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# A Study on the Effect of Deep and Differential Depths Placement of Fertilizers on Potato Crop Response

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***Abstract*** **– A 'Field Pot Experiment' was conducted at Pantnagar during 2012-13 to develop the basic concept for applying organic manures (vermicompost) and inorganic fertilizers either alone or in combination at appropriate depths and rates in the root zone of potato crop (Var : 'Kufri Khyati'). Nine treatments selected for the study were; $T_1$ : (100% inorganic + Mixing 150 mm depth)-control, $T_2$ : (50% N inorganic + 50% N organic + Mixing 150 mm depth), $T_3$ : (100% inorganic placed at 150 mm depth below full width of ridge), $T_4$ : (100% inorganic placed at 250 mm depth below full width of ridge), $T_5$ : (80% inorganic placed at 250 mm and 20% inorganic placed at 350 mm depth), $T_6$ : (50% N inorganic placed at 250 mm + 50% N organic placed at 350 mm depth), $T_7$ : (100% inorganic + Mixing 150 mm and hard pan formed manually at 250 mm depth), $T_8$ : (50% N inorganic + 50% N organic placed at 150 mm & tillage up to 250 mm depth) and $T_9$ : (100% inorganic placed at both sides of ridge i.e. in furrows at 150 mm depth). The experiment was laid in clay loam soil in RBD with three replications. The 'Field Pots' of 2.5 × 2.5 m size were dug manually and after placing the fertilizer as per above treatments, all the pots were filled with soil and potato tubers were planted on the ridges at 600 × 200 mm spacing. All the agronomical package of practices recommended for potato crop was followed. Different crop growth parameters were noted at 45, 60 and 75 DAP, and the yield attributes as well as root dry mass and length were noted as per standard protocols for field experiments. The maximum yield in treatment $T_5$ (51.16 t/ha) was found significantly ($p<0.05$) higher than treatments $T_1$ (39.12 t/ha), $T_4$ (35.61 t/ha) and $T_2$ (34.08 t/ha) but was at par with treatments $T_6$ (48.10 t/ha), $T_8$ (47.91 t/ha) $T_9$ (46.69 t/ha), $T_3$ (45.84 t/ha) and $T_7$ (44.31 t/ha). In treatments $T_5$, $T_6$ and $T_8$, the average yield was found to be higher by 23.5, 18.67 and 18.35%, respectively than that of conventional method ($T_1$). The maximum tuber yield under grade A (>75 g) was found significantly higher in treatment $T_5$ (30.91 t/ha) followed by treatments $T_1$ (24.06 t/ha), $T_4$ (21.42 t/ha) and $T_2$ (18.83 t/ha) which was at par with treatments $T_3$ (26.37 t/ha), $T_6$ (28.20 t/ha), $T_7$ (25.74 t/ha), $T_8$ (27.82 t/ha) and $T_9$ (24.86 t/ha). It was postulated that the placement of fertilizers deeply into the soil and at different depths and rates in the root zone would increase the fertilizer use efficiency leading to substantial saving of fertilizers and increase in the yield. Recommendations were made to develop / adopt deep and differential rate fertilizer application machinery to meet the above requirements.**

***Keywords*** **– Deep and Differential Rate Placement of Fertilizers, Enhancing Productivity and Quality of Potato, Fertilizer Placement in Root Zone, Field Pot Experiment on Potato.**

## I. INTRODUCTION

Potato is the third most important food crop in the world after rice and wheat which is consumed by more than a billion people worldwide. Both, potato production and consumption are accelerating in most of the developing countries including India. Two emerging Asian economies, viz. China and India together contribute nearly 1/3rd of the global potato production. Potato is preferred in these densely populated countries largely because of its high productivity, flexibility in terms of fitting into many prevailing cropping systems, and stable yields under conditions in which other crops may fail. Potato consumption in this region is increasing due to increasing industrialization and participation of women in the job market that created demand for processed, ready-to-eat convenience food, particularly in urban areas. Keeping in view the potential of food in the food security of developing nation, FAO has declared potato as 'Food for the Future'.

In India, potato is considered as a vegetable item and not as a staple food. The per capita consumption of potato in India is far below many of the developed nations. In fact, China has identified potato as the key crop from which 50% of its extra food demand could be met during next 20 years. Potato in India was cultivated in about 1.9 mha which is about 1.25% of total cultivable area and contributed approximately 2.42% of agricultural GDP in 2008. Among the vegetables segment, the share of potato is estimated to be approximately 26 percent.

