Original Research Article

RESIDUAL EFFECT OF INTEGRATED MANAGEMENT ON SOIL NUTRIENT STATUS AND YIELD IN ONION (*Allium cepa* L.)

ABSTRACT

A field experiment was conducted over a period of two Rabi seasons in 2021 and 2022, to study the effect of onion by embracing different organic manures, inorganic fertilizers and bio-additives (*Pseudomonas fluorescens* and *Bacillus subtilis*) over growth, yield, quality and persisting soil fertility of onion in the mineralized soils of Himachal Pradesh. The study was organized in thirteen treatments with amalgamation of organic manure, bio-additives and inorganic fertilizers. The analysis unveils that lowest soil pH (6.94), electrical conductivity (0.186 dSm^{-1}), highest soil organic carbon (0.85 %), available nitrogen (257.79 kg/ha) and available phosphorus (26.14 kg/ha) were recorded with treatment T_7 [75 % Recommended dose of NPK + 40 kg S/ha + *Bacillus subtilis* + FYM (250 q/ha)]. The highest available potassium was recorded in treatment T_{12} [100 % Recommended Dose of NPK (125:75:60 kg/ha)] and highest available sulphur was recorded in treatment in T_{11} [100 % Recommended Dose of NPK + 40 kg S/ha]. The maximum gross income (₹ 5,46,260 /ha), net income (₹ 3,86,350.73 /ha) and benefit: cost ratio (2.41) was obtained in treatment T_7 [75 % Recommended dose of NPK + 40 kg S/ha + *Bacillus subtilis* + FYM (250 q/ha)]. Therefore, it is apparent that consolidation of organic manure and inorganic fertilizer along with *Bacillus subtilis* provides more balance nutrition for plants which ameliorated the vegetative phenomenon, inflated soil nutrient status and nurtured sustaining crop prolificacy, leading to 50-70 % dwindling of fertilizer usage.

1. INTRODUCTION

Onion is one of the most important commercial vegetable crops cultivated extensively in India and belongs to family Alliaceae (Sultana et al. 2007). The crop is native of Asia (Jones and Mann 1963). Onion is an indispensable item in every kitchen as condiment, therefore onion is popularly known as 'queen of kitchen' (Selviraj 1976). Pungency in onion is due to the presence of a volatile oil 'allyl propyl disulphide' – an organic compound rich in sulphur (Sharma et al. 2022) Onion has a paramount effect in preventing heart diseases, diabetes

UNDER PEER REVIEW

(Saini 1997; Vohra et al. 1994) and also contains several anti cancerous agents which have shown to prevent cancer (Belay et al. 2015). The beneficial compound called 'quercetin' present in onion is a powerful antioxidant (Črnivec et al. 2021). Onion is used by processing industries to greater extent for preparing dehydrated products like powder and flakes (Ramkumar and Karuppusamy 2021). India occupies second position after China in production, cultivating onion over an area of 1431 thousand ha with annual production of 26148 thousand metric tonnes and in Himachal Pradesh, onion is cultivated over an area of 3411.08 ha with annual production of 74827 metric tonnes (Anonymous 2020).

In recent years, it has been realized that judicious application of nutrients has expanded many folds with the adoption improved technology for obtaining higher yield and better quality of onion (Shedeed et al. 2014). In modern agriculture, fertilizers constitute major portion of cost of production of onion. Inorganic fertilizers application will cause deleterious effect on soil health leading to soil acidity or alkalinity (Ramesh et al. 2017). Moreover, chemical fertilizers are very expensive and sometimes unavailable to small scale farmers and therefore sole application of inorganic fertilizers deteriorates soil fertility level day by day, that affect the production, economics of production and human health (Aisha et al. 2007; Hernandez et al. 2010). This anxiety has now led farmers to devise ways and means to switch over from conventional to organic farming systems which used no synthetic fertilizer and pesticide in crop production (Colla et al. 2002). Use of chemical fertilizers supplemented with organic manures and biofertilizers will be environmentally benign (Gupta et al. 1999), indirectly it improves the physical properties of soil such as aggregation, aeration, permeability and water holding capacity (Chandramohan 2002; Yafan and Barker 2004).

Improved management of nitrogen, phosphorus, potassium, sulphur and other inputs in the soil could improve the yield and quality of onion. Availability of nitrogen is salient for growing plants as it remains the major constituent of protein and nucleic acid molecules. Application of nitrogen with different doses increases the growth and yield of onion (Patel et al. 1992). Phosphorous is desired for the transfer of energy within the plant system and is involved in several metabolic activities (Rengel and Zhang 2011). It has its favourable outcomes on early root development, plant growth, yield and quality (Williamson et al. 2001). Potassium plays prime role in plant metabolism (Ali et al. 2021) and it improves color, glossiness and dry matter accumulation besides improving keeping quality of onion (Dorias et al. 2001). Sulphur is an essential macronutrient and at an optimum concentration accelerates

UNDER PEER REVIEW

the plant growth (Thomas et al. 2000; Anwar et al. 2001). It also influences the taste and pungency in the crop (Tripathy et al. 2013). Therefore, integrated nutrient management is available strategy for advocating judicious and efficient use of chemical fertilizers with matching addition of organic manures for sustainable onion cultivation.

