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# Nutrient Management for Sustainable Production of Sweet Potato (*Ipomoea batatas* L.) in Saline Inceptisols of West Bengal

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## Abstract

A field experiment was conducted for two consecutive rabi (winter) seasons during 2009-2010 and 2010-2011 in a natural saline Inceptisol to optimize the requirement of N and P for sustainable production of sweet potato. The results revealed that the mean tuber and vine yields increased significantly with increasing doses of N and P up to 50 kg ha$^{-1}$. Higher tuber yield (19.65 t ha$^{-1}$), total uptake of N (73.75 kg ha$^{-1}$) and N use efficiency (143.4 kg tubers per kg N) was observed due to the combined application of 50 kg each of N and $P_2O_5$ ha$^{-1}$. Significantly highest mean starch content (22.55 %) was obtained due to the application of N and $P_2O_5$ @ 50 and 75 kg ha$^{-1}$, respectively, while the highest dry matter content (31.45 %) was observed due to the combined application N and $P_2O_5$ @ 50 kg ha$^{-1}$ each. Significantly highest P and K uptake was observed due to the application of 75 kg ha$^{-1}$ each of N and $P_2O_5$. Highest P use efficiency (87.0 kg tubers per kg $P_2O_5$) was observed due to the application of 75 and 25 kg ha$^{-1}$ of N and $P_2O_5$ respectively. Application of N and $P_2O_5$ @ 50 kg ha$^{-1}$ each was found to be optimum for sustainable production of sweet potato with good quality tubers and higher nutrient use efficiency. Further, this recommendation offers good scope for food and nutritional security in the saline tracts of Eastern India.

**Key words**: Salinity, sweet potato, yield parameters, proximate composition, nutrient uptake, nutrient use efficiency

## Introduction

The plant response to salinity consists of numerous processes that must function in coordination to alleviate both cellular hyper-osmolarity and ion disequilibrium (Yokoi et al., 2002). India has a total of 9.38 m ha salt affected soils. Out of this around 5.5 m ha are saline soils, including 3.1 m ha of coastal saline soils, which constitute 30% of the total salt affected soils of the country, while 3.88 m ha is alkali soils (Dagar, 2005). Salt content of these coastal saline soils is generally low i.e. 2 - 3 dS m$^{-1}$ during rainy season due to dilution effect of heavy rains and it rises to 10 - 40 dS m$^{-1}$ during summer. Salt stress hampers the rice productivity in kharif (rainy season) and it will not allow cultivation of pulses and other sensitive crops during rabi (winter) season. Excess salts interfere with plant nutrition by affecting nutrient availability, uptake or their physiological role within the plant.

Dynamic field-specific management of N, P, and K fertilizers to optimize the supply and crop demand for nutrients and the nutrient supply from naturally occurring indigenous sources such as the soil, organic amendments, crop residues, manure and irrigation water is necessary in such situations. Selection of suitable crops and efficient genotypes are viable options for sustainable crop production in saline soils, besides other management practices like land ploughing, levelling, flushing, draining of excess water, application of amendments and flooding with good quality irrigation water. The osmotic stress due to salts is the major reason for low biological activity, which can be significantly overcome by the use of organic amendments and growing salt-tolerant crops/cultivars. The relative tolerance of different crops to salinity has been evaluated by many workers (Dagar, 2005).

Soil salinity is a serious problem for agriculture in coastal regions and has good agronomic significance. However, suitable interventions are required for sustainable production of sweet potato (Tripathi et al., 2007; Dasgupta et al., 2008a). Sweet potato (*Ipomoea batatas* L.) is tolerant to adverse environmental conditions such as drought, salinity, low soil fertility, high rainfall and it requires very little labor and care as compared to other crops (Abdissa et al., 2011). Nearly half of the sweet potatoes produced in Asia are used for animal feed, whereas it is used for human consumption in Africa referring to its importance as a staple and sustainable crop in the world (CIP, 2008). Sweet potato gives better and faster production under diverse agro-ecological conditions with less inputs (Lim et al., 2007) and has immense potential to combat food shortage, malnutrition and poverty (CIP, 2008). Optimization of fertilizer requirement for sustainable crop production of sweet potato in saline soils is complicated owing to the large temporal and spatial variations in the soil salinity level, differential ontogenic reactions of the plant to salinity and a large genotype x environment interactions (Ekanayake and Dodds, 1993). The present investigation was carried out to optimize the N and P requirement for sustainable production of sweet potato in the coastal saline soils of West Bengal.

