Contents available at http://epubs.icar.org.in, www.kiran.nic.in; ISSN: 0970-6429

Indian Journal of Hill Farming

June 2015, Volume 28, Issue 1, Page 27--34

Response of Levels of Inorganic Fertilizer with Organic Manure on Potato in Aquic Hapludoll of Himalayan Foothills

Dibyendu Chatterjee[1*] • Jaya Srivastava[2]

[1]*Indian Council of Agricultural Research, Research Complex for North Eastern Hill Region, Nagaland Centre, Jharnapani, Medziphema 797106, Nagaland*

[2]*Department of Soil Science, Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, Udham Singh Nagar 263145, Uttarakhand*

ARTICLE INFO

Article history:
Received 24 January 2015
Received Revised 20 April 2015
Accepted 21 April 2015

Key words:
Economic yield,
Fertilizer response,
Multiple regressions,
Potato,
Yield

ABSTRACT

Response of nutrient addition from combined sources like fertilizers and farmyard manure on potato (*Solanum tuberosum* L.) was studied in aquic Hapludoll in Uttarakhand. In the beginning, fertility gradient was established by growing an exhaustive crop, maize cv. Shweta. A test crop, potato cv. *Kufri* Jyoti was grown on the same site, where four levels of fertilizer nitrogen, phosphorus, potassium and three levels of farmyard manure were randomly distributed in 24 plots and 3 fertility strips with a total of 72 plots. Multiple regression equations were made using quadratic model. Response type (+ - -) for the nutrients phosphorus and potassium followed law of diminishing return, while the response type (- + +) observed for nitrogen. Application of 100-150 kg of nitrogen, 0-50 kg of phosphorus, and 0-50 kg of potassium showed maximum response at middle doses of other nutrients. Tuber yield was positively correlated with applied fertilizer nutrient (0.702** with fertilizer nitrogen, 0.481^{**} with fertilizer phosphorus and 0.476^{**} with fertilizer potassium) and with soil test value of potassium (0.202^{*}). These findings can successfully be used in the larger parts of Mollisol dominating areas as an effective guide of fertilizer application, because this is economically viable and suitable for the situation of resource constraint situation like in India and other countries having similar soil type.

1. Introduction

Potato (*Solanum tuberosum* L.), world's fourth important food crop after wheat, rice and maize (Pandey et al. 2005; Reshi et al. 2013), is a heavy feeder of plant nutrients having very high requirement of nitrogen, phosphorus, potassium and other nutrients. Potato provides a source of low cost energy to the human diet and it is the rich source of starch, vitamin C and B and minerals (Kumar et al. 2013; Lokendrajit et al. 2013). The combined use of inorganic and organic sources of nutrients in potato produce maximum yield (Singh and Kushwah 2006).

Application of nitrogen @ 240 kg ha^{-1} increased tuber number (38-293%) and yield (59-369%) of large grade tubers in all the cultivars (Trehan 2003). Phosphorus carriers had a significant effect on total dry matter of potato, though leaf litter tended to give the maximum dry matter of potato tuber over control Phosphorus carriers had a significant effect on total dry matter of potato, though leaf litter tended to give the maximum dry matter of potato tuber over control (Sud and Sharma 2001). Potassium plays a role in sugar translocation and starch synthesis in plants. Due to the high starch of the potato tuber, K is an important nutrient in tuber development (Rhue et al. 1986). In an experiment on potato cv. *Kufri Ashoka*, the maximum plant height and tuber yield were recorded at 120 kg K ha^{-1} and 160 kg N ha^{-1} (Singh and Raghav 2000).

*Corresponding author: dibyenducha@gmail.com

Sasani et al. (2003) reported, remunerative higher yield of potato cv. *Kufri Badsah* can be attained with 25% extra dose of NPK fertilization than recommended dose of inorganic fertilizer along with 25 tonnes farmyard manure. Concept of fertilizer prescriptions for desired targeted yields based on available nutrient status was pioneered by Truog (1960).