Organic manures like FYM and Vermicompost activate many species of living organism which release phytohormones and may stimulate the plant growth and absorption of nutrients. The increase in microbial population in the presence of organic manures may also be attributed to greater availability of organic carbon and mineralized nutrients for their proliferation and further cellular development (Marathe et al. 2012). Apart from improving physical and biological properties of soil organic manures help in improving the use and efficiency of chemical fertilizers (Gedam et al. 2008). Combined use of FYM and inorganic fertilizers is of special significance under intensive cropping system as these are complementary and supplementary to each other in sustaining crop yields and soil productivity (Abid et al. 2020). FYM improves the soil physical, chemical and biological properties along-with the provision of macro and micro nutrients (Augusti 1996). Use of organic manures in combination with chemical fertilizers in an appropriate proportion improves the overall soil health for sustainable onion production (Gupta et al. 1999).

Importance of nutrients supply in integrated manner in sustaining productivity is emphasized to restore and sustain soil health and productivity in the long run which otherwise is likely to deteriorate due to continuous and intensive cultivation without adequate nutrients management. Therefore, biofertilizers are widely accepted as low cost supplements to chemical fertilizers with no deleterious effect on either soil health or environment (Bhagyaraj and Suvarna 1999). Bio-fertilizer has recently gained with momentum for affecting the sustainable increase in crop yield under various agro-climatic conditions. Biofertilizers are live carrier based microbial preparations used in agriculture as low input resources to enhance the availability of plant nutrients or promote the growth by way of synthesizing growth factors and also improve building hormones along with anti-metabolite properties (Singh et al. 2021). Role of bio-fertilizer on the crop growth and yield was documented by Vijayakumar et al. 2000 and Ramakrishnan and Thamizhiniyan 2004. A small dose of biofertilizer is sufficient to produce desirable results because each gram of carrier of biofertilizers contains at least 10 million viable cells of a specific strain (Anandaraj and Delapierre 2010). These may be helpful for increasing the crop production by enhancing the soil fertility, therefore use of

UNDER PEER REVIEW

biofertilizers not only supplement the nutrient but also improve the efficiency of applied nutrients (Bayu T 2020).

Various bio-additives enhance emergence of seed, plant growth and improve crop production by residing in the rhizosphere of plants and enhancing growth by direct and indirect mechanisms such as nitrogen fixation, solubilization of nutrients (phosphorous, potassium), siderophores production and water & minerals uptake (Bhattacharya and Jha 2012; Pérez-Montaño et al. 2014). These bio-additives affect plant growth by producing growth substances such as IAA, GA and Cytokinins (Verma et al. 2010; Garcia de Salamone et al. 2001), fix nitrogen from the atmosphere and provide the plants with this element (Boddey and Dobereiner 1995) and are antagonistic towards phytopathogenic micro-organisms (Velivelli et al. 2012). Alternatively, these bio-additives supplement the role of chemical fertilizers, pesticides and other inputs by decreasing the inhibitory effects of various pathogens on plant growth and development (Lugtenberg and Kamilova. 2009).

Integrated nutrient management is a viable strategy for advocating judicious and efficient use of organic manures and plant growth promoting rhizobacteria in conjunction with chemical fertilizers has been found to be promising not only in sustaining high productivity but also for good growth, improving soil fertility on long term basis and reducing fertilizer input cost. Taking into consideration, current investigation was designed and implemented to appraise the effect of bio-additives (Bacillus subtilis and Pseudomonas fluorescens) and organic manures on growth, yield, quality and persisting soil fertility of onion in the mineralized soils of Himachal Pradesh.

1. MATERIALS AND METHODS

2.1 Experimental Site

During the *rabi* season of 2020-21 and 2021-22, the field experiment on onion was carried out at the College of Horticulture & Forestry’s research farm Hamirpur (Himachal Pradesh), located at a latitude of 31° 41’47.6" N and a longitude of 76° 28’06.3" E, and an elevation of 650 meters above sea level. The climate of the region is classified as subtropical, with average low to high temperatures of 20.1°C to 35.9°C and an average annual rainfall of 1225 mm. Maximum rainfall is recorded during monsoon, from June to September. The soil structure at the research location is classified as sandy clay loam. Ahead of experiment, soil samples were collected from different spots of the experimental site from a depth of 0-15 cm and composite sample was prepared. After analysis, soil pH was neutral (7.04) having normal electrical

UNDER PEER REVIEW

conductivity of 0.211 $dSm^{-1}$and organic carbon content was medium (0.70 %). The nutrient status of soil was low in available Nitrogen (197.56 kg/ha), however medium in available Phosphorous (15.73 kg/ha), available Potassium (156.78 kg/ha) and Sulphur (30.60 kg/ha).

The soil structure of experimental farm is to loam to clay loam with pH ranging from 6.8 to 7.0. Before planting of the crop, random soil samples were collected from different spots of the experimental site from a depth of 0-15 cm and the composite sample was prepared. These samples were air-dried, crushed and passed through a 2 mm sieve and stored in cloth bags for chemical analysis of parameters such assoil pH, electrical conductivity, organic carbon and for available nitrogen, available phosphorous and available potassium. The pH and EC of soil samples were measured using a digital pH meter and an electrical conductivity meter, respectively.

