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Integrated nutrient management for potato (*Solanum tuberosum*) in grey terrace soil (Aric Albaquipt)

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Abstract

Potato crop has strict requirement for a balanced nutrient management, without which growth and development are poor and yield is remarkably reduced, continuing with deterioration in soil health. An experiment was conducted to study the effect of organic manure and chemical fertilizers on soil properties and potato yield at Grey Terrace soil (poorly drained, grey and silty) from 2009-2010 and 2010-2011. There were seven treatments as: T1 (Control, native nutrient), T2 (100% recommended dose of fertilizers, RDF), T3 (Farmer's practice, FP), T4 (Cowdung, CD 6 t ha^{-1}+70% RDF), T5 (Poultry manure, PM 3 t ha^{-1}+70% RDF), T6 (CD 6 t h^{-1} + rest from RDF) and T7 (PM 3t ha^{-1}+ rest from RDF). Yield of potato was significantly ($p \leq 0.05$) influenced by the integrated use of organic manure and chemical fertilizers. The highest yield (25.2 t ha^{-1}) was achieved in T7, where PM 3 t ha^{-1} along with reduced rate of recommended dose of chemical fertilizers were applied. The maximum marginal benefit cost ratio was found in T7. The highest NPK uptake and nutrient availability were also found in T7. Therefore, PM 3 t ha^{-1} and reduced rate of chemical fertilizers can be recommended for cultivation of potato in the Grey Terrace soil for better growth, higher tuber yield, greater net return and maintaining soil fertility.

Keywords: Crop productivity, inorganic fertilizers, organic manure, soil fertility, *Solanum tuberosum.*
Abbreviations: ANOVA_Analysis of variance; $CaCl_2$ _Calcium chloride; CD_Cowdung, DAP_Days after planting; DMRT_ Duncan's Multiple Range Test; FAO_Food and Agriculture Organization; HCl_Hydrochloric acid; HNO_3_Nitric acid; K_ Potassium, MoP_Muriate of potash, N_Nitrogen, $NaHCO_3$ _Sodium bicarbonate, NH_4OAc_Ammonium acetate, PM_Poultry manure, P_Phosphorous, RDF_Recommended dose of fertilizer, RCBD_Randomized complete block design, S_Sulphur, TSP_Triple superphosphate.

Introduction

Potato is most important vegetable crop in Bangladesh. It is also used as food and cash crop in cool countries. It can meet vegetable demand and provide necessary nutrients for the people of the low income group (Islam et al., 2009; Hossain and Miah, 2012). The average yield of potato in Bangladesh is 18.25 tha^{-1}, which is much below the crop potential productivity (BBS, 2010). Potato crop has strict requirement for a balanced fertilization, without which growth and development of the crop are poor and both yield and quality of tubers are diminished. Yield can be increased by the improved production agrotechnologies, involves manure and fertilization.

Current fertilization rates are insufficient to sustain high yields and to replenish nutrient removal by the crop (Imas and Bansal, 2012). Potato yield could be increased by 50% only by improved nutrient management (Grewal et al., 1992). Great opportunities exist to increase potato yield and quality by improving nutrient management. Potato demands high level of soil nutrients due to relatively poor developed and shallow root system in relation to yield (Perrenoud, 1983). Compared with cereal crops, potato produces much more dry matter in a shorter cycle (Singh and Trehan, 1998). This high rate of dry matter production results in large amounts of nutrients removed per unit time, which generally most of the soils are not able to supply. Hence, nutrient application from external sources as fertilizers becomes essential.

In the recent years, intensive cropping with high yielding varieties (HYV) and imbalanced fertilization has led to mining out the inherent plant nutrients from the soils and; thus, fertility status of the soils has severely declined in Bangladesh (Karim et al., 1994; Ali et al., 1997), which is responsible for stagnation and in some cases, even declining crop yields (Cassman et al., 1995). The use of chemical fertilizers mainly NPK has been increasing steadily but they are not applied in balanced proportion (BARC, 2005). Moreover, deficiency of micronutrients like Zn, B, Mn, Mo has been reported in some parts of the country. On the other hand, organic matter content of most of the Bangladesh soils is very low, the majority being below the critical level (<1.5%). The organic matter content of Bangladesh soils has been depleted by 5 to 36% during the period of 1967-1995 (Ali et al., 1997). The organic matter decomposition in soils of Bangladesh is due to its tropical climate. Moreover, the addition of organic materials to soil through FYM, compost and organic residues has been reduced considerably because a major portion of these organic residues (cowdung and crop residue) is used as fuel by the rural people. These practices resulted in a serious deterioration of soil health showing cumulative negative nutrient balance which caused declining soil fertility and productivity. Restoring, maintaining and increasing soil fertility are major agricultural priorities in many parts of the developing world where soils are

Table 1. Treatment combinations of organic manure and chemical fertilizers.