The average yield of potato in India is much below its potential crop productivity. Though productivity of India is better than other top producers like China, Russian Federation and Ukraine, it is less than half of USA and major European countries. One of the reasons of poor productivity by subsistence farmers is the use of locally produced degenerated seeds and non- adoption of modern agro-techniques. Making available certified healthy seeds coupled with appropriate agro-techniques would undoubtedly improve its productivity. Another important factor responsible for low yield is inadequate fertilizer application and its method of placement. The potato has high requirement of nutrients like nitrogen, phosphorus and potash. Low use of fertilizers and serious imbalances in the NPK application ratio are partially responsible for low yield. The current fertilizer rates are not sufficient to sustain the higher yield of potato and to replenish nutrients removal by the crop. Non-availability and their higher cost as well as poor quality of inorganic fertilizers also play an important role in low productivity.

The incorporation of P and K in subsoils has positive results as reported by many researchers (Rowse and Stone, 1980; Godwin and Spoor, 1981; Mandal, 2007; Singh, 2008; Mandal and Thakur, 2010a). Organic manures are good sources of different macro and micro-nutrients, and have a significant role to play in nutrient supply. In addition to improving soil physico-chemical properties, the supplementary and complementary use of organic manures also improve the efficiency of mineral fertilizers. Many field studies have demonstrated a decrease in soil bulk density and increase in porosity by compost application (Bulluck and Ristaino, 2002). Vermicompost, which is an important and valuable source of plant nutrients, increases the root nodulation, microbial activity in the rhizosphere, soil organic carbon, crop growth and yield attributes, available NPKS and micronutrients, and decreases the bulk density of soil when used either alone or in combination with inorganic fertilizers (Sharma and Agrawal. 2003; Manjunatha *et al.,* 2006; Pawar and Patil, 2007). Packing of FYM in furrows has been found to increase the productivity of rainfed wheat in hill eco-system by about 38% over the conventional method (Anonymous, 2009).

Incorporation of P and K into subsoil has been found to increase the yield of potato by 16% in sandy loam soil (Mc Even and Johanston, 1979). Under Indian condition, subsoiling in sandy loam soil has been found to increase the potato yield by 9-10% over conventional method of seedbed preparation with a plough and harrow system. In another studies conducted at Pantnagar by Papal (2004) and Thakur *et al.* (2005) have revealed a significant increase in potato tuber yield by 11.70 % and 8.8% with subsoiling up to 350 mm depth by using a winged subsoiler with shallow leading tines over other methods of seedbed preparation i.e. a mounted disc harrow (150 mm depth), and a winged chiseler (200 mm depth), respectively.

A number of 'Pot Experiments' have been conducted in green houses under controlled conditions for observing the behaviour of top soil and subsoil taken from the lower depths on the response of plants. The results have indicated that the top soil gives plant food but the plants cannot obtain food from the subsoil due to poor soil structure and occurrences of multi-nutrient deficiencies. In 'Pot Experiments', the roots are confined inside the pot, hence interaction effects amongst the plants are altogether absent. An alternative method could be a 'Field Pot Experiment' to study the crop response in real life situation (Thakur, 2010). Singh (2010) and Singh *et al.* (2012) conducted a 'Field Pot Experiment' to study the effect of depth of placement of organic and inorganic fertilizers for depths upto 350 mm on the response of mustard crop (*var. Kranti*) and reported a substantial increase in yield with subsoil placement of fertilizers in comparison to mixing in the top 100 mm depth. In continuation of this concept, the current experiment was planned to study the response of potato crop in 'Field Pot Experiment', the results of which have been presented in this paper.

## II. Materials and Methods

A 'Field Pot Experiment' was conducted during 2012-13 at the Vegetable Research Centre of GBPUA&T, Pantnagar with an objective to establish the effect of deep placement of organic manure (vermicompost) and inorganic fertilizers on response of potato crop. This experiment was carried out to develop the basic concept for applying organic manures and inorganic fertilizers either alone or in combination at appropriate depths in the root zone of potato crop. The details of 'Field Pot Experiment' are given in Table 1.

