Australian Journal of Crop Science

AJCS

AJCS 15(07):1081-1088 (2021) ISSN:1835-2707
doi: 10.21475/ajcs.21.15.07.p3289

Performance of potato cultivars in an organic farming system using organic fertilizers, vermicompost and azolla

Amal K. Abou El-Goud[1], Fahad R. Al-Masoodi[2], Karam A. Elzopy[3*], Mona M. Yousry[2]

[1]Department of Botany (Organic Agriculture), Agriculture Faculty, Damietta University, Egypt
[2]Plant Production Dept., Faculty of Agriculture (Saba-Basha), Alexandria University, Egypt
[3]Department of Soil Science and Agricultural Chemistry, Faculty of Agriculture (Saba-Basha) Alexandria University, Egypt

***Corresponding author: karam2016@alexu.edu.eg**

Abstract

The challenges of food shortages and environmental pollution require the development of safe and effective alternatives to chemical fertilizers. Two field experiments were conducted during the summer season of 2019/2020 in two locations on a private farm to evaluate the performance of three potato cultivars (Sponta, Cara, and Elbieda) under different fertilizer treatments. The experiment was laid out in a split-plot design replicated thrice. The main plots had three potato cultivars, while the sub plots were comprised of seven fertilizer treatments. The results showed that the highest vegetative growth characters, viz. plant height, leaf chlorophyll index, and plant dry weight were produced by Sponta, followed by Cara, while the lowest growth attributes were recorded in Elbeida. Compared to the NPK inorganic fertilizer, organic fertilizers significantly improved the vegetative growth characteristics of potato in all treatments. Among the organic treatments, the highest growth parameters were recorded with the application of mixed organic fertilizer, vermicompost, and *Azollapinnata* (T_1). The highest yield, viz. tuber yield, number of tubers per plant, and tuber weight, and yield quality characteristics, viz. total carbohydrates, starch, and TSS, were also recorded in T_1. Our results demonstrate that the Sponta cultivar grown with the application of mixed organic fertilizer, vermicompost, and *Azollapinnata* (T_1) produced the highest growth, yield, and quality of potato tubers. Thus, we recommend this treatment combination as a sustainable agricultural practice for potato production in similar areas.

Keywords: Potato; Organic Fertilizers; Vermicompost; Azolla.

Introduction

Globally, potato (*SolanumtuberosumL.*) tuber productivity was 377 million tonnes in 2016, ranking as the fourth most productive crop after maize, wheat, and rice (FAO, 2017). Potato yields about 175 kg N/ha, 25 kg P/ha, and 250 kg K/ha (Meena et al., 2016; Romero et al., 2017). Approximately 80% of the tuber weight is water, and starches comprise approximately 70% of the total solids. Due to the high carbohydrate content, potato is a good energy source. Potato is also inexpensive, with high nutritional value and high productivity; thus, contributing to reducing global food shortages and providing food security for a growing world population (Zhang et al., 2018).

Vermicompost is the final product of the biological decomposition of organic materials by earth worms (Meghvansi et al., 2011). This process, called vermicomposting, is widely used to treat various types of organic residues. Vermicomposting is a sustainable, ecologically friendly, and cost-effective process for organic waste management that produces an environmentally safe organic fertilizer for sustainable agricultural practices (Brown, 1995; Tajbakhsh et al., 2011; Chaulagain et al., 2017; Abou El-Goud, 2020a, b, and c). Moreover, several studies have demonstrated the favorable effects of vermicompost organic fertilizer on the growth and yield of crops such as African marigold (Sharma et al., 2017), pakchoi (Churilova and Midmore, 2019), canola (Rashtbari et al., 2020), tomato (Ravindran et al., 2019), and potato (Pérez-Gómez et al., 2017; Darabi et al., 2018).

Azolla, also known as water fern, water velvet, or duckweed, is a genus of aquatic plants normally distributed in pools, streams, and paddy water. Azollais is known for its rapid biomass production and bioremediatory potential (Miranda et al., 2016). Azollaspecies symbiotically coexist with *Anabaena azollae* alga (Razavipour et al., 2018); the nitrogen-fixing capacity of *Anabaena azollae* provides fixed nitrogen for Azolla, while Azolla provides fixed carbon and shelter for the algae (Peters, 1978; Pereira et al., 2014). Azolla is a highly efficient biofertilizer due to its rapid growth and high nitrogen-fixation capacity (Wagner, 1997). Azollacan double its biomass every 3–5 daysand fix between 70 and 110 kg N ha^{-1} (Ventura et al., 1993). Used as abiofertilizer, Azolla increases N, P, K, and micronutrient contents in the soil and enhances microbial activity, porosity, soil water-holding capacity, and water infiltration rate (Mishra et al., 2013; Jumadi et al., 2014). Azolla has been used for centuries as green manure for rice in Vietnam (Lumpkin and Plucknett, 1980). Recently, several studies have confirmed the use of Azolla green manure to improve the growth and yield of maize (Maswada et al., 2021), wheat (Ripley et al., 2003), and chamomile inflorescences (Kawthar et al., 2017).

In this study, we investigate the effects of vermicompost (VC), Azolla (AZ), and mixtures of old organic fertilizers (MOF) on the growth, yield, and quality of three potato cultivars (cv. Cara, Sponta, and Elbieda) under eco-friendly field conditions to enhance crop productivity, produce healthier food, improve soil fertility, and increase farmer income.

