-1} per year, according to EU regulation nos. 834/2007 and 889/2008, www.imcert.it) An alternative to chemical and organic fertilizers is bio-fertilizers derived from microorganisms. Bio-fertilizer using mycorrhiza and *Azospirillum* was found to reduce nitrate and nitrite contents of potato tubers (Hammad and Abdel-Ati 1998; Abou-Hussein et al. 2002). Bio-fertilizers, therefore, can be useful in organic vegetable production.

In principle, bio-fertilizers are less expensive and more environmental-friendly than chemical fertilizers. Yazdani et al. (2009) discussed the benefits of using bio-fertilizers, which include impacts on the uptake of plant nutrients, such as phosphorus (Bojinova et al. 1997; Vessey 2003; Abou El-Khair and Nawar 2010; Abou-Zeid and Bakry 2011), nitrogen (Hammad and Abdel-Ati 1998), and potassium (Sheng et al. 2002). They also have beneficial effects on plant growth (Malboobi et al. 2009; Abou El-Khair and Nawar 2010; Abou-Zeid and Bakry 2011) and cause significant increase in yield in comparison with the non-inoculated control (Hammad and Abdel-Ati 1998; Atimanav and Adholeya 2002; Clarson 2004; Jen-Hshuan 2006; Douds et al. 2007; Abou El-Khair and Nawar 2010; Abou-Zeid and Bakry 2011).

Our objectives were (1) to determine if potato could be grown organically with no adverse effect on quantity or quality, as compared with conventional production; and (2) to identify how extra bio-fertilization would impact potato production under organic and mineral fertilization regimes.

Material and Methods

Location of the Experiment and its Layout

During the summers of 2009 and 2010, the current research was conducted at Maba Farm, Cairo—Alexandria Desert Road, Egypt, on a sandy soil type described below. The commercial potato cultivar Santé was used. Fertilizer treatments were arranged in a complete randomized block design with four replicates.

Soil Analysis

A soil sample was collected from the experimental field at the beginning of the experiment. Physical and chemical properties of the experimental soil were determined at the standard soil-testing laboratory of the Central Laboratory of Agricultural Climate (CLAC). The chemical analysis was carried out according to the procedures outlined by Richards (1954), while mechanical and physical analysis was carried out according to Jackson (1958). The chemical, mechanical, and physical properties of the collected soils are given in Table 1.

Table 1 Physical and chemical properties of sandy soil before fertilizer treatments application

Soil characteristics	Values
Particle size distribution (%)	
Coarse sand	58.63
Fine sand	37.23
Silt	2.07
Clay	2.07
Texture class	Sandy
Saturation percentage	19
Chemical analyses	
Organic matter (%)	0.13
$CaCO_3$ (%)	1.012
pH (1:2.5 soil suspension)	7.62
EC (dS/m)	2.34
Soluble ions (mol l^{-1})	
Ca^{++}	0.137
Mg^{++}	0.171
Na^{+}	0.124
K^{+}	0.011
CO_3^{--}	–
HCO_3^{-}	0.78
Cl^{-}	0.186
SO_4^{--}	0.181
Available nutrients (mg kg^{-1})	
15.12	N
7.2	P
74.85	K

Climatic Conditions

Climatic data from the Wadi El Natrown meteorological station managed by the Egyptian Ministry of Agriculture indicated that the weather experienced during the summers of 2009 and 2010 was typical. Average relative humidity during the growing period of potato (January–June) was 59.79 and 58.71% in 2009 and 2010, respectively. Average temperature during the same months was 29.44 and 32.94 °C for the 2 years (Table 2).

