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Review/Overview

Evaluation of potato (*Solanum tuberosum*) cultivars for productivity, nitrogen requirement and eco-friendly indices under different nitrogen levels

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ABSTRACT

A field experiment was conducted during the winter (*rabi*) seasons of 2011–12 and 2012–13 at Adisaptagram Block Seed Farm, Hooghly, West Bengal, to optimize the potato (*Solanum tuberosum* L.) cultivars and nitrogen levels for growth attributes, tuber yield, nitrogen-use efficiency, sustainability, eco-friendliness and economics in new alluvial zone of West Bengal. Fifteen treatment combinations, viz. 3 potato cultivars ('Kufri Himalini', 'Kufri Shailja' and 'Kufri Jyoti') and 5 N doses (0, 75, 150, 225 and 300 kg N/ha) were laid out in a factorial randomized block design with 4 replications. 'Kufri Himalini' recorded the maximum tuber yield (31.3 t/ha), which was significantly higher than 'Kufri Shailja' (26.6 t/ha) and 'Kufri Jyoti' (24.1 t/ha). Correlation between tuber yield and plant height (R^2=0.73), tuber yield and dry matter accumulation (R^2=0.84), tuber yield and tuber bulking rate (R^2=0.75) and tuber yield and total N uptake (R^2=0.62) were significant. The correlation study between nitrogen and tuber yield showed high degree of correlation (R^2=0.984) and $N_{opt.}$ was derived as 202.6 kg N/ha for optimum economic yield. Agronomic efficiency (AE_N) and physiological efficiency (PE_N) was more in 'Kufri Himalini' at all N levels. There was a positive balance of nitrogen in all the treatments except one treatment ('Kufri Jyoti' with 300 kg N/ha). 'Kufri Himalini' fertilized with 300 kg N/ha gave the highest net returns (₹1,45,156/ha) and benefit: cost ratio (2.58) with least difference from 225 kg N/ha, while the negative response was recorded in the control. 'Kufri Shailja' potato was more eco-friendly, as its index was 18.4% higher than 'Kufri Jyoti'. 'Kufri Shailja' required 18.4% less application of fertilizer N to give the highest yield obtained by 'Kufri Jyoti' (30.94 t/ha). So, for obtaining a given yield, less amount of fertilizer is being put to soil and hence comparatively less amount of N is being lost to the environment.

Key words : Correlation study, Eco-friendly indices, Economics, N balance, N-use efficiency, Potato, Tuber yield, Sustainability

West Bengal is the second largest potato-growing state in the country with a production of 13.4 thousand tonnes from 408.8 thousand hectares, while the productivity was 23.8 t/ha during 2010-11 (Directorate of Agriculture, WB, 2012). The state accounts for one-third of the country's total potato production. The fundamental setbacks in cultivation of potato in this area are lack of quality seed, new cultivar and appropriate doses of fertilizers. This situation can be overcome by using improved potato cultivars having better yield potential and also adopting proper nutrient management practices. The new potato hybrids two cultivars 'Kufri Himalini' and 'Kufri Shailja', having higher yield potential than existing popular variety of the region 'Kufri Jyoti', may provide stability to potato cultivation where late blight disease is a recurring feature. Potato crop being highly exhaustive and responsive, and having high rate of production per unit area and time, requires higher amount of nutrients especially nitrogen (N) on per day basis. On an average, a 90 days potato crop producing 20 tonnes tubers per hectare requires about 100 kg nitrogen to be removed in the form of tuber and haulm (above ground biomass). Nitrogen uptake on per day basis is sometime even more than 1.5 kg/ha during active growth period (Kumar and Trehan, 2012). Nitrogen plays a key role in crop growth and development resulting in increased size and number of tubers ultimately enhancing total yield (Kumar *et al.*, 2007). In addition, under- or oversupply of N may affect total number of tubers. Moreover, maintaining an adequate supply of N in the root zone of potato without leaching is important for optimal production of marketable quality tubers. On the contrary, excessive application leads to delayed maturity, poor tuber quality and occasional reduction in tuber yield (Alva, 2004). Agronomic research on macro-nutrient management aspect

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showed that some newly released potato cultivars for processing requires approximately 150% higher nitrogen and potassium over current table-purpose potato cultivars. Recent diagnostic survey also indicates that in many intensively cultivated areas, farmers have resorted to use of greater than the recommended dose of fertilizer (RDF), particularly N to maintain crop productivity. One approach to reduce N losses may be to increase the efficiency of N utilization by précising the N rate depending upon the cultivar used. Potato cultivars differ in their growth behaviour and yield potential, and therefore, it is important to evaluate each genotype for its attributes. Keeping this in view, the present study was planned to optimize the potato cultivars and nitrogen levels for growth attributes, higher tuber yield, nitrogen-use efficiency, sustainability, eco-friendliness and economics in new alluvial zone of West Bengal.