Treatment no.	Combinations of organic manure and chemical fertilizers
T1	Control (Native nutrient)
T2	100% Recommended dose of fertilizer (RDF) †
T3	Farmer's practice††
T4	Cowdung (CD) 6 t ha^{-1} + 70 % RDF
T5	Poultry manure (PM) 3 t ha^{-1} + 70 % RDF
T6	CD 6 t ha^{-1} + rest nutrients from RDF
T7	PM 3 t ha^{-1} + rest nutrients from RDF

100% RDF for Potato = $N_{135}P_{20}K_{135}S_{10}$ kg ha^{-1} (BARC, 2005).
†RDF = Recommended dose of chemical fertilizers.
††Farmer's practice = $N_{150}P_{50}K_{50}$ kg ha^{-1}.
† In Bangladesh, each crop has standard fertilizer dose depending on the characteristics of the soils, which is called recommended dose of chemical fertilizer (BARC, 2005).
††Most farmers of Bangladesh are not aware regarding crop management specially fertilizer management, they use a few chemical fertilizers in imbalanced way. On the basis of their practice, this treatment has been formulated.

inherently poor in nutrients, where the demand for grain food, vegetable and raw materials is increasing rapidly. A fertile soil provides a sound basis for flexible food production systems within the constraints of soil and climate, which can grow a wide range of crops to meet changing needs. Balanced fertilization is a prerequisite for getting optimum yield potential of potato (Kushwah et al., 2005). Sustainable production of crops cannot be maintained by using chemical fertilizers alone because of deterioration in soil physical and biological environments (Khan et al., 2008). However, integrated use of both organic manure and chemical fertilizers appeared as the best approach in providing greater stability in production and improving soil fertility status (Islam et al., 2011; Sood, 2007; Singh and Lal, 2006).

Integrated use of organic manure and chemical fertilizer for potato production in grey terrace soil has not been reported yet. Therefore, this study was initiated to develop a suitable fertilizer package in combination of organic manure and chemical fertilizers for sustainable potato production and to investigate the post-harvest soil properties.

Results and discussion

Effects of organic manure and inorganic fertilizers on yield contributing characters and yield of potato

Yield attributes and yield of potato varied significantly ($P\leq0.05$) due to application of different rate of organic manure and inorganic fertilizers (Table 2). Plant height, foliage coverage (%), stems per hill, tubers per hill, weight of tubers per hill and dry weight (%) are significantly influenced by the different treatments. The highest plant height of potato (56.4 cm in 2008-09 and 57.6 cm in 2009-10) was found in T2 (100% RDF), which was followed by T5 and T7. The lowest plant height (45.0 cm in 2008-09 and 43.0 cm in 2009-10) was observed in the control. T7 also showed highest number of stems per hill (7.69 in 2008-09 and 7.84 in 2009-10) followed by T6 (7.18 in 2008-09 and 6.93 in 2009-10) and T5 (6.87 in 2008-09 and 6.93 in 2009-10). Baishya et al. (2010) reported highest plant height and stem $hill^{-1}$ with addition of 75% RDF + 25% RDN through FYM which corroborated our findings. Maximum foliage coverage (96%) was found in T7 which was significantly higher than the other treatments and followed by T5 (92%). Minimum foliage coverage was in the control.

The highest tubers per hill was found in T7 (8.87 in 2008-09 and 9.50 in 2009-10) followed by T5 (7.88 in 2008-09 and 8.83 in 2009-10). In 2009-10, T7 was identical to T5 but different from rest of the treatments and the lowest tubers per hill were in the control. T7 also showed highest tubers weight per hill followed by T5 and the lowest was observed in the control. The dry matter (%) ranged from 21.0 to 25.2%. Maximum % dry matter was observed in T7 and the minimum was found in T3 treatment.