Results

Vegetative growth characteristics

Potato vegetative growth characteristics were significantly influenced by the cultivar, fertilizer source, and their interaction (Table 1). The Sponta cultivar, produced the highest plant height (36.44 and 67.83 cm in the first and second location, respectively), dry weight (37.58 and 57.34 g per plant), and leaf chlorophyll index (41.87 and 46.31 SPAD), followed by the Cara cultivar. The Elbeida cultivar produced the lowest growth attributes. Irrespective of potato cultivar, the application of organic fertilizer as MOF + VC+ AZ (T_1) produced significantly higher plant height (39.49 and 76.2 cm in the first and second location, respectively), dry weight (43.34 and 68.1 g per plant), and leaf chlorophyll index (45.39 and 54.14 SPAD) than the other fertilizer treatments. Conversely, the inorganic NPK fertilizer (T_7) produced significantly lower plant heights (23.95 and 41.3 cm, in the first and second location, respectively), dry weight (22.58 and 33.5 g per plant), and leaf chlorophyll index (27.42 and 28.7 SPAD) than all organic fertilizer treatments. The interaction effect between the Sponta cultivar and T_1 on potato growth attributes was significantly superior over the other combinations. The lowest growth parameters among all treatment combinations were recorded in the Elbeida cultivar and T_7 treatment.

Yield and yield attributes

The yield and yield attributes were also significantly influenced by the cultivar and fertilizer treatments. The highest number of tubers per plant (15.16 and 16.8 in the first and second location, respectively), tuber weight (232 and 249 g), and tuber yield (29.29 and 31.79 ton·ha^{-1}), were produced by Sponta, followed by Cara. The Elbeida cultivar produced the lowest yield and yield attributes (Table 2). The highest number of tubers per plant (15.85 and 18.4 in the first and second location, respectively), tuber weight (247 and 281 g), and tuber yield (32.05 and 36.33 ton·ha^{-1}) were produced in T_1. The lowest number of tubers per plant (9.59 and 9.5 in the first and second location, respectively), tuber weight (146 and 155 g), and tuber yield (19.38 and 20.31 ton·ha^{-1}) were produced in T_7. Moreover, the interaction effect between Sponta cultivar and T_1 on yield and yield attributes was significantly superior over the other treatments. The lowest yield and yield attributes among all treatment combinations were recorded in the Elbeida cultivar with T_7.

Tuber quality parameters

The Sponta cultivar produced the best quality tubers, with the highest values of total carbohydrates (59.03 and 51.52%in the first and second location, respectively), starch (12.28 and 14.99 %), and TSS (5.41 and 6.5 %), followed by Cara. Elbeida produced the lowest quality tubers (Table 3). The organic fertilizers in T_1 significantly increased the total carbohydrates (66.2 and 61.9 %in the first and second location, respectively), starch (12.91and 16.85%), and TSS (6.2 and 7.5%) compared with the other fertilizer treatments. The lowest total carbohydrates (40.3 and 33.5%in the first and second location, respectively), starch (7.86 and 9.04%), and TSS (3.6 and 3.6%) were produced in the T_7 treatment. Moreover, the highest quality tubers were produced in the treatment combination of Sponta cultivar and T_1, while the lowest quality tubers were produced by the Elbeida cultivar and T_7.

Tuber nutrient composition

In general, potato cultivars, fertilizer sources, and their interaction influenced tuber N, P, and K content. The Sponta cultivar produced tubers with the highest N (1.61 and 2.15% in the first and second location, respectively), P (0.36 and 0.52%), and K content (2.02 and 2.48%), followed by Cara (Table 4). The lowest NPK content was recorded in Elbeida tubers. The application of inorganic fertilizer (T_7) produced tubers with significantly lower N (1.08 and 1.14%in the first and second location, respectively), P (0.24 and 0.27%), and K (1.29 and1.41%) than those produced in all organic fertilizer treatments. Tubers with the highest N (1.78 and 2.79%in the first and second location, respectively), P (0.40 and 0.57%), and K content (2.13 and 2.81%) were produced in T_1.

Discussion

Our experimental results showed that the Sponta cultivar significantly out-performed Cara and Elbeida with respect to growth, yield, tuber quality, and NPK content, regardless of the fertilizer treatment. Cara ranked second, while Elbeida exhibited the lowest growth, yield, tuber quality, and NPK content. These results are consistent with those reported by Youseef et al. (2017), who found that Sponta and Cara cultivars produced the maximum plant height, plant dry weight, yield, and yield attributes. Similar findings were also reported by Marwaha (1998), Swamina than et al. (1999), and Shafeek et al. (2001), who found significant differences in the growth, yield, and yield attributes among potato cultivars.

Irrespective of potato cultivar, the application of organic fertilizers improved the growth, yield, yield attributes, tuber quality, and NPK content compared with inorganic fertilizers; these findings are consistent with our previous reports (Abou El-Goud, 2020a, b, and c). Enhanced growth and tuber quality with organic fertilizer application may be due to increased organic matter content, cation exchange capacity, and mineral nutrients in the soil, which in turn support potato growth (Mirdad, 2010). These results support those obtained by Shahein et al. (2014), Amara et al. (2015), Bilkis et al. (2018), and Abou El-Goud (2020a, b, and c), who found that the application of organic manure to potato, eggplant, cowpea, and watermelon significantly improved yield and crop characteristics. Organic fertilizer application increases the availability of soil macro- and micro-nutrients and provides nutrients to meet crop requirements, supporting crop production (Mirdad, 2010).