Ramamoorthy et al. (1967) established theoretical basis and experimental verification for the principle of fertilizer application for targeted yield of field crops. It was also emphasized that this concept should make a balance between 'fertilizing the crop' and 'fertilizing the soil'. The fertilizer applied on the basis of yield targets provided higher benefit to cost ratio, indicating superiority over other methods of fertilizer application. The application of fertilizer on the basis of yield targets is meaningful, precise and eco-friendly (Saxena et al. 2008, Chatterjee et al. 2010). In the field experiment, the yield variations due to management practices and soil factors other than the nutrient under study are avoided by creating the desired fertility gradient artificially by growing an exhaust crop followed by test crop. Presently there is no information regarding the fertilizer response on potato, the major tuber crop in daily diet. Keeping above factors in view, an experiment was conducted to find out the response of levels of inorganic fertilizer with organic manure on potato with

2. Materials and methods

Experimental details

Field experiment was conducted at the foot hills of Shivalik range of Himalayas in Pantnagar, Uttarakhand at 29^0 N latitude, 79^029' E longitude and an altitude of 243.8 m above the mean sea level. Before conducting the experiment, fertility gradient stabilizing experiment was conducted by sowing maize cv. Shweta as an exhaust crop to minimize interference of other soil and management factors affecting crop yield. Experimental site was divided into three equal strips with the dimension of 38.5 m × 9.5 m and three levels of nutrient viz. 0-0-0, 120-60-40, 240-120-80 kg ha^{-1} N, P_2O_5 and K_2O, respectively were applied. At the second phase, a test crop, potato cv. *Kufri Jyoti* was grown on same site of fertility gradient experiment. Layout was made according to approved plan of All India Coordinated Research Project on investigation for Soil Test Crop Response (STCR) Correlation. Each strip (made in the fertility gradient stabilizing experiment in the previous crop) was divided into 24 plots (21 treatments + 3 controls) resulting in 72 (24×3) plots. 3 blocks comprising of 8 treatments, were made within a strip randomized with farmyard manure level.

These treatments comprised of various selected combinations levels of nitrogen (N_0, N_1, N_2, N_3 i.*e.* 0, 100, 150, 200 kg N ha^{-1}), phosphorus (P_0, P_1, P_2, P_3 i.e. 0, 50, 100, 150 kg P_2O_5 ha^{-1}), potassium (K_0, K_1, K_2, K_3 i.e. 0, 50, 100, 150 kg K_2O ha^{-1}) and farm yard manure (F_0, F_1, F_2 i.e. 0, 10, 20 tonnes farmyard manure ha^{-1}) were randomized in each of the 3 strips.

Soil analysis

Soil samples at 0-15 cm depth were collected from each plot before and after sowing of test crop and analyzed for pH in soil water suspension (1:2.5) was measured using combined electrode in digital pH meter (Jackson 1958), electrical conductivity (μSm^{-1}) in supernatant liquid of soil water suspension (1: 2.5) with the help of conductivity bridge at 25ºC (Bower et al. 1965), per cent oxidizable organic carbon by wet digestion method of Walkley and Black (1934), mineralizable nitrogen (SN) by alkaline-$KMnO_4$ method (Subbiah and Asija 1956), available phosphorus (SP) by 0.5 *M* $NaHCO_3$ (pH 8.5) extraction method (Olsen et al. 1954) followed by colour development by ascorbic acid method (Murphy and Riley 1964), available potassium (SK) in soil was extracted by 1 *N* neutral NH_4OAc (Hanway and Hiedal 1964). Bouyoucos hydrometer method (Black 1965) was used for separation of sand, silt and clay and expressed in per cent.

Statistical analysis

Multiple regression approach is used to calculate the dose of nutrient to get the maximum yield of crops under given set of experimental conditions. This can further be used to calculate economic dose of fertilizer nutrients by incorporating a constant factor, i.e. per unit cost of produce divided by per unit cost of fertilizer. In this approach, yield is regressed with soil nutrients, fertilizer nutrients, their quadratic terms and the interaction term of soil and fertilizer nutrients as given below:

$$Y = A \pm b_1 SN \pm b_2 SN^2 \pm b_3 SP \pm b_4 + SP^2 \pm b_5 SK \pm b_6 SK^2 \pm b_7 FN \pm b_8 FN^2 \pm b_9 FP \pm b_{10} FP^2 \pm b_{11} FK \pm b_{12} FK^2 \pm b_{13} FNSN \pm b_{14} FPSP \pm b_{15} FKSK \;\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where, Y = crop yield (kg ha^{-1}); A= Intercept (kg ha^{-1}); b_i= Regression coefficients (kg ha^{-1}); SN, SP, SK= Available soil nitrogen, phosphorus and potassium (kg ha^{-1}) respectively; FN, FP, FK =Fertilizer nitrogen, phosphorus and potassium (kg ha^{-1}) respectively.

Nutrient requirement for maximum and economic yield

The ideal equation for the partial function of fertilizer nutrient is as follows-

$$y = a + bx - cx^2 – dxz \;\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

where, a = constant independent of x and z; b, c & d = regression coefficient of linear and quadratic terms of x; z = soil test values of nutrient in question; x = fertilizer doses (kg ha^{-1}).