Yield of potato was also significantly influenced by the integrated use of organic manure and inorganic fertilizers. The yield ranged from 13.8 to 26.4 t ha^{-1}. The highest yield (25.2 t ha^{-1} in 2008-09 and 26.5 t ha^{-1} in 2009-10) was found in T7, where PM 3 t ha^{-1} along with reduced rate of recommended dose of chemical fertilizers were applied in integrated manure, which was significantly higher than the other treatments (Table 2). The second highest yield (22.3 t ha^{-1} in 2008-09 and 23.6 t ha^{-1} in 2009-10) was obtained in T5 treatment, which was statistically identical to T_2 and T_6 but different from the rest of the treatments. The lowest yield (14.1 in 2008-09 and 13.8 t ha^{-1} in 2009-10) was in the control (Table 2). Noor et al. (2005) reported that the highest head yield of cabbage was due to integrated use of poultry manure (5 t ha^{-1}) along with reduced dose (70%) of chemical fertilizers, which are in agreement with the findings of the present study. Similar results were also observed by Mondal et al. (2005) and Thind et al. (2007). Poultry manure showed superior results than that of cowdung. This might be due to its higher nutrient composition and capacity to increase availability of native soil nutrients through higher biological activity (Pengthamkeerati et al., 2011). Brown (1958) observed that PM contained growth promoting hormones produced a better root growth.

Cost and return

The purpose of marginal analysis is to reveal how the benefit from investment increase as the amount of investment increases (Perrin et al., 1979). Economic analysis showed that the highest gross margin (US$ 3052.19 ha^{-1}) was found in T7 (PM 3 t ha^{-1} + rest from chemical fertilizer) (Table 3), which was followed by T5 (PM 3 t ha^{-1} + 70% RDF) and T6 (CD 6 t ha^{-1} + rest from RDF). The lowest gross margin (US$ 1722.22 ha^{-1}) was found in the control. Kumar et al. (2012) also noted that the highest gross and net returns were obtained from the crop receiving 50 % RDNPK through inorganic fertilizers and remaining 50% RDN through PM. Marginal benefit cost ratio (MBCR), varied from 5.26 to 11.00, the highest was observed in T7 and the lowest in T3 (Farmer's practice). The second highest MBCR (7.46) was recorded in T5 (PM 3 t ha^{-1} + rest from RDF), which was close to T6 (CD 6 t ha^{-1} + 70% RDF). These findings revealed that integrated use of PM 3 t ha^{-1} + rest from RDF may bring similar economic benefit with CD 6 t ha^{-1} + 70 %

RDF. Thus, farmers can choose any of them, but to get higher economic return as well as to improve the soil health for sustainable production farmers can use PM 3 t ha^{-1}+ reduced rate of recommended dose of chemical fertilizer. Sasani et al. (2003) also reported that higher yield and profit can be obtained through integrated use of FYM along with inorganic fertilizers, which are in agreement with the findings of our study.

Nutrient uptake

The highest nitrogen uptake (220 kg ha^{-1}) was found in T7, which was statistically identical to T5 but significantly higher than the other treatments (Table 4). The lowest N uptake was found in the control. It was observed that poultry manure in combination with inorganic fertilizer showed superiority over cowdung plus inorganic fertilizer. Similarly, highest nutrient uptake in the poultry manure incorporated treatment was also reported by Noor et al. (2005) where poultry manure (5 t ha^{-1}) along with reduced rate (70% RD) of chemical fertilizers were applied in integrated manner. Dixit and Gupta, (2000) observed that application of organic manures increased efficiency of chemical fertilizer and nitrogen uptake by different crops. Kumar and Sharma (2004) observed maximum nutrient uptake by cabbage in FYM + 150 % NPK. T7 also showed highest P uptake (16.5 kg ha^{-1}) followed by T5 (15.2 kg ha^{-1}) and T6 (14.8 kg ha^{-1}). The lowest P uptake (8.70 kg ha^{-1}) was in the control. Sen et al. (2008) reported that RDF along with PM 3 t ha^{-1} resulted highest P uptake. Similar results were also observed by Khanda et al. (2005). The highest K uptake (225 kg ha^{-1}) was found in T7, which was significantly higher than the other treatments. T5 showed second highest K uptake (210 kg ha^{-1}) followed by T6 (190 kg ha^{-1}) and T4 (180 kg ha^{-1}). Minimum K uptake was in the control. Mondal et al. (2007) reported maximum improvement of NPK status of soil after addition of farm yard manure along with mineral fertilizers. Kumar and Sharma, (2004) also observed the similar result. The increased uptake of nutrient due to NPKS fertilization and organic manure application was due to added supply of nutrients and proliferous root system developed under balanced nutrient application resulting in better absorption of water and nutrients along with improved physical environment (Pathak et al., 2005; Laxminarayana, 2006; Kler and Walia, 2006).