Table 1: Details of 'Field Pot Experiment' on potato crop (2012-13)

| **a) General information** | |
|---|---|
| Crop | Potato |
| Variety | Kufri Khyati |
| Seed rate | 3.5 t/ha |
| Pot size | 2.5×2.5 = 6.25 $m^2$ |
| Gross experimental area | 10.5×26.5 = 278.25 $m^2$ |
| Row to row spacing | 600 mm |
| Plant to plant spacing | 200 mm |
| Inorganic fertilizer (N:P:K) | 160:100:120 |
| Organic (Vermicompost) | 5 t/ha |
| Design | R.B.D. |
| No. of replications | Three |
| No. of treatments | 9 |

**b) Schedule of planting and post planting operations**

| **Operations** | **Date** |
|---|---|
| Field preparation, manually | October 15-26, 2012 |
| Sowing | October 27, 2012 |
| Irrigation | November 20, 2012 |
| First Spraying (Curzate M-8 + Tatamida) | November 30, 2012 |
| Earthing-up, manually | December 6, 2012 |
| Second Spraying (Curzate M-8 + Tatamida) | December 10, 2012 |
| Third Spraying (Curzate M-8 + Tatamida) | December 27, 2012 |
| Harvesting | March 13-15, 2013 |

The experimental area was divided in three blocks of nine pots. Soil samples were collected from the experimental field for determining the initial moisture content and bulk density. The initial soil moisture content and soil bulk density were measured at various depths of 0-100, 100-200, 200-300 and 300-400 mm. A total of nine treatments as described in Table 2 with three replications were laid out in RBD. The field pots of 2.5×2.5 m size for each treatment were dug manually at different depths as per the treatments and measured quantities of organic manure (vermicompost) or inorganic fertilizers or both were placed at desired depths and covered with loose soil up to the ground surface for planting of tubers.

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Table 2: Details of different treatments in 'Field Pot Experiment'

| Symbol | Treatments combination |
|---|---|
| $T_1$ | 100% (inorganic) + Mixing (150 mm depth) |
| $T_2$ | 50% N (inorganic) + 50% N (organic) + Mixing (150 mm depth) |
| $T_3$ | 100% (inorganic) placed at 150 mm depth (below full width of ridge) |
| $T_4$ | 100% (inorganic) placed at 250 mm depth (below full width of ridge) |
| $T_5$ | 80% (inorganic) placed at 250 mm and 20% (inorganic) placed at 350 mm depths |
| $T_6$ | 50% N (inorganic) placed at 250 mm + 50% N (organic) placed at 350 mm depths |
| $T_7$ | 100% (inorganic) + Mixing (150 mm) and hard pan formed manually at 250 mm depths |
| $T_8$ | 50% N (inorganic) + 50% N (organic) placed at 150 mm & tillage up to 250 mm depths |
| $T_9$ | 100% (inorganic) placed at both sides of ridge i.e. in furrows at 150 mm depths |

*Inorganic: Urea and NPK mixture (12% N, 32% P and 16% K)
**Organic: Vermicompost (1.5% N, 1.1% P and 1.3% K)
50% N (inorganic): 50% N through Urea, and 100% P and K

In each pot, 4 rows were formed at the spacing of 600 mm and a tuber was placed at 200 mm plant to plant spacing and covered with soil to form ridges of 150 mm height. In each row the total number of tubers was 12. The same procedure was followed in other field pots. The sequence of operations followed in the experiment is illustrated in Fig. 1. Full dose of P and K, and 50% of N in form of inorganic and 50% of N in form of organic manure (vermicompost) was placed as per experimental design. The remaining 50% of N was applied through placement to the sides during earthing up operation. The plant emergence was noted at 30 DAP. In each pot, three plants were tagged and all the crop growth parameters such as plant height, number of shoots, number of leaves etc. were noted at different time intervals of 45, 60 and 75 DAP. Yield attributes such as number of tubers per plant, total weight of tubers per plant, grades and yield of tubers were noted as per standard procedures recommended for field experiments. Root's length and its dry weight was also measured in each treatment.

a. Manual digging of field pots

b. Levelling of field pots after fertilizer placement

c. Planting of tubers

d. Ridge formation after planting

e. Crop growth during experiment

f. Harvesting of field pot

Fig.1. Sequence of different operations and stages followed in 'Field Pot Experiment' 2012-13

## III. Results and Discussion

### *3.1 Soil moisture content and bulk density*

The soil parameters such as moisture content and dry soil bulk density were noted while digging the field pots and are shown in Table 3. The initial soil moisture content (d.b.) and dry soil bulk density of experimental field was found to be 9.89, 11.94, 12.15 and 12.52%; and 1.28, 1.67, 1.82 and 2.00 Mg/m$^3$ for the depths of 0-100, 100-200, 200-300 and 300-400 mm, respectively. Significantly maximum bulk density of 2.00 Mg/m$^3$ was found at 300-400 mm depth which was in equivalence with the bulk density of 1.82 Mg/m$^3$ found at 200-300 mm depth.

