International Journal of Agricultural Technology 2024 Vol. 20(1):441-466
Available online http://www.ijat-aatsea.com
ISSN 2630-0192 (Online)

Agro-economic response of potato (*Solanum tuberosum* L.) as affected by the interaction of cultivars and combined application of organic fertilizers under stored moisture conditions

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Yousaf, G., Zia, H., Anwar, A., Fayyaz, F. A., Rahman, A. U. and Yousaf, M. H. (2024). Agro-economic response of potato (*Solanum tuberosum* L.) as affected by the interaction of cultivars and combined application of organic fertilizers under stored moisture conditions. International Journal of Agricultural Technology 20(1):441-466.

Abstract The results revealed that potato cultivars Rudolph and Constance gave highly significant results ($p \leq 0.05$) for agronomic characteristics of potato and had maximum tuber yield of 32.5 t ha^{-1} and 38.8 t ha^{-1} and 30.95 t ha^{-1} and 33.54 t ha^{-1} in two cropping years compared to Vogue and Kuroda, respectively. Maximum yield of tubers 33.72 t ha^{-1} and 38.42 t ha^{-1} was observed in a treatment with application of humic acid + vermicompost + compost and it was significant ($p \leq 0.05$) when differentiated with any other treatment. The partial budget analysis indicated that cultivars Rudolph gave highest net income benefits of US$ 2517.82 ha^{-1} and US$ 2916.95 ha^{-1} and Constance with benefits of US$ 2352.21 ha^{-1} and US$ 2787 ha^{-1} under similar treatment in two cropping years, respectively. The similar varieties gave highest marginal return rate of 3248 %, 4529 % and 2957 %, 2733 % which is highly recommended for commercial growing farmers.

Keywords: Potato cultivars, Agronomic response, Production economics, Net income benefits, Yield potential

Introduction

Intensive agricultural systems involve the cultivation of exhaustive crop linked with heavy doses of chemical fertilizers and pesticides. The conservation of biodiversity is negatively impacted by such agricultural practices; those also pollute the soil and water quality. The restoration of agro ecosystems under diverse climatic circumstances is one of the numerous potential benefits of the

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cropping systems based on sensibly planned mixture of species (Malézieux *et al.,* 2009). The change of cropping system in any region in modern day agriculture ensures sustainability in agro-food system. The inclusion of short duration crops not only produce more profitable yields per unit area of land but also increase net economic returns on same area and maintains agro biodiversity through efficient utilization of growth resources (Bennett *et al,* 2012). Adopting vegetable-based cropping systems are more dependable and economically successful than cereal-based systems due to their short growth pattern, which benefits farmers who lack access to resources in terms of food security, farm income, resource accessibility, and employment opportunities (Tiwari *et al.,* 2011).

Potato (*Solanum tuberosum* L.), a member of Solanaceae family is tuberous crop having abundance of starch. It is the world's fourth largest crop by cultivation area after wheat, maize and rice and serves as staple food in different countries across the globe (Zhang *et al.,* 2017). The worldwide overall annual production of potato is estimated to be 370 million tons on total area of 17.3 million ha (FAO Statistics, 2021). It is a main crop for resource poor farmers of Pakistan in terms of earning their livelihood and provides substantial amount of proteins, vitamins, carbohydrates, antioxidants and minerals (Hassan *et al.,* 2021). Its total area under cultivation in 2017 was 177.8 thousand ha, with total annual production of 3.8 million tones and a yield average of 22.5 tons per ha. The current export of Pakistan's potato is about 10 % of total production which earns up-to US$ 87.5 million of foreign exchange per annum. In plains it has two planting seasons e.g. spring and autumn, while in hilly areas it is cultivated only as summer crop (Farooq *et al.,* 2020).

It has a share in daily consumption all around the world due to its high nutritional quality which make it a balance diet (Çalışkan and Struik, 2010; Jansky *et al.,* 2019; Burgos *et al.,* 2020). Every 100 g potato contains an estimated 79.8 % of water, 2.1 g of protein, 0.1 g lipids, 17.1 g of carbohydrates, 0.5 g fibers, 0.9 g ash and minute quantity of other nutrient elements and some vitamins (Drewnowski and Rehm, 2013). A single medium-sized tuber of 200 g fresh weight provides 5 % to 13 % of the U.S. Dietary Reference Intake of Zn, Mg and Mn, 17 % to 18 % of the DRI of P, K and Fe and the highest percentage i.e. 26 % of the (DRI) of Cu (White *et al.,* 2009). The potato tubers have a comparatively larger content of organic substances, which encourages human absorption of mineral micronutrients e.g. ascorbate (Vitamin C), cysteine, protein and amino acids and low concentration of these substances restricts the absorption of these elements such as phytate (0.11 % to 0.27 % dry matter) and oxalate (0.03 % dry matter) (Kärenlampi and White, 2009).

Due to their extensive nutritional needs, potatoes are a demanding crop for soils (Stark and Porter, 2005). The conventional use of mineral fertilizers not only degrades the soil physical and chemical properties but also causes environmental pollution and also increases the total cost of production due to their high prices (El-Zehery, 2019). The modern trend emerged in agriculture is clean farming practices that emphasizes the inclusion of organic manures and bio-fertilizers which is recommended as the best alternative to mineral fertilizers (El-Akabawy, 2000). The application of organic manure and substrates in a cropping system in different combinations may affirm more sustainable and profitable crop yields through efficient resource utilization especially in areas more prone to moisture stress conditions (Ferdous *et al.,* 2021).

The concentration of organic matter in the soil is increased when organic fertilizers are used in farming systems (Li *et al.,* 2017), which improves its earthworm activity (Meng *et al.,* 2016). Additionally, it encourages the activity of other enzymes and soil microbes, which not only aids in increasing crop yields (Tejada and Benítez, 2020), but also rectifies the physical and chemical characteristics of the soil (Singh *et al,* 2020), which reduces the attack by pathogens (Dong and Shu, 2004; Olson and Papworth, 2006; Tagoe *et al.,* 2008). However, some crops like potatoes, have higher nitrogen levels due to the usage of organic fertilizers. So, the mineral fertilizers can be efficiently replaced with the mixed application of organic manures and bio-fertilizers derived from microorganisms (Dinesh *et al.,* 2010). The application of compost has great impact on crop production due to the presence of growth regulators which stimulates the plant growth through its root system. The nitrogen, phosphorus and potassium contents of potato tubers increase with increased concentration of compost in soil (García-gil *et al.,* 2000).

Humic substances contain adequate mineral nutritional elements which stimulates the growth of plant roots and shoots and thereby act positively in plant biomass formation (Feibert *et al.,* 2001; Hartwigsen and Evans, 2000; Hafez, 2003; El-Desuki, 2004). It enables the plant roots to grow and infiltrate into the soil and acts as transmissive media for the flow of nutrients within the plant from root zone and enhances the infiltration capacity of soil to hold maximum water and raise the processes of soil microbes (Selladurai and Purakayastha, 2016). Vermi-compost is a good source of macro nutrients NPKs and some micronutrients, enriched with organic matter contents for producing vegetables on large scale (Adhikary, 2012). It improves the biological, chemical and physical properties of soil and found to have a favorable influence on yield contributing parameters of major crops like wheat, potato, paddy and sugarcane (Lazcano and Dominguez, 2011).