Effects of manure and fertilizers on soil properties

After application of organic manure, soil bulk density was reduced. Minimum bulk density (1.43 g cm^{-3}) was found in T4 and T6 treatments. The control showed maximum bulk density (1.51 g cm^{-3}) followed by T2 and T3 (1.5 g cm^{-3}), where no manure was used (Table 5). The higher bulk density in the control, farmer's practice and in only fertilizer treated plots may be due to very low organic matter content in soil and formation of compact layer. It was also viewed by Islam et al. (2006). Mathur, (1997) reported that organic matter incorporation into soil decreased the bulk density from 1.46 to 1.40 g cm^{-3} which confirms the present findings. The soil pH was reduced in the control and inorganic fertilizer treated plots. The plots received only RDF showed the maximum reduction in pH value (5.82), showing an increase in acidity (Table 5). Among the organic treatments, the PM treatment resulted in the highest pH value because the poultry manure contained varying amounts of calcium carbonate (Camberato and Mitchell, 2011). The maximum increase in acidity was noted in treatments having the highest dose of inorganic fertilizers (T2). Kingery et al. (1993) reported that the application of poultry broiler litter over many years had an average surface soil pH of 6.3 compared to fields receiving only commercial fertilizers (pH 5.8). Hue, (1992) also showed that chicken manure was very effective in raising soil pH.

The total organic carbon content ranged from 0.75 to 0.99 %, having the highest (0.99%) in T6 (CD 6 t ha^{-1}+ rest from RDF) followed by T7 (0.98%) and T4 (0.97%). After harvesting, the soil organic carbon was reduced to 0.75% in the control, where no manure or fertilizer was applied (Table 5). However, the organic carbon was maintained around 0.80 % in recommended dose of chemical fertilizer treated plots. Singh et al. (1999) reported drastic reduction in organic carbon concentration on continuous application of chemical fertilizer, whereas addition of 5 t FYM ha^{-1} along with N fertilizer helped in maintaining the original organic matter status in soil. Kumar et al. (2012) reported that the total organic carbon varied from 9.13 to 14.43 gkg^{-1} in the control and 100% FYM (RDN) treated plots, respectively. Pengthamkeerati et al. (2011) also noted that incorporation of poultry litter significantly increased total organic carbon (TOC) in the plots ($P < 0.001$) than the non-treated plots which corroborated our study.

Nutrient availability

Addition of organic manure in combination with chemical fertilizer showed positive effect on the availability of N, P, K and S in soil as recorded after harvest of potato. The highest Total N (0.14%) was found in T5 and T7 followed by T6 (0.13%) and the lowest (0.08%) was found in the control (Table 5). The available P ranged from 16 to 23 ppm, having the highest in T7 and the lowest P content was in the control. The increase in P might be due to addition of P through inorganic fertilizer and organic manure. Like N and P, the maximum available K (0.21 c mol kg^{-1}) was also observed in T7. The highest available S (17.8 ppm) was found in T7 followed by T5 and T2. The lowest available K (0.12 c mol kg^{-1}) and S (12.2 ppm) were found in the control, where no manure or fertilizer was used (Table 5). Available K content was found higher in PM treated plots which can be attributed to higher supply of K from PM compared to CD. Kumar et al. (2012) reported that the plots receiving 50 % RDNPK (recommended dose of NPK) through inorganic fertilizers and remaining 50% RDN (recommended dose of N) through PM registered the highest available N, P and K status in the soil, which is in agreement with the findings of our results. The availability of N, P, K and S was increased in soil and this might be due to their release from poultry manure and cowdung (Islam et al., 2011).

