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Integrated Nutrient Management of Hilly Soil of Meghalaya Cropped with Potato (*Solanum tuberosum*)

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

Irrespective of treatment combinations total N, available P_2O_5, K_2O and S decreased with the age of potato crop. However, changes in organic C in soil showed an opposite trend of results. Irrespective of treatments, organic C content increased with increase in the period of crop growth. Pooled data of two years revealed that comparatively higher amount of total N, available P_2O_5, K_2O and S is accumulated in soil at maturation stage of potato which received recommended doses of N, P and K along with FYM at 10 t ha^{-1} as well as biofertilizer and S at 40 kg ha^{-1}(T_9). Statistical analysis of the results also revealed that T_9 treatment is significant with respect to control. Results thus pointed out that balanced and proper dose of fertilization increased available nutrient contents in soils.

Keywords: Integrated nutrient management; organic carbon; available macro nutrients; potato; hilly soil.

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1. INTRODUCTION

Potato, the second most important cash crop after rice, plays major role in the livelihood of resource-poor farmer in hilly region of Meghalaya. The significance of this crop to the rural economy as well as agriculture of the state could be comprehended from the fact that potato occupies more than 18 thousands hectares of land which accounts for 8.56% of the total cultivable area of the state. The potato productivity in Meghalaya is mere 9.78 tonnes ha^{-1}, which is far below the national average of 17.57 tonnes ha^{-1}. As well as productivity figures of major potato producing states of the country *viz.*, Uttar Pradesh (22.63 tonnes ha^{-1}), West Bengal (21.03 tonnes ha^{-1}), Punjab (18.73 tonnes ha^{-1}), *(Directorate of Economics and Statistics, Govt. of India* 2001). Potato is grown in Meghalaya both in summer and autumn seasons. The summer season is the main potato-growing season extends from the month of February to June-July, while autumn season lasts from the month of July- August to November- December. The area under potato in the autumn is comparatively less than in summer season [1]. However, low or imbalanced use of fertilizers are some of the reasons responsible for low production of potato crop in the region.

Potato requires higher amount of nutrients which may come from fertilizers as well as organic sources namely, Farmyard Manure (FYM), vermicompost, biofertilizer etc. Balanced use of organic and inorganic fertilizers plays an important role in improving quality of produce besides good yield of potato [2]. Crop receiving 50% of the recommended dose of NPK through inorganic fertilizers and remaining 50% of the recommended dose of N (RDN) through organic manures (FYM, PM or VC) or 100% recommended dose of NPK (60 kg N, 120 kg P_2O_5 and 60 kg K_2O ha^{-1}) through inorganic fertilizers favourably influenced yield of different grades of tubers and total tuber yield [3]. Keeping above information in view, two field experiments were conducted in succession consecutively for two years (2014-15 and 2015-16) in a farmer's field situated at Shillong in East Khasi Hills district of Meghalaya. The field used for experimentation purpose is generally cultivated for potato crop.

2. MATERIALS AND METHODS

Composite soil sample (0-15 cm depth) was collected from the experimental field before the start of experiment. The collected soil sample was air-dried, ground and passed through 0.5 mm sieve. The soil sample was analyzed for different physical, chemical and physico-chemical properties and the results are presented in Table 1.

The experiment on potato crop was conducted following simple Randomized Block Design. The plot size was 3 m x 2 m. Altogether 30 plots were included in the field experimentation. 10 treatments were adopted to study the effect of INM practices on potato. All the treatments were replicated thrice. Potato variety Kufri Jyoti (tuber size 40-50 g was selected for the experimentation purpose. Row-to-row spacing was maintained at 60 cm x 20 cm.