Several studies confirmed that use of organic manures and bio-fertilizers in mixture has raised the production of some vegetable crops including potatoes where tuber yield has been increased by about 17 % while minimizing the use of mineral fertilizers to about 25-50 % (Datta *et al.,* 2009).

It was hypothesized that replacing intensive cropping systems with short-season crops has significant role in maintaining ecological balance with improved crop growth and yields if chemical treatments are reduced to an extent. The research project was aimed to identify the suitable cultivars of potato which can grow under the rain-fed areas with limited available resources and reduced input costs through combined application of various sources of organic manures in recommended doses.

The objectives were to evaluate the susceptibility and efficiency of four different cultivars of potato in rainfed areas, to investigate the impacts of mixed application of different organic fertilizers e.g. humic acid, compost and vermi-compost on agronomic yield response of potato, and to determine the overall performance of potato cultivars through net economic returns in two-year research trials.

Materials and methods

Experimental site

A two-year field research experiment was performed at Potato Research Program, Horticulture Research Institute, National Agricultural Research Center (NARC) Islamabad, Pakistan located at 33º 43´ N of latitude, longitude of 73º 04´ E, and 490 m above the level of sea.

Land preparation and manuring

The land was prepared well enough by using blade harrow, disc harrow and land leveler to cut and invert the soil to break the clods and make smooth surface for planting. The various sources of organic manure and substrates including humic acid, vermi-compost and compost were broadcasted earlier and incorporated later into the root zone of plant 15 days before planting to make a favorable environment for plant growth.

Layout plan

The research trial was set up by a randomized complete block design (RCBD) with two factors factorial plan having four varieties of potato using five different combinations of organic fertilizer treatments in three replications. The first-year crop was sown in late September 2016 and second year crop was planted in Mid-September 2017 to evaluate the overall agronomic and yield performance of potato in two-year cropping.

Crop husbandary

The crop was sown in the field using a single-row hand drill keeping a net plot size of 4 m ×1.5 m (6 m^2) while maintaining row spacing of 30 cm and planting distance of 10 cm. The research trial was planted using four available cultivars of potato; V_1: Vogue, V_2: Kuroda, V_3: Constance and V_4: Rudolph. The fertilizer treatments in experimental trial included nationally recommended doses of organic manure and substrate fertilizers in different combinations as followed; i) Control, ii) 50 % humic acid @ 3 kg ha^{-1} + 50 % vermi-compost @ 4 t ha^{-1}, iii) 50 % humic acid @ 3 kg ha^{-1} + 50 % compost @ 5 t ha^{-1}, iv) 50 % vermi-compost @ 4 t ha^{-1} + 50 % compost @ 5 t ha^{-1}, v) 33.3 % humic acid @ 2 kg ha^{-1} + 33.3 % vermi-compost @ 2.7 t ha^{-1} + 33.3 % compost @ 3.33 t ha^{-1}, respectively.

Soil parameters

Soil parameters e.g. pH, texture, EC (ds m^{-1}), organic matter (%), total nitrogen (%), nitrate nitrogen (mg kg^{-1}), available phosphorus (mg kg^{-1}), extractable potassium (mg kg^{-1}) and amount of calcium carbonate (%) were recorded at crop sowing and harvesting stages in both cropping years.

Agronomic and yield traits

Several agronomic and yield parameters like plant height (cm), tubers $plot^{-1}$, tuber length (cm), small tubers number $plot^{-1}$, medium tuber numbers $plot^{-1}$, number of large tubers $plot^{-1}$, total weight of tubers (kg $plot^{-1}$) and tuber yield (tons ha^{-1}) were recorded. The data for the studied parameters was recorded in each treatment of all cultivated varieties by selecting 10 plants per plot and their means were evaluated. The tuber yield was determined in tons per m^2 which was later converted in tons per hectare.

Economic analysis

A partial budget analysis is to evaluate the net income returns of applied treatments in a followed cropping pattern and determines whether a specific treatment is practically suitable for farmer or not in any particular region. It consists of an average yield of a treatment which is reduced by a certain percentage considering the differences between experimental yield and the actual yield which farmers could obtain from the same treatment, termed as adjusted yield (CIMMYT, 1988). Gross field benefits were evaluated as follows: -

$$\text{Gross field benefits} = \text{Field price} \times \text{Yield adjusted}$$

The yield was reduced by 10 % in order to account for the fact that farmers would experience 10 % lower yields than researchers employing comparable technologies.

$$NR = GB_f - TVC$$

NR = Net returns of income, GB_f = Gross benefits in the field, TVC = Total cost that vary

The overall variable costs comprise the cost of operations in the field, seed, crop planting, the provision of fertilizers, crop protection measures, and harvesting for all treatments. The financial value of each cost and benefit was based on hectares and determined in US dollars (US$).

The applied treatments in all cultivars were categorized by listing in descending order with total varying cost. The treatments with less income benefits at higher variable costs compared to above with more income returns at lower costs was dominated and not considered for marginal analysis. The analysis for marginal return rate was done by using total costs that vary and potato cultivar seed in local market, bags of used organic fertilizers. It was calculated by dividing the variation in all costs by the variation in all benefits (CIMMYT, 1988).

$$\text{MRR (\%)} = \frac{\text{Marginal benefits}}{\text{Marginal cost}} \times 100$$

The minimum acceptable rate for the farmers is between 50 and 100%. The acceptable rate was established at 50% for the analysis because the interventions just call for farmers to switch from one farming system to another without having to pick up new skills or invest in new tools.

Statistical analysis

The collected data of different parameters in all treatments was subjected to analysis of variance (ANOVA) using analytical tool Statistix 8.1. Mean of treatments were separated by using the test of least significant difference (LSD) at 5 % level of probability. The graphical representation between agronomic and yield attributes in two-year trials of potato were done by using Microsoft Excel program and dendrogram of cluster analysis for used potato cultivars and fertilizer protocols was drawn by using Origin Pro.

Results

Soil characteristics as influenced by the application of organic fertilizers

The results of soil properties indicated that application of organic manure and substrate fertilizers had significant influence on soil physicochemical properties at crop harvesting stages in both cropping years. The soil contents of total nitrogen, organic matter, nitrate nitrogen, available P and K were low and the experimental results revealed that mixed application of organic manures improved the soil organic matter contents (0.56 to 0.75%) and (0.74 to 0.93 %), total nitrogen (0.24 to 0.41 %) and (0.32 to 0.46 %), nitrate nitrogen (0.61 to 0.74 mg kg^{-1}) and (0.54 to 0.72 mg kg^{-1}), available phosphorus (22.5 to 25 mg kg^{-1}) and (22.5 to 24 mg kg^{-1}), extractable potassium (120 to 140 mg kg^{-1}) and (120 to 130 mg kg^{-1}) and calcium carbonate (11.23 to 11.92 %) and (10.8 to 11.44 %) in soil root zone during first and second cropping years, respectively (Table 1).