## Materials and Methods

A field experiment was laid out for two consecutive rabi (winter) seasons during 2009-2010 and 2010-2011 at the farm of the Regional Research Station of Central Soil Salinity Research Institute, Canning Town, South 24 Paraganas district of West Bengal to optimize the N and P requirement for sustainable production of sweet potato. Composite soil samples were analyzed for physico-chemical properties by using standard procedures (Jackson, 1973). The experimental soil is silty clay (Typic Ustochrept), neutral (pH 6.23), saline (ECe 4.75 dS $m^{-1}$ at initial) and having 0.80% organic C, 0.131% total N and 261, 24.2 and 520 kg $ha^{-1}$ of available N, P and K, respectively. The trial was laid out with 13 treatments, which are possible combinations of 4 levels of N ($N_1$, $N_2$, $N_3$ and $N_4$: 25, 50, 75 and 100 kg N $ha^{-1}$) and 3 levels of $P_2O_5$ ($P_1$, $P_2$ and $P_3$: 25, 50 and 75 kg $P_2O_5$ $ha^{-1}$) apart from a control (control, $N_1P_1$, $N_1P_2$, $N_1P_3$, $N_2P_1$, $N_2P_2$, $N_2P_3$, $N_3P_1$, $N_3P_2$, $N_3P_3$, $N_4P_1$, $N_4P_2$, $N_4P_3$) in three replications in a Randomized Block Design. After the harvest of lowland kharif rice in December, the field was ploughed, leveled and the treatments were imposed.

A uniform dose of well rotten farmyard manure (FYM) (N, P and K contents of 0.56, 0.24 and 0.72% respectively) @ 5.0 t $ha^{-1}$ was applied in all the plots 15 days in advance of sweet potato planting. One-third of N in the form of urea and full dose of $P_2O_5$ as single super phosphate as per the treatments were applied before planting. The remaining two-third each of N was applied in two equal splits at 30 and 45 days after planting (DAP). Since the experimental soil had higher status of available K, a uniform dose of 20 kg $K_2O$ $ha^{-1}$ in the form of muriate of potash was applied in two equal splits before planting and at 45 DAP. Sweet potato (cv Samrat) vine cuttings were dipped for 30 min in monocrotophos (35% EC) solution and planted at a spacing of 60 x 20 cm. The crop was harvested at 120 DAP and growth and yield parameters (vine length, number of tubers/plant, tuber weight, vine yield and tuber yield) were recorded. It was observed that the soil salinity (ECe) rose up to 16.0 dS $m^{-1}$ at the time of harvest, which was due to capillary movement of salts to the soil surface due to increase in temperature. However, the pH showed no significant changes during the crop growth period.

Tuber and vine samples were collected at harvest, washed thoroughly, oven dried, ground, digested in diacid mixture ($HNO_3$: $HClO_4$, 7:3) and estimated for total P and K (Jackson, 1973). Plant samples were digested in concentrated $H_2SO_4$ and analyzed for N content by steam distillation (Humphries, 1956). Uptake of N, P and K was computed by multiplying the nutrient contents with the respective dry matter production of tubers and vines and the total plant nutrient uptake was computed. Tuber samples were analyzed for bio-chemical constituents. Total sugars were estimated in the alcohol filtrate and the starch was determined in the residue as per the procedure outlined by Moorthy and Padmaja (2002). Dry matter of the tubers was estimated by drying the samples in the oven at 60°C for 120 hrs. Per cent yield response, per cent nutrient uptake response, nutrient use efficiency and apparent nutrient recovery were derived as:

Per cent yield response = [(Treatment yield – control yield) ÷ (Control yield)] x 100

Per cent uptake response = [(Nutrient uptake in treatment – nutrient uptake in control) ÷ (Nutrient uptake in control)] x 100

Nutrient use efficiency (kg tubers per kg nutrient applied) = (Treatment yield – control yield) ÷ Amount of nutrient applied

Apparent nutrient recovery (%) = [(Uptake in treated plot – uptake in control plot) ÷ (Amount of nutrient applied)] x 100

The data was analyzed statistically and the critical difference values were computed for comparison and interpretation of data (Panse and Sukhatme, 1978).

## Results and Discussion

### Yield response

The highest mean tuber and vine yields of sweet potato (18.17 and 14.03 t $ha^{-1}$, respectively) were obtained due to the application of N @ 75 kg $ha^{-1}$ with 45.6% higher tuber yield over control (Table 1). However, this was on par with N application @ 50 kg $ha^{-1}$. Higher levels of P application resulted in an increasing trend of tuber and vine yields up to 50 kg $ha^{-1}$ with a tuber yield response of 45% over control. Other growth and yield parameters also followed similar trend as that of tuber and vine yields. Significant response to application of 50 kg $ha^{-1}$ each of N and $P_2O_5$ was observed in saline Inceptisols. Relatively, low yield response to the externally added N and P fertilizers was observed which might be due to higher inherent fertility status of the experimental soil.