Soil Preparation

As per standard commercial cultural practice for sandy soil, soil salt was leached before planting using a center pivot irrigation system for 5 days. After partial drying, the field was plowed using a chisel plow. Thereafter, the experimental field was divided into 180-cm-wide strips (using a soil marker). For each fertilizer treatment described below,

Table 2 Average of air temperature and relative humidity during the growing seasons 2009 and 2010

Date	Max. temp	Min. temp	Max. RH	Min. RH
9 Jan	25.8	10.2	84	30
9 Feb	25.1	10.2	84	30
9 Mar	30.9	10.0	83	26
9 Apr	30.7	10.1	88	30
9 May	30.5	9.7	86	35
9 Jun	31.9	12.9	86	36
9 Jul	31.2	10.6	94	45
10 Jan	25.1	10.3	84	32
10 Feb	29.8	9.5	82	31
10 Mar	35.5	11.4	84	32
10 Apr	31.3	12.6	85	30
10 May	37.7	12.4	88	24
10 Jun	37.5	11.3	90	26
10 Jul	33.7	12.3	99	35

two 1.80-m strips were divided into 50-m long sections. Total plot area was 180 m^2 (3.6 m by 50 m) to which compost, mineral fertilizers as well as feldspar and rock phosphate, according to fertilizer treatment described below, were broadcasted, using spreaders (Kuhn fertiliser spreaders, MDS models, UK and MDS Rauch Fertiliser Spreader 10.1/11.1/12.1, Holland, respectively). Organic, mineral fertilizers and natural rocks were then incorporated into the soil using a rotavator (Grimme GF 90-4, Holland).

Cultivation

Potato seeds were cut (approximately 35 g pieces) and left for a week for curing before planting. All potato tuber seeds were treated with the bio-fungicide Bio-health (containing *Trichoderma* sp. + *Bacillus subtilis*) at a rate of 150 ml per 100 l water to mitigate soil borne diseases. Potato tubers were mechanically planted on 26 January 2009 and 6 February 2010, respectively, using a four-row-planter (Grimme GL 34E, Holland) leaving 25 cm between hills and 90 cm between rows in all plots. Therefore, each plot was 50 m by 3.6 m with four rows of 0.90 m.

Treatments

The experiment consisted of eight treatments as follows: (1) Mineral fertilizer (full dose of NPK + 11.9 t ha^{-1} compost (control); (2) 23.8 t ha^{-1} compost; (3) 23.8 t ha^{-1} compost + bio-fertilizer + rock phosphate + feldspar; (4) 11.9 t ha^{-1} compost + bio-fertilizer + rock phosphate + feldspar; (5) 50% mineral fertilizer + 23.8 t ha^{-1} compost; (6) 50% mineral fertilizer + 23.8 t ha^{-1} compost + bio-fertilizer + rock phosphate + feldspar; (7) 50% mineral fertilizer + 11.9 t ha^{-1} compost + bio-fertilizer + rock phosphate + feldspar; and (8) 35.7 t ha^{-1} compost.

Mineral fertilizers were applied at a rate of 285.6 kg N+178.5 kg P_2O_5+ 357 K_2O ha^{-1} divided into two equal parts and applied during soil preparation and 6 weeks after planting. Bio-fertilizers consisted of nitrogen fixers (*Azospirillum brasilense* and *Azotobacter chroococcum*), P-dissolving bacteria [*Bacillus megaterium* and vesicular-arbuscular mycorrhiza (VAM)] and K-dissolving bacteria (*Bacillus cereus*) were applied just after planting, and three times after planting at a concentration of 1.2×10^9 CFU ml^{-1}. Each plant received 10 ml of the bio-fertilizer mixture. In addition, rock phosphates (22.8% P_2O_5) at 357 kg ha^{-1} + feldspar (10.6% KO_2) at 1547 kg ha^{-1} were applied to bio-fertilizer treatments during soil preparation. Bio-fertilizers were obtained from existing isolate samples in the Laboratory of Microbiology, Faculty of Agriculture, Cairo University.