Table 1. Two-year physicochemical analysis of soil from experimental site at crop sowing and harvesting stages

Soil property	2016		2017	
	Sowing	Harvesting	Sowing	Harvesting
Texture	Clay loam	Clay loam	Clay loam	Clay loam
pH	6.74	7.04	6.84	7.11
EC (dSm^{-1})	1.72	2.1	1.68	1.91
OM (%)	0.56	0.75	0.74	0.93
Total N (%)	0.24	0.41	0.32	0.46
N-NO_3(mg kg^{-1})	0.61	0.74	0.54	0.72
Ava. P(mg kg^{-1})	22.5	25	22.5	24
Ava. K(mg kg^{-1})	120	140	120	130
$CaCO_3$ (%)	11.23	11.92	10.8	11.44

Note: EC= Electrical conductivity, OM= soil organic matter, Total N= total nitrogen, N-NO_3= nitrate nitrogen, Ava. P= soil available phosphorus, Ava. K= soil available potassium, $CaCO_3$= calcium carbonate

Interaction of crop cultivars and organic fertility management on plant height, tubers per plot and tuber length of potato

The effects of the application of different sources of organic manure and planted cultivars were statistically significant on height of plants, number of tubers per plot and tuber length of potato in two copping years. The cultivar

Rudolph gave the maximum height of 78.67 cm and 74.06 cm in two years, respectively. It was followed by cultivar Constance with plant height of 70.54 cm and 66.62 cm, Vogue (54.84 cm) and (58.19 cm) and Kuroda (45.47 cm) and (48.79 cm). The fertilizer treatments showed an increase in plant height of potato where 33.3 % humic acid + 33.3 % vermicompost + 33.3 % compost were applied in mixture, followed by treatments with 50 % humic acid + 50 % compost, 50 % vermicompost + 50 % compost and 50 % vermicompost + 50 % humic acid. The results of plant height for all the treatments were maximum and significant from control where it was recorded as minimum. The highest tuber number plot^{-1} were found in Rudolph (234.81), (242.96) and Constance (224.83), (230.78) in two years of planting, respectively. The results in these cultivars were highly significant compared to other two cultivars which had least tubers per plot. The treatments where different organic manures were provided in various combinations gave the maximum number of tubers per plot compared to control where no fertilizer was applied (Table 2).

Table 2. Two-year impact of varietal trail and combination of organic fertilizer treatments on plant height (cm), tubers per plot and tuber length (cm) of potato (*Solanum tuberosum* L.)

Cultivars	Plant height (cm)		Tubers plot^{-1}		Tuber length (cm)	
	2016	2017	2016	2017	2016	2017
Vogue	54.84 C	58.19 C	212.56 B	214.02 C	6.60 C	6.94 B
Kuroda	45.47 D	48.79 D	188.50 C	183.94 D	5.25 D	4.34 C
Constance	70.54 B	66.62 B	224.83 A	230.78 B	6.94 B	7.07 B
Rudolph	78.67 A	74.06 A	234.81 A	242.96 A	7.66 A	7.82 A
F-test	***	***	**	***	***	**
S.E.d$_m$	1.59	1.61	1.29	2.88	0.12	0.13
Organic Fertilizer Treatments						
Control	52.84 D	53.14 D	197.93 C	201.29 D	5.50 D	5.75 D
50% HA + 50% VC	59.33 C	58.82 C	210.43 B	212.75 C	6.02 C	6.19 C
50% HA + 50% C	62.93 C	61.13 C	214.98 B	214.58 BC	6.94 B	6.46 C
50%VC + 50% C	66.56 B	65.67 B	220.72 AB	223.17 B	7.06 B	6.83 B
33.3 % HA + 33.3 % VC + 33.3 % C	70.24 A	70.98 A	231.82 A	237.84 A	7.56 A	7.51 A
F-test	**	**	**	**	**	**
S.E.d$_m$	1.78	1.8	3.68	3.22	0.13	0.15
Interaction between cultivars and combination of organic fertilizers						
Cultivar: Vogue						

Table 2. (Con.)

Cultivars	Plant height (cm)		Tubers plot^{-1}		Tuber length (cm)	
	2016	2017	2016	2017	2016	2017
Control	46.18 lm	47.84 m	193.91 fghi	197.93 ghi	5.81 i	5.78 k
50% HA + 50% VC	54 ijk	55.27 jkl	208 defg	209.98 efgh	6.34 ghi	6.31 jk
50% HA + 50% C	54.22 ijk	57.12 ijk	212.97 cdef	210.85 efgh	6.54 fgh	6.93 fghi
50%VC + 50% C	57.05 hij	61.67 ghij	220.28 bcde	218.32 def	6.27 efgh	7.46 def
33.3 % HA + 33.3 % VC + 33.3 % C	62.76 gh	69.06 cdef	227.58 abcd	233.03 bcd	7.70 abc	8.22 ab
Cultivar: Kuroda						
Control	34.78 n	40.48 n	172.97 i	164.44 k	3.21 k	3.34 o
50% HA + 50% VC	43.04 m	45.40 mn	179.42 hi	173.54 jk	3.85 j	3.91 no
50% HA + 50% C	49.02 klm	49.59 lm	184.63 ghi	182.99 ij	6.10 hi	4.48 mn
50%VC + 50% C	50.55 jkl	52.32 klm	197.24 efgh	193.26 hi	6.46 fgh	4.85 lm
33.3 % HA + 33.3 % VC + 33.3 % C	49.93 jklm	56 ijkl	208.26 def	205.48 fgh	6.65 efgh	5.13 l
Cultivar: Constance						
Control	58.56 hi	57.93 hijk	206.95 defg	216.39 defg	6.19 hi	6.51 ij
50% HA + 50% VC	66.64 fg	63.19 fghi	224.78 bcd	227.29 cde	6.59 efgh	6.87 ghij
50% HA + 50% C	70.38 ef	65.08 efgh	227.52 abcd	226.35 cde	7.14 cde	6.78 hij
50%VC + 50% C	75.08 cde	70.98 bcde	222.74 bcd	234.11 bcd	7.0 def	7.13 efgh
33.3 % HA + 33.3 % VC + 33.3 % C	82.15 abc	75.91 abc	242.18 ab	249.75 ab	7.75 ab	8.07 abc
Cultivar: Rudolph						
Control	71.84 def	66.30 defg	217.89 cde	226.4 cde	6.78 defg	7.36 defg
50% HA + 50% VC	73.64 def	71.44 bcde	229.56 abcd	240.18 bc	7.27 bcd	7.66 bcde
50% HA + 50% C	78.20 bcd	72.73 bcd	234.82 abc	238.12 bc	7.96 a	7.63 cde
50%VC + 50% C	83.56 ab	76.90 ab	242.62 ab	246.97 ab	8.16 a	7.88 bcd
33.3 % HA + 33.3 % VC + 33.3 % C	86.11 a	82.93 a	249.27 a	263.12 a	8.14 a	8.58 a
F-test	ns	ns	ns	ns	ns	ns
S.E.d$_m$	3.56	3.6	7.22	6.45	0.27	0.28
CV (%)	6.98	7.12	6.64	5.13	5.08	5.29

Note: HA= Humic acid, VC= vermicompost, C= compost, S.E.d$_m$= standard error for difference of two means, CV= coefficient of variation, ***= highly significant at 5 % probability level, **= statistically significant at 5 % probability level, Ns= non-significant, Means sharing common letter are not statistically different at $p \leq 0.05$

The interaction effects of all the cultivars further elaborated that all the varieties gave increased results for plant height, number of tubers per plot and potato tuber length where 33.3 % humic acid + 33.3 % vermicompost + 33.3 % compost treatment was applied but they were non-significant among each other ($p \leq 0.05$).