Significantly highest mean tuber yield (19.65 t $ha^{-1}$) was observed due to the combined application of 50 kg $ha^{-1}$ each of N and $P_2O_5$ with a yield increase of 57.5% (Table 2). However, significantly highest mean vine yield (15.06 t $ha^{-1}$) was obtained with the application of 50 and 75 kg $ha^{-1}$ of N and $P_2O_5$, respectively followed by 100 and 50 kg $ha^{-1}$ of N

Table 1. Effect of N and P on growth and yield parameters of sweet potato in saline soil

| Treatment | Vine length (cm) | | | No. of tubers/plant | | | Tuber weight (g) | | | Tuber yield (t $ha^{-1}$) | | | Yield response (%) | Vine yield (t $ha^{-1}$) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2010 | 2011 | Mean | 2010 | 2011 | Mean | 2010 | 2011 | Mean | 2010 | 2011 | Mean | | 2010 | 2011 | Mean |
| N levels (kg $ha^{-1}$) | | | | | | | | | | | | | | | | |
| 0 | 98.7 | 83.4 | 90.0 | 2.73 | 2.20 | 2.47 | 135.2 | 99.5 | 117.4 | 16.80 | 6.17 | 12.48 | - | 14.27 | 8.88 | 10.74 |
| 25 | 116.4 | 88.9 | 102.7 | 3.39 | 2.79 | 3.09 | 132.0 | 128.5 | 130.3 | 23.07 | 10.23 | 16.65 | 33.4 | 17.62 | 10.09 | 13.86 |
| 50 | 119.4 | 99.7 | 109.6 | 2.90 | 2.50 | 2.70 | 134.4 | 169.5 | 152.0 | 23.31 | 12.39 | 17.85 | 43.0 | 17.40 | 10.25 | 13.83 |
| 75 | 112.2 | 106.7 | 109.4 | 3.22 | 2.78 | 3.00 | 137.3 | 142.9 | 140.1 | 24.22 | 12.12 | 18.17 | 45.6 | 17.29 | 10.78 | 14.03 |
| 100 | 113.4 | 91.6 | 102.5 | 2.98 | 2.60 | 2.79 | 130.3 | 134.7 | 132.5 | 22.02 | 11.15 | 16.58 | 32.9 | 17.19 | 11.38 | 14.28 |
| CD (0.05) | 10.78 | 10.61 | 7.71 | 0.43 | 0.37 | 0.24 | 17.86 | 25.94 | 14.50 | 1.32 | 1.56 | 1.07 | - | 1.14 | 1.25 | 0.77 |
| P levels ($P_2O_5$ kg $ha^{-1}$) | | | | | | | | | | | | | | | | |
| 0 | 98.7 | 83.4 | 90.0 | 2.73 | 2.20 | 2.47 | 135.2 | 99.5 | 117.4 | 16.80 | 6.17 | 12.48 | - | 14.27 | 8.88 | 10.74 |
| 25 | 113.3 | 94.2 | 103.7 | 3.04 | 2.62 | 2.83 | 135.4 | 140.7 | 138.1 | 21.69 | 10.71 | 16.20 | 29.8 | 16.58 | 10.47 | 13.52 |
| 50 | 113.5 | 98.4 | 105.9 | 3.12 | 2.68 | 2.90 | 134.7 | 147.7 | 141.2 | 23.61 | 12.44 | 18.03 | 44.5 | 17.37 | 11.13 | 14.25 |
| 75 | 119.4 | 97.5 | 108.5 | 3.21 | 2.71 | 2.96 | 130.5 | 143.3 | 136.9 | 24.16 | 11.27 | 17.71 | 41.9 | 18.18 | 10.28 | 14.23 |
| CD (0.05) | 9.34 | 9.19 | 6.68 | 0.37 | 0.32 | 0.21 | 15.47 | 22.47 | 12.56 | 1.14 | 1.35 | 0.92 | - | 0.98 | 1.08 | 0.67 |

and $P_2O_5$, respectively (14.76 t $ha^{-1}$). Higher tuber yield response of the crop was observed due to the application of 50 kg $ha^{-1}$ each of N and $P_2O_5$ and further increase in N and P levels showed decreasing trend in crop yields.

Dasgupta et al. (2008b) reported that the activity of antioxidative enzymes like superoxide dismutase (SOD), guaiacol peroxidase (GPX) and catalase (CAT) activities in the leaves of salt tolerant genotypes increased than that in the susceptible ones, indicating that oxidative stress may play an important role in salt stressed sweet potato plants and that the greater protection of tolerant plants from salt induced oxidative damage resulted through the increase in the activity of antioxidant enzymes. Residual effect of organic manures and fertilizers, which were applied to kharif rice and incorporation of crop residues of rice, might have helped in higher response to limited doses of chemical fertilizers for sustainable production of sweet potato.

### Proximate composition

The starch content increased significantly with increase in the levels of N up to 50 kg $ha^{-1}$ and thereafter declined. Significantly highest mean starch content (21.37%) and total sugars (3.82%) were observed due to the addition of 50 kg $ha^{-1}$ N (Table 3). The starch content significantly increased due to super-optimal dose of P application up to 75 kg $ha^{-1}$ (21.06 %). However, higher amount of total sugars were observed due to the application of $P_2O_5$ up to 75 kg $ha^{-1}$ (3.76%), which was on par with 50 kg $ha^{-1}$ (3.74%). Significantly highest mean starch content (22.6 %) was observed due to the interaction effect, $N_2P_3$ i.e. application of 50 and 75 kg $ha^{-1}$ of N and $P_2O_5$, respectively (Table 4) which was on par with $N_3P_2$ i.e. application of 75 and 50 kg $ha^{-1}$ of N and $P_2O_5$, respectively (21.53%). Total sugars varied from 3.01 to 4.07% and combined application of 50 and 75 kg $ha^{-1}$ of N and $P_2O_5$, respectively resulted in highest sugars (4.01%).