The desired biofertilizer effect of Azolla application can be ascribed to its rapid decomposition, which supplies plants with essential nutrients and enhances the microbial activity, porosity, and water holding capacity of soil (Mishra et al., 2013; Jumadi et al., 2014). de Vries et al. (2016) reported that the application of Azolla with high N content improved soil microbial activity and biodiversity and increased the soil organic matter decomposition and mineralization rates,

Table 1. Effect of organic and inorganic fertilizers on plant height (cm), plant dry weight (g), and leaf chlorophyll index (SPAD) of three potato cultivars in two locations.

Treatments		Plant height (cm)		Plant dry weight (g)		Leaf chlorophyll index (SPAD)	
		1st loc.	2nd loc.	1st loc.	2nd loc.	1st loc.	2nd loc.
(A) Cultivars							
Sponta		36.44 a	67.83a	37.58 a	57.34a	41.87 a	46.31a
Cara		30.96 b	53.81b	32.42 b	50.99b	35.44 b	40.48b
Elbeida		26.32 c	50.08c	27.69 c	41.61c	30.35c	35.90c
$LSD_{0.05}$		0.19	1.47	0.66	0.44	0.24	0.76
(B) Fertilizers							
T_1		39.49a	76.2a	43.34a	68.1a	45.39a	54.14a
T_2		36.56b	70.2b	39.79b	61.9b	41.81b	49.6b
T_3		33.43c	61.4c	35.77c	54.7c	38.47c	44.6c
T_4		30.94d	56.3d	31.53d	49.1d	35.74d	39.9d
T_5		28.20e	50.4e	28.97e	43.6e	32.68e	36.3e
T_6		26.13f	44.9f	25.96f	39.04f	29.69f	33.1f
T_7		23.95g	41.3g	22.58g	33.5g	27.42g	28.7g
$LSD_{0.05}$		0.53	1.27	0.49	1.41	0.55	0.84
Interaction (A×B)							
Sponta	T_1	46.1	90.9	49.5	77.3	51.94	59.73
	T_2	42.9	83.0	45.2	72.2	49.31	56.93
	T_3	38.5	73.8	41.6	62.8	45.16	50.13
	T_4	36.0	67.3	36.9	56.3	41.78	45.03
	T_5	32.9	49.4	33.8	49.4	37.74	41.97
	T_6	30.7	53.0	30.3	44.5	35.17	39.13
	T_7	27.9	48.4	25.8	38.9	31.96	31.27
Cara	T_1	39.5	72.3	43.5	69.6	45.57	54.33
	T_2	36.3	64.8	40.2	59.0	40.72	48.40
	T_3	33.0	58.5	35.5	55.3	37.98	44.30
	T_4	30.9	53.4	30.8	51.7	34.99	39.40
	T_5	28.3	42.5	28.2	31.8	32.69	35.60
	T_6	25.5	40.9	25.1	40.3	28.88	32.00
	T_7	23.2	38.6	23.6	32.6	27.35	29.60
Elbeida	T_1	32.8	65.3	37.1	27.4	38.66	48.40
	T_2	30.5	62.7	33.9	51.1	35.40	43.40
	T_3	28.7	53.3	30.2	45.9	32.25	39.70
	T_4	25.9	48.2	26.9	39.3	30.44	35.30
	T_5	23.4	43.3	24.9	36.1	27.60	31.30
	T_6	22.2	40.7	22.4	32.4	25.03	28.20
	T_7	20.7	37.0	18.3	29.0	23.06	25.20
$LSD_{0.05}$		0.88	2.48	1.01	2.30	0.91	1.54

Table 2. Effect of organic and inorganic fertilizers on the number of tubers per plant, tuber weight (g), and tuber yield ($ton{\cdot}ha^{-1}$) of three potato cultivars in two locations.

Treatments		Number of tubers per plant		Tuber weight (g)		Tuber yield ($ton.ha^{-1}$)	
		1st loc.	2nd loc.	1st loc.	2nd loc.	1st loc.	2nd loc.
(A) Cultivars							
Sponta		15.16 a	16.8a	232.48 a	249.2 a	29.29a	31.79a
Cara		12.83 b	13.3b	190.09 b	207.6b	25.88b	26.74b
Elbeida		9.59 c	11.4c	161.67 c	189.3c	20.57c	25.02c
$LSD_{0.05}$		0.35	0.06	2.30	1.27	0.19	0.10
(B) Fertilizers							
T_1		15.85a	18.4a	246.78a	280.8a	32.05a	36.33a
T_2		14.39 b	16.6b	227.22b	256.1b	29.36b	32.71b
T_3		13.30c	14.9c	209.89c	235.4c	27.05c	30.74c
T_4		12.5d	13.7d	194.44d	212.8d	24.90d	27.55d
T_5		11.51e	12.3e	179.11e	193.8e	22.88e	24.83e
T_6		10.55f	11.2f	159.33f	174.2f	21.12f	22.50f
T_7		9.59g	9.5g	146.44g	154.6g	19.38g	20.31g
$LSD_{0.05}$		0.46	0.15	2.80	0.89	0.21	0.10
Interaction (A×B)							
Sponta	T_1	18.8	22.6	294	221	37.07	39.76
	T_2	17.5	20.3	275	204	33.95	35.86
	T_3	15.6	18.0	253	269	31.38	35.64
	T_4	15.2	16.4	235	251	28.83	32.00
	T_5	14.4	14.7	217	231	26.60	29.17