Number of small, medium and large tubers of potato as affected the interaction of cultivars and organic nutrient management

The consequences depicted a significant improvement in the small, medium and large tuber numbers of potato. In case of small tuber numbers, the cultivars of Rudolph (64.94), (66.64) and Constance (64.67), (65.82) increased tuber numbers in first and second year of cropping, respectively (Table 3). The outcomes of these varieties were non-significant from each other in both seasons; however, results had significantly compared to the cultivars of Vogue and Kuroda. The fertilizer treatment where different sources of organic substances provided in combination had maximal outcomes for small tubers per plot, these treatments were statistically at par but were significant ($p \leq 0.05$) when differentiated with control having no fertilizer.

The cultivars Rudolph (34.29) and (37.55) and Constance (32.89) and (37.76) dominated over other cultivars regarding medium tuber numbers and had paramount results being non-significant to each other at ($p \leq 0.05$). The repercussion from treatments with 50 % humic acid + 50 % vermicompost, 50 % humic acid + 50 % compost and 50 % vermicompost + 50 % compost had similar consequences which were at par in both seasons but had least number of medium tubers when differentiated to a treatment with all given sources of fertilizer (Table 3).

Table 3. Two-year impact of varietal trail and combination of organic fertilizer treatments on No. of small, medium and large tubers per m^2 of potato (*Solanum tuberosum* L.)

Cultivars	No. of small tubers (5-19 mm)		No. of medium tubers (20-39 mm)		No. of large tubers (>40 mm)	
	2016	2017	2016	2017	2016	2017
Vogue	54.97 B	56.39 B	25.43 B	26.80 B	9.35 C	9.42 C
Kuroda	49.96 C	49.49 C	19.75 C	23 C	6.24 D	7.04 D
Constance	64.67 A	65.82 A	32.89 A	37.76 A	11.09 B	13.82 B
Rudolph	64.94 A	66.64 A	34.29 A	37.55 A	13.74 A	15.73 A
F-test	**	**	**	**	***	***
S.E.d$_m$	1.52	1.54	0.75	0.88	0.31	0.35
Organic Fertilizer Treatments						
Control	49.22 D	51.61 D	20.92 C	24.46 D	7.43 D	9.3 D

Table 3. (Con.)

Cultivars	No. of small tubers (5-19 mm)		No. of medium tubers (20-39 mm)		No. of large tubers (>40 mm)	
	2016	2017	2016	2017	2016	2017
50% HA + 50% VC	54.90 C	57.11 C	26.88 B	29.50 C	10.07 B	10.8 C
50% HA + 50% C	59.22 B	58.20 C	27.25 B	30.71 BC	8.91 C	11 C
50%VC + 50% C	62.09 B	63.50 B	28.53 B	31.78 B	10.41 B	12.04 B
33.3 % HA + 33.3 % VC + 33.3 % C	67.76 A	67.51 A	36.88 A	39.95 A	13.7 A	14.35 A
F-test	**	**	**	**	**	**
S.E.d$_m$	1.70	1.72	0.84	0.98	0.34	0.40
Interaction between cultivars and combination of organic fertilizers						
Cultivar: Vogue						
Control	48.5 jk	46.37 hi	19.28 h	18.97 jk	6.61 f	6.9 fgh
50% HA + 50% VC	52.47 ij	52.74 gh	26.38 f	24.46 gh	9.86 ef	8.34 ef
50% HA + 50% C	56.42 ghi	57.98 efg	24.41 fg	26.34 fgh	8.35 g	9.15 de
50%VC + 50% C	56.85 fghi	62.87 cdef	24.65 f	28.02 efg	9.51 fg	10.25 d
33.3 % HA + 33.3 % VC + 33.3 % C	60.62 efgh	61.99 cdef	32.41 bcd	36.18 b	12.39 c	12.46 c
Cultivar: Kuroda						
Control	37.13 l	43.17 i	12.66 i	16.54 k	4.58 i	6.1 h
50% HA + 50% VC	44.94 k	46.65 hi	18.32 h	20.45 ijk	6.09 h	6.64 gh
50% HA + 50% C	51.27 ijk	48.27 hi	18.95 h	22.93 hij	5.80 hi	6.86 fgh
50%VC + 50% C	54.80 hij	52.72 gh	21.07 gh	23.78 hi	6.37 h	7.35 fgh
33.3 % HA + 33.3 % VC + 33.3 % C	61.65 defgh	56.63 fg	27.76 ef	31.35 de	8.33 g	8.22 efg
Cultivar: Constance						
Control	55.13 hij	58.10 defg	25.73 f	32.16 cd	8.24 g	10.74 d
50% HA + 50% VC	62.65 cdefg	64.96 bcd	30.81 de	37.49 b	11.77 cd	12.72 c
50% HA + 50% C	63.70 cdef	62.08 cdef	30.82 de	37.81 b	9.31 fg	12.77 c
50%VC + 50% C	68.64 abc	68.31 bc	32.60 bcd	36.19 b	10.93 de	15.1 b
33.3 % HA + 33.3 % VC + 33.3 % C	73.24 ab	75.64 a	44.48 a	45.15 a	15.19 b	17.76 a
Cultivar: Rudolph						
Control	56.11 ghi	58.77 defg	26 f	30.17 def	10.29 ef	13.47 c
50% HA + 50% VC	59.53 efgh	64.07 bcde	32 cd	35.60 bc	12.53 c	15.51 b
50% HA + 50% C	65.5 cde	64.46 bcde	34.81 bc	35.74 bc	12.17 cd	15.25 b
50%VC + 50% C	68.04 bcd	70.1 ab	35.77 b	39.11 b	14.82 b	15.44 b
33.3 % HA + 33.3 % VC + 33.3 % C	75.52 a	75.79 a	42.84 a	47.14 a	18.90 a	18.98 a
F-test	ns	ns	ns	ns	ns	ns
S.E.d$_m$	3.40	3.45	1.68	1.96	0.69	0.79
CV (%)	7.12	7.08	7.34	7.66	8.31	8.41

Note: HA= Humic acid, VC= vermicompost, C= compost, CV= coefficient of variation, S.E.d$_m$= standard error for difference of two means, ***= highly significant at 5 % probability level, **= statistically significant at 5 % probability level, Ns= non-significant, Means sharing common letter are not statistically different at $p \leq 0.05$

The maximum number of large tubers observed in potato variety Rudolph (13.74), (15.73) and Constance (11.09), (13.82), followed by Vogue (9.35), (9.42) and Kuroda (6.24), (7.04) in first and second cropping years, respectively. It was evident from the outcomes that treatments where two sources of organic manure applied in recommended doses gave least number of large potato tubers compared to a treatment where all three sources of fertilizer were applied together (Table 3). The control treatment was not much effective in this regard and gave limited number of potato tubers per plot.

Impacts of crop cultivars and combination of organic fertilizers application on total tuber weight and tuber yield of potato

It was evident from the findings that the better performing cultivars regarding total weight of tubers per plot (kg ha^{-1}) were Rudolph (32.43 kg ha^{-1}) and (34.18 kg ha^{-1}) and Constance (28.72 kg ha^{-1}) and (33.54 kg ha^{-1}) with significant outcomes that proved their superiority over other cultivars (Table 4). The given fertility protocols of organic manures showed the supremacy of a treatment with all three sources available at same plot, while the other treatments with two organic sources were non-significant ($p \leq 0.05$) among each other and had significant results compared to control. The interaction of varieties and fertility treatments also showed that treatment with no fertilizer showed minimum total tuber weight of potato.