Significantly highest mean dry matter content

Table 2. Interaction effect of N and P on growth and yield parameters of sweet potato in saline soil

| Treatment | Vine length (cm) | | | No. of tubers/plant | | | Tuber weight (g) | | | Tuber yield (t $ha^{-1}$) | | | Yield response (%) | Vine yield (t $ha^{-1}$) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2010 | 2011 | Mean | 2010 | 2011 | Mean | 2010 | 2011 | Mean | 2010 | 2011 | Mean | | 2010 | 2011 | Mean |
| $N_0P_0$ | 98.7 | 83.4 | 90.0 | 2.73 | 2.20 | 2.47 | 135.2 | 99.5 | 117.4 | 16.80 | 6.17 | 12.48 | - | 14.27 | 8.88 | 10.74 |
| $N_1P_1$ | 107.0 | 87.3 | 97.2 | 3.07 | 2.53 | 2.80 | 135.8 | 127.4 | 131.6 | 20.89 | 9.28 | 15.08 | 20.8 | 16.57 | 10.37 | 13.30 |
| $N_1P_2$ | 115.3 | 88.9 | 102.1 | 3.47 | 2.93 | 3.20 | 136.5 | 128.0 | 132.3 | 24.23 | 10.07 | 16.98 | 36.1 | 19.43 | 10.81 | 13.95 |
| $N_1P_3$ | 127.0 | 90.5 | 108.7 | 3.63 | 2.90 | 3.27 | 123.7 | 130.2 | 127.0 | 25.08 | 11.36 | 17.89 | 43.3 | 21.53 | 12.43 | 14.31 |
| $N_2P_1$ | 114.3 | 97.6 | 106.0 | 2.83 | 2.47 | 2.65 | 120.6 | 154.5 | 147.6 | 23.82 | 10.04 | 15.36 | 23.1 | 17.57 | 11.59 | 11.91 |
| $N_2P_2$ | 122.3 | 97.6 | 106.6 | 2.93 | 2.50 | 2.72 | 138.1 | 168.9 | 153.5 | 25.03 | 14.73 | 19.65 | 57.5 | 20.13 | 15.87 | 14.50 |
| $N_2P_3$ | 131.7 | 103.8 | 116.1 | 2.93 | 2.53 | 2.73 | 144.6 | 155.0 | 149.8 | 27.12 | 12.40 | 18.55 | 48.6 | 22.18 | 13.29 | 15.06 |
| $N_3P_1$ | 116.7 | 104.7 | 110.7 | 3.07 | 2.87 | 2.97 | 146.9 | 133.1 | 140.0 | 22.98 | 11.82 | 17.46 | 39.9 | 18.46 | 13.38 | 14.56 |
| $N_3P_2$ | 118.0 | 112.4 | 110.7 | 3.13 | 2.73 | 2.93 | 135.2 | 146.9 | 141.0 | 24.11 | 12.79 | 18.35 | 47.0 | 21.18 | 12.92 | 13.78 |
| $N_3P_3$ | 119.7 | 102.8 | 106.9 | 3.47 | 2.73 | 3.10 | 129.8 | 148.8 | 139.3 | 24.41 | 11.75 | 18.71 | 49.9 | 22.59 | 13.70 | 13.76 |
| $N_4P_1$ | 121.7 | 87.1 | 101.1 | 3.20 | 2.60 | 2.90 | 138.3 | 127.9 | 133.1 | 22.63 | 11.70 | 16.91 | 35.5 | 19.05 | 13.18 | 14.31 |
| $N_4P_2$ | 117.3 | 94.6 | 104.3 | 2.93 | 2.53 | 2.73 | 128.9 | 137.1 | 133.0 | 23.99 | 11.51 | 17.13 | 37.3 | 19.56 | 12.24 | 14.76 |
| $N_4P_3$ | 119.3 | 93.1 | 102.2 | 2.80 | 2.67 | 2.73 | 123.7 | 139.0 | 131.3 | 22.87 | 9.56 | 15.71 | 25.9 | 19.65 | 11.03 | 13.78 |
| CD (0.05) | 7.59 | 18.6 | 13.4 | 0.29 | 0.61 | 0.40 | 12.48 | 43.98 | 24.2 | 0.84 | 2.47 | 1.86 | - | 0.93 | 1.65 | 1.40 |

$N_1$, $N_2$, $N_3$ and $N_4$: N @ 25, 50, 75 and 100 kg $ha^{-1}$; $P_1$, $P_2$ and $P_3$: $P_2O_5$ @ 25, 50 and 75 kg $ha^{-1}$, respectively