All the treatments received both organic and inorganic fertilizers such as Farm Yard Manure (10 tonnes ha^{-1}) and N: P_2O_5: K_2O at 60:120:60 kg ha^{-1}. Nitrogen (N), Phosphorus (P_2O_5) and Potash (K_2O) were applied in the form of Urea, Single Super Phosphate and Muriate of Potash, respectively. Two doses of sulphur *i.e.* 20 kg ha^{-1} and 40 kg ha^{-1} as Elemental sulphur (applied 3 weeks prior to sowing) and biofertilizer (BF) in the form of *Azotobacter* and phosphorus solubilizing bacteria (PSB) mixed with FYM were included in the treatment combinations (Chart 1). Only well sprouted seed tubers were planted. After preparation of furrows, fertilizer mixtures were applied along with well decomposed FYM. Full dose of P and K and half dose of N fertilizers were applied as basal application. The rest half dose of N was applied in two split doses at vegetative and flowering stages of potato crop. Two doses of S were applied as basal along with N, P and K fertilizers as treatment material. Biofertlizer were applied as basal in the treatment plots and then the tubers were placed in the furrows. The potato crop was raised with best possible management practices. The seed tubers were immediately covered with soil after planting and ridges were made to a height of 8-10 cm. The treatments were as follows:

Chart 1. The treatments followed

T_0	=	Control
T_1	=	$N_{60}P_{120}K_{60}$
T_2	=	T_1+FYM (FYM at 10t ha^{-1})
T_3	=	T_1+S_1 (S_1 is equal to S at 20 kg ha^{-1})
T_4	=	T_1+S_2 (S_2 is equal to S at 40 kg ha^{-1})
T_5	=	T_3+FYM
T_6	=	T_4 +FYM
T_7	=	T_2 + BF (BF is equal to 4 kg Biofertilizer mixed with 80 kg FYM)
T_8	=	T_5+BF
T_9	=	T_6+BF

Table 1. Physical, chemical and physico-chemical properties of the initial soil samples collected from experimental field

Parameters	Values	Methods adopted
pH	4.48(Soil:water = 1:2.5)	Glass electrode pH meter [4]
pH	3.45($CaCl_2$ = 1:2.5)	
Electrical conductivity	0.09dSm^{-1} at 25ºC	Electrical conductivity meter [4]
Oxidizable organic carbon	0.57%	Wet digestion method [5]
Cation Exchange Capacity	7.00(C mol p^{+} kg^{-1})	Ammonium Acetate Leaching [6]
Mechanical analysis		
Sand	63.56%	Hydrometer Method [7]
Silt	16.00%	
Clay	25.44%	
Textural class	Sandy loam	ISSS(Soil textural triangle)
Water Holding Capacity	27.83%	Keen Rackzaw Ski [8]
Available N	98.88(mg kg^{-1})	Bremner and Keeney [9]
Available P_2O_5	21.00(mg kg^{-1})	Spectro photometer [10]
Available K_2O	186.56(mg kg^{-1})	Flame photometry with Ammonium acetate [11]
Available S	0.86(mg kg^{-1})	Turbidimetric method with $CaCl_2$ and Nephelometer [12]
Available Zn	0.43(mg kg^{-1})	DTPA extraction and atomic absorption spectrophotometer [13]

Rhizosphere soil samples were collected from each of 30 plots at vegetative, tuber initiation and maturation stages of potato. Soil samples were analyzed for organic carbon (OC) [5], total N [14], available P_2O_5 [10], available K_20 [11] and available S [12]. Data of soil samples were analyzed statistically to study the significance of means among treatments at different growth stages of potato crop [15].

3. RESULTS AND DISCUSSION

3.1 Changes in Oxidizable Organic Carbon Content in Soil

Irrespective of treatments, organic carbon increased with increase in the growth of potato. Highest amount of organic carbon is accumulated in soil at maturity stage of potato (Table 2). This trend of increase in organic carbon is observed in both the years of experimentation. Furthermore, comparatively higher amount of organic carbon is accumulated in the 2nd year of experimentation. The increase in organic carbon in soil with the age of crop is due to decomposition of rootlets of potato. Accumulation of comparatively higher amount of organic carbon in the 2nd year is due to enrichment of organic matter in soil. The results find support of earlier works carried out by Pervez [16] and Bashir [17]. Closer examination of the data in Table 2 further revealed that FYM treated systems showed comparatively higher amount of organic carbon in soil. This is the effect of added organic matter to soil [18,19]. Furthermore, significantly highest amount of organic carbon is accumulated in soil treated with FYM and recommended doses of N, P and K fertilizers along with biofertilizer and higher dose of S (40 kg ha^{-1}). Addition of balanced inorganic fertilizers including S and biofertilizer encouraged growth and proliferation of both roots and microorganisms which in turn increased organic carbon content in soil. Similar observation was also recorded earlier by Farag [20]. Perusal of the data in Table 2 also revealed that comparatively higher amount of organic carbon is accumulated in soils which received FYM treatment along with inorganic fertilizers. Combined application of organic, inorganic and biofertilizer accentuated higher accumulation of organic carbon in soils.