1.2 Experimental Design and Crop management

The experiment was laid out in Randomized Complete Block Design with three replications and thirteen treatments viz., [Control], [*Bacillus subtilis* + FYM (250 q/ha)], [*Pseudomonas fluorescens* + FYM (250 q/ha)], [75 % Recommended dose of NPK+ *Bacillus subtilis* + FYM (250 q/ha)], [75 % Recommended dose of NPK + *Pseudomonas fluorescens* + FYM (250 q/ha)], [50 % Recommended dose of NPK + *Bacillus subtilis* + FYM (250 q/ha)], [50 % Recommended dose of NPK + *Pseudomonas fluorescens* + FYM (250 q/ha)], [75 % Recommended dose of NPK + 40 kg S/ha + *Bacillus subtilis* + FYM (250 q/ha)], [75 % Recommended dose of NPK + 40 kg S/ha + *Pseudomonas fluorescens* + FYM (250 q/ha)], [50 % Recommended dose of NPK + 40 kg S/ha + *Bacillus subtilis* + FYM (250 q/ha)], [50 % Recommended dose of NPK + 40 kg S/ha + *Pseudomonas fluorescens* + FYM (250 q/ha)], [100 % Recommended Dose of NPK + 40 kg S/ha] and [100 % Recommended Dose of NPK (125:75:60 kg/ha)]in a plot size of 1 m x 0.75 mat spacing of 15 x 10 cm accommodating 50 plants per plot. Agrifound Dark Red variety developed by National Horticulture Research and Development Foundation, Nasik, Maharashtra of onion was employed for the study. The experimental field was thoroughly ploughed with the help of tractor followed by planking. Deep ploughing was done to bring the soil to a fine tilth and all the clods of the soil were thoroughly broken. All the stubble and weeds were removed. Plots were prepared according to the layout plan. The organic manure such as farmyard manure and recommended dose of fertilizers were applied at the time of field preparation as per the treatments in the respective plots. First irrigation was done immediately after sowing and

UNDER PEER REVIEW

daily irrigation is done till the plants are fully established thereafter, irrigation is done twice a week and then once in 6-7 days to retain optimum soil moisture, depending upon weather conditions. Weeding was done manually on a regular basis to keep the plot free from weeds and to keep the soil loose and airy. Two shallow weeding were done at 20 and 40 DAT to keep the field free from weeds. Harvesting was done at 60-70 % neck fall, while the leaves were still green.

Application of inorganic, organic manures and plant growth promoting rhizobacteria

Calculated amount of inorganic fertilizers nitrogen, phosphorous, potassium and sulphur (125:75:60:40 kg/ha) were applied in the form of urea (203.8 kg/ha), SSP (356.25 kg/ha), MOP (75 kg/ha) and Sulphur (40 kg/ha) in respective treatments before transplanting of seedlings. One third dose of N along with the full doses of P, K and S were applied as basal dose. Remaining dose of N was given in two splits; after 30 and 60 DAT. Organic manures such as FYM (250 q/ha) were applied during field preparation in the respective treatments. Seedling roots were dipped in plant growth promoting rhizobacteria viz., *Bacillus subtilis* and *Pseudomonas fluorescens* prior to sowing for 30 minutes as per the treatments and immediately transplanted in the field.

2.3 Soil Sampling and Analysis

Soil samples were taken from 0 -15 cm depth after completion of experiment from all plots. These samples were air-dried, crushed and passed through a 2 mm sieve and stored in cloth bags for subsequent chemical analysis of parameters such as soil pH, electrical conductivity (EC), organic carbon content, and available nitrogen (N), phosphorus (P), potassium (K) and sulphur content. The pH and EC of soil samples were measured using a digital pH meter and an electrical conductivity meter, respectively. Organic carbon content of the samples was determined using the Chromic and Titration method proposed by Walkley and Black (1934). Alkaline Potassium Permanganate Method was used to determine available N (Subbiah and Asija 1956), P was measured by the method inclined by Olsen (Olsen *et al.* 1954). Available K was measured by Normal Neutral Ammonium Acetate Method (Merwin and Peech 1951) and Sulphur was determined by 0.15 % $CaCl_2$ Extractant and Turbidimetric Method (Chesnin and Yien 1950). The mean values of data were subjected to analysis of variance as described by Gomez and Gomez (1984) for Randomized Complete Block Design.

Table 1.Physico-chemical properties of soil before planting of crop

UNDER PEER REVIEW

Particulars	Value Obtained	Method employed	Soil status
Soil Ph	7.04	Digital pH meter	Neutral
Soil EC (dSm^{-1})	0.211 (dSm^{-1})	Electrical Conductivity Meter	Normal
Soil OC (%)	0.70 (%)	Chromic and Titration Method (Walkley and Black, 1934)	Medium
Soil N (kg/ha)	197.56 (kg/ha)	Alkaline Potassium Permanganate Method (Subbiah and Asija, 1956)	Low
Soil P (kg/ha)	15.73 (kg/ha)	Olsen's Method (Olsen et al. 1954)	Medium
Soil K (kg/ha)	156.78 (kg/ha)	Normal Neutral Ammonium Acetate Method (Merwin and Peech, 1951)	Medium
Soil S (kg/ha)	30.60 (kg/ha)	0.15% $CaCl_2$ Extractant and Turbidimetric Method (Chesnin and Yien, 1950)	Medium

2.4 Statistical Analysis

The merging of data was subject to statistical analysis of variance as delineated by Gomez and Gomez (1984). The main aim of the analysis was to regulate the impact of treatments on different plant and soil parameters. Further, considering the costs associated with various treatments and the market rate of the crop an economic estimation was performed. The benefit-cost ratio (B/C ratio) was calculated by dividing the value of marketable produce by the total cost of cultivation.

