Productivity and Soil Health of Potato (*Solanum tuberosum* L.) Field as Influenced by Organic Manures, Inorganic Fertilizers and Biofertilizers under High Altitudes of Eastern Himalayas

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Abstract

Field experiments were conducted in three consecutive summer seasons of 2005 to 2007 to study the effect of integrated nutrient management on soil health and productivity of potato (*Solanum tuberosum* L.) under rainfed condition. The experiment was laid out in a split plot design with eight nutrient management practices (combinations of organic manures viz, farm yard manure (FYM), poultry manure (PM), vermicompost (VC) and

inorganic fertilizers in main plots and seed tuber treatment with three biofertilizers (*Azotobactor*, phosphorus solubilizing bacteria (PSB) and *Azotobactor* + PSB) in sub plots. The results showed that 50 % of the recommended dose of NPK through inorganic + 50% recommended dose of nitrogen (RDN) through organic manures (FYM, PM or VC) or 100% recommended dose of NPK through inorganic fertilizers alone favorably influenced the tuber yield, nutrient uptake, soil fertility and paid higher returns compared to other treatments. Seed treatment with *Azotobactor* + PSB proved better in tuber yield, nutrient uptake and recorded higher returns as compared to sole treatment of either *Azotobactor* or PSB. Three years pooled result revealed that integrated application of 50 % of recommended NPK through inorganic and 50 % RDN through PM recorded significantly highest tuber yield (22.73 t/ha) closely followed by 100 % recommended NPK through inorganic (22.20 t/ha) which were 228 % and 223 % respectively, higher than control. Integrated application of inorganic and organic fertilizers and seed treatment with *Azotobactor* + PSB biofertilizers improved tuber yield, nutrient uptake, and gave higher return as compared to other treatment combinations. Total organic carbon (TOC), soil microbial biomass carbon (SMBC), available N, P, and K status of the soil after 3 years were maximum when 50 % recommended dose of NPK were applied through inorganic and remaining 50 % RDN through PM.

Keywords: Organic manures, Inorganic fertilizer, Biofertilizer, Potato tuber yield, Economics, Soil health, Hill Agriculture

1. Introduction

Potato is an economical food and it provides a source of low cost energy to the human diet. Potato is the rich source of starch, vitamin C and B and minerals. It contains about 20.6 % carbohydrates, 2.1% protein, 0.3 % fat, 1.1 % crude fibre and 0.9 % ash. It also contains a good amount of essential amino acids like *leucine*, *tryptophane* and *isolucine* (Khurana and Naik, 2003). Potatoes are cultivated over an area of 19.3 million hectares in 150 countries of the world with a total production of 308 million tones. In India, potato is cultivated in an area of about 1.34 million hectares with a total production of about 24.7 million tones. It is cultivated on a large scale in Uttar Pradesh, West Bengal, Bihar and Punjab. The potato productivity is very low in North Eastern hill (NEH) region of India (8.64 t/ha) except in Tripura (17.3t/ha) due to poor management practices (Burman *et al.,* 2007).

There is a need for launching a National movement to safe guard soil health and improve soil fertility (Swaminathan, 2004) of potato fields. As no single source is capable of supplying the required amount of plant nutrients, integrated use of all sources of plant nutrients is a must to supply balanced nutrition to the crops (Arora, 2008). The integrated nutrient management (INM) systems envisage use of organic manures along with chemical fertilizers. A number of diverse organic sources are available for use in agriculture in the NEH region due to its favourable agroclimatic conditions. These sources can reduce the mining of soil nutrient and improve overall soil productivity in terms of improved physico-chemical and biological conditions of the soil. The soils of the NEH region are acidic to strongly acidic due to leaching of bases owing to high rainfall (> 2000 mm). The law availability of P due to fixation as Fe/Al- complex is the major problem of crop production in the region. Biofertilizers like phosphorus solubilizing bacteria (PSB) /Azotobactor may be useful for improving P and N nutrition in potato. The beneficial effects of organic manures are manifested through increase in soil organic matter and humus over the period. Soil organic matter and humus acts in several ways; it serves as slow release source of plant nutrients to the crops and increases water holding capacity to maintain the water regime of the soil and acts as a buffer against change in soil pH (Upadhayay and Singh, 2003).

Fertilizer requirement of potato is very high as compared to cereal crops. It responds well to applied fertilizers and gives good yield per unit area and time. Fertilizer being a costly input, PSB could supplement the nutrient requirement of the potato crop especially the phosphorus and thereby boosting the yield (Praharaj *et al*., 2002). Integrated nutrient management (INM) involving combination of organic manure and fertilizers is an essential tool for balanced fertilization and sustainability of crop production on long term basis (Hegde and Dwivedi, 1993). Application of organic manures in conjunction with fertilizers improves physical, chemical and biological properties of the soil besides improving fertilizer use efficiency and crop yield. Asiegbu and Oikeh (1995) found that N, P and K fertilizers were more efficient than the organic manures in supplying N, P and K to the growing plant at least in the short run, while the organic manure had an advantage to supply other macro- and micro-nutrients not contained in N, P and K fertilizers. But no such systematic study was made in acid soil of NEH region of India i.e, the Indian Eastern Himalayas. Keeping this in mind a field study was undertaken to investigate the effect of integrated use of organic manures and inorganic fertilizers along with biofertilizers on productivity of potato and its economics in the hills of Meghalaya, the Indian Eastern Himalayas.