On differentiating the equation (1), the following mathematical expression appears,

$$\frac{dy}{dx} = b - 2xc - dz \text{ .... (3)}$$

or, $0 = b - 2xc - dz$ (Since, $\frac{dy}{dx} = 0$ under condition of maximum yield) or, $x_{(max)} = \frac{b - dz}{2c}$ .... (4)

Where, $x_{(max)}$ = dose of fertilizer for maximum yield at soil test values z. Substituting the values b, c and d of regression equation, where response type '+ – –' was obtained on the need of fertilizer for maximum yield was calculated. For economic dose, consequence of 'law of diminishing return' is considered. Under such conditions where marginal return just equals the last rupee invested on fertilizer nutrient, that is output/input ratio become unity. Mathematically, it may be expressed as:

$p\Delta Y = q\Delta X$ or, $\frac{dy}{dx} = \frac{q}{p}$ .... (5)

Where, p = price of 1 kg of tuber in rupee, q = price of 1 kg of nutrient in rupee, y = yield in kg ha^{-1}. From the equations (3) and (5) it can be inferred as:

$b - 2cx - dz = q/p$

or, $x_{(eco)} = \frac{b - (q/p) - dz}{2c}$ ....(6)

By putting the value of b, c and d from the regression equation with (+ – –) response type, the economic dose was calculated at a particular level of ratio (q/p) and soil test value (z).

3. Results

Initial soil properties

Soil samples collected from several spots of the experimental field before sowing of potato were used to make composite soil samples, which were analyzed for various physico-chemical properties (Table 1). The experimental soil was sandy loam in texture having high organic carbon (0.80%) and available phosphorus (60.5 kg ha^{-1}), medium available potassium (170.2 kg ha^{-1}), while low in available nitrogen (138.7 kg ha^{-1}). Soil profile study at the experimental site was also conducted (Table 2). In the experimental site, slope was 1-3 per cent, drainage was moderately well, profile colour varied from yellowish brown to dark yellowish brown; soil texture was loam in A_p and E horizon, slightly gravely loam in B_1 and gravely sandy loam in B_2 and CB horizons where loamy sand in C horizon. Consistency varied from friable to loose in moist condition; soil structure was sub-angular blocky throughout the profile

Statistical verification for proper creation of fertility gradient

Statistical analysis was carried out by using the soil nutrients (SN, SP and SK) separately as dependent Statistical analysis was carried out by using the soil nutrients (SN, SP and SK) separately as dependent variable for each level of FYM as well as for whole plots (Table 3). The effect of the strips was found to be highly significant in all the cases by taking SN, SP and SK separately as dependent variable. This indicated that fertility gradient was created in respect of N, P and K, respectively at FYM at 0 t ha^{-1}, 10 t ha^{-1}, 20 t ha^{-1} and whole plots. Alkaline $KMnO_4$-N, Olsen's-P and neutral normal NH_4OAc-K content of soil increased in the order of strip I < strip II < strip III of the experimental site which represents that there was proper creation of fertility gradient.

Multiple regression of soil test values and fertilizer dose with potato tuber yield

Relationship between tuber yield as dependent variable and the soil test values, fertilizer doses, FYM doses, interactions between soil test values, fertilizer doses and among fertilizer nutrients as independent variables was established through multiple regression equations using the quadratic model. The following regression equations have been worked out by using the quadratic equation function on soil test values and fertilizer doses with potato tuber yield.

Multiple regression for all the treated plots

Y = 28.853 - 0.343 FN + 0.524 FP + 0.513 FK – 0.474 SN + 0.523 SP + 0.435 SK + 0.0007531 FN^2 – 0.000193 FP^2 – 0.002293 FK^{2}* + 0.003861 FNSN – 0.007046 FPSP – 0.0005357 FKSK (R^2 = 0.614**)................................... (7)

Multiple regression for FYM at 0 t ha^{-1}

Y = - 58.255 - 0.146 FN - 1.035 FP + 2.578 FK - 0.60177 SN - 0.456 SP + 1.437 SK + 0.00124 FN^2 + 0.00310 FP^2 – 0.00624 FK^2 + 0.00309 FNFP - 0.00523 FNFK + 0.00485 FPFK + 0.00314 FNSN – 0.00776 FPSP – 0.00602 FKSK (R^2 =0.611)................(8)

Multiple regression for FYM at 10 t ha^{-1}

Y = 38.754 - 0.0326 FN + 0.8374 FP + 0.06430 FK - 0.07661 SN -0.09963 SP + 0.27754 SK - 0.00069 FN^2 - 0.00336 FP^2 -0.00328 FK^2 + 0.00213 FNFP + 0.00464 FNFK - 0.00402 FPFK - 0.00150 FNSN + 0.00135 FPSP + 0.00164 FKSK (R^2 = 0.872*)..(9)