MATERIALS AND METHODS

A field experiment was conducted during the winter (*rabi*) seasons of 2011–12 and 2012–13 at Adisaptagram Block Seed Farm, Hooghly, West Bengal. The experimental site situated at 23°26'N and 88°22'E with altitude of 12.0 m above mean sea-level. The soil was loamy, slightly acidic (pH 6.34), medium in organic carbon (0.60%), low in available N (183.3 kg/ha), medium in available P (24.1 kg/ha) and high in available K (614.03 kg/ha). The seasonal mean temperature ranged between 20.0 and 36.3°C (Max.) and 6.9 and 21.6°C (Min.). While seasonal mean relative humidity ranged from 88.3 to 98.7% (Max.) and from 31.6 to 88.9% (Min.). Total average rainfall of 46.2 and 49.5 mm were sparsely distributed over November to March during both the seasons. Fifteen treatment combinations, viz. 3 potato cultivars ('Kufri Himalini', 'Kufri Shailja' and 'Kufri Jyoti') and 5 N doses (0, 75, 150, 225 and 300 kg N/ha) were laid out in a factorial randomized block design with 4 replications. Phosphorus and potassium were applied at a uniform rate of 150 kg/ha in all plots (plot size was 5 m × 3 m). Tubers weighing 30–40 g each were planted in the furrows spaced at 60 cm × 20 cm with a depth of 3–4 cm, and finally covered with soil. The crop was planted in the last week of November in both the seasons. Half of nitrogen (as per treatment) and full doses of phosphorus and potassium were broadcast as basal. Remaining N was top-dressed at 30 days after planting (DAP) followed by earthing up. Urea, single super phosphate and muriate of potash were used as source of N, P and K respectively. Pre-emergence application of Sencor (Metribuzin) @ 0.75 kg a.i./ha was done at 3 DAP followed by 1 hand-weeding at 20 DAP to promote early crop growth. As a prophylactic measure spraying (twice) with Dithane M-45 (Mancozeb) @ 2.5 kg/ha at 40 and 60 DAP was done against late blight. Metasystox 25 EC (Oxydemeton-methyl) @ 1% was also sprayed (twice) at 45 and 65 DAP for controlling aphids and other insects. Haulms were cut in the last week of February in both the seasons after the crop attained maturity. Harvesting was done 12–15 days after haulm cutting, and the crop lines were opened with the help of plough. Potato tubers were dug from each plot manually. In each plot, 3rd and 5th row were marked for destructive sampling and for recording biometric observations. The middle row was kept for the determination of yield.

Nitrogen efficiency was calculated using following formulae cited by Singh and Singh (2012).

$$\text{Agronomic efficiency of N } (AE_N) = \frac{Y_N - Y_C}{N_a}$$

$$\text{Apparent recovery of N } (RE_N) = \frac{U_N - U_C}{N_a}$$

$$\text{Physiological efficiency of N } (PE_N) = \frac{Y_N - Y_C}{U_N - U_C}$$

where, Y and U refer to yield of potato and N uptake by potato and subsequently N and C refer to nitrogen fertilized and control plots respectively. All values are in kg/ha.

Estimation of nutrient-use efficiencies followed the framework described by Cassman *et al.* (1998). Sustainable yield index (SYI) is the ratio of minimum assured seed yield to maximum observed yield and mathematically described as:

$$SYI = (Y_a - \sigma)/Y_m$$

where, Y_a is mean yield, σ is the standard deviation of yield, and Y_m is the maximum yield obtained under a set of management practices. The influence of nutrient on tuber yield is quantified through partial factor productivity (PFP). It is a ratio of tuber yield to applied nutrient and estimated as an index to efficiency of individual input.

Soil and plant samples were analysed for available and total N following standard procedures. The economic parameters (cost of cultivation, gross returns, net returns and benefit: cost ratio) were worked on the basis of prevailing market prices of inputs and outputs. The data on growth and yield-related characters of the tested crop, nutrient (N, P and K) uptake in plants and available nutrient (N, P and K) status of post-harvest soil were subjected to analysis of variance (ANOVA) technique. Significance (P£0.05) was tested using the Windows-based SPSS software (ver 10.0, SPSS Inc 1996).

Technique for selecting low N requirement cultivars and eco-friendly rating

Govindakrishnan *et al.* (1999) proposed a modified technique for selecting low N requiring cultivars with their eco-friendliness, and consists of the following steps:

(i) Fit the following quadratic responses model to tuber yield data and carried out the usual F-tests of significance by comparing the corresponding regression mean squares and deviation from regression mean squares as well as the later with the error mean square by appropriate F-tests, etc.

$$y = a + bN + cN^2$$

(ii) Worked out the economic optima for cultivars which revealed significant quadratic regression by using the formula:

$$N_{opt}\text{ (kg/ha)} = (q/p\text{-}b)/2c$$

(iii) Determined the nitrogen dose (kg/ha) for achieving the maximum yield of the standard cultivar (Kufri Jyoti) which will be referred to as fixed yield target (F) henceforth. The relevant formulae are:

For standard variety (Kufri Jyoti) only

$$N_{max} = -(b/2c)$$

$$F = a + b\,N_{max} + c\,(N_{max})^2$$

(iv) Determined the N dose for each cultivar for achieving fixed yield target F, by using the formula:

$$\text{N dose (kg/ha)} = \frac{-b \pm \sqrt{b^2 - 4c\,(a-F)}}{2c}$$

(v) Two types of eco-friendly indices are suggested, one index was based on the efficiency of nitrogen utilization of cultivars irrespective of source (soil or fertilizer) and other index was based on omitting the nitrogen application relative to that of standard cultivar ('Kufri Jyoti') and is described:

(a) Relative eco-friendly indices for a cultivar was computed by:

$$\lambda\ (relative) = \frac{(\text{N max} - \text{N dose}) \times 100}{\text{N max}}$$

(b) Absolute eco-friendly indices for a cultivar g was computed by

λ (absolute) = Dose of nitrogen (kg/ha) required for getting yield in a standard cultivar ('Kufri Jyoti') equal to the yield of genotype 'g' without nitrogen application and was calculated as:

$$= \frac{-b \pm \sqrt{b^2 - 4c\,(a-\alpha\alpha)}}{2c}$$

where a, b and c are the regression co-efficient of the quadratic equation, q is price per kg of nitrogen and p is price per kg of tubers, N_{max} (kg/ha) for maximum yield in standard cultivar 'Kufri Jyoti', N_{dose} (kg/ha) for cultivars leading to yield, equivalent to that of maximum yield of the standard cultivar. It is expressed in percentage and α = 'a' of the cultivar under test. Unit of λg (absolute) is in kg/ha.

RESULTS AND DISCUSSION

Growth attributes

The growth attributes of improved potato cultivars were significantly influenced by different N levels (Table 1). 'Kufri Shailja' recorded significantly taller plants than 'Kufri Himalini' and 'Kufri Jyoti'. Plant height increased with the increase in levels of N from 0 to 300 kg/ha and N at higher dose (300 kg/ha) recorded significantly highest average plant height at 70 days after planting (DAP), accounting 50.8% more over the control. Kumar *et al.* (2008) suggested that high dose of nitrogenous fertilizer seems to favour better uptake of N by haulm, resulting in bigger canopy for heavily fertilized crop. Production of branches/plant was almost similar for both 'Kufri Shailja' and 'Kufri Jyoti', while for 'Kufri Himalini' it was significantly less at 90 DAP. Trend showed that production of new shoots was increased with the increase in level of N from 0 to 225 kg/ha, thereafter it declined. At 90 DAP, average number of shoots/plant was higher with 225 kg N/ha (41.89% more over the control), which was statistically at par with 150 and 300 kg N/ha. Increase in compound leaf production was noticed with the increment in N level from 0 to 300 kg/ha, but difference in compound leaf production with $N_{150,}$ N_{225} and N_{300} (N @ 150, 225 and 300 kg/ha) was non-significant. Application of N @ 300 kg/ha produced the maximum number of compound leaves (64.66% over the control) closely followed by 150 (58.76% over the control) and 225 kg N/ha (56.03% over the control).

As compared to 'Kufri Jyoti', maximum dry matter (haulm + tuber) was produced by both the new cultivars, 'Kufri Shailja' (22.32 and 26.22% higher than 'Kufri Jyoti', respectively) and 'Kufri Himalini' (19.83 and 19.71% higher than 'Kufri Jyoti' respectively), though the difference was non-significant. Total dry matter at harvest increased significantly with increase in N dose from 0 to 225 kg N/ha. This might be due to better nitrogen acquirement by adding N in the soil (Majic *et al.,* 2007). Data also showed that further increase in N dose (300 kg N/ha) showed declining trend for dry-matter (DM) accumulation, but statistically at par with 225 and 150 kg N/ha. This might be due to the fact that plant vigour and yield of bigger size tuber (> 75g) were more for all tested cultivars up to 225 kg N/ha. On the other hand, the control plants had low dry-matter (DM) accumulation. Nitrogen deficiency decreased leaf area and chlorophyll content, resulting in lower DM accumulation (Zhao *et al.,* 2005). All the 3 cultivars showed no significant variation in leaf-area index (LAI) at 50 DAP, but variation was significant with varied

Table 1. Growth attributes of potato as influence by potato cultivars and N levels (pooled data of 2 years)