The two year research trials suggested that potato cultivars named; Rudolph (32.5 t ha^{-1}) and (38.8 t ha^{-1}) and Constance (30.95 t ha^{-1}) & (33.54 t ha^{-1}) gave the highest yield of tuber in the year 2016 and 2017 which was statistically different ($p \leq 0.05$) compared to Vogue (22.57 t ha^{-1}) and (28.56 t ha^{-1}) and Kuroda (18.62 t ha^{-1}) and (18.35 t ha^{-1}) in followed cropping years, respectively. The treatment with 33.3 % humic acid + 33.3 % vermicompost + 33.3 % compost gave highest tuber yield of 33.72 t ha^{-1} in 2016 and 38.42 t ha^{-1} in 2017, followed by 50 % vermicompost + 50 % compost having tuber yield of 26.98 t ha^{-1} and 32.11 t ha^{-1}, 50 % humic acid + 50 % compost (25.76 t ha^{-1}) & (28.83 t ha^{-1}), 50 % humic acid + 50 % vermicompost (23.72 t ha^{-1}) and (27.11 t ha^{-1}) and all these treatments were statistically significant at $p \leq 0.05$ as compared to control where the tuber yield of 20.62 t ha^{-1} and 22.61 t ha^{-1} was observed as lowest in both planted years, respectively (Table 4).

Table 4. Two-year impact of varietal trail and combination of organic fertilizer treatments on total tuber weight (kg/plot) and tuber yield (t ha^{-1}) of potato (*Solanum tuberosum* L.)

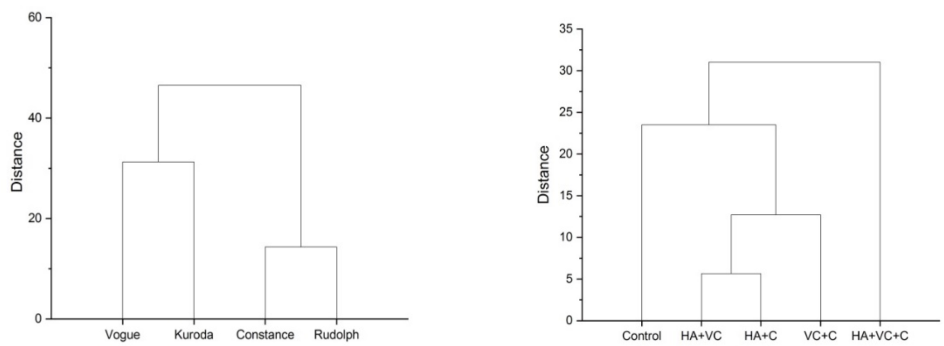
Cultivars	Tuber weight (kg plot^{-1})		Tuber yield (t ha^{-1})	
	2016	2017	2016	2017
Vogue	24.29 C	24.12 B	22.57 B	28.56 C
Kuroda	20.08 D	18.81 C	18.62 C	18.35 D
Constance	28.72 B	33.54 A	30.95 A	33.54 B
Rudolph	32.43 A	34.18 A	32.5 A	38.8 A
F-test	***	**	**	***
S.E.d$_m$	0.42	0.48	0.82	0.88
Organic Fertilizer Treatments				
Control	21.14 D	22.17 D	20.62 D	22.61 D
50% HA + 50% VC	25.89 C	25.79 C	23.72 C	27.11 C
50 % HA + 50 % C	25.43 C	28.04 B	25.76 B	28.83 C
50 %VC + 50 % C	27.86 B	29.09 B	26.98 B	32.1 B
33.3 % HA + 33.3 % VC + 33.3 % C	31.57 A	33.16 A	33.72 A	38.42 A
F-test	**	**	**	**
S.E.d$_m$	0.46	0.53	0.92	0.99
Interaction between cultivars and combination of organic fertilizers				
Cultivar: Vogue				
Control	18.83 kl	18.67 ij	18.29 hi	20.83 h
50% HA + 50% VC	24.45 i	23.1 h	21.71 fgh	25.96 g
50% HA + 50% C	24.6 i	26 fg	23.22 efg	28.20 fg
50%VC + 50% C	25.05 i	25.42 fg	20.05 ghi	31.65 ef
33.3 % HA + 33.3 % VC + 33.3 % C	28.49 fg	27.38 f	29.57 cd	36.13 cd
Cultivar: Kuroda				
Control	16.02 m	15.33 k	12.99 j	13.15 i
50% HA + 50% VC	19.65 k	16.62 jk	16.92 i	14.97 i
50% HA + 50% C	17.24 lm	18.26 ij	16.94 i	17.07 hi
50%VC + 50% C	22.04 j	19.15 i	21.63 fgh	20.84 h
33.3 % HA + 33.3 % VC + 33.3 % C	25.44 hi	24.67 gh	24.6 ef	25.73 g
Cultivar: Constance				
Control	24.89 i	27.51 f	24.56 ef	25.16 g
50% HA + 50% VC	27.27 gh	31.37 e	26.4 de	30.43 f
50% HA + 50% C	29.11 efg	34.05 cd	32.93 bc	32.14 def
50%VC + 50% C	29.36 ef	35.38 bc	31.65 bc	34.69 cde
33.3 % HA + 33.3 % VC + 33.3 % C	32.96 c	39.38 a	39.22 a	45.29 a
Cultivar: Rudolph				
Control	24.83 i	27.18 f	26.65 de	31.29 ef
50% HA + 50% VC	32.18 cd	32.07 de	29.85 cd	37.07 c
50% HA + 50% C	30.75 de	33.85 cd	29.94 cd	37.89 bc
50%VC + 50% C	35 b	36.4 b	34.59 b	41.21 b
33.3 % HA + 33.3 % VC + 33.3 % C	39.39 a	41.18 a	41.48 a	46.52 a
F-test	**	**	ns	ns
S.E.d$_m$	0.92	1.07	1.84	1.98
CV (%)	4.28	4.73	8.58	8.13

Note: HA= Humic acid, VC= vermicompost, C= compost, CV= coefficient of variation, S.E.d$_m$= standard error for difference of two means,***= highly significant at 5 % probability level, **= statistically significant at 5 % probability level, Ns= non-significant, Means sharing common letter are not statistically different at $p \leq 0.05$

Cluster analysis of crop cultivars and applied combinations of organic fertilizers

The analysis of cultivars showed that potato cultivars Rudolph and Constance did duster tightly which clearly indicated similarities between them. The same was observed between cultivars Vogue and Kuroda. The first two cultivars didn't cluster tightly with later twos and had great Euclidean distance which elaborated that they had large differences among each other based on their studied parameter (Figure 1A).

The dendrogram represented treatments with organic manures did not cluster tightly with each other and had vast similarities, while all the treatments fertilized with manures showed major differences with unfertilized treatment (Figure 1B).