Multiple regression for FYM at 20 t ha^{-1}

Y = 173.96082 - 0.53829 FN + 0.08150 FP - 0.25930 FK - 0.80180 SN - 0.40233 SP + 0.13866 SK + 0.000569 FN^2 + 0.000148 FP^2 - 0.00000576 FK^2 - 0.00101 FNFP + 0.00164 FNFK - 0.00332 FPFK + 0.00580 FNSN + 0.00563 FPSP + 0.00199 FKSK (R^2 = 0.896*)... (10)

Table 1. Physicochemical properties of the soil of experimental site (0-15 cm. soil depth)

Property	Value obtained
Textural analysis	
Sand (%)	51.80
Silt (%)	33.75
Clay (%)	16.25
Textural class	Sandy loam
pH (1:2.5 soil water suspension)	6.55
Electrical conductivity (μSm^{-1})	79.7
Organic carbon (%)	0.80
Available nitrogen (kg N ha^{-1})	138.7
Available phosphorus (kg P ha^{-1})	60.5
Available potassium (kg K ha^{-1})	170.2

Table 2. Characteristics of the horizons at the experimental site

Horizon	Depth(cm)	Characteristics
A_p	0-27	Yellowish brown 10YR4/3 dry; loam; medium, moderate, subangular blocky structure; mottles nil; mollic epipedon, medium porosity, slightly hard, dry consistency, medium porosity, cutans, nodule and effervescence nil, abrupt-smooth boundary.
E	27-59	Brown 10YR5/3; dry; loam; medium, moderate, subangular blocky structure; mottles nil; friable consistency, medium porosity, medium roots, cutans, nodule and effervescence nil, clear-smooth boundary.
B_1	59-85	Light yellow brown 10YR6/4 dry; slightly gravely loam; medium, week, subangular blocky structure; mottles nil; friable consistency, coarse porosity, organic cutans, coarse roots, effervescence nil, abrupt-smooth boundary.
B_2	85-116	Yellowish brown 10YR5/6 dry; gravely sandy loam; medium, week, subangular blocky structure; friable consistency, coarse porosity, organic cutans, coarse roots, effervescence nil, clear -smooth boundary.
CB	116-131	Pale brown 10YR6/3 dry; gravely sandy loam; medium, week, subangular blocky structure; very friable consistency, coarse porosity, organic cutans, slight effervescence, clear -smooth boundary; mottles nil.
C	131+	Dark yellow brown 10YR4/4 dry; loamy sand; fine, week, subangular blocky structure; few, medium, distinct mottles; loose moist consistency, coarse porosity, organic cutans, strong effervescence, abrupt-smooth boundary.

Table 3. Statistics of soil test values of FYM level 0 t ha^{-1}, 10 t ha^{-1}, 20 t ha^{-1} and whole plots

FYM level	Dependent Variable	Prob. > F	R Square	Co-eff. of Variation	Mean
0 t ha^{-1}	SN	0.0223**	0.30	9.78	116.55
	SP	0.0002**	0.56	8.71	68.45
	SK	0.0002**	0.56	7.24	182.52
10 t ha^{-1}	SN	0.0013**	0.47	9.80	116.03
	SP	<0.0002**	0.55	15.17	62.52
	SK	0.0002**	0.45	9.06	170.86
20 t ha^{-1}	SN	0.0260**	0.29	12.16	114.47
	SP	<0.0001**	0.67	11.15	66.97
	SK	<0.0327*	0.28	10.56	164.13
Whole plots	SN	0.0008**	0.19	11.43	115.68
	SP	<0.0001**	0.55	12.23	65.98
	SK	<0.0001**	0.33	9.94	172.50

SN= Alkaline $KMnO_4$-N, SP= Olsen's-P, and SK= neutral normal NH_4OAc-K

Soil test value of potassium as ammonium acetate-K (kg ha^{-1}); FN= Fertilizer nitrogen (kg ha^{-1}); FP = Fertilizer phosphorus (kg ha^{-1}); FK = Fertilizer Potassium (kg ha^{-1}); PR (Price ratio) = q/p = price of 1 kg nutrient in question/price of 1 kg potato tuber.

From R^2 value described the extent of variations in potato tuber yield which can be explained by the variation in soil test values and fertilizer doses. Multiple regression equation enables fertilizer recommendation based on soil tests to calculate the maximum yield per hectare and maximum profit per hectare at varying input and output prices.