Nitrogen (kg/ha)	Plant height (cm) at 70 DAP				Branches/plant at 90 DAP				Compound leaves/plant at 70 DAP			
	'Kufri Himalini'	'Kufri Shailja'	'Kufri Jyoti'	Mean	'Kufri Himalini'	'Kufri Shailja'	'Kufri Jyoti'	Mean	'Kufri Himalini'	'Kufri Shailja'	'Kufri Jyoti'	Mean
N_0	43.8	47.5	45.5	45.6	1.50	2.50	2.25	2.08	28.0	27.0	20.0	25.0
N_{75}	62.3	65.0	63.5	63.6	2.50	3.50	2.00	2.67	40.8	30.3	46.3	39.9
N_{150}	75.5	90.5	70.3	78.7	2.50	4.25	3.50	3.42	44.0	73.8	54.5	57.4
N_{225}	74.8	99.3	70.0	81.3	2.75	3.50	4.50	3.58	44.8	58.8	58.0	53.8
N_{300}	89.0	109.0	79.8	92.6	3.50	2.75	4.25	3.50	66.5	64.5	60.0	63.7
Mean	69.1	82.3	65.8		2.55	3.30	3.30		44.8	50.9	47.75	
	Cultivar	Nitrogen	Cultivar × nitrogen		Cultivar	Nitrogen	Cultivar × nitrogen		Cultivar	Nitrogen	Cultivar × nitrogen	
SEm±	1.9	2.5	4.3	0.23	0.29	0.51	3.4	4.4	7.6			
CD P=0.05)	5.5	7.1	12.2	0.65	0.84	NS	NS	12.6	NS			
	Total DMP (g/m^2) at harvesting				Leaf area index at 50 DAP				CGR (g/m^2/day) at 50–70 DAP			
N_0	270.9	419.4	435.6	375.1	0.31	0.21	0.49	0.34	0.50	0.95	0.73	0.73
N_{75}	1028.2	1258.6	451.3	912.7	0.64	0.78	0.65	0.69	1.04	2.90	1.25	1.73
N_{150}	1256.1	1425.0	997.2	1226.1	0.71	1.24	0.86	0.94	2.18	6.15	3.54	3.96
N_{225}	1235.5	1467.4	1110.1	1271.0	0.85	0.78	0.87	0.83	3.14	5.53	3.02	3.90
N_{300}	1358.4	1032.7	1139.2	1176.8	1.08	0.92	0.99	1.00	4.80	4.80	3.96	4.52
Mean	1029.7	1120.6	826.66		0.72	0.78	0.77		2.33	4.06	2.49	
	Cultivar	Nitrogen	Cultivar × nitrogen		Cultivar	Nitrogen	Cultivar × nitrogen		Cultivar	Nitrogen	Cultivar × nitrogen	
SEm±	84.9	109.6	189.7	0.07	0.10	0.16	0.71	0.92	1.59			
CD (P=0.05)	NS	312.68	NS	NS	0.27	NS	NS	2.62	NS			

DAP, Day after planting; DMP, Dry matter production; CGR, Crop-growth rate

level of N which suggested that canopy of all three cultivars was almost same. Nitrogen nutrition showed positive effect on leaf area index (LAI) and increasing trend with the increase of N level from 0 to 150 kg/ha. Further increase up to 300 kg N/ha although increased the LAI but the increase was non-significant. This again proved the assumption that excessive N application might cause more leaf production and delay maturity of the crop. Crop-growth rate (CGR) for all the cultivars reached at peak level during 50–70 DAP, beyond that it showed a declining trend towards maturity. Difference in CGR of cultivars was non-significant, although higher rate of growth was observed in 'Kufri Shailja' followed by 'Kufri Jyoti' and 'Kufri Himalini'. In contrary, N dose exhibited significant effect on CGR, and it was increased at an increasing rate up to 300 kg N/ha. The control plants grew at slower rate than the fertilized plants. Higher mean CGR (83.84% over the control) was exhibited by the plants with 300 kg N/ha closely followed by 225 and 150 kg N/ha, which were statistically at par.

Yield and yield attributes

Total number and yield of tubers were significantly influenced by the potato cultivars and N levels (Table 2). 'Kufri Shailja' recorded the maximum number of tubers, whereas 'Kufri Jyoti' the minimum. On the other hand, tuber number increased with the increase in level of N from 0 to 225 kg N/ha. Further increase in N level (300 kg N/ha) resulted in 3.09% reduction from that of 225 kg N/ha. Both 'Kufri Himalini' and 'Kufri Shailja' out yielded 'Kufri Jyoti'. The cultivar, 'Kufri Himalini' recorded the maximum tuber yield which was significantly higher than 'Kufri Shailja' (26.6 kg/ha) and 'Kufri Jyoti' (24.1 t/ha). It produced 15.17% and 23.08% higher yield than 'Kufri Shailja' and 'Kufri Jyoti' respectively. Higher tuber yield of 'Kufri Himalini' and 'Kufri Shailja' might be owing to higher LAI acted over the tuber bulking period resulting in increased dry-matter accumulation and greater tuber bulking rate (TBR). In general, the tuber yield increased with the increase in N dose up to 225 kg N/ha (65.2% increased over the control) and thereafter declined following the principles of 'law of diminishing return'. Minimum total tuber yield was recorded in the control. Getting more tuber yield with increasing fertilizer dose was also supported by Sarkar *et al*. (2011) and observed 2.8% increase in tuber yield with 150% recommended dose of fertilizer (RDF) over 100%. Response to higher fertilization may be linked to the increase in total leaf area which in turn increased the amount of solar radiation intercepted, and more photo-assimilate might have been produced and assimilated to the tubers (Baishya *et al.,* 2013). The higher yield of 'Kufri Himalini' can be well explained with TBR and the data revealed that 'Kufri Himalini' recorded significantly greater TBR at early stage of tuber development