A B

Figure 1. Dendrogram of hierarchical cluster analysis showing Euclidean Distances between; (A) potato cultivars, (B) combination of organic fertilizer treatments, based on agronomic parameters

Partial budget and marginal analysis of potato cultivar Vogue

The net income benefits for cultivar Vogue using all the treatments are presented in Table 5. It depicted that treatment with all available sources of humic acid + vermicompost + compost gave highest net income benefits of US$ 1617 ha^{-1} in 2016 and US$ 2051.34 in 2017 which suggested it to be a best available treatment for the cultivar. The treatment with humic acid + compost gave net returns of US$ 1270.14 ha^{-1} & US$ 1604.49 ha^{-1}, followed by vermicompost + compost with US$ 1078.23 ha^{-1} & US$1802.58 ha^{-1} and humic acid + vermicompost US$ 1187.54 ha^{-1} & US$1478.84 ha^{-1}, respectively. The treatment with no fertilizer gave minimum net benefits of US$ 1031.67 ha^{-1} & US$1211.83 ha^{-1} which suggested it to be at loss (Table 5).

Table 5. Partial budget analysis of potato (*Solanum tuberosum* L.) cultivar "Vogue" as affected by the combined application of organic manures in two cropping seasons

Treatments	Adj. yield (t ha^{-1})		GB US$ ha^{-1}		TVC US$ ha^{-1}		NB US$ ha^{-1}	
	2016	2017	2016	2017	2016	2017	2016	2017
Control	16.46	18.75	1069.9	1256.3	38.3	44.47	1031.67	1211.83
HA + VC	19.53	23.36	1270.04	1565.12	82.5	86.28	1187.54	1478.84
HA + C	20.89	25.38	1358.37	1700.46	88.23	95.97	1270.14	1604.49
VC + C	18.05	28.94	1172.93	1908.83	94.7	106.25	1078.23	1802.58
HA + VC + C	26.61	32.52	1729.85	2178.84	112.85	127.5	1617	2051.34

Note: HA= Humic acid, VC= vermicompost, C= compost, Adj. yield = adjusted yield, GB= gross benefits of income, TVC= total variable cost, NB= net benefits of income

It was indicated in that treatment with vermicompost + compost provided non-consistent results and least income benefits at higher cost and, therefore dominated the system and not considered for further analysis (Table 6). The treatments with humic acid + vermicompost + compost gave marginal return rate of 1409 % and 1171 % and humic acid + compost with return rate of 1442 % & 1297 % gave beneficial results and evaluated as only possible recommended treatments for farmers using this cultivar (Table 6).

Table 6. Marginal rate of return analysis of potato (*Solanum tuberosum* L.) cultivar "Vogue" as affected by the combined application of organic manures in two cropping seasons

Treatments	TVC (t ha^{-1})		MC US$ ha^{-1}		MB US$ ha^{-1}		MRR %	
	2016	2017	2016	2017	2016	2017	2016	2017
Control	38.3	44.47	-	-	-	-	-	-
HA + VC	82.5	86.28	44.2	41.81	155.87	267	353	639
HA + C	88.23	95.97	5.73	9.69	82.6	125.65	1442	1297
VC + C	94.7	106.25	D	10.28	-	198	-	1927
HA + VC + C	112.85	127.5	24.62	21.25	346.86	248.76	1409	1171

Note: HA= Humic acid, VC= vermicompost, C= compost, MC= marginal cost, MB= marginal benefits, MRR= marginal rate of return, D= dominated treatment which was eliminated

Partial budget and marginal analysis of potato cultivar Kuroda

The treatment applied with mixed doses of all available sources of organic fertilizers produced highest economic yield and net income returns of US$ 1256.2 ha^{-1} & US$ 1267 ha^{-1}, respectively. All the other fertilizer treatments had less net economic returns when compared to this treatment and were not recommended while planting this cultivar (Table 7).

Table 7. Partial budget analysis of potato (*Solanum tuberosum* L.) cultivar "Kuroda" as affected by the combined application of organic manures in two cropping seasons

Treatments	Adj. yield ($t\ ha^{-1}$)		GB US$ ha^{-1}		TVC US$ ha^{-1}		NB US$ ha^{-1}	
	2016	**2017**	**2016**	**2017**	**2016**	**2017**	**2016**	**2017**
Control	11.69	11.84	701.4	686.72	32.61	34.24	668.79	652.48
HA + VC	15.23	13.47	913.8	781.26	59.71	62.67	854	718.58
HA + C	15.25	15.36	915	890.88	55.78	59.37	859.22	831.51
VC + C	19.47	18.76	1168.2	1088	51.78	56.4	1116.42	1031.68
HA + VC + C	22.14	23.16	1328.4	1343.28	72.24	76.27	1256.2	1267

Note: HA= Humic acid, VC= vermicompost, C= compost, Adj. yield = adjusted yield, GB= gross benefits of income, TVC= total variable cost, NB= net benefits of income

The highest marginal return rate of 3209 % & 4032 % was recorded in treatment with 33.3 % humic acid + 33.3 % vermicompost + 33.3 % compost and it was the only reliable treatment for this cultivar under the given conditions (Table 8).

Table 8. Marginal rate of return analysis of potato (*Solanum tuberosum* L.) cultivar "Kuroda" as affected by the combined application of organic manures in two cropping seasons

Treatments	TVC ($t\ ha^{-1}$)		MC US$ ha^{-1}		MB US$ ha^{-1}		MRR %	
	2016	**2017**	**2016**	**2017**	**2016**	**2017**	**2016**	**2017**
Control	32.61	34.24	-	-	-	-	-	-
VC + C	51.78	56.4	19.17	22.16	447.63	379.2	2335	1171
HA + C	55.78	59.37	4	2.97	-	-	-	-
HA + VC	59.71	62.67	3.93	3.3	-	-	-	-
HA + VC + C	72.24	76.27	12.53	13.6	402	548.41	3209	4032

Note: HA= Humic acid, VC= vermicompost, C= compost, MC= marginal cost, MB= marginal benefits, MRR= marginal rate of return

Partial budget and marginal analysis of potato cultivar Constance

The partial budget analysis of variety Constance under all given fertilizer treatments showed it gave reasonable economic yield and income benefits when planted under the combined dose of humic acid, vermicompost and compost in both cropping years (Table 9). The consequences of the cultivar were at top having net returns of US$ 2352.21ha^{-1} & US$ 2787 ha^{-1}, respectively. The treatment with 50 % vermicompost + 50 % compost was the second best with net benefits of US$ 1891.1 ha^{-1} & US$ 2142 ha^{-1}, followed by treatment with 50 % humic acid + 50 % compost and 50 % humic acid + 50 % vermicompost, while the control where no fertilizer was applied gave least income benefits of US$ 1474.96 ha^{-1} & US$ 1552.6 ha^{-1} in two years of cropping, respectively (Table 9).

Table 9. Two-year impact on partial budget analysis of potato (*Solanum tuberosum* L.) cultivar "Constance" as affected by the combined application of organic manures

Treatments	Adj. yield (t ha^{-1})		GB US$ ha^{-1}		TVC US$ ha^{-1}		NB US$ ha^{-1}	
	2016	**2017**	**2016**	**2017**	**2016**	**2017**	**2016**	**2017**
Control	22.1	22.64	1547.3	1630	72.3	77.5	1475	1553
HA + VC	23.76	27.39	1663.2	1972	85.8	92.3	1577	1880
HA + C	29.64	28.93	2074.8	2082.96	95.7	105.3	1979	1978
VC + C	28.49	31.22	1994.3	2247.84	103.2	105.8	1891	2142
HA + VC + C	35.3	40.75	2471	2916	118.79	129.4	2352	2787

Note: HA= Humic acid, VC= vermicompost, C= compost, Adj. yield = adjusted yield, GB= gross benefits of income, TVC= total variable cost, NB= net benefits of income

The marginal returns obtained in plots with all available sources of organic manures were constant in both years and recorded as 2957 % & 2733 % and thereby considered as most reliable treatment with limited input cost (Table 10).