3 RESULTS AND DISCUSSION

3.1 Soil pH

Application of organic manure, inorganic fertilizer and plant growth promoting rhizobacteria improved the soil pH as compared to initial status. Perusal of data presented in Table 2, revealed that minimum pH (6.94) was recorded by the treatment T_7 (75 % Recommended dose of NPK + 40 kg S/ha + *Bacillus subtilis* + FYM (250 q/ha). The soil pH decreased moderately due to inoculation with plant growth promoting rhizobacteria like *Bacillus* and *Pseudomonas* significantly enhanced the population of soil microorganisms in the rhizosphere which increased their dehydrogenase activity and then dehydrogenase released hydrogen ions in the rhizosphere resulting in the formation of carbonic acid that decreases the pH value as

UNDER PEER REVIEW

reported by Khadiga et al. (2015). Decrease in pH values might be ascribed to H+ ion released during sulphur oxidation. When elemental sulphur is applied to soil, a biological reaction takes place carried out by sulphur oxidizing bacteria, producing sulfuric acid that reduces soil pH as stated by Nemat et al. (2011).

3.2 Electrical conductivity (dSm^{-1})

Electrical conductivity is important trait as it indicates the availability of nutrients and provides information related to the concentration of soluble salts present in the soil. The data revealed that maximum electrical conductivity (0.202 dSm^{-1}) was observed in treatment T_0 (Control) while, the minimum electrical conductivity (0.186 dSm^{-1}) was recorded in treatment T_7 (75 % Recommended dose of NPK + 40 kg S/ha + *Bacillus subtilis* + FYM) after harvesting the crop (Table 2). This may be due to plant uptake of soluble salts through root systems by plants or leaching of cations and at the same time chloride accumulation in the surface due to capillary action can be accountable for the decrease in electrical conductivity as mentioned by Prasad (2021).

3.3 Organic carbon (%)

Organic carbon induces changes in microbial activities that affect the transformation and availability of nutrients, organic matter and overall soil health. Data revealed that highest organic carbon (0.85 %) was observed in treatment T_7 (75 % Recommended dose of NPK + 40 kg S/ha + *Bacillus subtilis* + FYM) whereas, minimum organic carbon was obtained in treatment T_0 (Control) after harvesting the crop (Table 2). This might be due to inoculation by *Bacillus subtilis* and *Pseudomonas fluorescens* as plant growth promoting rhizobacteria strains which are required for maximizing the plant yield and improved soil quality by increasing the organic carbon as reported by Hosam et al. (2013). Similar findings are reported by Prasad (2022).

UNDER PEER REVIEW

Table 2. Effect of integrated nutrient management on pH, EC (dSm^{-1}) and organic carbon (%) in soil

Treatment Code	Treatment Details	Soil pH	EC (dSm^{-1})	Organic carbon (%)
T_0	Control	7.07	0.202	0.61
T_1	*Bacillus subtilis* + FYM (250 q/ha)	7.01	0.197	0.73
T_2	*Pseudomonas fluorescens* + FYM (250 q/ha)	7.03	0.198	0.75
T_3	75 % Recommended dose of NPK+ *Bacillus subtilis* + FYM (250 q/ha)	7.00	0.194	0.77
T_4	75 % Recommended dose of NPK + *Pseudomonas fluorescens* + FYM (250 q/ha)	7.02	0.195	0.74
T_5	50 % Recommended dose of NPK + *Bacillus subtilis* + FYM (250 q/ha)	7.03	0.194	0.76
T_6	50 % Recommended dose of NPK + *Pseudomonas fluorescens* + FYM (250 q/ha)	7.02	0.196	0.78
T_7	75 % Recommended dose of NPK + 40 kg S/ha + *Bacillus subtilis* + FYM (250 q/ha)	6.94	0.186	0.85
T_8	75 % Recommended dose of NPK + 40 kg S/ha + *Pseudomonas fluorescens* + FYM (250 q/ha)	6.96	0.189	0.83
T_9	50 % Recommended dose of NPK + 40 kg S/ha + *Bacillus subtilis* + FYM (250 q/ha)	6.98	0.192	0.80
T_{10}	50 % Recommended dose of NPK + 40 kg S/ha + *Pseudomonas fluorescens* + FYM (250 q/ha)	6.99	0.193	0.79
T_{11}	100 % Recommended Dose of NPK + 40 kg S/ha	7.04	0.198	0.70
T_{12}	100 % Recommended Dose of NPK (125:75:60 kg/ha)	7.05	0.199	0.71
	Mean	7.00	0.194	0.75
	$CD_{(0.05)}$	0.01	0.002	0.01
	SE(m)	0.00	0.00	0.00
	C.V	0.16	0.51	1.33

UNDER PEER REVIEW

3.4 Available Nitrogen (kg/ha)

The data for available nitrogen is presented in Table 3. Maximum available nitrogen (257.79 kg/ha) was recorded in treatment T_7 (75 % Recommended dose of NPK + 40 kg S/ha + *Bacillus subtilis* + FYM) and minimum available nitrogen (188.86 kg/ha) was observed in treatment T_0 (Control) after harvesting the crop. Breakdown of complex nitrogenous compounds to nitrate due to action of micro-organisms might have increased nitrogen and enhanced nitrogen uptake in plants as reported by Ramesh et al. (2017). Whereas, Saharan and Nehra (2011) reported that it might be due to the use of mixture of plant growth promoting rhizobacteria including *Bacillus spp.* which fix the atmospheric nitrogen and excretes growth promoters that increase nitrogen content in soil.