Table 2. Total tuber number, tuber yield and tuber bulking rate (TBR) of potato tuber as influenced by the potato cultivars and N levels (pooled data of 2 years)

Nitrogen (kg/ha)	Total number of tubers (× 10^5 /ha)				Tuber yield (t/ha)				TBR (kg/ha/day) at 50–70 DAP				TBR (kg/ha/day) at 70–90 DAP			
	'Kufri Himalini'	'Kufri Shailja'	'Kufri Jyoti'	Mean	'Kufri Himalini'	'Kufri Shailja'	'Kufri Jyoti'	Mean	'Kufri Himalini'	Kufri Shailja'	'Kufri Jyoti'	Mean	'Kufri Himalini'	'Kufri Shailja'	'Kufri Jyoti'	Mean
N_0	3.75	3.42	2.13	3.10	12.4	12.1	11.4	11.9	172	167	146	162	246	126	189	187
N_{75}	3.43	4.04	2.16	3.21	31.9	31.3	20.3	27.8	789	468	283	513	365	665	441	490
N_{150}	4.45	3.95	2.82	3.74	34.4	32.7	30.2	32.4	976	624	650	750	703	886	681	757
N_{225}	3.80	5.02	2.82	3.88	38.4	32.7	31.6	34.2	963	603	567	711	708	651	561	640
N_{300}	4.27	4.28	2.71	3.76	39.5	24.1	26.9	30.2	1341	490	683	838	899	320	352	524
Mean	3.94	4.14	2.53		31.3	26.6	24.1		848	470	466		584	530	445	
	Cultivar	Nitrogen	Cultivar × nitrogen		Cultivar	Nitrogen	Cultivar × nitrogen		Cultivar	Nitrogen	Cultivar × nitrogen		Cultivar	Nitrogen	Cultivar × nitrogen	
SEm±	0.14	0.18	0.32	1.3	1.7	2.9	82.9	107.1	185.6	89.7	115.8	200.5				
CD (P=0.05)	0.41	0.52	NS	3.6	4.7	NS	236.8	305.7	NS	NS	330.5	NS				

(50–70 DAP), and it was 44.54 and 45.08% more than 'Kufri Shailja' and 'Kufri Jyoti', respectively. No significant difference in TBR was observed between 'Kufri Shailja' and 'Kufri Jyoti'. During later stage (70–90 DAP), difference in TBR was non-significant. On the other hand, N levels exhibited significant effect on TBR both early and later stages. Maximum TBR was recorded with 300 kg N/ha during 50–70 DAP, and it was statistically on a par with 150 and 225 kg N/ha. While during later stage (70–90 DAP), TBR was increased with increase in N dose up to 150 kg N/ha and then decreased linearly with further increase in N dose. Plants in control plot gave the lowest TBR resulting in lowest tuber yield among all other treatment combinations.

Correlation study and curve fitting

Correlations between tuber yield and plant height, tuber yield and total dry matter accumulation tuber yield and TBR and tuber yield and total N uptake were highly significant (Fig. 1). The rates of increase in tuber yield/unit increase in plant height and total dry-matter accumulation (DMA) were 0.59 and 0.02 t/ha respectively. The slopes of the equations indicated that 0.03 and 0.06 t/ha increase in tuber yield/unit increase in TBR and total N uptake respectively. The results indicated that tuber yield of potato is largely dependent on plant height, total DMA, TBR and total N uptake, and finally increase in N level enhanced these growth attributes and gave the higher tuber yield. The correlation coefficient between nitrogen and tuber yield showed that it was highly correlated (Fig. 2) and from the regression equation, the economic optimum level of N_{Opt} was derived as 202.68 kg N/ha (considering mean yield data of three potato cultivar).

Nitrogen-use efficiency

Agronomic efficiency (AE_N) was higher in 'Kufri Himalini' potato and it was 55.79 and 43.00% higher than 'Kufri Shailja' and 'Kufri Jyoti' respectively (Table 3). Agronomic efficiency was the maximum at 75 kg N/ha, and decreased to lowest at highest N dose (300 kg N/ha). It decreased linearly with every incremental dose of N, confirming the findings of Love *et al.* (2005) and Kumar *et al.* (2008). Apparent recovery (RE_N) was maximum in 'Kufri Himalini' closely followed by 'Kufri Shailja' and 'Kufri Jyoti. In all the cultivars, apparent recovery decreased with the increase in N level from 75 to 300 kg N/ha, being maximum and minimum at 75 and 300 kg N/ha respectively. Physiological efficiency (PE_N) was the maximum in 'Kufri Himalini' almost at all levels of N, but only at 150 kg N/ha 'Kufri Jyoti' showed the maximum PE_N. Data also revealed that all the cultivars showed lower PE_N with highest N level (300 kg N/ha).