Table 10. Two-year impact on marginal return rate analysis of potato (*Solanum tuberosum* L.) cultivar "Constance" as affected by the combined application of organic manures

Treatments	TVC (t ha^{-1})		MC US$ ha^{-1}		MB US$ ha^{-1}		MRR %	
	2016	**2017**	**2016**	**2017**	**2016**	**2017**	**2016**	**2017**
Control	72.3	77.5	-	-	-	-	-	-
HA + VC	85.8	92.3	13.5	14.8	102.42	327.26	758.67	2209
HA + C	95.7	105.3	9.9	13	401.7	97.88	4057	753
VC + C	103.2	105.8	D	D	-	-	-	-
HA + VC + C	118.79	129.4	15.59	23.6	461.11	645	2957.72	2733

Note: HA= Humic acid, VC= vermicompost, C= compost, MC= marginal cost, MB= marginal benefits, MRR= marginal rate of return, D= dominated treatment which was eliminated

Partial budget and marginal analysis of potato cultivar Rudolph

The results revealed that cultivar Rudolph was superior compared to other planted cultivars of potato as it gave highest economic yield and net income benefits under all the possible treatments. The income returns of this cultivar were increased with the application of humic acid, vermicompost and compost together and recorded the highest values of US$ 2517.82 ha^{-1} in the experimental year of 2016 and US$ 2916.95 ha^{-1} in year 2017. The income benefits were minimized in either of the treatment where one source of fertilizer was not provided, i.e. vermicompost + compost had income returns of US$ 2096.78 ha^{-1} and US$ 2579.52 ha^{-1}, humic acid + compost recorded the returns of US$ 1806 ha^{-1} & US$ 2370.53 ha^{-1}, humic acid + vermicompost had US$ 1802.7 ha^{-1} and US$ 2318.66 ha^{-1} of income benefits, respectively. The control gave least benefits of US$ 1616 ha^{-1} and US$ 1894 ha^{-1} in two seasons (Table 11).

Table 11. Two-year impact on partial budget analysis of potato (*Solanum tuberosum* L.) cultivar "Rudolph" as affected by the combined application of organic manures

Treatments	Adj. yield (t ha^{-1})		GB US$ ha^{-1}		TVC US$ ha^{-1}		NB US$ ha^{-1}	
	2016	2017	2016	2017	2016	2017	2016	2017
Control	23.99	27.26	1679	1963	63.24	68.7	1616	1894
HA + VC	26.87	33.27	1881	2402	78.24	83.26	1803	2319
HA + C	26.95	34.1	1887	2455	80.39	84.67	1806	2371
VC + C	31.13	37.08	2179	2670	82.32	90.24	2097	2580
HA + VC + C	37.33	41.87	2613	3015	95.28	97.69	2518	2917

Note: HA= Humic acid, VC= vermicompost, C= compost, Adj. yield = adjusted yield, GB= gross benefits of income, TVC= total variable cost, NB= net benefits of income

The marginal analysis depicted that cultivar Rudolph was the best performing under organic sources of fertilizer treatments and gave highest marginal return rates of 3248.76 % and 4529 % when cultivated under all the possible sources of organic manures (Table 12). The remaining treatments having great variation in two-year outcomes with 1244 % and 2916 % in humic acid + vermicompost and 160.46 % 3678 % in humic acid + compost was due to greater economic yield.

Comparison of net income returns of potato cultivars planted under combined application organic fertilizers in two-year trials

The comparison of net benefits in all potato cultivars in two years of cropping explained that there was major difference in net economic returns among three cultivars, i.e. Vogue, Constance and Rudolph while the variety Kuroda had almost similar results in both cropping seasons. These three cultivars gave maximum returns of income in second season compared to first season. The results of potato variety Kuroda indicated its least adaptability into the system under all the possible treatments (Figure 2).

Table 12. Two-year impact on marginal return rate analysis of potato (*Solanum tuberosum* L.) cultivar "Rudolph" as affected by the combined application of organic manures

Treatments	TVC ($t\ ha^{-1}$)		MC US\$ ha^{-1}		MB US\$ ha^{-1}		MRR %	
	2016	2017	2016	2017	2016	2017	2016	2017
Control	63.24	68.7	-	-	-	-	-	-
HA + VC	78.24	83.26	15	14.56	186.6	424.57	1244	2916
HA + C	80.39	84.67	2.15	1.41	3.45	51.87	160.46	3678
VC + C	82.32	90.24	D	5.57	-	209	-	3752
HA + VC + C	95.28	97.69	12.96	7.45	421	337.43	3249	4529

Note: HA= Humic acid, VC= vermicompost, C= compost, MC= marginal cost, MB= marginal benefits, MRR= marginal rate of return, D= dominated treatment which was eliminated

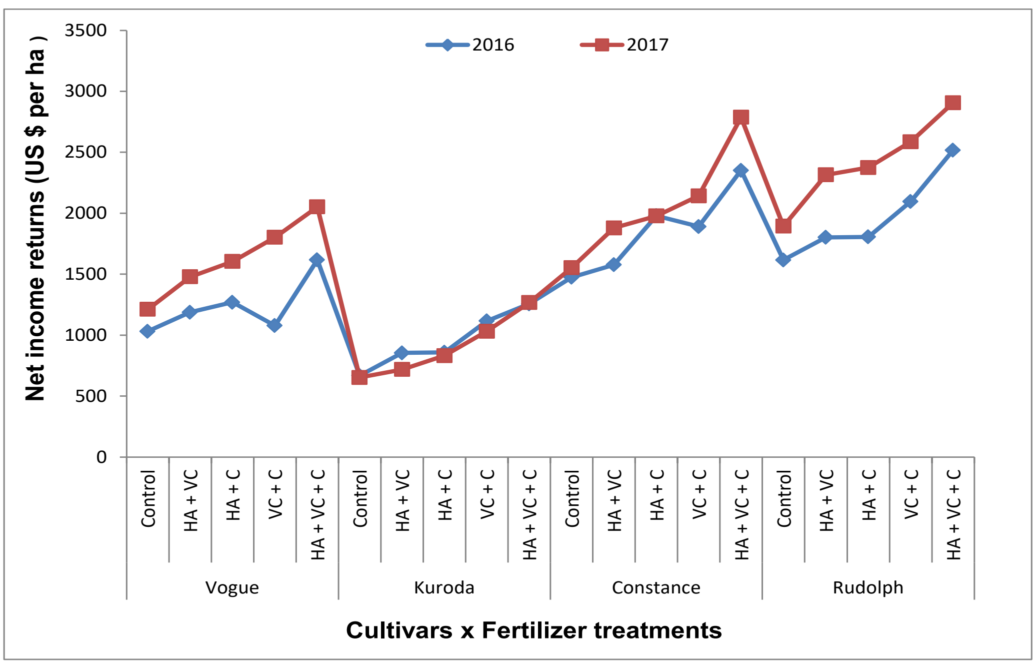


Figure 2. Difference of net income returns obtained from different potato cultivars planted under mixed application of organic fertilizers in two-year research trials

Discussion

The improvent in soil cheracteristics at harvesting stage in both cropping years was due to improved nutrients availability. The soil pH and electrical conductivity were increased due to the application of compost and vermicompost which had alkaline nature. It was due to the fact that application of vermicompost and various other organic fertilizers enhance soil microbial activity and release nutrients into the soil which improve soil chemical composition and provides favorable structure for plant growth and development. The incorporation of compost adds organic matter, enriches the soil with nitrogen and acts as a nutrient source for indigenous soil micro-organisms (Marinari *et al.,* 2000). Addition of humic substances improved soil nutrient contents including total nitrogen, nitrate nitrogen, available phosphorus and potassium due to increased microbial diversity and enzymatic activities (Li *et al.,* 2019).