3.5 Available Phosphorus (kg/ha)

An examination of data regarding available phosphorus presented in Table 3 and depicted that maximum available phosphorus (26.14 kg/ha) in soil after harvesting of crop was recorded in treatment T_7 (75 % Recommended dose of NPK + 40 kg S/ha + *Bacillus subtilis* + FYM) while, minimum available phosphorus (14.87 kg/ha) was recorded in treatment T_0 (Control). Increase in available phosphorus over initial value might be ascribed to the role of *Bacillus* which solubilizes the insoluble phosphorus compounds and increases the plant growth as reported by Bektas and Kusek (2021). Whereas, Hosam et al. (2013) mentioned that inoculation with isolates of *Pseudomonas* had a stimulatory effect on plant growth and produces indolic compounds and siderophores, to solubilize phosphate. Plant growth promoting rhizobacteria enhance phosphorous uptake by releasing organic acids such as fumeric acid, butyric acid, citric acid etc. which improves microbial activity and increases phosphorous availability as reported by Shahzad et al. (2020).

3.6 Available Potassium (kg/ha)

Maximum available potassium (174.59 kg/ha) in soil after harvesting was recorded in treatment T_{12} (100 % Recommended dose of NPK + FYM) whereas, minimum available potassium (142.13 kg/ha) was recorded in treatment T_0 (Control) after harvesting the crop (Table 3). Overall mean for available potassium was 157.76 kg/ha. Greater availability of nutrients from inorganic sources might have increased available potassium in soil. Similar results are in conformity with Nainwal et al. (2015), Behairy et al. (2015) and Ramesh et al. (2017).

UNDER PEER REVIEW

Table 3. Effect of integrated nutrient management on available N (kg/ha), P (kg/ha), K (kg/ha) and S (kg/ha) in soil

Treatment Code	Treatment Details	Available N in soil (kg/ha)	Available P in soil (kg/ha)	Available K in soil (kg/ha)	Available S in soil (kg/ha)
T_0	Control	188.86	14.87	142.13	29.31
T_1	*Bacillus subtilis* + FYM (250 q/ha)	215.46	17.57	148.01	36.62
T_2	*Pseudomonas fluorescens* + FYM (250 q/ha)	212.53	16.41	145.77	35.68
T_3	75 % Recommended dose of NPK+ *Bacillus subtilis* + FYM (250 q/ha)	240.52	19.50	156.12	42.76
T_4	75 % Recommended dose of NPK + *Pseudomonas fluorescens* + FYM (250 q/ha)	237.27	18.17	154.18	41.36
T_5	50 % Recommended dose of NPK + *Bacillus subtilis* + FYM (250 q/ha)	228.76	17.95	153.01	40.70
T_6	50 % Recommended dose of NPK + *Pseudomonas fluorescens* + FYM (250 q/ha)	226.53	17.71	150.61	39.55
T_7	75 % Recommended dose of NPK + 40 kg S/ha + *Bacillus subtilis* + FYM (250 q/ha)	257.79	26.14	167.89	48.72
T_8	75 % Recommended dose of NPK + 40 kg S/ha + *Pseudomonas fluorescens* + FYM (250 q/ha)	254.54	24.70	165.74	46.59
T_9	50 % Recommended dose of NPK + 40 kg S/ha + *Bacillus subtilis* + FYM (250 q/ha)	251.42	23.82	162.91	44.42
T_{10}	50 % Recommended dose of NPK + 40 kg S/ha + *Pseudomonas fluorescens* + FYM (250 q/ha)	249.24	22.66	159.78	43.86
T_{11}	100 % Recommended Dose of NPK + 40 kg S/ha	246.38	21.82	170.17	53.45
T_{12}	100 % Recommended Dose of NPK (125:75:60 kg/ha)	242.52	20.53	174.59	41.64
	Mean	234.75	20.14	157.76	41.89
	$CD_{(0.05)}$	1.35	1.14	0.71	0.52
	SE(m)	0.46	0.39	0.24	0.17
	C.V	0.34	3.35	0.26	0.73

UNDER PEER REVIEW

3.7 Available Sulphur (kg/ha)

Data pertaining to available sulphur depicted that maximum available sulphur (53.45 kg/ha) was recorded in treatment T_{11} (100 % Recommended dose of NPK + 40 kg S/ha + FYM) however, minimum available sulphur (29.31 kg/ha) was recorded in treatment T_0 (Control) in soil after harvesting of crop. Overall mean value was 42.66 kg/ha. Sulphur application enhances the population of sulphur consuming microorganisms leading to oxidation of S to SO_4^{2-} producing sulfuric acid that reduces the soil pH and increase the concentration of available sulphur in soil. The results are in line with the findings of Nemat et al. (2011), Jaggi (2005) and Sankaran et al. (2005).

3.8 Economics of Onion Cultivation

Data for economics of onion cultivation is presented in Table 4. Maximum gross income (₹ 5,46,260/ha) was recorded by treatment T_7 (75 % Recommended dose of NPK + 40 kg S/ha + *Bacillus subtilis* + FYM) whereas, minimum gross income (₹ 2,90,120/ha) was obtained with treatment T_0 (Control). Highest net income (₹ 3,86,350.73/ha) was obtained with treatment T_7 (75 % Recommended dose of NPK + 40 kg S/ha + *Bacillus subtilis* + FYM) however, minimum net income (₹ 1,82,900/ha) was observed by treatment T_2 (*Pseudomonas fluorescens* + FYM). Maximum B: C ratio (2.41) was observed by treatment T_7 (75 % Recommended dose of NPK + 40 kg S/ha + *Bacillus subtilis* + FYM) while, lowest B: C ratio (1.21) was recorded by treatment T_2 (*Pseudomonas fluorescens* + FYM).