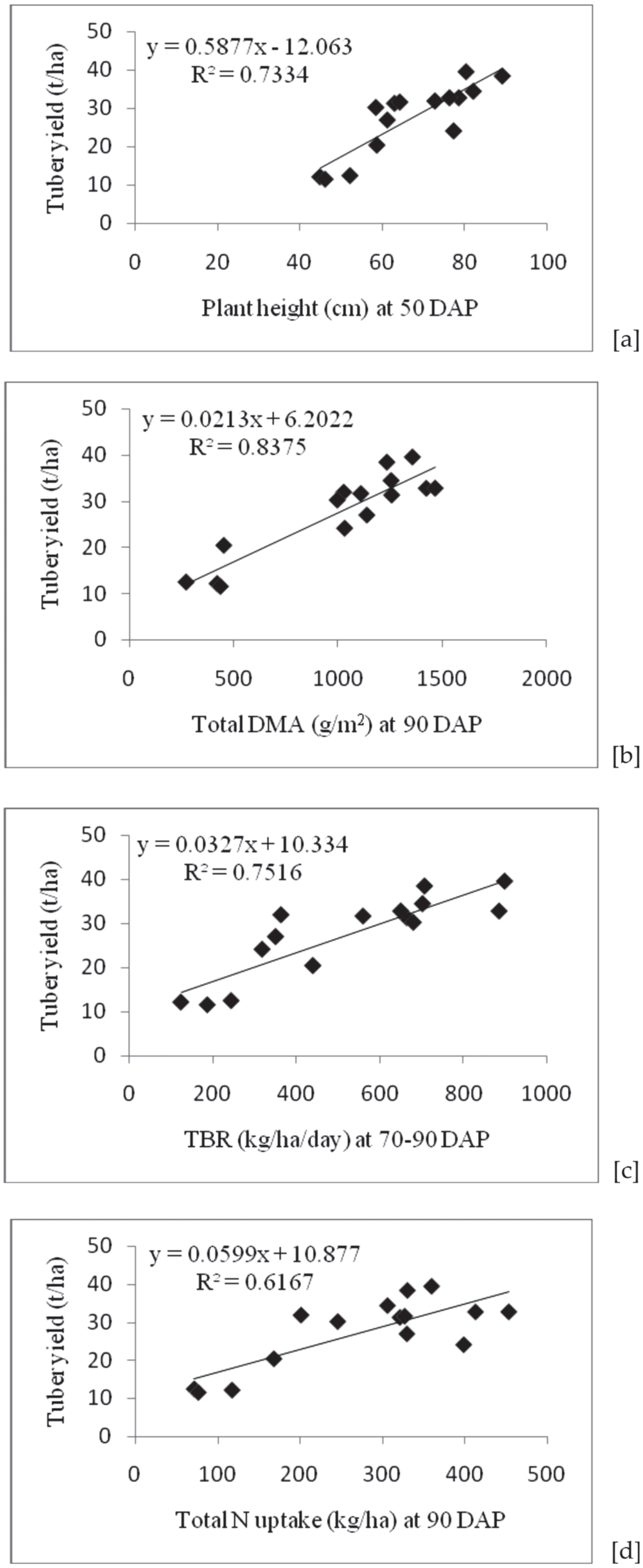

Fig. 1. Relationship of tuber yield with [a] plant height, [b] total dry-matter accumulation (DMA), [c] tuber bulking rate (TBR) and [d] total N uptake during tuber bulking stage (50–90 day after planting (DAP)

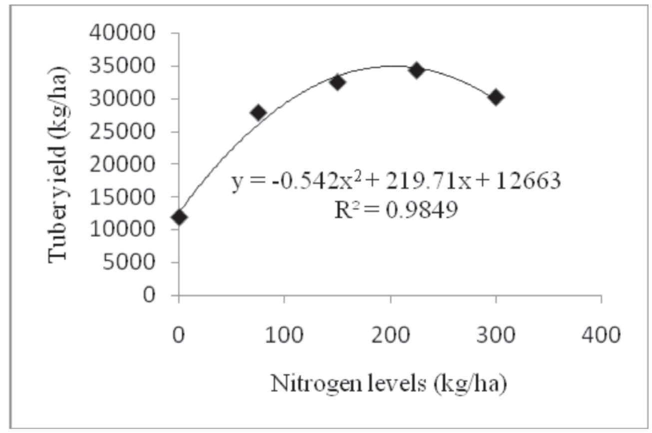

Fig. 2. Curve fitting and correlation studies between tuber yield and nitrogen levels