2. Materials and Methods

2.1 Experimental Site

The experiment was carried out during the summer seasons (March to July) of 2005, 2006 and 2007 at Central Potato Research Station (ICAR), upper Shillong, Meghalaya, India. The maximum temperature ranged from 20.11 to 26.34 ^{0}C in 2005, 20.06 to 25.66 ^{0}C in 2006 and 16.83 to 26.99 ^{0}C. The minimum temperature varied from 9.71 to 18.16 ^{0}C in 2005, 9.96 to 21.29 ^{0}C in 2006 and 7.43 to 18.44 ^{0}C in 2007. The temperature began to rise from the month of March and reaches maximum in July during all three years. The distribution pattern of rainfall is presented in the fig 1.The experimental soil was acidic in reaction (pH 5.3), high in organic carbon (1.23%), low in available P (13.35kg/ha), medium in N (178.50 kg/ha), and potassium (195.10 kg/ha).

2.2 Experimental Details and Crop Culture

The field experiment was laid out in a split plot design with eight nutrient management options in main-plot and three seed (tuber) treatment with biofertilizers in sub-plot and replicated thrice. Nutrient management practices were F_1= Control, F_2=100% recommended dose of Nitrogen (RDN) through FYM, F_3=100% RDN through poultry manure (PM), F_4=100% RDN through vermicompost (VC),F_5 = 50% recommended dose of NPK through inorganic fertilizers + 50% RDN through FYM, F_6= 50% recommended dose of NPK through inorganic fertilizers + 50% RDN through poultry manure (PM),F_7=50% recommended dose of NPK through inorganic fertilizers + 50% RDN through vermicompost (VC), F_8=100% recommended dose of NPK (RDNPK) through inorganic fertilizers. The Biofertilizers seed treatments were T_1= *Azotobactor* T_2= Phosphate solubilizing bacteria (PSB), T_3= *Azotobactor* + PSB. The hybrid potato variety 'Kufri Giriraj' tubers were planted in second week of March and harvested in first week of July in all the three years. The average duration of the crop was 120 days. The recommend dose of nitrogen was 120 kg N/ha. FYM 23.0 t/ha, PM 8.0 t/ha and VC 10.0 t/ha were used to supply 100% RDN (120 kg N/ha) to the potato crop. The nutrient composition of organic manures is presented in Table 1.Well decomposed FYM, PM and VC as per treatment were applied 15 days before final land preparation. Half dose of N and full dose of P and K in the form of urea, single super phosphate, and muriate of potash, respectively were applied as per treatment as basal dose before planting. The remaining half dose of N was applied at earthling up (35 days after planting). For seed tuber treatment, half kg each of *Azotobactor* and PSB biofertilizers were dissolved in 40 litres of water separately. A slurry was prepared by boiling 2 kg jaggary in one litre of water. After cooling, it was added to each solution of biofertilizers. In case of combined application of both the biofertilizers, 250 g of each biofertilizer were dissolved in 40 litres of water and added to the jaggary solution. In this way three solutions of biofertilizers (solution of *Azotobactor,* PSB and *Azotobactor* + PSB) were prepared. Potato (cv. kufri giriraj) tubers were dipped in the biofertilizer solution for 30 minutes as per treatment and shade dried before sowing. The tubers were planted at 20 cm apart in the furrows of 60 cm distance and covered immediately after planting. The earthing up was done at 35 days after planting along with weeding to facilitate the development of tubers at the stolon tips. During earthing up the remaining nitrogen dose was side dressed and mixed thoroughly with the soil. Other than late blight there were no major incidence of insect pest. For controlling of late blight two spray with 0.2 % mancozeb and one spray of Ridomil MZ (metalaxyl + mancozeb) 0.25 % were sprayed. The crop was harvested manually at maturity in bright sunny days. All the tubers were dried and graded in shade and their weight and number were recorded as grades A (50g and above), B (30-50 g) and C (less than 30 g). Then tuber yield of different plots were estimated and converted into tonnes/hectare.

2.3 Plant and Soil Sampling

The tubers of each plot were separated into A, B and C grades and their weights were recorded from each plot and converted into t/ha. Total yield was recorded by addition of grade A, B and C. The post harvest soil samples were collected from 0 to 20 cm horizon for analyzing the available nutrient status.

2.4 Chemicals Analysis

Percent nutrient content of potatoes and nutrient uptake was determined at harvest following standard procedure. Soil samples were collected (0-20 cm depth) after harvest of crop each year and analyzed for various physico-chemical and biological parameters following standard procedures. The pH was determined in a 1:2.5 soil: water suspension (Jackson, 1973), organic carbon (OC) determined following Walkey and Black (1934), available N by alkaline Potassium Permanganate method (Subbiah and Asajia, 1956), available P by Bray's method (Bray and Kurtz, 1945) and available K by Ammonium Acetate Extraction method (Jackson, 1973). The SMBC was determined by the ethanol-free chloroform fumigation extraction method (Vance *et al*. 1987) using K_c value of 0.45 (Jenkinson and Ladd, 1981).