Application of Compost, NPK, and Bio-Fertilizer

Application of compost was done at two equal doses, the first one was applied during land preparation and the second one was added 45 days after planting. Analysis of compost used is presented in Table 3. Regarding mineral fertilization application, all amounts of phosphorus and potassium were applied manually during soil preparation in the form of superphosphate (15%) and potassium sulfate (48%), while nitrogen was

Table 3 Analysis of compost

Characters	Value
Organic carbon (%)	36.1
Organic matter (%)	65
C / N ratio	1:16
pH	8.5
EC (dS/m)	4.3
Total nitrogen %	1.5
N (ammonium) ppm	460
N (nitrate) ppm	120
Total phosphor %	0.5
Total potassium	1.26
Sodium chloride %	1.31
Zn (ppm)	28
Fe (ppm)	1025
Mn (ppm)	115
Cu (ppm)	180
Ash %	9
Nematode	No
Humidity (%)	26
Weight per m^3 (kg)	500
Weed seeds	No
Parasites	No

divided into two equal portions, and applied during soil preparation and 6 weeks after planting in the form of ammonium sulfate (20.5%). On the other hand, bio-fertilizer was applied just after planting, and 3, 6, and 9 weeks after planting. Bio-fertilizer was applied in the form of liquid using knapsack pesticide sprayer.

Field Management and Harvest

Biological control for aphids was followed as needed using a predator, viz. lacewings, and for potato tuber moth using a mixture of *Trichogramma* species, viz. *T. euproctidis*, *T. cordubensis*, *T. bourarchae* and *T. evanescens* carts were used four times, every 10 days, starting 40 days after planting. All treatments were also given a bio-fungicide; viz. Biocit (extract), every 10 days, starting 60 days after planting, as a foliage treatment, using a tractor sprayer (Puma), at the rate of 480 l ha^{-1}, to avoid infection with potato foliage diseases. Spray irrigation using pivot was used. Vines were killed in all plots when the majority of tubers had reached 3.2–7 cm in diameter. Vines were manually mowed 3 days before harvest. Mechanical harvest (using digger, Grimme, RL 1500, Holland) was done 105 days after planting in both seasons. Potatoes were graded for size; thereafter, each size was weighed to record marketable, unmarketable, and total yield. After harvest, potatoes were placed in a dark storage at 12 °C for 15 days for curing; then tubers were sorted to select only healthy tubers to store them until postharvest evaluation.

Data Recorded

Total, Marketable, and Unmarketable Yield

At harvest, the following yield data were recorded: total yield (t ha^{-1}); marketable yield (healthy (free of pathogens and insects) tubers larger than 30 mm in diameter) and unmarketable yield (healthy tubers smaller than 30 mm in diameter).

Tuber Quality

At harvest, a sample of 100 g fresh weight of tubers was taken from each plot to determine their contents of nitrate, starch, N, P, and K.

Tuber Weight Loss

At harvest, a sample of tubers was taken from each plot and packed in a sack. These samples were cured (in room at 25 °C and 95% relative humidity), then 10 kg of healthy and marketable tubers were stored at 10 °C and ≥90 relative humidity for 4 months. Weight loss was determined 60 and 120 days after harvest.

Chemical Analysis

To analyze N, P, and K in potato tubers, samples were taken at harvest from each plot, dried at 70 °C, by using stainless steel equipment. From each sample, 0.2 g was digested using 5 ml of a mixture of sulfuric (H_2SO_4) and per chloric ($HClO_4$) acids (1:1) as described by Peterburgski (1968) to determine NPK concentrations. Total nitrogen was determined by micro-Kjeldahl method as explained by Hesse (1971). Total phosphorus was determined calorimetrically at wavelength 680 nm using a spectrophotometer (Hitachi, U-1000) as described by Cottenie et al. (1982). Total potassium was determined by using a Gallen Kamp flame photometer as mentioned by Cottenie et al. (1982). Starch was determined in the dried samples of tuber according to the method of Luff-Schoorl, which proceeds by the acid hydrolysis of starch and titration by sodium fthio-sulfate (AOAC 1990). Plant nitrate concentration was determined in the dried samples of tubers using the hydrazine reduction method in 2% acetic acid plant extract and analyzed using an auto analyzer (Kampshake et al. 1967).