UNDER PEER REVIEW

Table 4. Effect of integrated nutrient management on economics of onion cultivation

Treatment Code	Treatment Details	Total Bulb Yield (q/ha)	Total cost of Cultivation (₹/ha)	Gross Income (₹/ha)	Net Income (₹/ha)	B: C Ratio
T_0	Control	145.06	1,04,800	2,90,120	1,85,320	1.76
T_1	*Bacillus subtilis* + FYM (250 q/ha)	168.86	1,50,200	3,37,720	1,87,520	1.24
T_2	*Pseudomonas fluorescens* + FYM (250 q/ha)	166.60	1,50,300	3,33,200	1,82,900	1.21
T_3	75 % Recommended dose of NPK+ *Bacillus subtilis* + FYM (250 q/ha)	226.66	1,58,909.27	4,53,320	2,94,410.73	1.85
T_4	75 % Recommended dose of NPK + *Pseudomonas fluorescens* + FYM (250 q/ha)	224.40	1,59,009.27	4,48,800	2,89,790.73	1.82
T_5	50 % Recommended dose of NPK + *Bacillus subtilis* + FYM (250 q/ha)	221.00	1,56,006.14	4,42,000	2,85,993.86	1.83
T_6	50 % Recommended dose of NPK + *Pseudomonas fluorescens* + FYM (250 q/ha)	218.73	1,56,106.14	4,37,460	2,81,353.86	1.80
T_7	75 % Recommended dose of NPK + 40 kg S/ha + *Bacillus subtilis* + FYM (250 q/ha)	273.13	1,59,909.27	5,46,260	3,86,350.73	2.41
T_8	75 % Recommended dose of NPK + 40 kg S/ha + *Pseudomonas fluorescens* + FYM (250 q/ha)	265.20	1,60,009.27	5,30,400	3,70,390.73	2.31
T_9	50 % Recommended dose of NPK + 40 kg S/ha + *Bacillus subtilis* + FYM (250 q/ha)	258.40	1,57,006.14	5,16,800	3,59,793.86	2.29
T_{10}	50 % Recommended dose of NPK + 40 kg S/ha + *Pseudomonas fluorescens* + FYM (250 q/ha)	255.00	1,57,106.14	5,10,000	3,52,893.86	2.24
T_{11}	100 % Recommended Dose of NPK + 40 kg S/ha	247.06	1,62,412.34	4,94,120	3,31,707.66	2.04
T_{12}	100 % Recommended Dose of NPK (125:75:60 kg/ha)	243.66	1,62,312.34	4,87,320	3,25,007.66	2.00

UNDER PEER REVIEW

CONCLUSION

Treatment T_7 was found superior for majority soil parameters. Highest gross income (₹ 5,46,260/ha), net income (₹ 3,86,350.73/ha) and B: C ratio (2.41) was observed by treatment T_7 (75 % Recommended dose of NPK + 40 kg S/ha + *Bacillus subtilis* + FYM). Hence, it can be concluded that combined application of organic manure and inorganic fertilizer along with *Bacillus subtilis* provides more balanced nutrition for plants which improve the vegetative phenomenon, nutrient uptake, residual soil fecundity and results in better production of onion by minimizing the usage of inorganic fertilizers by more than 50%.

REFERENCES

Abid M, Batool T, Siddique G, Ali S, Binyamin R, Shahid MJ, Rizwan M, Alsahli AA, Alyemeni MN. Integrated nutrient management enhances soil quality and crop productivity in maize-based cropping system. Sustainability. 2020;12:10214.

Aisha AH, Rizk FA, Shaheen AM, Abdel-Mouty MM. Onion plant growth, bulbs yield and its physical and chemical properties as affected by organic and natural fertilization. Research Journal of Agriculture and Biological Sciences. 2007;3:380-388.

Ali MM, Petropoulos SA, Selim DA, Elbagory M, Othman MM, Omara AE, Mohamed MH. Plant growth, yield and quality of potato crop in relation to potassium fertilization. Agronomy. 2021;11:675.

Anandaraj B, Delapierre LRA. Studies on influence of bioinoculants (*Pseudomonas fluorescens, Rhizobium* sp., *Bacillus megaterium*) in green gram. Journal of Bioscience and Technology. 2010;1:95-99.

Anonymous http://nhb.gov.in/statistics/state_Level/2018-19 .2020.

Anwar MN, Sarker JU, Rahman M, Islam MA, Begum M. Response of onion to nitrogen, phosphorus, potassium, sulphur and zinc. Bangladesh Journal of Environment Science. 2001;7:68−72.

Augusti K. Therapeutic values of onion and effect of organic and inorganic fertilizers on

UNDER PEER REVIEW

garlic. Indian Journal of Experimental Biology. 1996;34:634-640.

Bayu T. Review on contribution of integrated soil fertility management for climate change mitigation and agricultural sustainability. Cogent Environmental Science. 2020;6:1823631.