Materials and methods

Experimental site and soil characteristics

The experiment was conducted at Tuber Crops Research Centre, Bangladesh Agricultural Research Institute, Gazipur, Bangladesh from October 2008 to March 2010. The experimental site was located in the center of the Madhupur Tract at about 24^0 23´ north latitude and 90^0 08´ east longitude having a mean elevation of 8.4m above mean sea level and about 34 km north of Dhaka city. The experimental plot was a high land having silty clay soil. The soils are poorly drained, grey and silty and overlie heavy, grey, little-altered, deeply weathered Madhupur or Piedmont clay. The major part of the subsoil is an E-horizon (FAO, 1988;

Table 2. Effects of integrated nutrient management on yield attributes and yield of Potato.

Trt.	Plant height (cm)		Foliage coverage (%)		Stems hill^{-1} (no)		Tubers per hill (no)		Weight of tubers per hill (kg)		(%) Dry matter by wt.		Yield (t ha^{-1})	
	1st yr	2nd yr	1st yr	2nd yr	1st yr	2nd yr	1st yr	2nd yr	1st yr	2nd yr	1st yr	2nd yr	1st yr	2nd yr
T1	45.0 d	43.0 e	86.0 c	84 c	4.98 c	4.68 d	5.25 e	5.00 e	0.28 c	0.27 d	22.5 bc	22.0 bc	14.1 d	13.8 e
T2	56.4 a	57.6 a	92.0 b	92 b	6.53 c	6.75 b	6.24 cd	7.17 cd	0.32 bc	0.35 ab	21.6 c	21.47 c	20.3 bc	21.4 c
T3	46.6 c	47.5 de	84.0 c	86 c	5.60 d	5.82 c	5.54 de	6.00 de	0.30 cd	0.31 bc	21.0 c	21.53 c	18.5 c	23.6 b
T4	52.6 b	54.8 a-c	91.0 b	92 b	6.87 bc	6.93 b	6.90 c	7.33 cd	0.32 bc	0.36 ab	22.0 bc	23.0 a-c	20.9 bc	22.5bc
T5	48.3 c	51.4 b-d	89 b	90 bc	6.01 d	6.24 bc	7.88 b	8.83 ab	0.34 ab	0.38 a	22.9 ab	23.8 ab	22.3 b	23.6 b
T6	49.4 c	50.5 cd	91.0 b	92 b	7.18 b	6.93 b	7.00 bc	7.90 bc	0.33 bc	0.37 ab	22.5 a-c	23.5 ab	22.1 b	22.8 b
T7	54.2 ab	55.4 ab	96 a	100 a	7.69 a	7.84 a	8.87 a	9.50 a	0.37 a	0.40 a	23.3 a	24.2 a	25.2 a	26.4 a
CV (%)	6.58	5.00	3.24	2.76	4.40	7.41	7.98	5.57	7.79	10.0	3.20	4.00	6.58	4.00

Notes: T1= Control, T2= 100% RDF, T3= FP, T4= CD 6 t ha^{-1}+70%RDF, T5= PM 3 t ha^{-1}+70% RDF, T6= CD 6 t h^{-1}+ rest from RDF and T7= PM 3 t ha^{-1}+ rest from RDF. Figure(s) in a column having common letter(s) do not differ significantly.

Table 3. Cost and benefit analysis for potato as influenced by integrated nutrient management.

Treat.	Mean Potato yield (t ha^{-1})	Gross return (US$ ha^{-1})	Nutrient cost (US$ ha^{-1})	Gross margin (US$ ha^{-1})	MBCR
T1	13.95	1722.22	0	1722.22	-
T2	20.85	2574.07	162.00	2412.07	5.26
T3	21.05	2598.77	147.00	2451.77	5.96
T4	21.70	2679.01	167.00	2512.01	5.73
T5	22.95	2833.33	149.00	2684.33	7.46
T6	22.45	2771.60	152.00	2619.60	6.90
T7	25.80	3185.19	133.00	3052.19	11.0

Notes: T1= Control, T2= 100% RDF, T3= FP, T4= CD 6 t ha^{-1}+70%RDF, T5= PM 3 t ha^{-1}+70% RDF, T6= CD 6 t ha^{-1}+ rest from RDF and T7= PM 3 t ha^{-1}+ rest from RDF.
Input price: Urea = US$ 0.15/ kg, TSP = US$ 0.27/ kg, MoP = US$ 0.31/ kg, Gypsum = US$ 0.123/ kg, Poultry manure = US$ 0.012/ kg, Cowdung = US$ 0.009/ kg
Output price: Potato = US$ 0.123/ kg.