2.4 Economics Analysis

The cost of organic manures and chemical fertilizers, other inputs (labour, seeds, pescticides etc) and outputs (Tuber) were estimated as per prevailing market price. The gross return, net return and return per dollar invested in different nutrient management systems were assessed by computing the cost of the inputs and price of the produce/output.

2.5 Statistical Analysis

The analysis of variance methods (Panse and Sukhatme, 1978) was followed to statistically analyze the various data. The significance of different sources of variations was tested by Error mean square of Fisher Snedecor's 'F' test at probability level ($P = 0.05$). In the summery tables of the results, the standard error of mean (Sem $\pm$), the value of critical difference (CD) and coefficient of variation (CV) to compare the difference between the means have been provided.

3. Results and Discussion

3.1 Grade Wise Tuber Yield

Various nutrient management practices had significant effect on grade wise tuber yield of potato during all the three years. In general there was maximum production of grade 'B' tubers followed by grade 'A' and 'C'. Integrated use of 50 % recommended dose of NPK (50% RDNPK) through inorganic fertilizers and remaining 50% RDN through organic sources (FYM, PM or VC) and application of 100% RDNPK through inorganic fertilizers recorded higher tuber yield of all grades (grade A, B and C) which were significantly greater than other fertility treatments during all the three years . The highest tuber yield of different grades were obtained with the application of 50 % RDNPK through inorganic fertilizers and remaining 50% RDN through PM, which were at par with the crop receiving 50 % RDNPK through inorganic fertilizers and remaining 50% RDN through FYM or VC or 100% RDNPK through inorganic fertilizers. The results (Table 2) emphasized the need of integrated use of 50 % RDNPK through inorganic fertilizers and remaining 50% RDN through organic sources (FYM, PM or VC) for producing high tuber yield of different grades under Meghalaya hill region. The results further indicated that supply of 100% nutrients through only organic manures was not much helpful in recording high production of different grades tubers under this situation. This might be due to slow mineralization of plant nutrients under low temperature condition prevailing in the hilly and mountainous Himalayan region. The favourable effect of integrated nutrient management through both inorganic fertilizers and organic manures on increasing the different grades tuber production was also noticed by Kumar *et al.* (2008 and 2011) and Das *et al*., (2009). Use of biofertilizer exerted significant effect on influencing yield of different grades tubers during all the three years of study. Seed treatment with combination of *Azotobactor* & PSB recorded the highest tuber yield of different grades which were significantly greater than those of the crop receiving either *Azotobactor* or PSB only. Interaction effect of nutrient management and biofertilizers was found not significant in influencing the production of different grades tubers during all the three years.

3.2 Total Tuber Yield

The results showed (Table 3) significant variation in total tuber yield due to the different nutrient management practices. The highest tuber yield was obtained with the application of 50 % RDNPK through inorganic fertilizers and remaining 50% RDN through PM, but it was statistically at par with 50 % RDNPK through inorganic fertilizers and remaining 50% RDN through FYM or VC or 100% RDNPK through inorganic fertilizers only during all the three years. These yields were significantly superior to sole application of 100 % RDN either through FYM or PM or VC as well as control. Single application of PM, FYM and VC also recorded significantly higher tuber yield than control. There was 128 % increase in tuber yield due to combined application of 50 % RDNPK through inorganic fertilizers and remaining 50% RDN through PM and 123 % increase with 100% RDNPK through inorganic fertilizers only over the control. Seed treatment with combination of *Azotobactor* + PSB recorded significantly higher tuber yield compared to either only *Azotobactor* or PSB treatment during all the years. Interaction effect of fertility management and biofertilizers on tuber yield of potato was found significant during all the years. The crop receiving 50 % RDNPK through inorganic fertilizers and remaining 50% RDN through PM along with combined biofertilizers seed treatment (*Azotobactor* + PSB) recorded the highest tuber yield that was closely followed by the crop receiving 50 % RDNPK through inorganic fertilizers and remaining 50% RDN through FYM or VC and 100% RDNPK through inorganic fertilizers along with *Azotobactor* or PSB. Supply of 100% RDNPK through inorganic fertilizers along with biofertilizers exerted relatively lower effect on increasing tuber yield as compared to those of the crop receiving 50 % RDNPK through inorganic fertilizers and remaining 50% RDN through organic manures. The biofertilizer seed treatments applied without manures and fertilizers showed very poor performance on tuber productivity of potato

under the study. The results showed that biofertilizer required organic manuring for its early establishment necessary for exerting beneficial effect on tuber productivity. The results corroborate the findings of Kumar *et al.* (2001) and Raghav and Kamal (2008). Similar results were reported by Kumar *et al.,* (2011).