Fertilizer response type

The response types (Table 4) were observed from regression equation (Eqn. 7). The response type (+ - -) characterizes at a given soil test value, the yield increases upto a limit with increasing doses of fertilizer but above which there will be no increase but decrease in yield. These response types (+ - -) for the nutrients phosphorus and potassium followed law of diminishing return (Table 4). While the response type (- + +) observed for nitrogen, characterizes that there is positive and increasing response to applied fertilizer and negative correlation between soil and fertilizer nutrients (Table 4). If the soil test values are below 74.37 kg ha 1 as Olsen's P and 957.63 kg ha^{-1} as NH_4OAc-K for potassium, then positive response with increasing fertilizer doses may be expected. At and above the critical soil test values for given fertilizer dose, no response to fertilizer dose may be expected with respect to variety Kufri Jyoti of potato in Mollisol.

Response to a nutrient at middle doses of other nutrients had been worked out (Table 5, 6, 7). Yield of potato tuber (q ha^{-1}) at different doses of nitrogen and FYM with constant level of P and K (middle or recommended) were taken and then averaged (Table 5). The response of 100, 150 and 200 kg of nitrogen application over control were found to be 0.396, 0.395, and 0.387 q ha^{-1} in terms of potato tuber, respectively. These results showed constancy in tuber yield over increasing application of nitrogen. Considering over successive doses, for 0 to 100 kg i.e. increment of 100 kg N resulted in increasing of yield to the extent of 36.5 q ha^{-1}. So the increment was 0.365 q ha^{-1} potato tubers per kg of N application in this range. Similarly, for 100 to 150 kg i.e. increment of 50 kg N resulted in increasing of yield to the amount of 22.8 q ha^{-1}. So, the increment was 0.456 q ha^{-1} potato tubers per kg of N application in this range. Increment of potato tuber yield was 0.362 q ha^{-1} potato tubers per kg of N application for 150 to 200 kg range. Increment of N application from 100 to 150 kg, hence, showed highest response at the middle doses of P and K. Yield of potato tuber (q ha^{-1}) at different doses of phosphorus and FYM with constant level of N and K (middle or recommended) were taken and then averaged (Table 7).

Table 4. Response type and critical limit for soil test value obtained by regression equation of treated plots

R^2 value	Nutrient	Response type	Critical soil test value
0.614**	Nitrogen	- + +	88.84 kg ha^{-1} (Min.)
	Phosphorus	+ - -	74.37 kg ha^{-1} (Max.)
	Potassium	+ - -	957.63 kg ha^{-1} (Max.)

Table 5. Response to N at middle doses of P and K (kg ha^{-1}) (N_{100} P_{100} K_{100})

	OM_0	OM_{10}	OM_{20}	Average	Over N_0	Over Successive Doses
N_0	106.5	72.4	74.9	84.6	-	-
N_{100}	99.3	139.8	124.1	121.1	0.365	0.365
N_{150}	152.1	144.3	135.3	143.9	0.395	0.456
N_{200}	153.1	154.2	178.7	162.0	0.387	0.362
Average	127.8	127.7	128.2	127.9	-	-

Table 6. Response to P at middle doses of N and K (kg ha^{-1}) (N_{150} P_{50} K_{100})

	OM_0	OM_{10}	OM_{20}	Average	Over P_0	Over Successive Doses
P_0	106.5	72.4	74.9	84.6	-	-
P_{50}	147.1	149.4	142.5	146.4	1.235	1.235
P_{100}	152.1	144.3	135.3	143.9	0.593	-0.049
P_{150}	166.4	165.0	156.5	162.6	0.520	0.375
Average	143.0	132.8	127.3	134.4	-	-

Fertilizer nutrients (i.e. phosphorus and potassium) which showed (+ - -) type of response were further used for maximum yield ha^{-1} and maximum profit ha^{-1} or economic yield calculation. As the three co-efficient of liner, quadratic and interaction terms are also required to be significant at 5 per cent level of significance, for deriving optimum fertilizer dose, which was not found in the present study. Optimum fertilizer dose, therefore, was not worked out further. The usual response type (+ – –) for linear, quadratic and interaction term was found with phosphorus and potassium. Adjustment equations for maximum and economic yield have been worked out for the same as follows:

$FP_{(max)}$ = 1357.5 – 18.254 SP ………………... (12)

$FP_{(eco)}$ = 1357.5 – 2590.67 PR - 18.254 SP…….. (13)

$FK_{(max)}$ = 112.00 – 0.1169 SK …………………(14)

$FK_{(eco)}$ = 112.00 – 218.34 PR - 0.1169 SK ………(15)

where, SP = Soil test value of phosphorus as Olsen's P (kg ha^{-1}); SK = Soil test value of potassium as Am. Ac.-K (kg ha^{-1}); FP = Fertilizer phosphorus (kg ha^{-1}); FK = Fertilizer

The response of 50, 100 and 150 kg of phosphorus application over control was found to be 1.235, 0.593, and 0.520 q ha^{-1} in terms of potato tuber, respectively.