Table 3. Effect of N and P on proximate composition of sweet potato

| Treatment | Starch (% on FW basis) | | | Sugars (% on FW basis) | | | Dry matter (%) | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2010 | 2011 | Mean | 2010 | 2011 | Mean | 2010 | 2011 | Mean |
| N levels (kg ha$^{-1}$) | | | | | | | | | |
| 0 | 18.19 | 18.78 | 18.48 | 3.01 | 3.12 | 3.06 | 25.8 | 26.3 | 22.3 |
| 25 | 20.05 | 19.82 | 19.93 | 3.63 | 3.61 | 3.62 | 27.8 | 29.7 | 28.7 |
| 50 | 20.01 | 22.71 | 21.37 | 3.72 | 3.93 | 3.82 | 29.4 | 31.4 | 30.4 |
| 75 | 19.27 | 22.00 | 20.64 | 3.52 | 3.84 | 3.68 | 27.8 | 31.6 | 29.7 |
| 100 | 18.54 | 21.44 | 19.99 | 3.60 | 3.72 | 3.66 | 27.3 | 30.9 | 29.1 |
| CD (0.05) | 0.52 | 0.78 | 0.49 | 0.18 | 0.24 | 0.14 | 0.72 | 1.06 | 0.98 |
| P levels ($P_2O_5$ kg ha$^{-1}$) | | | | | | | | | |
| 0 | 18.19 | 18.78 | 18.48 | 3.01 | 3.12 | 3.06 | 25.8 | 26.3 | 22.3 |
| 25 | 18.71 | 20.77 | 19.74 | 3.55 | 3.64 | 3.60 | 27.8 | 30.1 | 29.0 |
| 50 | 19.51 | 21.77 | 20.64 | 3.64 | 3.85 | 3.74 | 28.6 | 31.2 | 29.9 |
| 75 | 20.18 | 21.93 | 21.06 | 3.66 | 3.84 | 3.76 | 27.8 | 31.3 | 29.5 |
| CD (0.05) | 0.45 | 0.68 | 0.42 | 0.15 | 0.21 | 0.12 | 0.85 | 1.08 | 0.94 |

Table 4. Interaction effect of N and P on proximate composition of sweet potato

| Treatment | Starch (% on FW basis) | | | Sugars (% on FW basis) | | | Dry matter (%) | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2010 | 2011 | Mean | 2010 | 2011 | Mean | 2010 | 2011 | Mean |
| $N_0P_0$ | 18.19 | 18.78 | 18.48 | 3.01 | 3.12 | 3.06 | 25.82 | 26.32 | 26.07 |
| $N_1P_1$ | 19.41 | 19.24 | 19.33 | 3.37 | 3.38 | 3.38 | 26.45 | 28.83 | 27.64 |
| $N_1P_2$ | 20.00 | 19.46 | 19.73 | 3.64 | 3.79 | 3.72 | 28.15 | 29.75 | 28.95 |
| $N_1P_3$ | 20.73 | 20.75 | 20.74 | 3.88 | 3.66 | 3.77 | 28.73 | 30.45 | 29.59 |
| $N_2P_1$ | 18.64 | 21.88 | 20.26 | 3.46 | 3.67 | 3.57 | 28.93 | 29.41 | 29.17 |
| $N_2P_2$ | 20.02 | 22.54 | 21.28 | 3.71 | 4.07 | 3.89 | 30.24 | 32.66 | 31.45 |
| $N_2P_3$ | 21.38 | 23.71 | 22.55 | 3.97 | 4.05 | 4.01 | 29.06 | 32.04 | 30.55 |
| $N_3P_1$ | 18.69 | 20.57 | 19.63 | 3.34 | 3.66 | 3.50 | 28.33 | 30.83 | 29.58 |
| $N_3P_2$ | 19.33 | 23.72 | 21.53 | 3.53 | 3.91 | 3.71 | 28.61 | 31.85 | 30.23 |
| $N_3P_3$ | 19.80 | 21.70 | 20.75 | 3.68 | 3.95 | 3.82 | 26.59 | 32.03 | 29.31 |
| $N_4P_1$ | 18.09 | 21.41 | 19.75 | 4.03 | 3.84 | 3.93 | 27.42 | 31.54 | 29.48 |
| $N_4P_2$ | 18.71 | 21.35 | 20.03 | 3.66 | 3.63 | 3.64 | 27.51 | 30.55 | 29.03 |
| $N_4P_3$ | 18.81 | 21.56 | 20.19 | 3.11 | 3.70 | 3.41 | 26.86 | 30.50 | 28.68 |
| CD (0.05) | 0.42 | 1.39 | 1.14 | 0.15 | 0.42 | 0.23 | 0.46 | 1.66 | 1.24 |

$N_1$, $N_2$, $N_3$ and $N_4$: N @25, 50, 75 and 100 kg ha$^{-1}$; $P_1$, $P_2$ and $P_3$: $P_2O_5$ @ 25, 50 and 75 kg ha$^{-1}$, respectively
FW: fresh weight

(30.4%) was obtained due to the application of 50 kg N ha$^{-1}$ followed by 75 kg N ha$^{-1}$ (29.7%), whereas application of 50 kg $P_2O_5$ ha$^{-1}$ resulted in higher dry matter (29.9%) on par with 75 kg $P_2O_5$ ha$^{-1}$ (29.5%). Combined application of 50 kg ha$^{-1}$ each of N and $P_2O_5$ produced significantly highest mean dry matter (31.5%). It was observed that higher doses of N showed lower status of starch and dry matter, while it increased due to increased doses of P application. The use of inorganic fertilizers not only enhanced the crop yields but also had significant effect on bio-chemical constituents of sweet potato, similar to the findings of Mozafar (1993).