Table 3: Initial soil moisture content and dry bulk density at different depths in 'Field Pot Experiment'

| Depth, mm | Moisture content (d.b.), % | Bulk density (d.b.), Mg/m$^3$ |
|---|---|---|
| 0-100 | 9.89 | 1.28 |
| 100-200 | 11.94 | 1.67 |
| 200-300 | 12.15 | 1.82 |
| 300-400 | 12.52 | 2.00 |
| **S. Em.±** | **0.28** | **0.05** |
| **C. D. at 5%** | **0.98** | **0.18** |
| **C.V.** | **4.21** | **5.41** |

### *3.2 Plant emergence*

The data obtained on percentage plant emergence are presented in Table 4 for different tillage treatments. At 30 DAP, the maximum emergence was found in treatment $T_2$

(94.28%) followed in order by treatments $T_3$ and $T_7$ (91.67%), $T_5$ (89.58), $T_1$, $T_4$, $T_6$ and $T_9$ (88.89%) and $T_8$ (88.19%). However, there was no significant difference found among different treatments which shows that the depths of placement of fertilizers had no effect on plant emergence. Also, no significant difference was found among replications.

Table 4: Plant emergence percentage in different treatments

| Treatments | Emergence per pot, % | | | |
|---|---|---|---|---|
| | $R_1$ | $R_2$ | $R_3$ | Average |
| $T_1$ | 93.75 | 93.75 | 79.17 | 88.89 |
| $T_2$ | 97.92 | 95.33 | 89.58 | 94.28 |
| $T_3$ | 100 | 91.67 | 83.33 | 91.67 |
| $T_4$ | 93.75 | 91.67 | 81.25 | 88.89 |
| $T_5$ | 91.67 | 87.50 | 89.58 | 89.58 |
| $T_6$ | 89.58 | 91.67 | 85.42 | 88.89 |
| $T_7$ | 89.58 | 97.92 | 87.50 | 91.67 |
| $T_8$ | 83.33 | 91.67 | 89.58 | 88.19 |
| $T_9$ | 89.58 | 93.75 | 83.33 | 88.89 |

S. Em.± = 2.46 C. D. at 5% = 7.38 C. V. = 4.73

### *3.3 Plant height*

Effect of the methods of placement of fertilizers on plant height at 45$^{th}$, 60$^{th}$ and 75$^{th}$ day after planting is shown in Fig. 2a. At 45$^{th}$ day stage, the maximum height of plants was found in treatment $T_5$ (208 mm) i.e. 80% (inorganic) placed at 250 mm and 20% (inorganic) placed at 350 mm depth which was statistically at par with $T_1$ (193 mm), $T_6$ (191 mm), $T_3$ (190 mm), $T_9$ (179 mm), $T_8$ (176 mm), $T_2$ (170 mm) and $T_4$ (164 mm). The lowest plant height was found in treatment $T_7$ (141 mm) i.e. mixing of 100% (inorganic) in 150 mm depth and hard pan formed manually at 250 mm depth but the variations among treatments were found to be non-significant.

Again, at 60$^{th}$ day stage the variations in height of plants among the treatments were found non-significant. However, the maximum average value was obtained in treatment $T_5$ (469 mm) followed in order by treatments $T_6$ (465 mm), $T_8$ (432 mm), $T_3$ (427 mm), $T_1$ (421 mm), $T_9$ (404 mm), $T_4$ (397 mm) and $T_2$ (392 mm). The lowest plant height was found in treatment $T_7$ (391 mm). At 75$^{th}$ day stage, it is evident that the maximum average height of plants was in treatment $T_5$ (490 mm) followed in order by treatments $T_6$ (479 mm), $T_8$ (454 mm), $T_3$ (453 mm), $T_1$ (440 mm), $T_9$ (422 mm), $T_4$ (417 mm), $T_7$ (411 mm) and $T_2$ (408 mm) but these variations were found to be non-significant.