3.2 Changes in Total N Content in Soil

Results in Table 3 revealed that irrespective of treatments, total N decreased with increase in the period of crop growth of potato. This trend of results is observed during both the years of experimentation. The decrease in total N in soil is due to its uptake by the growing potato crops. Perusal of the data in Table 3 also revealed that highest amount of total N is accumulated in soil treated combinedly with FYM along with recommended doses of N, P and K fertilizers and higher dose of S as well as biofertilizer. Addition of inorganic N and FYM increased total N content in soil. Furthermore, presence of

Table 2. Changes in the amount of organic C (%) in soil at different growth stages of potato grown consecutively for two years (2014-15 and 2015-16) under different treatment combinations

Treatments	Growth stages of potato								
	Vegetative			Tuber initiation			Maturation		
	2014-15	2015-16	Pooled	2014-15	2015-16	Pooled	2014-15	2015-16	Pooled
T_0	0.55	0.69	0.62	0.73	0.80	0.77	0.82	0.88	0.85
T_1	0.68	0.78	0.73	0.77	0.93	0.85	1.00	1.04	1.02
T_2	0.76	0.84	0.80	0.86	1.07	0.97	1.12	1.15	1.14
T_3	0.84	0.87	0.86	0.91	1.06	0.99	1.24	1.28	1.26
T_4	0.88	0.97	0.93	0.95	1.24	1.09	1.39	1.45	1.42
T_5	0.93	1.08	1.00	0.99	1.35	1.17	1.44	1.56	1.50
T_6	1.07	1.16	1.11	1.12	1.41	1.27	1.55	1.64	1.59
T_7	1.18	1.24	1.21	1.22	1.59	1.40	1.62	1.71	1.67
T_8	1.26	1.37	1.32	1.46	1.67	1.57	1.120	1.84	1.79
T_9	1.38	1.43	1.41	1.67	1.77	1.72	1.87	1.91	1.89
CD(P=0.05)	0.02	0.03	0.06	0.01	0.03	0.16	0.02	0.02	0.04
SEm(±)	0.01	0.01	0.01	0.01	0.01	0.05	0.01	0.01	0.01

Note: To=Control; T_1=Recommended doses of NPK at 60:120:60 kg ha^{-1} as Urea, SSP and MOP; T_2=T_1+FYM at 10 t ha^{-1}; T_3=T_1+S at 20 kg ha^{-1} as Elemental S; T_4=T_1+S at 40 kg ha^{-1}; T_5=T_2+S at 20 kg ha^{-1}; T_6=T_2+S at 40 kg ha^{-1} T_7=T_2+Biofertilizer at 4 kg per 80 kg FYM as Azotobacter and P Solubilizing Bacteria; T_8=T_7+S at 20 kg ha^{-1}; T_9=T_7+S at 40 kg ha^{-1}

Azotobacter in biofertilizer fixes atmospheric N_2 which in turn increased total N content in soil [8]. Highest amount of total N was accumulated in soil which received combined application of organic and inorganic along with biofertilizer (Table 3). Addition of only inorganic N fails to increase total N content in soil. This is due to loss of N either through volatilization [17] or leaching [21]. It has been reported earlier that the loss of N is comparatively less in soil treated with both organic and inorganic N fertilizers [22].

3.3 Changes in the Available P_2O_5 Content in Soil

Irrespective of treatments, available P_2O_5 decreased with increase in the period of crop growth (Table 4). This trend of result is observed in both the years of experimentation. Again, irrespective of treatments, comparatively higher amount of available P_2O_5 was accumulated in the 2nd year of experiment. The decrease in available P_2O_5 with increase in the period of crop growth was due to its utilization by the growing potato crop. Highest amount of available P_2O_5 was accumulated in T_9 treatment which received recommended doses of N, P and K along with FYM at 10 tonnes ha^{-1} as well as biofertilizer and S at 40 kg ha^{-1}. Presence of phosphate solubilizing bacteria (PSB) in biofertilizer makes organic P in available form which in turn increased available P content in soil. The results are in accordance with earlier works carried out by Sayed [23] and Congera [24]. The pooled data of available P_2O_5 also showed similar trend of results. Results in Table 4 further revealed that on average, increase of about 20 mg kg^{-1} was recorded in T_9 over that of control. The recorded increase in available P_2O_5 is more or less same in both the years of experimentation. Perusal of the data in Table 4 also pointed out that application of P-solubilising bacteria even in absence of added S, increased available P content in soil.