	T_6	23.0	13.4	184	202	24.60	26.36
	T_7	11.6	12.0	170	180	22.50	23.64
Cara	T_1	16.3	17.6	241	271	32.86	35.76
	T_2	14.3	15.8	222	249	30.24	32.17
	T_3	14.1	14.4	204	230	27.79	29.12
	T_4	12.9	12.9	189	201	25.60	25.98
	T_5	11.6	11.9	174	183	23.38	23.38
	T_6	10.8	11.1	157	171	21.52	21.33
	T_7	9.9	9.6	144	149	19.88	19.43
Elbeida	T_1	12.4	15.1	205	150	26.19	33.45
	T_2	11.4	13.6	185	228	23.86	30.12
	T_3	10.2	12.4	173	208	21.98	27.43
	T_4	9.4	12.0	159	187	20.31	24.64
	T_5	8.5	10.1	146	167	18.64	21.93
	T_6	7.9	9.0	136	150	17.24	19.79
	T_7	7.3	7.3	126	135	15.74	17.83
$LSD_{0.05}$		0.82	0.25	5.01	1.89	0.43	0.17

Table 3. Effect of organic and inorganic fertilizers on tuber total carbohydrates, starch, and TSS contents of three potato cultivars in two locations.

Treatments		Total carbohydrates (%)		Starch (%)		TSS (%)	
		1st loc.	2nd loc.	1st loc.	2nd loc.	1st loc.	2nd loc.
(A) Cultivars							
Sponta		59.03 a	51.52a	12.28 a	14.99a	5.41 a	6.5a
Cara		52.12 b	46.83b	10.01 b	12.35b	4.72 b	5.4b
Elbeida		45.92 c	39.91c	8.33 c	10.12c	3.87 c	4.6c
$LSD_{0.05}$		0.77	2.07	0.20	0.09	0.22	0.118
(B) Fertilizers							
T_1		66.2a	61.9a	12.91a	16.85a	6.2 a	7.5a
T_2		61.1b	55.8b	11.96b	15.04b	5.4b	6.8b
T_3		56.1c	51.3c	10.88c	13.49c	5.1c	5.9c
T_4		51.7d	45.3d	10.04d	12.17d	4.6d	5.4d
T_5		47.2e	40.6e	9.32e	10.89e	4.2e	4.9e
T_6		43.8f	34.1f	8.49f	9.94f	3.9f	4.4f
T_7		40.3g	33.5f	7.86g	9.04g	3.6g	3.6g
$LSD_{0.05}$		0.63	2.15	0.15	0.16	0.11	0.099
Interaction (A×B)							
Sponta	T_1	73.8	99.5	15.4	20.5	7.0	8.7
	T_2	68.9	62.9	14.5	18.1	6.4	7.9
	T_3	63.4	56.9	13.1	16.1	5.8	6.9
	T_4	58.6	52.4	12.1	14.7	5.2	6.4
	T_5	53.6	46.0	11.3	13.0	4.8	5.8
	T_6	49.4	35.5	10.2	11.9	4.5	5.2
	T_7	45.5	37.0	9.4	11.0	4.2	4.5
Cara	T_1	66.5	62.2	12.7	16.5	6.0	7.4
	T_2	60.7	56.3	11.8	14.8	5.5	6.8
	T_3	55.6	50.4	10.6	13.5	5.1	6.0
	T_4	51.1	45.4	9.8	11.9	4.7	5.5
	T_5	47.1	41.4	9.1	10.7	4.2	4.8
	T_6	43.8	37.8	8.4	10.0	4.0	4.4
	T_7	40.1	34.3	7.7	9.1	3.6	3.2
Elbeida	T_1	58.5	53.8	10.6	13.5	5.0	6.3
	T_2	53.7	48.2	9.6	12.1	4.4	5.7
	T_3	49.4	43.6	8.9	10.9	4.2	5.0
	T_4	45.5	38.2	2.3	9.9	3.7	4.4
	T_5	41.1	34.1	7.6	8.9	3.5	4.1
	T_6	38.1	32.2	6.9	8.1	3.1	3.7
	T_7	35.1	29.3	6.4	7.4	3.0	3.1
$LSD_{0.05}$		1.26	3.99	0.30	0.27	0.28	0.196

Table 4. Effect of organic and inorganic fertilizers on tuber NPK contents of three potato cultivars in two locations.