3.3 Nutrient (N, P and K) Uptake

The highest uptake of N, P and K by tuber and haulm (Table 4 & 5) were noticed with the application of 50 % RDNPK through inorganic fertilizers and remaining 50% RDN through PM, but it was statistically at par with those obtained from the crop receiving 50 % RDNPK through inorganic fertilizers and remaining 50% RDN through VC and 100% RDNPK through only inorganic fertilizers. The favourable effect of integrated nutrient management through inorganic fertilizers and organic manures on increasing the N, P and K uptake by tubers were also noticed by other researchers (Kumar *et al.,* 2008; Baishya 2009; Das *et al*., 2009). Biofertilizer treatments also exerted significant effect on N, P and K uptake by tubers during all the three years. Seed treatment with combination of *Azotobactor* + PSB recorded the highest uptake of N, P and K by tubers. Interaction effect of fertility management and biofertilizers on uptake of N, P and K by tubers was found significant during all the years. The crop receiving 50 % RDNPK through inorganic fertilizers and remaining 50% RDN through PM along with *Azotobactor* + PSB seed treatment recorded the highest N, P and K uptake by tubers. The results are in conformity with the findings of Kumar *et al.,* (2001) and Raghav and Kamal, (2008).

3.4 Effect of Treatment on Soil Fertility

The TOC, SMBC and ratio of SMBC to TOC varied significantly among the different nutrient management treatments (Table 6). The TOC varied from 9.13 in control to 14.43 g/kg of soil in 100% FYM (RDN) plots, whereas, the SMBC ranged from 121.5 in control to 197.0 mg/kg of soil in 100% VC (RDN) treated plots. Both TOC and SMBC reduced substantially in control plots (without manure and fertilizer) from their initial values (12.3 g/kg and 145.0 mg/kg of soil respectively). The ratio of SMBC to TOC increased over its initial value (11.79 mg/g) due to different fertility management treatments except in plots receiving 100% RDNPK through inorganic fertilizers alone which recorded SMBC to TOC ratio much below the control and initial value. Application of 100% RDN through organic manures (PM, VC and FYM) exerted maximum benefit in increasing both TOC and SMBC which were markedly higher than those plots receives 50 % RDNPK through inorganic fertilizers and remaining 50% RDN through organic manures which in turn also significantly increased both TOC and SMBC over the initial value and that of the control plots. Application of organic manures either alone or in combination with inorganic fertilizers was beneficial for improving or maintaining organic carbon pool in soil. The results corroborate the findings of Manna *et al.,* (2006) and Ghosh *et al.,* (2009).

Biofertilizers treatments did not exert significant effect on soil TOC, SMBC and ratio of SMBC/TOC under the study. Interaction effect of nutrient management and biofertilizers on total organic carbon, microbial biomass carbon and ratio of SMBC/TOC were not significant.

3.5 Available Soil Nutrient Status of the Experimental Soil

The available N, P and K contents in the soil increased gradually after each year due to the application of recommended dose of nutrients either through inorganic fertilizers or through integrated application of inorganic fertilizers and organic manures. The plots receiving 50 % RDNPK through inorganic fertilizers and remaining 50% RDN through PM registered the highest available N, P and K status in the soil and it was closely followed by the plots receiving 50 % RDNPK through inorganic fertilizers and remaining 50% RDN through VC or FYM, but was markedly higher than those of the plots receiving 100% RDNPK through only inorganic fertilizers during all the three years (Table 7). Application of 100% RDN through organic manures only (PM, VC and FYM) also significantly enhanced the available N, P and K status of soil over its initial values and those of the control plots. Application of 100% RDNPK through only inorganic fertilizers also increased the available N, P and K status in the soil over its initial values. Whereas, the available N, P and K status in the soil decreased gradually over the years in control plots. The results emphasized the need for integrated nutrient management practices through inorganic fertilizers and organic sources (particularly PM or VC) for enhancing the available N, P and K contents in soil. Similar favourable effect of integrated nutrient management involving inorganic fertilizers and organic manures on increasing the available N, P and K contents in soil have been noticed by Jayaram *et al.,* (1990), Kumar *et al.,* (2008) and Baishya (2009). Zaman *et al.*, (2011) also reported that FYM @30 t/ha along with biofertilizers recorded maximum soil fertility build-up after harvest of the crop. Biofertilizers treatments did not exert significant effect on available N, P and K status of the soil under the study.