Sustainable yield index and partial factor productivity

There was no considerable difference in potato cultivars with respect to sustainable yield index (SYI), while it responds positively to N application (Table 3). Successive improvement in fertilizer N level from 0 to 225 kg N/ha increased the SYI from 0.077 to 0.720. Higher value of SYI was obtained with 225 kg N/ha (89.3% increased over the control), and further increase in N level at 300 kg N/ha reduced SYI (17.9% less than 225 kg N/ha). Increment in tuber yield of 'Kufri Himalini' per unit increase in N was the highest followed by 'Kufri Shailja' and 'Kufri Jyoti'. This might be due to efficient translocation of nutrient and photosynthates to the tubers. Partial factor productivity (PFP) was declined at an increasing rate with increase in N level, and it was reduced by 41.7% (at 150 kg N/ha), 59.0% (at 225 kg N/ha) and 72.9% (at 300 kg N/ha), indicating poor rate of utilization of N at higher application rate (Table 3). It is also due to the curvilinear return to the conversion of plant nutrients to seed as yield approaches the ceiling at higher levels of nutrients (Premi *et al.*, 2012).

Nitrogen balance

There was a positive balance of nitrogen in all plots, except one where 'Kufri Jyoti' was fertilized with 300 kg N/ha (Table 4). Fixed nitrogen might have been made available to potato and enriched the soil, resulting in positive balance of N observed in these treatments. The negative balance of nitrogen after harvesting of crop ('Kufri Jyoti') might be ascribed to the fact that loss of nitrogen (Ramesha *et al.*, 2011) and lower N-use efficiency of the crop, here cultivar in particular. Net gain (+) of N was higher in plots with 'Kufri Shailja' receiving N (75 to 225 kg N/ha) than other potato cultivars, while it was lower in plots with 'Kufri Jyoti'.

Table 3. Nitrogen-uptake efficiency, sustainable yield index and partial factor productivity of potato as influenced by potato cultivars and N levels (pooled data of 2 years)

Nitrogen (kg/ha)	Agronomic efficiency (kg tuber/kg N)			Apparent recovery (%)			Physiological efficiency (kg/kg N)			Sustainable yield index				Partial factor productivity			
	'Kufri Himalini'	'Kufri Shailja'	'Kufri Jyoti'	'Kufri Himalini'	'Kufri Shailja'	'Kufri Jyoti'	'Kufri Himalini'	'Kufri Shailja'	'Kufri Jyoti'	'Kufri Himalini'	'Kufri Shailja'	'Kufri Jyoti'	Mean	'Kufri Himalini'	'Kufri Shailja'	'Kufri Jyoti'	Mean
N_0	-	-	-	-	-	-	-	-	-	0.034	0.097	0.100	0.077	-	-	-	-
N_{75}	260	256	118	1.73	2.72	1.22	150	94.3	96.9	0.528	0.684	0.381	0.531	425	416	271	371
N_{150}	146	137	124	1.56	1.97	1.13	93.8	69.9	110	0.592	0.728	0.693	0.671	229	218	201	216
N_{225}	115	91.9	89.5	1.15	1.49	1.11	100	61.6	80.4	0.693	0.729	0.737	0.720	170	145	140	152
N_{300}	90.5	40.0	51.6	0.96	0.94	0.84	94.2	42.7	61.1	0.721	0.464	0.589	0.591	131	80.2	89.7	100
Mean	-	-	-	-	-	-	-	-	-	0.514	0.540	0.500	-	239	215	175	-

Economics

The present study also showed that the profitability of 'Kufri Himalini' cultivation was more than 'Kufri Shailja' and 'Kufri Jyoti' because 'Kufri Himalini' with 300 kg N/ha gave the highest net returns and benefit: cost ratio. Next best net returns and benefit: cost ratio were recorded with the same variety receiving with 225 kg N/ha. Higher economic returns and net benefit: cost ratio were obtained with 'Kufri Himalini' at higher N doses because of increased marketable and total tuber yield realized at higher N application.

Selection of low N requirement cultivar

The calculation of N rate by the proposed technique for attaining a fixed yield (Table 6) showed that 'Kufri Shailja' required only 173.42 kg N/ha to give a yield of 30.94 tonnes/ha as against required by the standard cultivar 'Kufri Jyoti' (202.68 kg N/ha), while 'Kufri Himalini' required 240.94 kg N/ha. So, 'Kufri Shailja' was more N-efficient than 'Kufri Himalini'. The yield of a cultivar requiring less input of N would be more sustainable than requiring higher inputs (Govindakrishnan *et al.,* 1999).