Treatments		N in tubers (%)		P in tubers (%)		K in tubers (%)	
		1st loc.	2nd loc.	1st loc.	2nd loc.	1st loc.	2nd loc.
(A) Cultivars							
Sponta		1.61 a	2.15a	0.36 a	0.52a	2.02 a	2.48a
Cara		1.36 b	1.82b	0.31 b	0.40b	1.63 b	2.02b
Elbeida		1.19 c	1.60c	0.27 c	0.33c	1.39 c	1.82c
$LSD_{0.05}$		0.23	0.20	0.012	0.021	0.022	0.049
(B) Fertilizers							
T_1		1.78 a	2.79a	0.40 a	0.57a	2.13 a	2.81a
T_2		1.60b	2.35b	0.36b	0.50b	1.95b	2.57b
T_3		1.46c	2.14c	0.33c	0.46c	1.81c	2.33c
T_4		1.37d	1.8d	0.31d	0.41d	1.67d	2.09d
T_5		1.26e	1.51e	0.28e	0.38e	1.53e	1.9e
T_6		1.15f	1.26f	0.26f	0.33f	1.39f	1.63f
T_7		1.08g	1.14g	0.24g	0.27g	1.29g	1.41g
$LSD_{0.05}$		0.022	0.15	0.011	0.013	0.018	0.071
Interaction (A×B)							
Sponta	T_1	2.08	3.39	0.47	0.71	2.56	3.23
	T_2	1.87	2.61	0.41	0.63	2.36	3.02
	T_3	1.70	2.54	0.38	0.57	2.17	2.75
	T_4	1.62	2.10	0.35	0.51	2.01	2.41
	T_5	1.47	1.80	0.32	0.47	1.86	2.30
	T_6	1.31	1.34	0.29	0.41	1.66	1.94
	T_7	1.22	1.24	0.28	0.35	1.55	1.70
Cara	T_1	1.75	2.57	0.40	0.56	2.07	2.74
	T_2	1.58	2.28	0.36	0.48	1.89	2.42
	T_3	1.44	1.99	0.34	0.44	1.75	2.25
	T_4	1.34	1.77	0.30	0.41	1.61	2.05
	T_5	1.23	1.51	0.28	0.37	1.46	1.80
	T_6	1.13	1.40	0.26	0.31	1.37	1.56
	T_7	1.06	1.24	0.23	0.21	1.25	1.34
Elbeida	T_1	1.51	2.41	0.34	0.44	1.76	2.45
	T_2	1.35	2.17	0.31	0.40	1.61	2.26
	T_3	1.25	1.90	0.29	0.36	1.50	2.00
	T_4	1.15	1.53	0.27	0.32	1.38	1.81
	T_5	1.07	1.23	0.24	0.29	1.25	1.60
	T_6	1.02	1.03	0.23	0.27	1.15	1.39
	T_7	1.95	0.92	0.21	0.24	1.06	1.21
$LSD_{0.05}$		0.042	0.30	0.021	0.029	0.036	0.123

Table 5. Physical and chemical characteristics of soil collected from two experimental locations in the summer growing season, 2019.

Properties	Location 1	Location 2	Unit
Sand	49.5	47.9	%
Silt	12.0	13.0	%
Clay	38.5	39.1	%
Textural Class	Sandy Clay		
pH	8.4	8.5	-
EC	0.874	0.922	ds/m
O.M.	1.50	1.65	%
O.C.	0.31	0.35	%
C/N ratio	15/1	23.1/1	-
$CaCO_3$	5.26	5.41	%
	Nutrients available		
Nitrogen	7.4	8.1	(mg/kg)
Phosphorus	30.08	28.75	(mg/kg)
Potassium	550.43	547.98	(mg/kg)

Table 6. Chemical analysis of mixed organic fertilizers (MOF), vermicompost (VC) and Azolla (AZ).

Parameters	MOF	VC	AZ	Unit
pH	9.8	8.1	8.3	-
EC	6.4	5.2	9.8	**ds/m**
OM	28.3	15.3	3.2	**%**
OC	16.4	8.9	1.9	**%**
C/N ratio	13.7:1	3.5:1	0.7:1	-
Total Nitrogen	1.2	3.5	2.9	**%**
Total Phosphorous	1.07	4.53	3.66	**%**
Total Potassium	6.4	3.0	6.3	**%**

releasing nutrients, organic acids, enzymes, and hormones in the rhizosphere. Azab and Soror (2020) stated that Azolla has an excellent carbon-nitrogen ratio, which facilitates rapid decomposition and accelerates the decomposition of other organic residues in compost pits.

Edwards et al. (2006) demonstrated that crops respond to the application of vermicompost due to the release of substantial quantities of essential nutrients and growth-promoting substances. Additionally, Li et al. (2020) and Abou El-Goud (2020 a, b, and c) found that vermicompost not only contributes to improve soil texture, aeration, and soil compaction, enhancing plant water and nutrient uptake, but also produces hormones, vitamins, plant regulators, antibiotics, and beneficial microbes that further improve plant health. Similarly, Najar and Khan (2013) reported a significant increase in vegetative plant growth of tomato in plots amended with 6 t·ha^{-1} vermicompost. The macronutrients provided by vermicompost improve crop yield via activation of enzymes involved in chlorophyll synthesis, growth, yield, and enzyme system maintenance (Piya et al., 2018; Abou El Goud, 2020 a and c).

Materials and methods

Two field experiments were conducted in two locations on a private farm (Elmalawany) in Kafr El-Dawar, El Bahira, Egypt during the summer growing season of 2019/2020 to investigate the effect of organic fertilizers on the growth, yield, and tuber quality of three potato cultivars, Cara, Elbeida, and Sponta.

Soil physical and chemical characteristics

Two experimental locations were selected and a combined soil sample from each site was collected from the surface layer (0–30 cm) for analysis. The soil pH, electrical conductivity (EC), organic matter (OM), organic carbon (OC), calcium carbonate ($CaCO_3$), available N, P, and K, and mechanical properties were assessed according to the methods described by Page et al. (1982), and Klute and Page (1986). The soil physical and chemical properties are presented in Table 5.