First it increased at 0 to 50 kg P application and then decreased, fitting well with the law of diminishing return. Considering over successive doses, for 0 to 50 kg i.e. increment of 50 kg P resulted in increasing of yield to the amount of 61.8 q ha^{-1}. So the increment was 1.235 q ha^{-1} potato tubers per kg of P application in this range. Similarly for 50 to 100 kg i.e. increment of 50 kg P resulted in increasing of yield to the amount of -2.5 q ha^{-1}. So the increment was -0.049 q ha^{-1} potato tubers per kg of P application in this range. Increment of potato tuber yield was 0.375 q ha^{-1} potato tubers per kg of P application for 100 to 150 kg range. Hence increment of P application from 0 to 50 kg showed highest response at middle doses of N and K. Yield of potato tuber (q ha^{-1}) at different doses of potassium and FYM with constant level of N and P (middle or recommended) were taken and then averaged (Table 8). The response of 50, 100 and 150 kg of potassium application over control was found to be 0.804, 0.593, and 0.301 q ha^{-1}, respectively. First it was increasing at 0 to 50 kg K application and then decreasing. Considering over the successive doses, for 0 to 50 kg *i.e.* increment of 50 kg K resulted in increasing of yield to the amount of 40.2 q ha^{-1}. So the increment was 0.804 q ha^{-1} potato tubers per kg of K application in this range. Similarly for

Table 6. Response to P at middle doses of N and K (kg ha^{-1}) (N_{150} P_{50} K_{100})

	OM_0	OM_{10}	OM_{20}	Average	Over P_0	Over Successive Doses
P_0	106.5	72.4	74.9	84.6	-	-
P_{50}	147.1	149.4	142.5	146.4	1.235	1.235
P_{100}	152.1	144.3	135.3	143.9	0.593	-0.049
P_{150}	166.4	165.0	156.5	162.6	0.520	0.375
Average	143.0	132.8	127.3	134.4	-	-

Table 7. Response to K at middle doses of N and P (kg ha^{-1}) (N_{150} P_{100} K_{50})

	OM_0	OM_{10}	OM_{20}	Average	Over K_0	Over Successive Doses
K_0	106.5	72.4	74.9	84.6	-	-
K_{50}	132.1	110.3	131.9	124.8	0.804	0.804
K_{100}	152.1	144.3	135.3	143.9	0.593	0.382
K_{150}	103.1	133.2	153.1	129.8	0.301	-0.282
Average	123.4	115.1	123.8	120.8	-	-

Table 8. Correlation between potato tuber yield and nutrients treatments

	TY	FN	FP	FK	FYM	SN	SP	SK	OC
TY	1.000	0.702**	0.481**	0.476**	NS	NS	NS	0.202*	NS
FN		1.000	0.556**	0.556**	0.000	-0.197*	NS	NS	NS
FP			1.000	0.529**	0.000	NS	NS	NS	NS
FK				1.000	0.000	NS	NS	NS	NS
FYM					1.000	NS	NS	-0.361**	-0.282*
SN						1.000	0.312**	0.422**	0.250*
SP							1.000	0.395**	0.387**
SK								1.000	0.343**
OC									1.000

Sig. (1-tailed); *Significant at 5% level; **Significant at 1% level

Similarly for 50 to 100 kg i.e. increment of 50 kg K resulted in increasing of yield to the amount of 19.1 q ha^{-1}. So the increment was 0.382 q ha^{-1} potato tubers per kg of K application in this range. Increment of potato tuber yield was -0.282 q ha^{-1} potato tuber per kg of K application for 100 to 150 kg range. Increment of K application from 0 to 50 kg, therefore, showed highest response at middle doses of N and P.

Correlation studies

Correlation between tuber yield and nutrients applied through fertilizers, FYM and soil was studied (Table 8).