3.4 Changes in the Available K_2O Content in Soil

Available K decreased with increase in the period of crop growth of potato (Table 5). However, like P_2O_5 the decrease in available K_2O ranged from 64 to 110 mg kg^{-1} depending upon the treatment combinations as well as year of cultivation. It is interesting to note that irrespective of treatments, the intensity of decrease in available K_2O is more prominent in the 2nd than that of 1st year of experiment over the whole cropping season of potato. Recorded higher amount of depletion of available K_2O in the 2nd year of experiment is due to comparatively higher amount of uptake of K by potato crop. The demand of K for potato is comparatively higher than other staple food crops [25]. Results in Table 5 further revealed that highest amount of available K_2O is accumulated in T_9 treatment which received recommended doses of N, P and K along with FYM at 10t ha^{-1} as well as biofertilizer and S

Table 3. Changes in the amount of total N (%) in soil at different growth stages of potato grown consecutively for two years (2014-15 and 2015-16) under different treatment combinations

Treatments	Growth stages of potato								
	Vegetative			Tuber initiation			Maturation		
	2014-15	2015-16	Pooled	2014-15	2015-16	Pooled	2014-15	2015-16	Pooled
T_0	0.09	0.11	0.10	0.08	0.09	0.08	0.05	0.06	0.06
T_1	0.09	0.11	0.10	0.07	0.09	0.08	0.05	0.07	0.06
T_2	0.10	0.12	0.11	0.08	0.11	0.09	0.07	0.08	0.07
T_3	0.10	0.13	0.12	0.10	0.12	0.11	0.07	0.09	0.08
T_4	0.11	0.14	0.12	0.11	0.12	0.12	0.09	0.10	0.09
T_5	0.11	0.15	0.13	0.11	0.13	0.12	0.10	0.11	0.10
T_6	0.13	0.17	0.15	0.12	0.13	0.12	0.11	0.12	0.12
T_7	0.14	0.17	0.16	0.12	0.14	0.13	0.11	0.13	0.12
T_8	0.15	0.18	0.16	0.13	0.15	0.14	0.12	0.13	0.13
T_9	0.16	0.19	0.17	0.14	0.16	0.15	0.13	0.14	0.14
CD(P=0.05)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
SEm(±)	0.003	0.04	0.004	0.004	0.003	0.003	0.004	0.003	0.002

Note: To=Control; T_1=Recommended doses of NPK at 60:120:60 kg ha^{-1} as Urea, SSP and MOP; T_2=T_1+FYM at 10 t ha^{-1}; T_3=T_1+S at 20 kg ha^{-1} as Elemental S; T_4=T_1+S at 40 kg ha^{-1}; T_5=T_2+S at 20 kg ha^{-1}; T_6=T_2+ S at 40 kg ha^{-1} T_7=T_2+Biofertilizer at 4 kg per 80 kg FYM as Azotobacter and P Solubilizing Bacteria; T_8=T_7+S at 20 kg ha^{-1}; T_9=T_7+S at 40 kg ha^{-1}

Table 4. Changes in the amount of available P_2O_5 (mg kg^{-1}) in soil at different growth stages of potato grown consecutively for two years (2014-15 and 2015-16) under different treatment combinations