The characteristics of organic fertilizers

Three organic fertilizers i.e. mixed organic fertilizer (MOF), vermicompost (VC), and *Azollapinnata* (AZ), were selected as eco-friendly and sustainable alternatives to chemical fertilization. A 1:1:1 mixture of cow dump, chicken manure, and plant compost was composted for 25 days to produce the MOF. VC was produced by 2000 red wiggler earthworms *Eiseniafetida* with a marginal number of other species in the worm compost bin (120-cm length, 70-cm width, and 40-cm height) for two months (Abou El Goud 2020a). The AZ fertilizer was applied as an aqueous suspension. The chemical characteristics of the organic fertilizers are shown in Table 6.

Experimental design

The field experiment was laid out in a split-plot design with three replications. Potato cultivars were arranged as the main factor with fertilizer treatments as a subfactor. The treated potato cultivars were Cara, Elbeida, and Sponta. The fertilizer treatments were as follows:

T_1 $MOF\ (1.6\ kg.m^{-2}) + VC\ (1.6\ kg.m^{-2}) + AZ\ (0.6\ l.m^{-2})$

T_2 $VC\ (1.6\ kg.m^{-2})$

T_3 $MOF\ (1.6\ kg.m^{-2}) + AZ\ (0.6\ l.m^{-2})$

T_4 $VC\ (1.6\ kg.m^{-2}) + AZ\ (0.6\ l.m^{-2})$

T_5 $VC\ (1.6\ kg.m^{-2}) + MOF\ (1.6\ kg.m^{-2})$

T_6 $MOF\ (1.6\ kg.m^{-2})$

T_7 Recommended doses of NPK chemical fertilizers (Control)

Experimental procedure

MOF and VC were applied to the soil 25 days before sowing the potato tubers at rates of 1.6 kg·m^{-2}. AZ was applied as an aqueous suspension at a rate of 200 ml·m^{-2}for three installments at 40, 50, and 60 days after sowing as a soil supplement. For the chemical fertilizer treatment, the recommended doses of N, P, and K were applied in the form of ammonium sulfate (33.5% N), super calcium phosphate (15.5% P_2O_5), and potassium sulfate (48% K_2O) at a rate of 440:165:400 kg N, P_2O_5, K_2O per hectare. An area of 4.4 m^2 (5.5-m length × 0.8-m width) was allocated for each experimental plot. Twelve potato tubers per plot were sown 40 cm apart on December 5, 2019. Organic farming system protocols were followed in all plots throughout the whole growing season. Neem oil (4 ml·L^{-1}) was applied to the leaves to protect plants from pathogens. Plants were also covered with nets for protection from insects (Mrema and Maerere, 2018). All plots were well irrigated throughout the season using a drip-irrigation system. Weeds were controlled by hand-howling every 10 days after sowing. Potato tuber yields were harvested on April 5 for Elbeida, April 25 for Sponta, and May 15 for Cara, 2020.

Experimental observations

Three plants were randomly selected from each treatment, and plant height (cm), number of leaves and main stems per plant, and plant fresh and dry weight (g) were measured at90 days after planting for cv. Elbeida, 120 days after planting for cv. Sponta, and 140 days after planting for cv. Cara. Leaf chlorophyll indication (SPAD) was measured using a chlorophyll meter (SPAD-502, Minolta Co. Japan) in three recently fully expanded leaves (Yadawa, 1986; Marquard and Tipton, 1987).

Well-matured tubers were collectively harvested from each plot to measure yield. Total tuber number and weight per plot were used to calculate the tuber number per plant, tuber yield per plant (g), and tuber yield per hectare (ton). Standard methods were followed in measuring tubers tarch (%) (Holm et al., 1986), total carbohydrates (Cronin and Smith, 1979), and total soluble solids (TSS%) (Sugiura et al., 1983).

Statistical analysis

Statistical analysis of variance was conducted according to the procedure described by Gomez and Gomez (1984). Treatment means were compared using the least significant differences (LSD) test using the split-plot model and Duncan's multiple range test. All analyses were conducted using SAS (SAS, 2001) at a 5% level of probability.

Conclusions

The responses of potato cultivars to organic fertilizers and mineral NPK fertilizer revealed that organic fertilizer application significantly improved the growth, yield, quality, and NPK content of tubers. Moreover, Sponta cultivar produced the highest growth, yield, tuber quality, and NPK content, followed by Cara, while Elbeida cultivar exhibited the lowest production. The application of mixed organic fertilizer (1.6 $kg \cdot m^{-2}$) + vermicompost (1.6 $kg \cdot m^{-2}$) + *Azollapinnata* (0.6 $l \cdot m^{-2}$) in T_1 produced significantly higher growth, yield, tuber quality, and NPK content in all potato cultivars, outperforming the other organic and inorganic fertilizer treatments. Therefore, the application of organic fertilizers facilitates the sustainable use of resources while also improving potato growth, yield, and quality.

Acknowledgement

The authors thank the Egyptian Knowledge Bank (EKB) in partnership with ENAGO for offering free language and grammar editing.

References

Abou El-Gould AK (2020a) Efficiency response of Vermicompost and Vermitea levels on growth and yield of Eggplant Solanum melongena. Alexandria Sci Exchange J. 41(1): 69 -75.

Abou El-Gould AK (2020b) Organic cowpea "*Vigna unguiculate*" production by Smart Agritechnique of Organic Fertilizers Mixture" OFM" and Vermitea levels and Beneficial Microbes "BM". J Plant Prod. 11(5): 399-405.