Eco-friendly rating of cultivars

The relative eco-friendly index (´) measured the degree of eco-friendliness of new cultivars relative to standard cultivar ('Kufri Jyoti'). Indirectly, it also shows the combined utilization of N from soil and fertilizer sources (Govindakrishnan *et al.,* 1999). 'Kufri Shailja' was more eco-friendly, as its index was 18.4% higher than 'Kufri Jyoti' (Table 6). Therefore, 'Kufri Shailja' required 18.4% less application of fertilizer N to produce the highest yield obtained by 'Kufri Jyoti' (30.94 t/ha). So, for obtaining a given yield, less amount of fertilizer is being put to soil and hence comparatively less amount of N is being lost to the environment. The cultivar 'Kufri Himalini' showed negative value which means this cultivar was less eco-friendly. The eco-friendliness of the cultivar was also judged by the absolute eco-friendly index and it measures the utilization of N by the cultivars from the soil source, in other terms it gives fertilizer N requirement equivalent (kg N/ha) due to increase in yield in absence of N of a cultivar over the standard cultivar (Govindakrishnan *et al.,*1999). The value of absolute eco-friendly indices of 'Kufri Himalini' was higher than that of 'Kufri Shailja' (Table 6). The value of absolute index also showed superiority of both the new cultivars over 'Kufri Jyoti' with respect to use of N from soil. 'Kufri Himalini' and 'Kufri Shailja' gave the same yield without any fertilizer application which 'Kufri Jyoti' was producing with application of 19.38 and 14.75 kg N/ha.

It could be concluded that cultivation of 'Kufri

Table 4. Nitrogen balance in soil after harvesting of potato as influenced by potato cultivars and N levels

Treatment combination	Initial soil N status (a) (kg N/ha)	N added through fertilizer (b) (kg N/ha)	Total N (c=a+b) (kg N/ha)	Crop uptake (d) (kg N/ha)	Expected balance (e=c-d) (kg N/ha)	Actual balance(f) (kg N/ha)	Net gain (+) or loss (-) (f-e) (kg N/ha)
V_1N_0	183.3	0	183.3	71.7	111.6	130.9	19.4
V_1N_1	183.3	75	258.3	201.4	56.9	127.1	70.1
V_1N_2	183.3	150	333.3	306.3	26.9	130.9	103.9
V_1N_3	183.3	225	408.3	330.4	77.9	134.8	56.9
V_1N_4	183.3	300	483.3	359.7	123.5	146.3	22.8
V_2N_0	183.3	0	183.3	117.7	65.6	138.6	73.0
V_2N_1	183.3	75	258.3	321.3	-63.1	138.6	201.7
V_2N_2	183.3	150	333.3	413.1	-79.8	134.8	214.6
V_2N_3	183.3	225	408.3	453.4	-45.1	134.8	179.8
V_2N_4	183.3	300	483.3	398.8	84.4	142.5	58.0
V_3N_0	183.3	0	183.3	76.7	106.6	115.5	8.9
V_3N_1	183.3	75	258.3	168.4	89.8	142.5	52.6
V_3N_2	183.3	150	333.3	245.9	87.3	142.5	55.1
V_3N_3	183.3	225	408.3	327.1	81.2	123.2	42.0
V_3N_4	183.3	300	483.3	329.8	153.4	134.8	-18.7

V_1, 'Kufri Himalini'; V_2, 'Kufri Shailja'; V_3, 'Kufri Jyoti'; N_0, 0; N_1, 75; N_2, 150; N_3, 225; N_4, 300 kg N/ha

Table 5. Economics of potato production/ha as affected by potato cultivars and N levels (pooled data of 2 years)

Treatment	Total cost ($\times 10^3$ ₹/ha)	Net returns ($\times 10^3$ ₹/ha)	Benefit: cost ratio
V_1N_0	88.1	-13.8	0.84
V_1N_1	89.0	102.2	2.15
V_1N_2	90.0	116.4	2.29
V_1N_3	90.9	139.4	2.53
V_1N_4	91.9	145.2	2.58
V_2N_0	88.1	-15.7	0.82
V_2N_1	89.0	98.5	2.11
V_2N_2	90.0	106.3	2.18
V_2N_3	90.9	105.4	2.16
V_2N_4	91.9	52.4	1.57
V_3N_0	88.1	-19.4	0.78
V_3N_1	89.0	32.9	1.37
V_3N_2	90.0	91.1	2.01
V_3N_3	90.9	98.5	2.08
V_3N_4	91.9	69.5	1.76

Cost of urea, ₹6/kg; single super phosphate, ₹8/kg; muriate of potash, ₹18/kg; labour wages @ ₹167/m.u.; product cost: ₹300/bag (1 bag=50 kg)

Table 6. Nitrogen rate required for target yields and eco-friendly indices (pooled data of 2 years)

Cultivar	Optimum N dose (kg/ha)*	Relative eco-friendly indices (%)	Absolute indices (kg N/ha)
'Kufri Himalini'	240.94	-13.37	19.38
'Kufri Shailja'	173.42	18.40	14.75

*Maximum yield (30.94 t/ha) of standard cultivar ('Kufri Jyoti') served the purposes of target yield of potato

Himalini' is more profitable than 'Kufri Shailja' and 'Kufri Jyoti' as the cultivar met all the necessary requirements, especially higher yield and highest net returns. But eco-friendly rating showed that 'Kufri Shailja' is more eco-friendly than 'Kufri Himalini'. It might be recommended that 202.68 kg N/ha along with 150 kg N/ha each of phosphorus and potassium could result higher tuber yield and also improved the environmental sustainability.

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