3.6 Economics

Both gross return and net return varied markedly among the nutrient management practices. The crop receiving 50 % RDNPK through inorganic fertilizers and remaining 50% N through organic sources (FYM, PM or VC) and 100% RDNPK through inorganic fertilizers paid higher gross and net return than those of the crop at other fertility treatments. The highest gross and net returns were obtained from the crop receiving 50 % RDNPK through inorganic fertilizers and remaining 50% RDN through PM followed by the crop receiving 50 % RDNPK through inorganic fertilizers and remaining 50% RDN through VC or FYM or 100% RDNPK through inorganic fertilizers (Table 8). Application of 100 % RDN through organic manures (FYM, PM or VC) though recorded higher gross and net returns over the control plots, but these treatments were found less effective in increasing both gross and net returns as compared to those of the crop receiving both inorganic fertilizers and organic manures. The crop at control plots paid very low gross and net returns mainly due to low productivity. The return per **$** invested followed a trend similar to that of gross and net returns. The crop at 50 % RDNPK through inorganic fertilizers and remaining 50% RDN through organic sources (FYM, PM or VC) and 100% RDNPK through inorganic fertilizers paid much higher net return per **$** invested (NRP) than those of other fertility treatments. Vermicompost was found less economic due to its high price, reducing the net return per **$** invested. Application of 100 % RDN through organic manures paid lesser NRP compared to those of 100 % RDNPK or 50 % RDNPK through inorganic fertilizers + 50 % RDN through organic manures, mainly due to high cost involvement with organic sources alone. The results are in conformity with the findings of Ghosh and Malik, (1999), Das *et al.,* (2006), Kumar *et al.,* (2008) and Baishya, (2009). Seed treatment with *Azotobactor* + PSB combination recorded higher gross and net returns as compared to those of the crop treated with either *Azotobactor* or PSB during all the three years (Table 8). The net return per **$** invested did not vary appreciably among the biofertilizer treatments.

4. Conclusion

Potato requires adequate nutrition under acid soils of high hills in eastern Indian Himalayas that may be achieved by judicious and balanced use of organic and inorganic sources of nutrients. The application of 50 % recommended dose of NPK (60:60:30) through inorganic fertilizers and remaining 50% recommended dose of N (60 kg N/ha) through organic manures like poultry manure, FYM or vermicompost are recommendable practices for higher tubers productivity, enhanced N, P and K uptake and higher returns. Application of organic manures either alone or in conjunction with inorganic fertilizer improved fertility status of soil over the years. Thus organic manures and biofertilizers should be a part of the agronomic practices for potato cultivation in hills.

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Table 1. Average nutrient content of different organic manures

Organic Manures	N (%)	P (%)	K (%)	Fe (ppm)	Cu (ppm)	Zn (ppm)	Mn (ppm)
FYM	0.53	0.29	0.61	3520	57	315	281
Vermicompost	1.20	0.65	0.80	8618	61	328	345
Poultry manure	1.52	0.82	0.87	1400	7	90	210

Table 2. Effect of nutrient management and biofertilizers on grade wise tuber yield (t/ha) of potato

	2005			2006			2007		
Nutrient management	Grade A	Grade B	Grade C	Grade A	Grade B	Grade C	Grade A	Grade B	Grade C
Control (No manures and fertilizers)	1.70	5.48	3.42	1.61	4.98	3.05	1.6	4.94	3.10
100% RDN* through FYM	3.82	8.46	3.37	4.06	9.04	3.15	4.31	9.26	3.1
100% RDN through Poultry manure	4.06	8.9	3.54	4.58	9.5	2.96	4.62	9.52	2.95
100% RDN through Vermicompost	3.94	8.72	3.43	4.28	9.24	3.12	4.40	9.37	3.1
50% RDNPK through fertilizers + 50% RDN through FYM	6.46	10.73	4.17	6.76	11.68	3.41	6.79	11.73	3.4
50% RDNPK through fertilizers + 50% RDN through Poultry manure	6.63	11.28	4.27	7.07	12.16	3.61	7.24	12.39	3.55
50% RDNPK through fertilizers + 50% RDN through Vermicompost	6.53	11.06	4.41	6.88	11.86	3.52	6.87	11.91	3.42
100% RDNPK through fertilizers	6.59	10.83	4.22	6.95	12.02	3.41	7.03	12.17	3.37
SEm (±)	0.097	0.193	0.082	0.112	0.201	0.078	0.182	0.273	0.85
C D ($P = 0.05$)	0.294	0.581	0.245	0.336	0.607	0.235	0.509	0.765	2.54
Biofertilizer									
Azotobactor	4.75	9.24	3.69	5.05	9.81	3.07	5.13	9.92	30.42
Phosphate solubilising bacteria (PSB)	4.87	9.33	3.85	5.20	9.92	3.17	5.32	10.10	32.40
Azotobactor + PSB	5.28	9.73	4.11	5.57	10.45	3.6	5.63	10.46	34.63
SEm (±)	0.071	0.085	0.069	0.065	0.105	0.062	0.101	0.118	0.74
C D ($P = 0.05$)	0.215	0.253	0.206	0.194	0.312	0.179	0.301	0.352	2.08
C V (%)	6.5	5.9	7.0	7.7	6.3	8.5	10.4	7.5	9.3

*RDN (Recommend dose of N) = 120 kg N/ha; RDNPK (Recommend doses of fertilizers) = 120 kg N/ha, 120 kg P_2O_5/ha and 60 kg K_2O/ha. SEm (±) standard error of means, CD critical difference, CV coefficient of variation

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Table 3. Effect of nutrient management and biofertilizers on total tuber yield (t/ha) of potato