In the present investigation, strip wise creation of fertility gradient was proper and this is in line of the finding by Mahajan et al. (2013) in wheat grown in alluvial soil. Generally at a given soil test value the yield will increase up to a limit with increasing dose of fertilizer and beyond which the yield will not increase but decrease, following the 'Law of diminishing return'. The fertilizer dose, at which maximum yield increase occurs, decreases with increasing soil test value of the nutrient in question. In a quadratic type response curve, this happens only when the linear term is positive for any fertilizer nutrient and quadratic and interaction terms are negative (+ - -). Eight different types of responses are possible that is there are eight ways in which the algebraic symbols (+) and (-) of the linear, quadratic and interaction terms of regression co-efficient could be arranged (ICAR 1970). Only in (+ - -) type of response situation, site specific optimum fertilizer dose of nutrient can be derived by differentiation provided that the three coefficient are significant at least at 5 per cent level of significance. In case of nitrogen, the ideal response type (+ – –) has not been obtained, therefore, adjustment equations for maximum and economic yield could not be worked out. The critical dose of P and K was observed as 74.37 kg ha^{-1} as Olsen's P and 957.63 kg ha^{-1} as NH_4OAc-K. Very high response in case of potassium indicates the requirement of this nutrient in potato tuber development. High utilization efficiency of absorbed K From native soil source indicated the desirability for maintenance of fertilization for soil K status (Singh and Marwaha 1996). Likewise in foothills, the luxurious vegetative growth of the crop during tuber bulking phase on account of onset of monsoon put more demand on K supply from fertilizer and soil pool. Moreover, the response to K also depends upon the soil organic matter. The response to applied K had been found to increase with increase in organic matter status of the soils. Since the soil contained high amount (0.8%) of organic carbon, more response can be expected. Deka and Dutta (1999) also found that tuber yield increased with increasing N and K rate, and the fertilizers also increased the net profit and net production value. .

Increment of N application from 100 to 150 kg ha^{-1}, hence, showed highest response at the middle doses of P and K. Application of nitrogen increased the tuber number and size of large grade tubers in all the cultivars and thus increased yield (Trehan 2003). Sarkar et al. (2007) showed that application of 180:150:150 kg N, P_2O_5, K_2O ha^{-1} (150% recommended dose of fertilizers) in India significantly increased the tuber yield of potato when it was used along with organic manure.Tuber yield was positively and significantly correlated with applied fertilizer nutrient (0.702** with FN, 0.481^{**} with FP and 0.476^{**} with FK) and with soil test value of potassium (0.202^{*}).

4. Discussion

On the basis of soil profile study, the soil of the experimental site was classified as Mollisol. More precisely, the soil was classified as aquic Hapludoll in subgroup level (Despande et al. 1971). Increment of P application from 0 to 50 kg showed highest response at middle doses of N and K. On contrary, research finding showed that potato and high value vegetable crops have shown responses to higher P levels (Kellig and Speth 1997). Increment of K application from 0 to 50 kg, therefore, showed highest response at middle doses of N and P. In a study, Kumar et al. (2001) found that three cultivar *viz. Kufri Jyoti, Kufri Ashoka, Kufri Sindhuri* responded to 150% of currently recommended dose of fertilizers and hence required 240 kg N, 90 kg P_2O_5, and 180 kg K_2O ha^{-1}. Tuber yield was positively and significantly correlated with applied fertilizer nutrient and with soil test value of potassium. Similarly, Chettri et al. (2002) observed, potassium content in potato plant was positively correlated with tuber yield and application of potassium increased potassium content of potato plant.

Conclusion

The tendency of the farmers in developing countries is to use imbalance and inappropriate dose of fertilizer by overlooking the return per unit investment of fertilizer. These findings can successfully be used in the larger parts of Mollisol dominating areas as an effective guide of fertilizer application, because this is economically viable and suitable for the situation of resource constraint situation like in India and other countries having similar soil type.

References

Black CA (1965). Methods of soil chemical analysis. Part-1 and 2. Agronomy series. American Society of Agronomy, Madison, Wisconsin, USA.

Bower CA and LA Wilcox (1965). Soluble salts. In: Black CA (Ed.), Methods of Soil Analysis, Part-1, chemical and microbiological properties, American Society of Agronomy, Madison, Wisconsin 62: 933-951

Chatterjee D, Srivastava A and RK Singh (2010). Fertilizer recommendations based on targeted yield concept involving integrated nutrient management for potato (*Solanum tuberosum*) in tarai belt of Uttarakhand. Indian J Agric Sci 80: 1048-1053.

Chettri M, Mondal SS and B Roy (2002). Influence of potassium and sulphur with or without FYM on growth, productivity and disease index of potato in soils of West Bengal. J. Indian Potato Assoc 29: 61-65.

Deka NC and TC Dutta (1999) Response of potato (*Solanum tuberosum* L.) to nitrogen and potassium in acidic soil of Assam. Adv Plant Sci 12: 515-520.

Despande SB, Ferenbacher JB, Beavers AH, and BW Ray (1971). Mollisols of *tarai* region of Uttar Pradesh, Northern India. II Genesis and Classification. Geoderma 6: 195-201.