Statistical Analysis

The experiment was performed twice in 2009 and 2010 each in a complete randomized block design with four replicates. Results from identical experiments of the 2 years were combined for analysis. Significant differences among treatments means were determined at $P \leq 0.05$ by using Duncan test. Data of the present study were statistically analyzed using the M Stat program (version 4).

Results

Effect of Organic and Bio-Fertilizers on Total, Marketable, and Unmarketable Yield

The effect of organic and bio-fertilizers on unmarketable, marketable, and total yield is presented in Table 4. Plots treated with compost at 23.8 t ha^{-1} with bio-fertilizer, or plus 50% mineral fertilizer, or plus both bio-fertilizer and 50% of mineral fertilizer, and plots treated with 35.7 t ha^{-1} compost had a significantly higher marketable yield compared with control plots. These treatments, except compost at 23.8 t ha^{-1} with bio-fertilizer were higher in total yield compared with the conventional control treatment. In contrast, total yield obtained from plots treated with compost at 23.8 t ha^{-1} alone or plus bio-fertilizer did not significantly differ from the conventional control treatment. Plots which received 23.8 t ha^{-1} compost plus bio-fertilizer or plus 50% of mineral fertilizer had significantly lower unmarketable yield than those that received conventional mineral fertilizer. On the other hand, there were no significant differences between control treatment and the other treatments.

Effect of Organic and Bio-Fertilizers on NPK Content of Potato Tubers

As shown in Table 5, using compost at 11.9 t ha^{-1}+50% of mineral fertilizer + bio-fertilizer significantly decreased tuber N content as compared with the control. Meanwhile, no significant differences were recorded for N tuber content between control and the other treatments. There were no significant differences among treatments for P content of tubers. Compared with control, lower K content in tubers was obtained in plots that received compost at 23.8 or 35.7 t ha^{-1}.

Table 4 Effect of some organic and bio-fertilizers on unmarketable, marketable and total yield (tons per hectare)

Treatments per hectare	Unmarketable yield	Marketable yield	Total yield
MF + 11.9 t ha^{-1} compost (control)	2.69 abc	8.18 d	10.88 cd
23.8 t ha^{-1} compost	1.88 cd	8.68 cd	10.57 cd
23.8 t ha^{-1} compost+BF	1.62 d	10.38 bc	12.00 c
11.9 t ha^{-1} compost+BF	1.95 bcd	7.65 d	9.60 d
50% MF+23.8 t ha^{-1} compost	1.67 d	16.31 a	18.03 a
50% MF+23.8 t ha^{-1} compost+BF	2.78 ab	14.63 a	17.66 a
50% MF+11.9 t ha^{-1} compost+BF	3.32 a	7.56 d	10.91 cd
35.7 t ha^{-1} compost	2.96 a	11.67 b	14.67 b

Means followed by different letters in the same column differ significantly according to the Duncan test at $P<0.05$

MF Mineral fertilizer, *t* tons, *BF* Bio-fertilizers

Effect of Organic and Bio-Fertilizers on Nitrate and Starch Content of Potato Tubers

The effect of organic and bio-fertilizers on nitrate and starch content of potato tubers is presented in Table 5. The highest nitrate content of tubers was obtained in control plots and plots that received 35.7 t ha^{-1} compost. In contrast, the lowest nitrate content was recorded in plots that received compost at 23.8 t ha^{-1} alone or 11.9 t ha^{-1}+50% of mineral fertilizer + bio-fertilizer. These two treatments showed significantly lower nitrate content of potato tubers than the control. On the other hand, no significant differences were detected among all treatments for starch content of tubers.