### Nutrient uptake

#### N uptake

Significantly highest total uptake of N (70 kg ha$^{-1}$) was observed due to the application of N up to 75 kg ha$^{-1}$ with an uptake response of 46% (Table 5) followed by

50 kg ha$^{-1}$ of N (68.3 kg ha$^{-1}$, with an uptake response of 43%). Higher doses of P application favoured N uptake, but significant response on N uptake was observed due to the application of 50 kg ha$^{-1}$ of $P_2O_5$ . The N uptake was highest (73.8 kg ha$^{-1}$) due to the interaction effect of $N_2P_2$ with an uptake response of 54 per cent over control (Table 6) on par with $N_2P_3$ (71.58 kg ha$^{-1}$). It was observed that vines showed significantly highest uptake of N, irrespective of nutrient levels as compared to tubers, which might be due to higher concentration of N in the foliage rather than tubers. Nitrogen regime also had a significant effect on the concentration of N in the leaves of plants, with the higher N regime having higher levels of leaf N. However, the variation in the dry matter yields of tubers and vines have contributed to variation in the uptake of NPK by the crop. These results are in accordance to the findings of Marti and Mills (2002).

### P uptake

Significant improvement on total P uptake was observed up to 75 kg N ha$^{-1}$, while it decreased due to higher doses of N (Table 5). Significantly highest total uptake of P (34.5 kg ha$^{-1}$) was observed at 75 kg $P_2O_5$ ha$^{-1}$ with an uptake response of 54% over control and on par with 50 kg $P_2O_5$ ha$^{-1}$ (33.7 kg ha$^{-1}$, with an uptake response of 50%). However, the application of 75 kg ha$^{-1}$ each of N and $P_2O_5$ resulted in the highest total P uptake (37.2 kg ha$^{-1}$) with an uptake response of 65.6 % followed by $N_2P_3$ (35.8 kg ha$^{-1}$) (Table 6). Application of 20 kg $K_2O$ ha$^{-1}$ along with N up to 75 kg ha$^{-1}$ had positive effect on K uptake with an uptake response of 52%; however, the K uptake response was higher due to N application rather than P fertilization, which might be due to synergistic effect between N and K. The supplementary and complementary use of organic and inorganic fertilizers facilitated higher retention and supply of essential nutrients as well as improvement in soil physical and biological properties. These enhanced the efficiency of applied fertilizers so as to maintain a high level of soil productivity. These results corroborates with the findings of Ravindran and Bala Nambisan (1987) and Svotwa et al. (2007).

### Nutrient use efficiency

Application of 25 kg ha$^{-1}$ of N resulted in highest N use efficiency (167 kg tubers per kg N), whereas addition

Table 5. Effect of N and P on nutrient uptake by sweet potato (mean of 2010 and 2011)

| Treatment | Nutrient uptake (kg ha$^{-1}$) | | | | | | | | | Uptake response (%) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Tuber | | | Vine | | | Total | | | | | |
| | N | P | K | N | P | K | N | P | K | N | P | K |
| N levels (kg ha$^{-1}$) | | | | | | | | | | | | |
| 0 | 15.94 | 10.92 | 34.14 | 32.00 | 11.51 | 32.70 | 47.94 | 22.43 | 66.84 | - | - | - |
| 25 | 21.23 | 15.08 | 46.71 | 41.38 | 14.90 | 41.82 | 62.61 | 30.23 | 88.53 | 30.6 | 34.8 | 32.5 |
| 50 | 22.54 | 16.07 | 50.74 | 45.77 | 16.82 | 45.67 | 68.31 | 33.27 | 96.42 | 42.5 | 48.3 | 44.3 |
| 75 | 23.72 | 17.58 | 54.69 | 46.31 | 17.21 | 46.69 | 70.03 | 35.24 | 101.26 | 46.1 | 57.1 | 51.5 |
| 100 | 19.66 | 15.03 | 48.37 | 45.55 | 17.45 | 45.12 | 65.21 | 32.86 | 93.48 | 36.0 | 46.5 | 39.9 |
| CD (0.05) | 1.15 | 0.91 | 3.11 | 2.12 | 0.67 | 2.02 | 2.11 | 0.76 | 2.79 | - | - | - |
| P levels ($P_2O_5$ kg ha$^{-1}$) | | | | | | | | | | | | |
| 0 | 15.94 | 10.92 | 34.14 | 32.00 | 11.51 | 32.70 | 47.94 | 22.43 | 66.84 | - | - | - |
| 25 | 20.37 | 14.63 | 46.93 | 42.64 | 15.43 | 42.90 | 63.01 | 30.43 | 89.74 | 31.4 | 35.7 | 22.9 |
| 50 | 22.81 | 16.59 | 51.80 | 45.31 | 16.77 | 45.47 | 68.12 | 33.74 | 97.26 | 42.1 | 50.4 | 45.5 |
| 75 | 22.18 | 16.58 | 51.65 | 46.31 | 17.59 | 46.11 | 68.49 | 34.53 | 97.77 | 42.9 | 53.9 | 46.3 |
| CD (0.05) | 0.99 | 0.78 | 2.69 | 1.83 | 0.58 | 1.75 | 1.83 | 0.66 | 2.42 | - | - | - |