Hanway JJ and H Hiedal (1952). Soil analysis method used in Iowa State Soil Testing Laboratory. Iowa Agric. 57, 1-31. In: Black CA (Ed.), Methods of Soil Analysis, part 2, American Society of Agronomy, Madison, Wisconsin: 1025-1027.

ICAR (1970). Coordinator's Progress report. All India Scheme for Investigation on Soil Test Crop Response Correlation.

Jackson ML (1958). Soil chemical analysis. Prentice Hall. Inc. Englehood cliffs, N.J., USA

Reshi M, Bhat A, Kaul RK and M Gupta (2013). Evaluation of various potato cultivars of Jammu region for processing attributes. Bioscan 8: 1203-1205.

Rhue RD, Hensel DR and G Kidder (1986). Effect of K fertilization on yield and leaf nutrient concentrations of potatoes grown on a sandy soil. American Potato J 63: 665-681.

Sarker B, Mondal SS, Nayek SS and MS Saha (2007). Integrated nutrient management for the productivity and quality improvement of potato under irrigated condition. Potato J 34: 99-100.

Sasani GV, Patel CK, Patel RN and NH Patel (2003). Effect of levels of inorganic fertilizer with and without organic manure on yield of potato in North Gujarat. J Indian Potato Assoc 30: 77–78.

Saxena AK, Singh S, Srivastava A and P Gautam (2008). Yield target approach under integrated nutrient management for assessing fertilizer requirements of onion in Mollisols of Uttarakhand. Indian J Hort 65: 302–306

Singh JP, Marwaha RS and JS Grewal (1996). Effect of sources and levels of K on potato yield, quality and storage behavior. J Indian Potato Assoc 23: 153-156.

Singh NP and M Raghav (2000). Response of potato to nitrogen and potassium fertilization under U.P. *tarai* conditions. J Indian Potato Assoc 27: 47-48.

Singh SP and VS Kushwah (2006). Effect of integrated use of organic and inorganic sources of nutrients on potato (*Solanum tuberosum*) production. Indian J Agron 51: 236–238.

Subbiah BV and GL Asija (1956). A rapid procedure for estimating of available nitrogen in soil. Curr Sci 31: 196-200.

Kelling KA and PE Speth (1997). Influence of phosphorus rate and timing on Wisconsin potatoes. Proc Annual Wisconsin Potato Meetings 10: 68-79.

Kumar D, Praharaj CS, Sharma RC and SMP Khurana (2001). Response of potato varieties in Indo-Gangetic plains of Bihar. J Indian Potato Assoc 28: 56-57.

Kumar M, Baishya LK, Ghosh DC, Ghosh M, Gupta VK and MR Verma (2013). Effects of organic manures, chemical fertilizers and biofertilizers on growth and productivity of rainfed potato in the eastern Himalayas. J Plant Nutr 36: 1065–1082.

Lokendrajit N, Singh CB, Swapana N and MS Singh (2013). Evaluation of nutritional value of two local potato cultivars (Aberchaibi and Amubi) of Manipur, Northeast India. Bioscan 8: 589-593.

Mahajan GR, Pandey RN, Datta SC, Kumar D, Sahoo RN and Parsad R 2013. Soil test based fertilizer recommendation of nitrogen, phosphorus and sulphur in wheat (*Triticum aestivum* L.) in an alluvial soil. Int J Agric Environ Biotechnol 6: 271-281.

Murphy J and JP Riley (1962). A modified single method for determination of phosphates in natural waters. Anal Chem Acta 27: 31-36.

Olsen SR, Cole CV, Watanabe FS and LA Dean (1954). Estimation of available phosphorus in soils by extraction with sodium bicarbonate. USDA Circ.939, Washington DC, USA.

Pandey SK, Singh SV and D Sarkar (2005). Potato (*Solanum tuberosum*) for sustaining food and nutrition security in developing world. Indian J Agric Sci 75: 3-18.

Ramamoorthy B, Narasimham RL and RS Dinesh (1967). Fertilizer application for specific yield targets of Sonora 64. Indian Farming 17: 43-44.

Sud KC and RC Shama RC (2001). Effect of crop residue on phosphorus availability to potato in acid soil. J Indian Potato Assoc 28: 46-47

Trehan SP (2003). Evaluation of N efficiency of different potato cultivars. J Indian Potato Assoc 30: 63-64.

Truog E (1960). Fifty years of soil testing. Transactions of Seventh Int Congress Soil Sci, 3, Commission IV, Paper No. 7: 46–53.

Walkley A and IA Black (1934). An examination of degtjareff method for determining soil organic and a proved modification of chromic acid titration method. Soil Sci 37: 29-38.