Table 5 Effect of some organic and bio-fertilizers on the percentage of nitrogen, phosphorus, potassium, starch and nitrate in tubers at harvest stage

Treatments per hectare	N (%)	P (%)	K (%)	Starch (%)	Nitrate (%)
MF+11.9 t ha^{-1} compost (control)	2.40 a	0.88 a	4.67 a	77.61 a	0.23 ab
23.8 t ha^{-1} compost	2.25 ab	0.91 a	2.89 c	77.60 a	0.11 d
23.8 t ha^{-1} compost+BF	1.26 ab	0.97 a	4.87 a	75.48 a	0.21 bc
11.9 t ha^{-1} compost+BF	2.16 ab	0.96 a	4.41 a	75.95 a	0.23 abc
50% MF+23.8 t ha^{-1} compost	2.26 ab	0.66 a	4.13 ab	77.49 a	0.21 b
50% MF+23.8 t ha^{-1} compost+BF	2.20 ab	0.77 a	4.85 a	73.92 a	0.22 abc
50% MF+11.9 t ha^{-1} compost+BF	2.05 b	0.84 a	4.68 a	73.89 a	0.19 c
35.7 t ha^{-1} compost	2.23 ab	0.94 a	3.61 bc	77.02 a	0.25 a

Means followed by different letters in the same column differ significantly according to the Duncan test at $P<0.05$

MF Mineral fertilizer, *t* tons, *BF* Bio-fertilizers

Effect of Organic and Bio-Fertilizers on Weight Loss of Potato Tubers

The results shown in Table 6 indicate that the weight loss rates of the samples from control plots were statistically higher than in the samples from the other treatments after 60 and 120 days from harvest. After 60 and 120 days from harvest, the lowest weight loss rates were obtained from plots that received compost at a rate of 11.9 t ha^{-1} + bio-fertilizer and those that received 50% of mineral fertilizer + 11.9 or 23.8 t ha^{-1} compost + bio-fertilizer. Moreover, compost at a rate of 11.9 t ha^{-1} + % of mineral fertilizer + bio-fertilizer was the most effective treatment in reducing weight loss after 120 days from harvest.

Discussion

The present study indicated that using compost at the rate of 23.8 t ha^{-1} gave similar yield to the plots that received the recommended treatment of mineral fertilizers under the same conditions. It was reported that yields of crops grown in organic and conventional production systems can be the same (Drinkwater et al. 1995; Stamatoados et al. 1999; Delate et al. 2003; Lang 2005). Increasing rate of compost to 35.7 t ha^{-1} led to a significant increase in both marketable and total yield (Table 4). The sandy soil in the experimental site is characterized with poor water holding capacity and low mineral content. Adding high rate of compost improved water holding capacity of soil and improved plant growth and productivity especially marketable tubers (data not shown). Organic fertilizers improve the physical condition of the soil (Stamatoados et al. 1999). Compost application once in a 3-year potato rotation was beneficial for both soil physical and biological properties, and for potato productivity (Carter et al. 2003). Likewise, Amber et al. (2011) indicated that US #1 tuber yields were significantly higher for composted treatments in comparison to the control treatment. Some of these increases in growth may have been due to increases in

Table 6 Effect of some organic and bio-fertilizers on weight loss after 60 and 120 days from harvest

Treatments per hectare	60 DAH Weight loss (%)	120 DAH Weight loss (%)
MF+11.9 t ha^{-1} compost (control)	4.20 a	10.07 a
23.8 t ha^{-1} compost	1.75 cd	6.45 cd
23.8 t ha^{-1} compost+BF	2.20 b	6.80 c
11.9 t ha^{-1} compost+BF	1.12 ef	5.80 de
50% MF+23.8 t ha^{-1} compost	2.05 bc	6.40 cd
50% MF+23.8 t ha^{-1} compost+BF	1.40 de	5.20 ef
50% MF+11.9 t ha^{-1} compost+BF	0.90 f	4.65 f
35.7 t ha^{-1} compost	2.20 b	8.13 b

Means followed by different letters in the same column differ significantly according to the Duncan test at $P<0.05$

MF Mineral fertilizer, *t* tons, *BF* Bio-fertilizers, *DAH* Days after harvest microbial biomass in soils receiving composts which increased nutrient mineralization (Norman et al. 2003) or to the effects of humates (Canellas et al. 2000).