Treatments	Growth stages of potato								
	Vegetative			Tuber initiation			Maturation		
	2014-15	2015-16	Pooled	2014-15	2015-16	Pooled	2014-15	2015-16	Pooled
T_0	22.03	26.22	24.13	16.84	21.25	19.04	11.02	19.88	15.45
T_1	24.40	28.58	26.49	17.58	22.70	20.14	13.71	21.81	17.76
T_2	27.50	30.92	29.21	21.27	26.69	23.98	16.95	24.22	20.59
T_3	28.32	33.70	31.01	25.20	28.50	26.85	19.07	24.48	21.78
T_4	33.19	37.33	35.26	30.94	31.45	31.19	21.49	28.10	24.79
T_5	38.05	40.09	39.07	33.10	36.120	34.93	27.59	31.29	29.44
T_6	36.93	42.88	39.91	32.06	35.73	33.90	28.11	33.52	30.81
T_7	39.66	45.67	42.66	37.42	39.38	38.40	30.93	35.65	33.29
T_8	40.30	46.35	43.32	36.90	39.71	38.30	32.42	35.99	34.20
T_9	40.33	48.39	44.36	37.31	39.37	38.34	33.85	36.40	35.13
CD(P=0.05)	3.07	1.18	2.74	1.94	3.05	2.45	1.07	1.30	3.35
SEm(±)	1.02	0.39	0.84	0.64	1.18	0.120	0.36	0.43	1.03

Note: To=Control; T_1=Recommended doses of NPK at 60:120:60 kg ha^{-1} as Urea, SSP and MOP; $T_2=T_1$+FYM at 10 t ha^{-1}; $T_3=T_1$+S at 20 kg ha^{-1} as Elemental S; $T_4=T_1$+S at 40 kg ha^{-1}; $T_5=T_2$+S at 20 kg ha^{-1}; $T_6=T_2$+S at 40 kg ha^{-1} $T_7=T_2$+Biofertilizer at 4 kg per 80 kg FYM as Azotobacter and P Solubilizing Bacteria; $T_8=T_7$+S at 20 kg ha^{-1}; $T_9=T_7$+S at 40 kg ha^{-1}

Table 5. Changes in the amount of available K_2O (mg kg^{-1}) in soil at different growth stages of potato grown consecutively for two years (2014-15 and 2015-16) under different treatment combinations

Treatments	Growth stages of potato								
	Vegetative			Tuber initiation			Maturation		
	2014-15	2015-16	Pooled	2014-15	2015-16	Pooled	2014-15	2015-16	Pooled
T_0	187.09	210.46	198.78	141.25	171.12	156.18	123.95	154.12	139.04
T_1	193.35	249.31	221.33	159.12	203.87	181.49	152.10	1120.90	164.00
T_2	225.72	334.29	280.01	203.72	237.53	220.63	191.95	212.04	202.00
T_3	276.67	386.94	331.80	226.13	274.33	250.23	202.30	249.89	226.09
T_4	304.55	410.03	357.29	267.39	362.13	314.76	219.39	295.00	257.20
T_5	315.10	423.87	369.48	268.69	384.51	326.60	238.71	312.12	2120.42
T_6	324.98	441.42	383.20	296.30	396.42	346.36	274.00	350.99	312.50
T_7	337.03	465.48	401.26	305.98	408.85	357.42	287.52	394.37	340.95
T_8	344.80	485.34	415.07	315.95	427.30	371.63	303.03	402.78	352.91
T_9	353.15	493.84	423.50	328.49	463.80	396.15	312.01	425.42	368.72
CD(P=0.05)	4.58	47.89	60.03	7.65	23.91	62.45	1.32	6.87	56.26
SEm(±)	1.53	15.99	18.50	2.55	7.98	19.25	0.44	2.29	17.34

Note: To=Control; T_1=Recommended doses of NPK at 60:120:60 kg ha^{-1} as Urea, SSP and MOP; $T_2=T_1$+FYM at 10 t ha^{-1}; $T_3=T_1$+S at 20 kg ha^{-1} as Elemental S; $T_4=T_1$+S at 40 kg ha^{-1}; $T_5=T_2$+S at 20 kg ha^{-1}; $T_6=T_2$+S at 40 kg ha^{-1} $T_7=T_2$+Biofertilizer at 4 kg per 80 kg FYM as Azotobacter and P Solubilizing Bacteria; $T_8=T_7$+S at 20 kg ha^{-1}; $T_9=T_7$+S at 40 kg ha^{-1}

at 40 kg ha^{-1}. Critical examination of the data in Table 5 also showed that application of biofertilizer increased available K content in soil. This trend of results is observed both in presence and absence of added S. Addition of inorganic K increased available K content in soil [26]. Application of free living N_2 fixing *Azotobacter* and P- solubilising bacteria increased available K content in soil through proliferation of K-mobilizing bacteria in soil [27]. The pooled data of two years also showed similar trend of results.