Behairy AG, Mahmoud AR, Shafeek MR, Ali AH, Hafez MM. Growth, yield and bulb quality of onion plants (*Allium cepa* L.) as affected by foliar and soil application of potassium. Middle East Journal of Agriculture. 2015;4:60-66.

Bektas I, Kusek M. The isolation and characterization of phosphate solubilizing bacteria from the onion rhizosphere and their effect on onion growth. Journal of Agriculture and Nature. 2021;24:1084-1092.

Belay S, Mideksa D, Gebrezgiabher S, Seifu W. Yield components of Adama red onion (*Allium cepa* L.) cultivar as affected by intra-row spacing under irrigation in fiche condition. Plant. 2015;3:75-79.

Bhagyaraj DJ, Suvarna CV. Biofertilizers and their application. Agrieast. 1999;1:16-21.

Bhattacharya PN, Jha DK. Plant growth promoting rhizobacteria (PGPR): emergence in agriculture. World Journal of Microbiology and Biotechnology. 2012;28:1327-1350.

Boddey RM, Dobereiner J. Nitrogen fixation associated with grasses and cereals: recent progress and perspectives for the future. Fertility Research. 1995;42:241-250.

Črnivec IG, Skrt M, Šeremet D, Sterniša M, Farčnik D, Štrumbelj E, Poljanšek A, Cebin N, Pogačnik L, Možina SS, Humar M. Waste streams in onion production: Bioactive compounds, quercetin and use of antimicrobial and antioxidative properties. Waste management. 2021;126:476-86.

Chesnin L, Yien CH. Turbidimetric determination of available sulphates. Soil Sciences Society of America Proceeding. 1950;15:149-151.

Chandramohan S. Organic farming in cotton + blackgram intercropping system. M.Sc. (Agri.) Thesis, Tamil Nadu Agricultural University, Coimbatore (India), 2002.

UNDER PEER REVIEW

Colla G, Mitchell J, Poudel D, Temple S. Change of tomato yield and fruit elemental composition in conventional, low input, and organic system. Journal of Sustainable Agriculture. 2002;20:53-67

Dorais M, Papadoulos AP, Gosselin A. Greenhouse tomato fruit quality. Horticultural Review. 2001;26:262-319.

Garcia de Salamone IE, Hynes RK, Nelson LM. Cytokinin production of plant growth promoting rhizobacteria and selected nutrients. Canadian Journal of Microbiology. 2001;47:404-411.

Gedam VB, Rametke JR, Rudragouda, Power MS. Influence of organic manures on yield, nutrient uptake of groundnut and change in physic-chemical properties of soil after harvest of groundnut. Crop Research. 2008;36:111-114.

Gomez KA, Gomez AA. Statistical Procedures for Agricultural Research. 2nd ed. John Wiley & Sons Inc. New York. 1984;427p.

Gupta RP, Sharma VP, Singh DK, Srivastava KJ. Effect of organic manures and inorganic fertilizers on growth, yield and quality of onion variety Agrifound Dark Red. News Letter National Horticultural Research and Development Foundation. 1999;19:7-11.

Hernandez A, Castillo H, Ojeda D, Arras A, Lopez J, Sanchez E. Effect of vermicompost and compost on lettuce production. Chilean Journal of Agricultural Research. 2010;70:583-589.

Hosam EAF, Hamuda B, Patkó I. PGPR strains selection to improve plant productivity and soil quality. Academy Food Research and Development Institute. International Scientific Practical Conference. "Food, Technologies & Health". 2013;44-50p.

Jaggi RC. Sulphur as production and protection agent in onion (*Allium cepa*). Indian Journal of Agricultural Sciences. 2005;75:805-808.

Jones HA, Mann LK . Onion and their allies. Leonard Hill, (Books) Ltd., London. 1963;1-169p.

Khadiga IM El-G, Sanaa SHS, Amal WA El-K. Effect of some microbial activators on onion plantlets growth quality. Middle East Journal of Agriculture Research. 2015;4:932-937.

UNDER PEER REVIEW

Lugtenberg B, Kamilova F. Plant growth promoting rhizobacteria. Annual Review of Microbiology. 2009;63:541-556.

Marathe RA, Bharambe PR, Sharma R, Sharma UC. Leaf nutrient composition, its correlation with yield and economics of sunflower. Karnataka Journal of Agriculture Sciences. 2012;22:198-99.

Merwin HD, Peech M. Exchange ability of soil potassium in the sand, silt and clay fraction as influenced by the nature and complementary exchangeable cations. Soil Science American Proceedings. 1951;15:125-128.

Nainwal RC, Singh D, Katiyar RS, Sharma L, Tewari SK. Response of garlic to integrated nutrient management practices in a sodic soil of Uttar Pradesh, India. Journal of Spices and Aromatic Crops. 2015;24:33-36.

Nemat MA, El-Kader AAA, Attia M, Alva AK. Effects of nitrogen fertilization and soil inoculation of sulfur-oxidizing or nitrogen-fixing bacteria on onion plant growth and yield. International Journal of Agronomy. 2011;1-6.

Olsen SR, Cole CV, Watenable DS, Dean LA. Estimation of available phosphorusin soils by extraction with sodium bicarbonate. USDS Circular. 1954;939:19.

Patel KP, Patel JC, Patel BS, Sadaria SG. Yield and nutrient uptake by onion (*Allium cepa*) as influenced by irrigation, nitrogen and phosphorus. Indian Journal of Agronomy. 1992;37:395-396.