The variation in plant height of different potato cultivars was probably due to the genetics of planted variety and quality of used material (Eaton *et al,* 2017). The obtained results were similar with the findings of Haq *et al.* (2021) who reported that genetic diversity in the germplasm of various cultivars caused great variations among different studied agronomic attributes of potato. The increase in plant height among treatments was due to the application of organic manures that improved the process of respiration and plant photosynthetic activity due to increased permeability of cell membrane (Berlyn and Russo, 1990).

The previous research studies indicated that number of potato tubers per plant depends upon main stems per plant, and sufficient nitrogen availability increased the biosynthesis of Gibberellins which regulated the stolons number and caused an increase in tubers number per plant (Bhujel *et al.,* 2021).

The effect of treatment with mixed application of humic acid, vermicompost and compost was greater on potato tuber length compared to other treatments. It was probably due to the fact that all the planted cultivars had greater nutrients uptake efficiency under this fertilizer protocol compared to any other treatment and maximized the results for potato tuber length. The increased results were due to better uptake of available nutrients caused by the application of organic components which regulated the plant growth processes (Abdel-Mawgoud *et al.,* 2007).

The number of small, medium and large potato tubers is actual yield determining factor and overall tuber yield depends upon it. The variation for tuber numbers among cultivars might be due to genetic trait of a particular variety as because potato plant can’t fight against weeds due to its weak shallow root system and most of nutrients are lost and utilized by weeds which may result in small sized tubers (Ullah *et al.,* 2019).

The tubers having the size in between (20-39 mm) were categorized as medium tubers of potato. The increased number of medium potato tubers per plant among various cultivars was probably due to the use of improved quality tuber source that produced healthy plants and tubers of good marketable size. The superior growth of plant and its rapid appearance resulted in higher number of medium size tubers (Kumar and Ezekiel, 2006; Patel *et al.,* 2013).

The tubers having the size of > 40 mm were ranked among large potato tubers and least in number compared to small and medium tubers. The least number of large size tubers produced was solely dependent upon the genetic character of a variety which was due to the lack of its defensive mechanism against weeds. The weeds competed with plants for nutrients, water, light and space as a result of which plants produced highest number of small size tubers (Singh *et al.,* 2017).

The total weight of tuber depends upon its seed source which produced maximum tubers of less marketable size that resulted in reducing total weight of tubers per plot among different cultivated varieties (Ahmed *et al.,* 2019). The less tuber weight in treatments with limited or no fertilizer was due to less availability of nutrients which reduced the production of photosynthates and resulted in slow growth and limited tuber dry matter per plant.

Potato tuber yield is a most important parameter which evaluated the net performance and productivity of two-year research trials. The increased outcomes in second year were clearly due to the best availability and more efficient use of natural resources. The increased potato tuber yield was due to the cultivar type which had good plant emergence, excellent spread and produced more stems per plant. The more spreading of plant exposed it more to sunlight, which enhanced the rate of photosynthesis and starch accumulation that improved the tuber yield (Qasim *et al.,* 2013).

The multivariate analysis of agronomic research trials provided useful additional information as supplement to normal univariate analysis. The basic purpose of the analysis was to show the similarity and difference between the four cultivars used in this experimental trial based on agronomic parameters of potato. The similar results were evaluated for used fertilizer treatments based on crop agronomic traits by Squared Euclidean Distance through Ward's method of hierarchical cluster analysis (Meena *et al.,* 2017).

The feasibility of two-year cropping of potato using any available variety under specific fertilizer treatments was determined through net monetary gains. It was calculated through gross benefits into the field while deducting the total cost that vary. The cultivar Kuroda was not feasible for cultivation using applied treatments under given conditions for farmers as it gave less income returns compared to other varieties due to minimum economic yield. The net economic returns in potato crop greatly influenced by the tuber character which may affect the economic yield. The cultivars producing more tubers with good marketable size would enhance net income gains in potato (Love and Thompson-Johns, 1999). Kumar *et al.* (2008) reported that planting best available potato cultivar which is fertilized with optimum dose of N can maximize the net income returns of the system. The three cultivars other than Kuroda gave maximum returns of income in second season compared to first season, which might be due to sufficient availability of crop nutrients in successive season caused by deeply incorporation of crop residues of previous season crop into the soil, which all these cultivars utilized efficiently required for the optimum plant growth. This led to increasing the plant population and economic yield of potato which ultimately gave highest net income benefits in year 2017.

The marginal rate of return analysis acknowledged that the treatment with all available sources of organic fertilizers e.g. humic acid + vermicompost + compost that provided maximum returns with less input costs under all circumstances was the best fit and highly recommended to farmers for adopting at commercial level. The treatments having two sources of organic fertilizers with minimum marginal return rate were not reliable enough to be recommended for commercial cultivation using the best performing cultivars e.g. Constance and Rudolph as they gave minimum returns with higher inputs. The treatments in different cultivars having marginal rate more than the acceptable rate are strongly recommended to the farmers under these growing conditions.

This research study concluded that use of organic manures caused significant improvement in agronomic and yield parameters of potato cultivars when applied in different combinations compared to unfertilized plots which ensured in maximizing the economic yield and net income returns of potato in both seasons. The repercussions of this two-year experimental trials suggested that potato cultivars Rudolph and Constance adapted well in these conditions and gave satisfactory results for crop agronomic attributes, economic yield and gave maximum net income returns under all possible fertility protocols as compared to other varieties, and therefore highly suggested for farmers for future cultivations. While the marginal return rate analysis represented that treatment with all available sources of organic manures i.e. humic acid + vermicompost + compost, in a single plot gave highest marginal return rate which suggested it be best suited treatment recommended for farmers for their farming at commercial scale. So, the use of organic fertilizer was not only important in getting more economical and profitable crop yields, but it also enriched soil fertility status without damaging it's physical and chemical properties, so it was eco-friendly approach.

Acknowledgements

The two-year research project was funded by Dept. of Agronomy, Faculty of Agriculture, Arid Agriculture University, Rawalpindi with an aim to determine the feasibility of replacing intensive cropping systems of rainfed Pothwar region with short duration vegetables using potential cultivars in a way to obtain maximum yields while keeping the input cost at minimal. All the authors made significant contributions in this research study and gave valuable insights while writing this article.

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(Received: 29 July 2023, Revised: 4 January 2024, Accepted: 9 January 2024)