Nutrient management	2005	2006	2007	Pooled
Control (No manures and fertilizers)	10.60	9.64	9.64	9.96
100% RDN* through FYM	15.65	16.25	16.67	16.19
100% RDN through Poultry manure	16.46	17.05	17.08	16.86
100% RDN through Vermicompost	16.09	16.64	16.88	16.54
50% RDNPK through fertilizers + 50% RDN through FYM	21.37	21.85	21.92	21.71
50% RDNPK through fertilizers + 50% RDN through Poultry manure	22.18	22.85	23.17	22.73
50% RDNPK through fertilizers + 50% RDN through Vermicompost	22.01	22.27	22.21	22.16
100% RDNPK through fertilizers	21.64	22.38	22.58	22.20
SEm (±)	0.53	0.54	0.52	0.53
C D (P = 0.05)	1.61	1.62	1.56	1.26
Biofertilizer				
Azotobactor	17.69	17.93	18.09	17.90
Phosphate solubilising bacteria (PSB)	18.05	18.29	18.66	18.33
Azotobactor + PSB	19.12	19.62	19.55	19.43
SEm (±)	0.27	0.29	0.30	0.20
C D (P = 0.05)	0.80	0.88	0.89	0.59
C V (%)	7.70	8.10	8.30	

*RDN (Recommend dose of N) = 120 kg N/ha; RDNPK (Recommend doses of fertilizers) = 120 kg N/ha, 120 kg P_2O_5/ha and 60 kg K_2O/ha . SEm (±) standard error of means, CD critical difference, CV coefficient of variation

Table 4. Effect of nutrient management and biofertilizers on nutrient uptake (kg/ha) by tuber

	2005			2006			2007		
Nutrient management	N	P	K	N	P	K	N	P	K
Control (No manures and fertilizers)	37.58	7.75	44.95	38.49	8.94	47.74	37.77	8.59	47.45
100% RDN* through FYM	52.77	10.54	64.02	55.42	12.75	68.21	57.93	13.29	71.33
100% RDN through Poultry manure	55.77	11.25	67.53	57.37	13.74	72.25	60.53	14.49	73.43
100% RDN through Vermicompost	55.18	10.97	68.52	56.21	12.16	71.16	59.51	12.89	72.10
50% RDNPK through fertilizers + 50% RDN through FYM	65.98	15.40	91.42	71.21	16.17	91.09	71.24	18.17	95.70
50% RDNPK through fertilizers + 50% RDN through Poultry manure	74.01	17.11	97.62	74.53	18.00	96.50	75.47	19.23	98.09
50% RDNPK through fertilizers + 50% RDN through Vermicompost	72.05	16.16	96.44	73.65	17.64	95.93	74.31	19.11	97.86
100% RDNPK through fertilizers	72.08	16.38	95.46	72.31	17.67	95.66	72.41	18.50	96.36
SEm (±)	0.84	0.44	1.27	1.05	0.45	0.70	1.22	0.36	1.03
C D (P = 0.05)	2.25	1.75	3.86	3.15	1.33	2.14	3.42	1.01	2.89
Biofertilizer									
Azotobacter	58.83	12.03	76.40	60.46	13.77	77.63	61.51	14.41	79.51
Phosphate solubilising bacteria (PSB)	60.79	13.18	78.61	62.43	14.91	80.16	64.26	15.77	81.83
Azotobacter + PSB	62.42	14.38	79.73	63.90	15.23	81.66	65.18	16.42	83.42
SEm (±)	0.52	0.28	0.57	0.44	0.31	0.65	0.75	0.29	0.73
C D (P = 0.05)	1.53	0.83	1.64	1.31	0.91	1.92	2.23	0.87	2.15
C V (%)	7.7	8.9	7.3	7.4	6.8	7.4	7.6	7.0	6.7

*RDN (Recommend dose of N) = 120 kg N/ha; RDN PK (Recommend doses of fertilizers) = 120 kg N/ha, 120 kg P_2O_5/ha and 60 kg K_2O/ha . SEm (±) standard error of means, CD critical difference, CV coefficient of variation

Table 5. Effect of nutrient management and biofertilizers on nutrient uptake (kg/ha) by haulm

	2005			2006			2007		
Nutrient management	N	P	K	N	P	K	N	P	K
Control (No manures and fertilizers)	18.79	3.50	25.01	20.30	4.38	30.31	21.26	4.22	29.01
100% RDN* through FYM	27.45	7.73	38.17	30.04	8.15	41.62	31.10	9.05	42.07
100% RDN through Poultry manure	29.21	8.63	41.75	33.66	9.87	42.13	33.02	9.97	44.11
100% RDN through Vermicompost	28.17	8.27	39.76	32.26	9.21	41.95	32.92	9.79	43.17
50% RDNPK through fertilizers + 50% RDN through FYM	37.64	11.72	47.44	40.38	12.74	51.75	43.13	14.71	50.53
50% RDNPK through fertilizers + 50% RDN through Poultry manure	41.13	13.50	50.51	44.15	15.68	54.47	46.99	17.39	53.99
50% RDNPK through fertilizers + 50% RDN through Vermicompost	38.19	12.32	48.62	42.55	14.33	52.90	43.84	15.41	52.18
100% RDNPK through fertilizers	41.52	14.04	51.04	44.03	15.37	54.17	45.58	16.70	53.25
SEm (±)	0.74	0.32	0.94	0.85	0.28	0.81	0.85	0.30	0.80
C D (P = 0.05)	2.25	0.98	2.86	2.60	0.83	2.48	2.37	0.85	2.38
Biofertilizer									
Azotobactor	31.39	9.36	40.78	34.31	10.01	44.11	35.39	11.00	44.25
Phosphate solubilising bacteria (PSB)	32.49	9.98	42.76	36.00	11.55	46.28	37.02	12.46	46.44
Azotobactor + PSB	34.40	10.51	44.66	37.00	12.03	47.48	39.31	13.00	47.43
SEm (±)	0.51	0.21	0.63	0.54	0.19	0.71	0.52	0.21	0.43
C D (P = 0.05)	1.47	0.62	1.83	1.55	0.54	2.04	1.53	0.62	1.27
C V (%)	6.1	7.9	4.7	8.7	7.5	5.6	6.8	7.5	6.3