Table 6. Interaction effect of N and P on nutrient uptake by sweet potato (mean of 2010 and 2011)

| Treatment | Nutrient uptake (kg ha$^{-1}$) | | | | | | | | | Uptake response (%) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Tuber | | | Vine | | | Total | | | | | |
| | N | P | K | N | P | K | N | P | K | N | P | K |
| $N_0P_0$ | 15.94 | 10.92 | 34.14 | 32.00 | 11.51 | 32.70 | 47.94 | 22.43 | 66.84 | - | - | - |
| $N_1P_1$ | 18.41 | 13.08 | 40.06 | 38.23 | 13.61 | 38.49 | 56.64 | 26.68 | 78.55 | 18.1 | 18.9 | 17.5 |
| $N_1P_2$ | 22.27 | 16.19 | 49.25 | 40.77 | 14.74 | 41.59 | 63.04 | 30.93 | 90.84 | 31.5 | 37.9 | 35.9 |
| $N_1P_3$ | 23.01 | 16.72 | 50.83 | 45.14 | 16.36 | 45.38 | 68.14 | 33.08 | 96.21 | 42.1 | 47.5 | 43.9 |
| $N_2P_1$ | 19.80 | 14.21 | 45.44 | 39.81 | 14.13 | 39.07 | 59.61 | 28.34 | 84.25 | 24.3 | 26.3 | 26.0 |
| $N_2P_2$ | 24.78 | 17.94 | 54.29 | 48.97 | 17.73 | 49.40 | 73.75 | 35.67 | 103.69 | 53.8 | 59.0 | 55.1 |
| $N_2P_3$ | 23.05 | 17.20 | 52.76 | 48.54 | 18.61 | 48.55 | 71.58 | 35.81 | 101.31 | 49.3 | 59.7 | 51.6 |
| $N_3P_1$ | 22.96 | 17.09 | 52.30 | 46.15 | 16.63 | 47.50 | 69.11 | 33.72 | 99.80 | 44.2 | 50.3 | 49.3 |
| $N_3P_2$ | 23.88 | 17.82 | 54.09 | 45.59 | 17.03 | 45.46 | 69.47 | 34.84 | 99.55 | 44.9 | 55.3 | 48.9 |
| $N_3P_3$ | 24.30 | 19.16 | 57.34 | 47.20 | 17.98 | 47.11 | 71.50 | 37.15 | 104.44 | 49.1 | 65.6 | 56.3 |
| $N_4P_1$ | 20.31 | 15.62 | 49.85 | 46.37 | 17.36 | 46.52 | 66.69 | 32.98 | 96.37 | 39.1 | 47.0 | 44.2 |
| $N_4P_2$ | 20.30 | 15.93 | 49.57 | 45.91 | 17.60 | 45.42 | 66.21 | 33.53 | 94.98 | 38.1 | 49.5 | 42.1 |
| $N_4P_3$ | 18.37 | 14.66 | 45.68 | 44.36 | 17.39 | 43.42 | 62.73 | 32.06 | 89.10 | 30.9 | 42.9 | 33.3 |
| CD (0.05) | 2.11 | 1.62 | 10.30 | 3.63 | 1.13 | 3.53 | 3.87 | 1.36 | 5.37 | - | - | - |

$N_1$, $N_2$, $N_3$ and $N_4$: N @ 25, 50, 75 and 100 kg N ha$^{-1}$; $P_1$, $P_2$ and $P_3$: $P_2O_5$ @ 25, 50 and 75 kg ha$^{-1}$, respectively

of 25 kg ha$^{-1}$ $P_2O_5$ showed higher P use efficiency (149 kg tubers per kg $P_2O_5$) and higher doses of N and P considerably decreased the nutrient use efficiency (Table 7). Higher K use efficiency (285 and 278 kg tubers per kg $K_2O$) was observed due to the combined application of 20 kg $K_2O$ ha$^{-1}$ and 75 kg N ha$^{-1}$ and 20 kg $K_2O$ with 50 kg $P_2O_5$ ha$^{-1}$ respectively. The combination, 25 kg N and 75 kg $P_2O_5$ ha$^{-1}$ resulted in higher N use efficiency (216 kg tubers per kg N). The highest P use efficiency (87 kg tubers per kg $P_2O_5$) was observed due to the combined application of 75 kg N and 25 kg $P_2O_5$ ha$^{-1}$. Highest K use efficiency (359 kg tubers per kg $K_2O$) was obtained due to the application of 20 kg ha$^{-1}$ of $K_2O$ in combination with 50 kg ha$^{-1}$ each of N and $P_2O_5$. This may be ascribed to higher biomass production and nutrient uptake due to balanced fertilization. Thus, the results emphasized the need for balanced and optimum fertilization to improve the efficiency of applied NPK fertilizers and to obtain higher productivity. These results are in agreement with the findings of Marti and Mills (2002).