### *3.4 Number of shoots per plant*

The data obtained on the average number of shoots per plant at 45$^{th}$, 60$^{th}$ and 75$^{th}$ day after planting are illustrated in Fig. 2b. At 45$^{th}$ day stage, the maximum average number of shoots per plant was found in treatments $T_1$, $T_3$ and $T_9$ (2.78), followed in order by treatments $T_6$ (2.67), $T_7$ (2.66), $T_4$ (2.45), $T_5$ (2.33) and $T_2$ (2.22). The lowest average number of shoots per plant was found in treatment $T_8$ (1.78) but these differences were non-significant. At 60$^{th}$ day after planting stage, the average number of shoots per plant was found in treatments $T_1$ and $T_9$ (3.22), followed in order by treatments $T_3$ and $T_7$ (3.11), $T_6$ (2.89), $T_4$ and $T_5$ (2.67), $T_2$ (2.44) and $T_8$ (2.00). The same trend was observed up to 75$^{th}$ day after planting. No significant difference was found among replications at all the three growth stages. It was observed that majority of the shoots emerged at 45 DAP with a very small increase up to 60 DAP and thereafter, no increase was observed.

### *3.5 Number of leaves per plant*

The number of leaves per plant obtained at 45$^{th}$, 60$^{th}$ and 75$^{th}$ day stages after planting is illustrated in Fig. 2c. At 45$^{th}$ day stage, the maximum number of leaves per plant found in treatment $T_5$ (35) was significantly higher than the treatments $T_8$ (30), $T_1$, $T_4$ and $T_9$ (25), $T_7$ (24), $T_3$ (23) and $T_2$ (22), but was at par with treatment $T_6$ (32). At 60$^{th}$ day stage, the maximum average value was obtained in treatment $T_5$ (75) which was at par with treatments $T_6$ (69) and $T_8$ (64) but significantly higher than treatments $T_1$ (57), $T_9$ (55), $T_4$ and $T_7$ (53), $T_3$ (50) and $T_2$ (47). Similarly, at 75$^{th}$ day stage, the maximum number of leaves was observed in treatment $T_5$ (89) followed by $T_6$ (79) and $T_8$ (74) but it was non-significant. The variations among different treatments i.e. $T_9$ (64), $T_3$ (63), $T_1$, $T_4$ and $T_7$ (61), and $T_2$ (54) were found to be significant ($p \leq 0.05$). It could be seen that the average number of leaves per plant was found maximum in treatment $T_5$ but having no significant difference with $T_6$ at all the growth stages of plants. Also, no significant difference was found among replications.

### *3.6 Number of tubers per plant*

The observation on tuberization status of crop was taken at the time of harvest. The effects of different treatments on tuberization are shown in Table 5. At harvest, the average number of tubers per plant was found to be approximately equal in all the treatments. The maximum average number of tubers per plant was found in $T_5$ (12), followed in order by treatments $T_1$ (11), $T_2$, $T_4$ and $T_6$ (9), and $T_3$, $T_7$, $T_8$ and $T_9$ (10). No significant difference was found among various treatments. At harvest, the variation in tubers weight per plant was found to be significant ($p \leq 0.05$) and the maximum average value was obtained in treatment $T_5$ (1605 g) which was at par with treatments $T_6$ (1421g) and $T_8$ (1528g). However, the variation in tubers weight per plant was found significant ($p \leq 0.05$) in treatments $T_2$ (941g), $T_4$ (1021g), $T_7$ (1045g), $T_1$ (1098 g), $T_3$ (1163 g) and $T_9$ (1263g).

### *3.7 Dry matter accumulation in roots*

The visuals of roots of different treatments at harvest are shown in Fig.3. It is clear that the deep placement of organic and inorganic fertilizers had affected substantially the root length of potato crop. The root length obtained in treatment $T_5$ (510 mm) was highest but was at par with treatment $T_6$ (480 mm). However, the lowest root length of 260 mm was obtained in treatment $T_1$ (control). The maximum root length in $T_5$ and $T_6$ may be due to soil loosing up to 350 mm depth and placement of vermicompost and inorganic fertilizer at deeper depths which provided pathways for easy penetration of roots to deeper soil layers in search of water and nutrients.