*RDN (Recommend dose of N) = 120 kg N/ha; RDNPK (Recommend doses of fertilizers) = 120 kg N/ha, 120 kg P_2O_5/ha and 60 kg K_2O/ha . SEm (±) standard error of means, CD critical difference, CV coefficient of variation

Table 6. Effect of nutrient management and biofertilizers carbon pool of the soil after three years of potato cultivation

Nutrient management	^TOC (g/kg)	**SMBC (mg/kg)	SMBC/TOC (mg/g)
Control (No manures and fertilizers)	9.13	121.5	13.31
100% RDN* through FYM	14.43	196.4	13.61
100% RDN through Poultry manure	14.33	193.8	13.52
100% RDN through Vermicompost	14.23	197.0	13.84
50% RDNPK through fertilizers + 50% RDN through FYM	13.73	173.2	12.61
50% RDNPK through fertilizers + 50% RDN through Poultry manure	13.63	171.4	12.58
50% RDNPK through fertilizers + 50% RDN through Vermicompost	13.63	175.4	12.87
100% RDNPK through fertilizers	13.13	143.9	10.96
SEm (±)	0.13	3.71	0.55
C D (P = 0.05)	0.37	10.75	1.60
Biofertilizer			
Azotobactor	13.09	170.4	13.02
Phosphate solubilising bacteria (PSB)	13.25	172.0	12.98
Azotobactor + PSB	13.51	173.9	12.87
SEm (±)	0.18	2.32	0.36
C D (P = 0.05)	NS	NS	NS
Initial value	12.30	145.0	11.79

*RDN (Recommend dose of N) = 120 kg N/ha; RDNPK (Recommend doses of fertilizers) = 120 kg N/ha, 120 kg P_2O_5/ha and 60 kg K_2O/ha .TOC=Total organic Carbon; **SMBC= Soil Microbial Biomass Carbon. SEm (±) standard error of means, CD critical difference, CV coefficient of variation

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Table 7. Effect of nutrient management practices on available soil nutrient status (kg/ha) of the experimental soil

Nutrient management	After 1st crop (2005)			After 2nd crop (2006)			After 3rd crop (2007)		
	N	P	K	N	P	K	N	P	K
Control (No manures and fertilizers)	177.7	13.66	193.7	174.2	12.81	192.4	172.0	11.23	190.2
100% RDN* through FYM	217.3	15.63	221.2	233.3	17.44	246.8	244.8	21.91	263.6
100% RDN through Poultry manure	219.8	17.05	225.7	235.5	18.05	249.8	246.7	22.70	264.7
100% RDN through Vermicompost	216.8	15.35	221.7	233.5	16.50	245.3	244.0	21.6	262.0
50% RDNPK through fertilizers + 50% RDN through FYM	222.5	18.15	232.7	242.4	21.36	253.6	252.0	24.85	269.2
50% RDNPK through fertilizers + 50% RDN through Poultry manure	224.0	19.03	235.6	245.1	22.52	256.4	253.3	26.37	271.1
50% RDNPK through fertilizers + 50% RDN through Vermicompost	221.5	17.88	232.4	242.1	20.27	251.6	251.6	24.01	268.8
100% RDNPK through fertilizers	210.2	15.01	216.5	226.2	16.16	233.2	236.5	21.63	252.8
SEm (±)	3.6	0.76	4.6	4.1	0.69	6.1	3.7	0.51	5.1
C D ($P = 0.05$)	10.5	2.20	13.9	12.2	2.05	17.5	10.8	1.51	14.2
Biofertilizer									
Azotobactor	212.0	16.58	223.2	228.1	16.81	240.6	237.0	21.32	259.1
Phosphate solubilising bacteria (PSB)	212.9	16.91	224.0	229.0	17.27	241.3	237.5	21.66	260.7
Azotobactor + PSB	214.0	17.00	225.0	230.4	17.40	243.0	238.3	22.10	261.3
SEm (±)	1.8	0.26	2.2	2.0	0.28	2.3	1.8	0.30	2.1
C D ($P = 0.05$)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Initial value	179.5	13.35	195.1						