Abou El-Gould AK (2020c) Organic Watermelon Production by Smart Agritechnique Using Organic Fertilizers, Vermitea levels and AMF in poor nutrients soil. Plant Arch. 20(2): 4107-4116.

Amara DG, Kherraz K, Nagaz K, Senoussi MM (2015) Effect of chicken manure and organic nitrogen levels on yielding and antioxidant content of tuber potato at Algeria sahara. Int J Agr Innov Res. 4(1):17-21.

Azab E, Soror AFS (2020) Physiological Behavior of the Aquatic Plant Azolla sp. in Response to Organic and Inorganic Fertilizers. Plants. 9(7): 924.

Bilkis S, Islam MR, Jahiruddin M, Rahman MM, Hoque TS (2018) Residual effects of different manures and fertilizers applied to preceding potato crop on succeeding Mung bean (*vigna radiate* l.) crop in potato-mung bean-rice cropping pattern. SAARC J Agr. 16(2): 167-179.

Brown GG (1995) How do earthworms affect microfloral and faunal community diversity?. Plant Soil. 170(1): 209-231.

Chaulagain A, Gauchan DP, Lamichhane J (2017) Vermicompost and its role in plant growth promotion. Int J Res. 4(8): 850-864.

Churilova EV, Midmore DJ (2019) Vermiliquer (*Vermicompost Leachate*) as a Complete Liquid Fertilizer for Hydroponically-Grown Pak Choi (*Brassica chinensis* L.) in the Tropics. Horticulturae. 5(1): 26.

Cronin DA, Smith S (1979) A simple and rapid procedure for the analysis of reducing, total and individual sugars in potatoes. Potato Res. 22(2): 99-105.

Darabi A, Omidvari S, Shafiezargar A, Rafie M, Javadzadeh M (2018) Impact of integrated management of nitrogen fertilizers on yield and nutritional quality of potato. J Plant Nutr. 41(19): 2482-2494.

de Vries J, Fischer AM, Roettger M, Rommel S, Schluepmann H, Bräutigam A, Carlsbecker A, Gould SB (2016) Cytokinin-induced promotion of root meristem size in the fern Azolla supports a shoot-like origin of euphyllophyte roots. New Phytologist. 209(2): 705-720.

Edwards CA, Arancon NQ, Greytak S (2006) Effects of vermicompost teas on plant growth and disease. Biocycle. 47(5): 28.

FAO (2017) FAOSTAT data. Food and Agriculture Organization (FAO) of the United Nations, Rome, Italy. Available at http://www.fao.org/faostat/en/#data/QC (accessed August 2020).

Gomez KA, Gomez AA (1984) Statistical procedures for agricultural research: John Wiley & Sons.

Holm J, Björck I, Drews A, Asp NG (1986) A rapid method for the analysis of starch. Starch-Stärke. 38(7): 224-226.

Jumadi O, Hiola SF, Hala Y, Norton J, Inubushi K (2014) Influence of Azolla (*Azolla microphylla* Kaulf.) compost on biogenic gas production, inorganic nitrogen and growth of upland kangkong (Ipomoea aquatica Forsk.) in a silt loam soil. Soil Sci. Plant Nutr. 60(5): 722-730.

Kawthar AE, Ashour HM, Fatma SI (2017) Growth Characters and some Chemical Constituents of Matricaria chamomilla L. Plants in Relation to Green Manure and Compost Fertilizer in Sandy Soil. Middle East J. 6(1): 76-86.

Klute A, Page AL (1986) Methods of soil analysis. Part 1. Physical and mineralogical methods; Part 2. Chemical and microbiological properties. American Society of Agronomy, Inc..

Li W, Bhat SA, Li J, Cui G, Wei Y, Yamada T, Li F (2020) Effect of excess activated sludge on vermicomposting of fruit and vegetable waste by using novel vermireactor. Bioresource Technol. 302: 122816.

Lumpkin TA, Plucknett DL (1980) Azolla: botany, physiology, and use as a green manure. Econ Bot. 34(2): 111-153.

Marquard RD, Tipton JL (1987) Relationship between extractable chlorophyll and an in situ method to estimate leaf greenness. HortScience. 22(6)

Marwaha RS (1998) Evaluation of Indian and exotic potato cultivars for processing into French fries. J Indian Potato Assoc. 25(1-2): 61-65.

Maswada HF, Abd El-Razek UA, El-Sheshtawy ANA, Mazrou YS (2021) Effect of Azolla filiculoides on Growth, Physiological and Yield Attributes of Maize Grown under Water and Nitrogen Deficiencies. J Plant Growth Regul. 40(2): 558-573.

Meena BP, Kumar A, Dotaniya ML, Jat NK, Lal B (2016) Effect of organic sources of nutrients on tuber bulking rate, grades and specific gravity of potato tubers. Proceedings of the National Academy of Sciences, India Section B: Biol Sci 86(1): 47-53.

Meghvansi MK, Singh L, Srivastava RB, Varma A (2011) Assessing the role of earthworms in biocontrol of soil-borne plant fungal diseases. In Biology of earthworms (pp. 173-189). Springer, Berlin, Heidelberg.

Miranda AF, Biswas B, Ramkumar N, Singh R, Kumar J, JamesA, Roddick F, Lal B, Subudhi S, Bhaskar T, Mouradov A (2016) Aquatic plant Azolla as the universal feedstock for biofuel production. Biotech biofuels. 9(1): 1-17.