Because use of organic fertilizers in Egypt is limited by the threshold of allowable nitrogen level (170 kg N ha^{-1} per year, according to EU regulation nos. 834/2007 and 889/2008 (www.imcert.it), especially for exportation of organic products, using bio-fertilizer was involved in the present study to reduce the rate of organic fertilizer. The present results indicated that plots treated with compost at 23.8 t ha^{-1} with bio-fertilizer or plus 50% of mineral fertilizer or plus both bio-fertilizer and 50% of mineral fertilizer had a significantly higher marketable yield compared with control plots. These treatments, except compost at 23.8 t ha^{-1} with bio- fertilizer, caused also significantly greater total yield compared with the conventional control treatment (Table 4). The enhancement effects of bio-fertilizers in increasing total and marketable potato yield (Table 4) can be attributed to the production of plant growth regulators by microorganisms (Norman et al. 2003). Our results indicated that marketable tubers l (larger than 30 mm in diameter) were increased significantly by organic and bio-fertilizers. The organisms found in bio-fertilizers solubilize the unavailable forms of inorganic-P (Venkateswarlu et al. 2007) and potassium rock through production and secretion of organic acids (Bin Zakaria 2009). *Azotobacter* spp. are most specifically noted for their nitrogen fixing ability but they have also been noted for their ability to produce different growth hormones (IAA and other auxins, such as gibberellins and cytokinins), vitamins and siderophores. *Azotobacter* is capable of converting nitrogen into ammonia, which, in turn, is taken up by the plants (Kamilet al. 2008). *Azotobacter* spp. can also produce antifungal compounds to fight against many plant pathogens (Jen-Hshuan 2006). Inoculation with *Azospirillum* spp. mainly changes growth or morphology of roots, by increasing the number of lateral roots and root hairs; the enlargement of the root surface results in better nutrient uptake and an improved water status that may be the main factor enhancing plant growth (Bottini et al. 2004).

Using a mixture of bio-fertilizers + organic fertilizer at a rate of 11.9 t ha^{-1} instead of using organic fertilizer at a rate of 23.8 t ha^{-1} compost, reduced marketable yield by 11.8% and total yield by 9.2%. So, for export of organic potato, which is characterized with 2–3-fold higher product prices, bio-fertilizer in the present study could not be an alternative to organic fertilizer.

Compost alone at 23.9 or 35.7 t ha^{-1} had no effect on the nitrogen and phosphorus contents of potato tubers, while these treatments significantly reduced the potassium content of the tubers (Table 5). The present results are compatible with the results obtained by Mourão et al. (2008) who indicated that the differences between the composted organic pig manure and conventional mineral fertilizer regarding the concentration of nitrogen tubers were not significant.