Pérez-Montaño F, Alías-Villegas C, Bellogín RA. Plant growth promotion in cereal and leguminous agricultural important plants: from microorganism capacities to crop production. Microbiological Research. 2014;169:325-336.

Prasad K. Impact of biological fertilizer Arbuscular mycorrhiza fungi and conventional fertilizers mobilization on growth, yield, nutrient's uptake, quercetin and alliin contents in allium crops cultivation under field conditions in semi-arid region of India. South Asia Journal of Experimental Biology. 2021;11:15-26.

Prasad K. Stimulation effect of rhizospheric microbes' plant growth promoting rhizobacteria, glycoprotein producing AM fungi and synthetic fertilizers application on growth, yield,

UNDER PEER REVIEW

nutrient’s acquisition and alliin content of garlic cultivation under field conditions in southeast region of Rajasthan, India. Advances in Earth and Environmental Science. 2022;3:1-15.

Ramakrishnan K, Thamizhiniya P. The effect of NPK fertilizer and VAM fungi on the yield and quality characters of cotton var. LRA 5166. Plant Archives. 2004;9:87-88.

Ramesh G, Ajithkumar K, Amaresh YS, Savitha AS. Influence of integrated nutrient management on growth parameters, yield and severity of disease in onion (*Allium cepa* L.) International Journal of Current Microbiology and Applied Sciences. 2017;6:1020-1028.

Ramkumar TR, Karuppusamy S. Plant diversity and ethno botanical knowledge of spices and condiments. Bio-prospecting of Plant Biodiversity for Industrial Molecules. 2021;19:231-60.

Rengel Z, Zhang F. Phosphorus sustains life. Plant Soil. 2011;349:1-2.

Saharan BS, Nehra V. Plant growth promoting rhizobacteria: A critical review. Life Sciences and Medicine Research. 2011;21.

Saini GS. A textbook of olericulture and floriculture. Mar publication House Meerut, U.P. India,1997.

Sankaran K, Bharathi C, Sujatha S. Effect of sulphur fertilization on yield and nutrient uptake by onion in red soils (Udic Haplustalf). Journal of Maharashtra Agricultural Universities. 2005;30:135-36.

Selvaraj S. Onion queen of kitchen. Kisan Word. 1976;3:32-34.

Singh D, Thapa S, Geat N, Mehriya ML, Rajawat MV. Biofertilizers: mechanisms and application. In Biofertilizers Woodhead Publishing. 2021;151-166.

Shahzad F , Asghar HN, Mushtaq Z, Hadayat A, Zuhra N, Ahmad R, Ali MA. Role of endomycorrhizae, rhizobacteria and compost to improve phosphorus availability in onion. Asian Journal Agriculture & Biology. 2020;8:194-200.

Sharma K, Almulla S, Mahato N, Pradhan S, Pashikanti S. 16 metabolomics of allium. Edible Alliums: Botany, Production and Uses. 2022;270.

UNDER PEER REVIEW

Shedeed SI, EL-Sayed SAA, Abo Bash DM. Effectiveness of bio-fertilizers with organic matter on the growth, yield and nutrient content of Onion (*Allium cepa* L.) plants. European International Journal of Science and Technology. 2014;3:115-122.

Subbiah BV, Asija GL. A rapid procedure for the estimation of the available nitrogen in soils. Current Science. 1956;25:259-260.

Sultana M, Islam AKMA, Rasul MG, Mian MAK, Hossain T. Estimation of correlation and path coefficients of seed yield contributing traits in onion (*Allium cepa* L.). Indian Journal of Horticulture. 2007;329-333.

Thomas SG, Bilsborrow PE, Mocking TJ, Bennet J. Effect of sulphur deficiency on the growth and metabolism of sugarbeet (Beta vulgaris). Journal of Science, Food and Agriculture. 2000;80:2057-2062.

Tripathy P, Sahoo BB, Priyadarshini A, Das SK, Dash DK. Effect of sources and levels of sulphur on growth, yield and bulb quality in onion (*Allium cepa* L.). International Journal of Bio-resource and Stress Management. 2013;4:641-644.

Velivelli S, Herlihy EO, Janczura B, Ghyselinck, De Vos P. Efficacy of rhizobacteria on plant growth promotion and disease suppression in vitro. Acta Horticulturae. 2012;961:525-532.

Verma P, Yadav J, Nath K, Lavakush T, Singh V. Impact of plant growth promoting rhizobacteria on crop production. International Journal of Agricultural Research. 2010;5:954-983.

Vijayakumar BS, Bhairavamurthy PV, Anand MC. VAM fungi association in *Lycopersicon esculentum* L. grown in semi-arid tropical soils of Puttaparthy, APJ. Ecobiol. 2000;12:73-74.

Vohra SB, Rizaman M, Khan JA. Medical uses of common Indian vegetables. Planta Medica. 1994; 23:381-393.

Walkley A, Black TA. An estimation of soil organic matter and proposed modification of the chromic acid titration method. Soil Science. 1934;37:29-38.

Williamson LC, Ribrioux SP, Fitter AH, Leyser HO, Phosphate availability regulates root

UNDER PEER REVIEW

system architecture in Arabidopsis. Plant Physiol. 2001;126:875-882.

Yafan H, Barker AV. Effect of composts and their combinations with other materials and their combinations with other materials on nutrient accumulation in tomato leaves. Communications in Soil Science and Plant Analysis. 2004;35:2809-2823.

UNDER PEER REVIEW