Mirdad ZM (2010) The effect of organic and inorganic fertilizers application on vegetative growth, yield and its components and chemical composition of two potato (*Solanum tuberosum,* L.) cultivars. Alex Sci Exchange J. 31(1): 102-119.

Mishra D, Rajvir S, Mishra U, Kumar SS (2013) Role of bio-fertilizer in organic agriculture: a review. Res J Recent Sci. 2: 39-41.

Mrema E, Maerere AP (2018) Growth and yield performance of watermelon during dry and wet seasons under tropical conditions. Int J Vegetable Sci. 24(5):483-489.

Najar IA, Khan AB (2013) Effect of vermicompost on growth and productivity of tomato (*Lycopersicon esculentum*) under field conditions. Acta Biol Malaysiana. 2(1): 12-21.

Page AL, Miller RH, Keeney DR (1982) Methods of soil analysis, part 2. Chemical and microbiological properties, *2*.

Pereira AL, Vasconcelos V (2014) Classification and phylogeny of the cyanobiont Anabaena azollae Strasburger: an answered question?. Int J Syste Evolu Microbio. 64(6):1830-1840.

Pérez-Gómez JDJ, Abud-Archila M, Villalobos-Maldonado JJ, Enciso-Saenz S, Hernández de León H, Ruiz-Valdiviezo VM, Gutiérrez-Miceli FA (2017) Vermicompost and vermiwash minimized the influence of salinity stress on growth parameters in potato plants. Compost Sci Util. 25(4): 282-287.

Peters GA (1978) Blue-green algae and algal associations. Bioscience. 28(9): 580-585.

Piya S, Shrestha I, Gauchan DP, Lamichhane J (2018) Vermicomposting in organic Agriculture: Influence on the soil nutrients and plant growth. Int J Res. 5(20): 1055-1063.

Rashtbari M, Hossein Ali A, Ghorchiani M (2020) Effect of Vermicompost and Municipal Solid Waste Compost on Growth and Yield of Canola under Drought Stress Conditions. Commun Soil Sci Plan.51(17): 2215-2222.

Ravindran B, Lee SR, Chang SW, Nguyen DD, Chung WJ, Balasubramanian B, Mupambwa HA, Arasu MV, Al-Dhabi NA, Sekaran G (2019) Positive effects of compost and vermicompost produced from tannery waste-animal fleshing on the growth and yield of commercial crop-tomato (*Lycopersicon esculentum* L.) plant. J Environ Manage. 234: 154-158.

Razavipour T, Moghaddam SS, Doaei S, Noorhosseini SA, Damalas CA (2018) Azolla (*Azolla filiculoides*) compost improves grain yield of rice (*Oryza sativa* L.) under different irrigation regimes. Agr Water Manage. 209: 1-10.

Ripley BS, Kiguli LN, Barker NP, Grobbelaar JU (2003) Azolla filiculoides as a biofertiliser of wheat under dry-land soil conditions. S Afr J Bot. 69(3): 295-300.

Romero AP, Alarcón A, Valbuena RI, Galeano CH (2017) Physiological assessment of water stress in potato using spectral information. Front Plant Sci. 8: 1608.

Shafeek MR, El-Desuki M, Shaheen AM (2001) Growth and yield of some potato cultivars as affected by sources of fertilization. Egypt J Appl Sci. 16(4): 242-260.

Shahein MM, Husein ME, Ahmed AR, Shaker NA (2014) Effect of integrated inorganic and organic nitrogen fertilizer on quantity and quality of potatoes plant grown on new reclaimed sandy soil. J Soil Sci Agr Eng. 5(11): 1451-1472.

Sharma G, Sahu NP, Shukla N (2017) Effect of bio-organic and inorganic nutrient sources on growth and flower production of African marigold. Horticulturae. 3(1): 11.

Sugiura A, Kataoka I, Tomana T (1983) Use of refractometer to determine soluble solids of astringent fruits of Japanese persimmon (*Diospyros kaki* L.). J Hortic Sci. 58(2): 241-246.

Swaminathan V, Jayapaut P, Nanjan K, Uthayakumar B (1999) Suitable variety of potato for the Nilgiri district of Tamil Nadu. Crop Res. 17(2): 216-218.

Tajbakhsh J, Goltapeh EM, Varma A (2011) Vermicompost as a biological soil amendment. In Biology of Earthworms (pp. 215-228). Springer, Berlin, Heidelberg.

Ventura W, Watanabe I (1993) Green manure production of Azolla microphylla and Sesbania rostrata and their long-term effects on rice yields and soil fertility. Biol Fert Soils. 15(4): 241-248.

Wagner GM (1997) Azolla: a review of its biology and utilization. Bot Rev. 63(1): 1-26.

Yadawa UL (1986) A rapid and nondestructive method to determine chlorophyll in intact leaves. Hortscience. 21(6): 1449-1450.

Youssef MES, Al-Easily IAS, AS Nawar D (2017) Impact of biochar addition on productivity and tubers quality of some potato cultivars under sandy soil conditions. Egypt J Horticulture. 44(2): 199-217.

Zhang E, Li J, Zhang K, Wang F, Yang H, Zhi S, Liu G (2018) Anaerobic digestion performance of sweet potato vine and animal manure under wet, semi-dry, and dry conditions. Amb Express. 8(1): 45.