Table 4. Effect of integrated nutrient management on nutrient uptake by potato.

Treatment	Nitrogen uptake (kg/ha)	Phosphorous uptake (kg/ha)	Potassium uptake (kg/ha)
T1	107.8e ±9.83	8.7e ±1.16	112f ±10.4
T2	172.5c ±6.94	12.4c ±1.73	175d ±12.1
T3	145.6d ±8.67	10.9d ±1.62	150e ±11.5
T4	176.4bc ±9.25	12.8c ±1.16	180cd ±12.1
T5	210.3a ±11.5	15.2ab ±2.20	210b ±13.3
T6	188.7b ±10.4	14.8b ±1.45	190c ±13.3
T7	220.6a ±11.5	16.5a ±2.02	225a ±14.4

Notes: T1= Control, T2= 100% RDF, T3= FP, T4= CD 6 t ha^{-1}+70%RDF, T5= PM 3 t ha^{-1}+70% RDF, T6= CD 6 t h^{-1}+ rest from RDF and T7= PM 3 t ha^{-1}+ rest from RDF. Figure(s) in a column having common letter(s) do not differ significantly at 5% level of DMRT. [1] Values of standard error of mean are given after ±.

Table 5. Effects of integrated nutrient management on soil properties as influenced by different treatments.

Treatment	Bulk density	pH	Organic carbon (%)	Total N (%)	Available P (ppm)	Available K (ppm)	Available S (ppm)
T1	1.51a±0.035[1]	5.98cd±0.082	0.75d±0.029	0.08d±0.012	16d±0.98	46.9e±6.36	12.2e±1.09
T2	1.50a±0.012	5.82d±0.243	0.80c±0.029	0.11c±0.014	18bc±1.15	78.2ab±4.62	17.4a±1.09
T3	1.50a±0.012	6.00cd±0.197	0.86b±0.017	0.10c±0.015	17cd±1.22	58.7d±4.62	15.2cd±1.16
T4	1.43b±0.017	6.22b±0.127	0.97a±0.027	0.12b±0.013	19b±1.20	66.5c±6.35	16.1bc±1.15
T5	1.44b±0.023	6.12bc±0.069	0.96a±0.029	0.14a±0.015	22a±1.52	74.3b±5.20	17.4a±1.79
T6	1.43b±0.029	6.25b±0.145	0.99a±0.023	0.13ab±0.014	19b±1.22	66.5c±3.47	16.3b±1.73
T7	1.44b±0.017	6.29b±0.092	0.99a±0.052	0.14a±0.024	23a±1.68	82.1a±4.62	17.5a±1.25
Before planting	1.48a±0.046	6.5a±0.139	0.88b±0.046	0.09d±0.012	18bc±1.16	54.7d±6.09	14.6d±0.925

Notes: T1= Control, T2= 100% RDF, T3= FP, T4= CD 6 t ha^{-1}+70%RDF, T5= PM 3 t ha^{-1}+70% RDF, T6= CD 6 t h^{-1}+ rest from RDF and T7= PM 3 t ha^{-1}+ rest from RDF. Figure(s) in a column having common letter(s) do not differ significantly at 5% level of DMRT. [1] Values of standard error of mean are given after ±.

Brammer, 1996). Potato is grown in winter and generally no rainfall occurs in this season. The soil was also slightly acidic (pH of 6.4) and low in organic matter (0.88%), total N (0.09%) and exchangeable K (0.14 c mol kg^{-1}). The soil S content was at par with critical level, while P was above the critical level (Critical levels of P and S were 14 and 14 ppm, respectively and that of K was 0.2 c mol kg^{-1}). Poultry manure contained 0.99% N, 1.12% P, 1.10% K and 0.50% S, while cowdung had 0.55% N, 0.80% P, 0.56% K and 0.12% S.