3.5 Changes in the Available S Content in Soil

Irrespective of treatments, S decreased with increase in the period of crop growth of potato (Table 6). This trend of results is observed in

Table 6. Changes in the amount of available S (mg kg^{-1}) in soil at different growth stages of potato grown consecutively for two years (2014-15 and 2015-16) under different treatment combinations

Treatments	Growth stages of potato								
	Vegetative			Tuber initiation			Maturation		
	2014-15	2015-16	Pooled	2014-15	2015-16	Pooled	2014-15	2015-16	Pooled
T_0	0.88	0.90	0.89	0.79	0.64	0.71	0.67	0.32	0.49
T_1	1.33	1.36	1.35	1.05	1.19	1.12	1.03	1.08	1.05
T_2	1.56	1.59	1.57	1.24	1.87	1.56	1.30	1.23	1.27
T_3	2.31	2.37	2.34	2.00	2.71	2.36	2.07	1.70	1.88
T_4	4.00	4.04	4.02	3.95	3.19	3.57	3.19	2.59	2.89
T_5	4.91	5.01	4.96	4.15	3.90	4.03	3.95	3.77	3.86
T_6	5.82	5.97	5.90	4.86	4.37	4.61	4.10	4.27	4.19
T_7	6.94	7.08	7.01	5.98	5.78	5.88	4.91	5.85	5.38
T_8	7.26	7.26	7.26	6.90	6.81	6.85	5.47	6.23	5.85
T_9	7.77	7.96	7.86	7.04	7.21	7.12	6.08	6.99	6.53
CD(P=0.05)	0.30	0.05	0.10	0.07	0.39	0.74	0.07	0.21	0.90
SEm($\pm$)	0.10	0.01	0.03	0.02	0.13	0.22	0.02	0.07	0.28

Note: To=Control; T_1=Recommended doses of NPK at 60:120:60 kg ha^{-1} as Urea, SSP and MOP; T_2=T_1+FYM at 10 t ha^{-1}; T_3=T_1+S at 20 kg ha^{-1} as Elemental S; T_4=T_1+S at 40 kg ha^{-1}; T_5=T_2+S at 20 kg ha^{-1}; T_6=T_2+S at 40 kg ha^{-1}T_7=T_2+Biofertilizer at 4 kg per 80 kg FYM as Azotobacter and P Solubilizing Bacteria; T_8=T_7+S at 20 kg ha^{-1}; T_9=T_7+S at 40 kg ha^{-1}

both the years of experimentation. The pooled data of two years also showed similar trend of results. Results further revealed that addition of S as treatment material increased available S content in soil. However, highest amount of available sulphur is accumulated in T_9 treatment which received recommended doses of N, P and K along with FYM at 10 tonnes ha^{-1} as well as biofertilizer and S at 40 kg ha^{-1}. Addition of higher dose of S along with biofertilizer increased available S content in soil. Addition of biofertilizer increased proliferation of S oxidizing bacteria which in turn mineralise organic S present in FYM as well as in soil and increased available S content in the system. The present result finds support of earlier investigation carried out by Sharma [28] and Shaheen [29]. Statistical analysis of the data in Table 6 revealed that addition of either dose of S in presence of biofertilizer did not show variation in results between T_8 and T_9 treatment. However, critical analysis of the pooled data revealed that the intensity of increase in available S is more prominent in soil which received added S. This is due to uptake of comparatively higher amount of S by potato crops from the available pool. Similar observations were also reported earlier by Pervez [16], Khan [22] and Islam [30].

4. CONCLUSION

Integrated nutrient management promotes accumulation of comparatively higher amount of organic C at the maturity stage of potato. However, total N, available P_2O_5, K_2O and S decreased with increase in the period of crop growth. It was recorded that T_9 treatment which received recommended doses of N, P and K along with FYM at 10t ha^{-1} as well as biofertilizer and S at 40 kg ha^{-1} improved the available nutrient content in soil as well as maintain for longer period during a cropping season. The authors recommend treatment 9 for the potato growers of hilly regions of Meghalaya.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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