Compost at 11.9 t ha^{-1}+50% of mineral fertilizer + bio-fertilizer reduced tuber content of nitrogen as compared with conventional fertilization. A previous study indicated that using compost (city garbage) at a rate of 57 t ha^{-1} + rock phosphate (28.0% P_2O_5) and feldspar (16.4% K_2O) as natural sources of P and K at the rate of 321 and 700 kg ha^{-1}, respectively + biogein (bio-mixture containing nitrogen fixing bacteria, manufactured by Egyptian Ministry of Agriculture) + *Bacillus megaterium* as phosphate-dissolving bacteria (PDB) + *Bacillus circulans* as silicate decomposing bacteria (SDB), in clay soil, caused significantly lower values of N in tubers 75 days after planting than for the control (recommended full dose of mineral fertilizer (NPK) at the rate of 432 kg N ha^{-1} N, 180 kg P_2O_5 ha^{-1}, and 230.4 kg K_2O ha^{-1} (Awad 2002). In contrast, Arafa and El-Maghraby (2004) found that using a mixture of bio-fertilizers (consisting of nitrogen fixation bacteria, a mixture of phosphate dissolving bacteria, and spray liquid fertilizer containing 24% K and 5% N) in plots that received 240+ 33.6+192 kg ha^{-1} of N, P, and K, respectively, gave significantly higher concentrations of N, P, K, Fe, Mg, and Zn in potato tubers as compared to plots that received the recommended NPK rate (300, 50.5, and 240 kg ha^{-1} of N, P, and K, respectively) but without bio-fertilization inoculation. The contradiction between the present results and the previous ones may be attributed to the variation in the effectiveness of the different strains used in the different studies, the soil type and conditions, cultivar, and the amounts of organic or mineral fertilizers used with the bio-fertilizers. The results of Maggio et al. (2008) indicated that cultivar-specific genetic determinants and cultivation factors, including the farming system, may strongly and specifically interact to affect important quality parameters of potato tubers. They added that this should be considered to improve quality standards in organic farming.

Compost at 23.8 t ha^{-1} showed the lowest nitrate concentration in tubers, followed by 50% of mineral fertilizer + 11.9 t ha^{-1} compost + bio-fertilizer. The observation that organic potatoes contain significantly lower levels of nitrate than conventionally produced tubers (Table 5) is in agreement with findings from several other controlled field experiments (Boligłowa and Gleń 2003; Erhart et al. 2005), and is conceivably related to the lower nitrogen input in organic farming (Rembialkowska 1999). Increasing level of compost to 35.7 t ha^{-1}, however, led to an increase in nitrate percentage in tubers to be similar to that recorded in mineral fertilization. Such results revealed that compost should not exceed a certain level; otherwise, it will have, as mineral fertilizers, an adverse effect on the tuber quality. In this regard, Eppendorfer et al. (1970) reported that tuber N content (expressed as crude protein nutritive value) was positively related to the N available to crops, regardless of N form as initially supplied by various fertilizers, including manure. Muller and Hippe (1987) found that among 10 crop fertility treatments, organic N-treated potatoes contained higher levels of nitrate. On the other hand, the able favorable effect of using 50% MF+ 11.9 t ha^{-1} compost + BFas was similar to that recorded, under sandy soil conditions, by Abou-Hussein et al. (2002) who used 40 m^3 ha^{-1} cattle manure + half rate of mineral NPK, i.e., 360 kg rock phosphate and 180 kg N and 210 kg K_2O ha^{-1} + adding suspensions of bio-fertilizers consisting of soil yeast (*Candida tropicalis*), *Pseudomonas aeruginosa,* and phosphate solubilizing bacteria (*Bacillus megaterium* var. *phosphaticum)* to the soil as compared with using recommended mineral fertilization, which consisted of 96 m^3 ha^{-1} cattle manure, 720 kg rock phosphate, and 360 kg N and 420 kg K_2O ha^{-1}.

In Table 6, our results indicated that potato tubers produced from plots that received organic and bio-fertilizers had the lowest reduction of weight loss compared to plots that received mineral fertilizers (control). Weight losses (separated into water and dry matter) for potato tubers stored at 4 °C and 90% relative humidity were enhanced by increasing N and K fertilization (Kolbe et al. 1995). In organic cultivation, the tubers' content of dry matter was higher than in conventional cultivation (Järvan and Edesi 2009). As a result, this reduction in weight loss may be due to the increase of tuber dry matter by organic and bio-fertilizers.

Hence, these results suggest that organic production of potato (at the level of 23.8 t ha^{-1} compost) could be an alternative to conventional production (mineral fertilization at a rate of 285.6 kg N + 178. 5 kg P_2O_5 + 357 K_2O ha^{-1} + 11.9 t compost ha^{-1}) without significant reduction in yield, and with low nitrate content and better storage ability.

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