### Apparent nutrient recovery

Highest N recovery (59%) was obtained due to the application of 25 kg N ha$^{-1}$, whereas highest P recovery (32%) was noticed due to the application of 25 kg $P_2O_5$ ha$^{-1}$. Both N and P recovery declined with super optimal doses of N and P fertilization (Table 7). Addition of 20 kg $K_2O$ ha$^{-1}$ combined with 75 kg N ha$^{-1}$ resulted in highest K recovery (172%). Integrated application of 25 and 75 kg ha$^{-1}$ of N and $P_2O_5$ showed highest N recovery (81%), whereas highest P recovery (45%) was noticed due to the application of 75 and 25 kg ha$^{-1}$ of N and $P_2O_5$, respectively. However, highest K recovery (188%) was observed due to the application of 20 kg ha$^{-1}$ of K in combination with 50 kg ha$^{-1}$ each of N and $P_2O_5$. The results indicated that recovery of N, P and K was higher at lower doses of NPK application. Application of optimum doses of N and P fertilizers along with lower doses of K also contributed to highest K recovery.

Table 7. Main and interaction effects of N and P on nutrient use efficiency and apparent nutrient recovery (mean of 2010 and 2011)

| Treatment | Nutrient use efficiency (kg tubers per kg nutrient applied) | | | Apparent nutrient recovery (%) | | |
|---|---|---|---|---|---|---|
| | N | P | K | N | P | K |
| N levels (kg ha$^{-1}$) | | | | | | |
| 25 | 166.8 | - | 208.5 | 58.7 | - | 108.5 |
| 50 | 107.4 | - | 268.5 | 40.7 | - | 147.9 |
| 75 | 75.9 | - | 284.5 | 29.5 | - | 172.1 |
| 100 | 41.0 | - | 205.0 | 17.3 | - | 133.2 |
| P levels ($P_2O_5$ kg ha$^{-1}$) | | | | | | |
| 25 | - | 148.8 | 186.0 | - | 32.0 | 114.5 |
| 50 | - | 111.0 | 277.5 | - | 22.6 | 152.1 |
| 75 | - | 69.7 | 261.5 | - | 16.1 | 154.7 |
| Interaction (N x P) | | | | | | |
| $N_1P_1$ | 104.0 | 45.4 | 130.0 | 34.8 | 17.0 | 58.6 |
| $N_1P_2$ | 180.0 | 38.8 | 222.0 | 60.4 | 17.0 | 120.0 |
| $N_1P_3$ | 216.4 | 31.5 | 270.5 | 80.8 | 14.2 | 146.9 |
| $N_2P_1$ | 57.6 | 50.3 | 144.0 | 23.3 | 23.6 | 87.1 |
| $N_2P_2$ | 143.4 | 62.6 | 358.5 | 51.6 | 26.5 | 184.2 |
| $N_2P_3$ | 121.4 | 35.3 | 303.5 | 47.3 | 17.8 | 172.4 |
| $N_3P_1$ | 66.4 | 87.0 | 249.0 | 28.2 | 45.2 | 164.8 |
| $N_3P_2$ | 78.3 | 51.3 | 293.5 | 28.7 | 24.8 | 163.6 |
| $N_3P_3$ | 83.1 | 36.3 | 311.5 | 31.4 | 19.6 | 188.0 |
| $N_4P_1$ | 44.3 | 77.4 | 221.5 | 18.8 | 42.2 | 147.7 |
| $N_4P_2$ | 46.5 | 40.6 | 232.5 | 18.3 | 22.2 | 140.7 |
| $N_4P_3$ | 32.3 | 18.8 | 161.5 | 14.8 | 12.8 | 111.3 |

$N_1$, $N_2$, $N_3$ and $N_4$: N @ 25, 50, 75 and 100 kg ha$^{-1}$; $P_1$, $P_2$ and $P_3$: $P_2O_5$ @ 25, 50 and 75 kg ha$^{-1}$, respectively

The present study emphasized that for saline soil conditions application of 50 kg ha$^{-1}$ each of N and $P_2O_5$ was sufficient to produce sustainable yields of sweet potato with good quality tubers. However, application of lower doses of N and P resulted in higher nutrient use efficiency and recovery of applied nutrients. Thus, cultivation of salt tolerant genotypes of sweet potato along with the application of N, $P_2O_5$ and $K_2O$ @ 50:50:20 kg ha$^{-1}$ results in higher crop yields and offers good scope for livelihood and nutritional security in the saline tracts of West Bengal, India.

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