*RDN (Recommend dose of N) = 120 kg N/ha; RDNPK (Recommend doses of fertilizers) = 120 kg N/ha, 120 kg P_2O_5/ha and 60 kg K_2O/ha. SEm (±) standard error of means, CD critical difference, CV coefficient of variation

Table 8. Effect of nutrient management and biofertilizers on economics of potato production (Mean of 3 years)

Nutrient management	Cost of cultivation ($/ha)	Gross return ($/ha)	Net return ($/ha)	Net Return /$ Invested
Control (No manures and fertilizers)	706.70	1236.67	529.97	1.75
100% RDN* through FYM	820.52	1612.57	792.05	1.97
100% RDN through Poultry manure	867.50	1673.67	806.17	1.93
100% RDN through Vermicompost	939.70	1652.90	713.20	1.76
50% RD through fertilizers + 50% RDN through FYM	816.58	2169.23	1352.65	2.66
50% RD through fertilizers + 50% RDN through Poultry manure	843.02	2261.23	1418.21	2.68
50% RD through fertilizers + 50% RDN through Vermicompost	880.16	2229.03	1348.87	2.53
100% RD through fertilizers	812.52	2219.87	1407.35	2.73
Biofertilizer				
Azotobactor	913.54	1812.77	899.23	1.98
Phosphate solubilising bacteria (PSB)	912.78	1858.87	946.09	2.04
Azotobactor + PSB	913.28	1969.87	1056.59	2.16

*RDN (Recommend dose of N) = 120 kg N/ha; RDF (Recommend doses of fertilizers) = 120 kg N/ha, 120 kg P2O5/ha and 60 kg K2O/ha respectively. Potato seed @ $160/- per ton, Urea @ $ 0.11/- per kg, SSP @ $ 0.09/- per kg, MOP @ $ 0.1/- per kg, Cow dung @ $ 5.5/- per ton, Poultry manure @ $.20/- per ton, vermicompost (own farm production) @ $ 30/- per ton, Biofertilizers @ $ 5/- per kg, Labour charges @ $ 1.2 /- per man-day and price of potato tubers @ $ 100/-per ton.

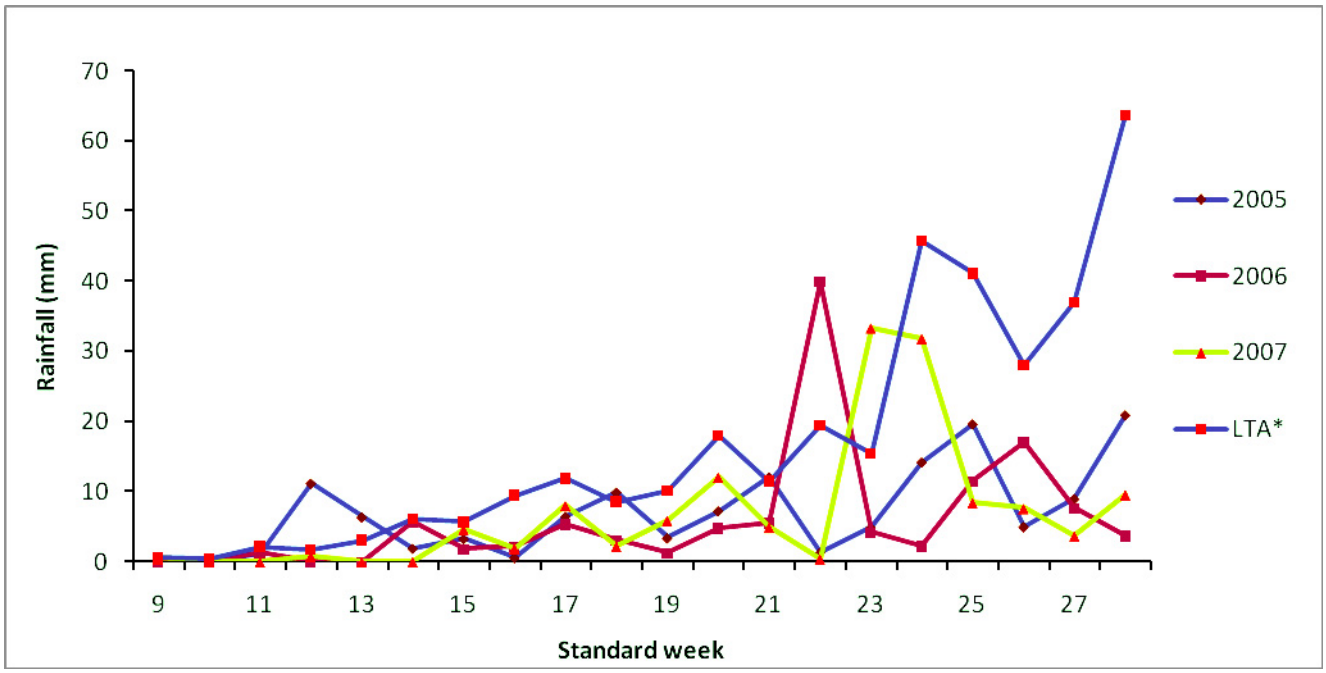

Figure 1. Weekly rainfall received during the cropping season

*LTA – Long term average

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