Treatment details, fertilizer and manure application

The treatment combinations are presented in Table 1. The experiment was laid out in a randomized complete block design (RCBD) with four replications. Urea, triple superphosphate (TSP), muriate of potash (MoP) and gypsum were used as sources of N, P, K and S, respectively. Entire quantity of cowdung, poultry manure, Phosphorous, Sulphur, Zinc and half of nitrogen and potassium were applied before planting and mixed into the soil. Remaining nitrogen and potassium were side-dressed at 30 DAP (days after planting) at the time of earthing up.

Planting and harvesting

Potato variety Diamant (*Solanum tuberosum*) was used as a test crop. The unit plot size was 3 m × 3 m. Whole tubers of the potato variety `Diamant' were planted with a spacing of 60 cm × 25 cm on 15 and 17 November of 2008 and 2009, respectively. Potato was harvested on 25 and 30 February of 2009 and 2010, respectively.

Intercultural operation

Intercultural operations such as weeding and mulching were done as and when required. Irrigations were given four times during the whole growing season. First time, light irrigation was applied at 7 days after planting (DAP) to ensure proper germination. Second irrigation was given at 30 DAP followed by earthing up and side-dressing (urea and MoP fertilizers). Third and fourth irrigations were applied at 48 and 63 DAP, respectively. Dithen M45 2g L^{-1} was sprayed at 50 DAP to prevent the late blight disease.

Plant and soil sampling and chemical analysis

Soil samples were collected, dried and ground for chemical analysis. Bulk density was determined by core sampler Method (Blake, 1965), soil pH was measured by glass electrode pH meter (1:2.5) and organic carbon by wet oxidation method (Walkley and Black, 1935). Total N content of soil was determined by Kjeldahl method, and available P, exchangeable K and available S contents by 0.5M $NaHCO_3$ (pH 8.5), NH_4OAc and $CaCl_2$ extraction methods, respectively as outlined by Page et al. (1982).
Plant samples (whole plants) at harvest were collected for NPK levels. Concentrated HNO_3 was used for digestion of plant samples. Extractable P was estimated colorimetrically by spectrophotometer and extractable K directly by Atomic

Absorption Spectrophotometer (Model No. 170-30 HITACHI, Japan). Nutrient uptake was calculated as: Nutrient uptake = (yield in kg ha^{-1} × nutrient concentration in %) / 100.

Data collection

The number of tubers, stems per hill and plant height foliage coverage was assessed at 60 days after planting using green method (Groves et al., 2005). A square quadrat was used which was divided into 100 equal sized squares.
Three quadrat counts per plot were made at approximately equal intervals along the length of the plot. The quadrat was placed above the crops so that it spanned the row exactly, and the number of squares with in the quadrate which contain more than 50% green haulm were counted. The level of foliage coverage was estimated as the percentage of squares with more than 50% green haulm. The yield data were collected at harvest and dry weight was recorded at 7 days after harvest.

Economic analysis

The cost of organic manures and chemical fertilizers (inputs) 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. Economic analysis was performed through partial budgeting followed by marginal benefit cost ratio (MBCR) as suggested by Perrin et al (1979).

Statistical analysis

The analysis of variance for crop characters and nutrient uptake of the plant samples were done following the ANOVA test and the mean values were compared by DMRT ($P \leq 0.05$) (Steel and Torrie, 1960). One way ANOVA table was used to perform this analysis. Computation and preparation of graphs were done by the use of Microsoft EXCEL 2003 program.

Conclusion

Addition of organic manure in combination with reduced rate of inorganic fertilizers showed significant effects on the yield parameters and yield of potato. The combination of poultry manure 3 t ha^{-1} + reduced RDF was found to be best for the cultivation of potato. The highest marginal benefit cost ratio (MBCR) (11.00) was also recorded in the same combination.
The N, P and K uptake by the potato increased significantly due to addition of organic manure and inorganic fertilizers, with the highest N, P and K uptake by PM + reduced RDF treatment. Physical properties improved by incorporation of organic manure having the better in T4 and T6. Highest available N, P, K and S were found in T7. PM 3 t ha^{-1} + reduced recommended dose of chemical fertilizer can be recommended for cultivation of potato and to maintain soil health in Grey Terrace Soil.

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