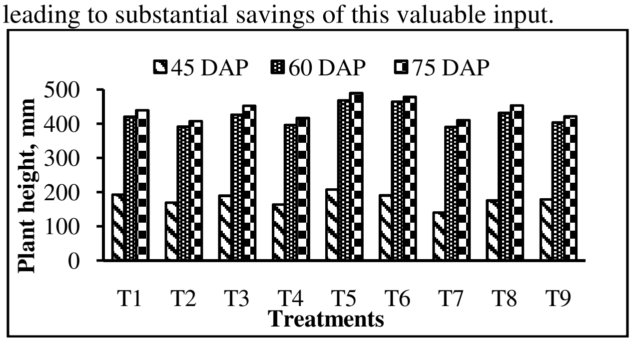
It is also evident from the data that the treatments which had soil loosing up to 250 mm depth such as $T_4$, $T_7$ and $T_8$ gave variations in root lengths as 320, 400 and 450 mm, respectively. Similarly, the treatments with soil loosing up to 150 mm such as $T_1$, $T_2$ $T_3$ and $T_9$ resulted in root lengths of 260, 320, 300 and 450 mm, respectively. The above results clearly indicated the positive effect of soil loosening, and deep and differential rate fertilizer placement methods on the root development of potato crop.

The observations in respect of plant roots in different treatments at harvest are shown in Table 5. The maximum root dry mass was found in treatments $T_5$ (0.74 g) followed in order by treatments $T_6$ (0.70 g), $T_8$ (0.68 g), $T_1$ (0.63 g), $T_2$ (0.56 g), $T_4$ (0.55 g), $T_3$ (0.41 g), and $T_9$ (0.40 g). The lowest root dry mass was found in treatment $T_7$ (0.33 g), but the differences were found non-significant. There was no statistical difference found in roots dry mass with deep placement of fertilizer.

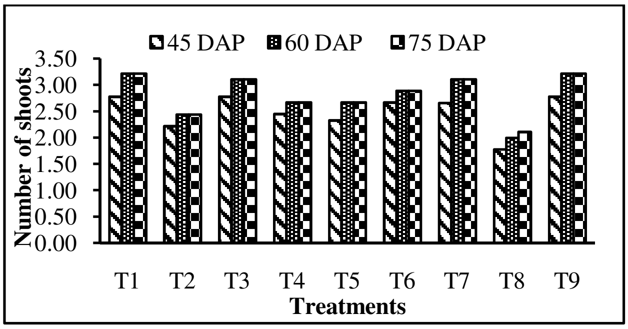
*3.8 Yield of potato*

The data obtained on yield of potato at the time of harvest are presented in Table 6.

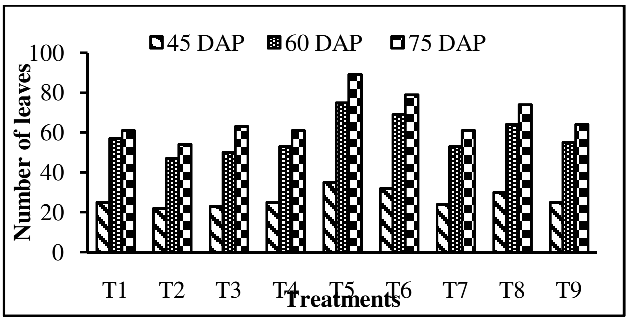
It could be seen from the table that a different trend was observed in case of total yield of potato. Treatment $T_5$, where 80% of the total fertilizer dose was applied at 250 mm depth and 20% fertilizer dose at 350 mm depth, has produced the maximum average yield of (51.16 t/ha) which was significantly higher than treatments $T_1$ (39.12 t/ha), $T_4$ (35.61 t/ha) and $T_2$ (34.08 t/ha), but was at par with treatments $T_6$ (48.10 t/ha), $T_8$ (47.91 t/ha), $T_9$ (46.69 t/ha), $T_3$ (45.84 t/ha) and $T_7$ (44.31 t/ha). It could, therefore, be postulated that the placement of fertilizers deeply into the soil and at different depths and rates as per density of roots would increase the fertilizer use efficiency leading to substantial savings of this valuable input.




(a) Plant height




(b) Number of shoots




(c) Number of leaves

Fig.2. Effect of placement of fertilizers on different crop growth parameters

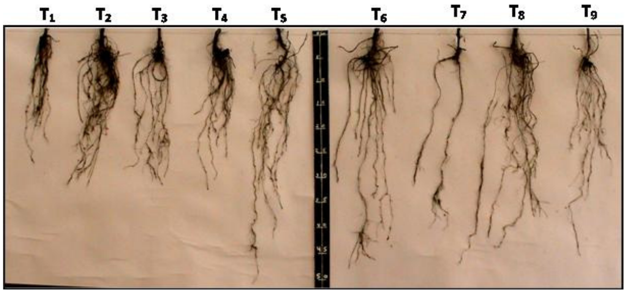



Fig. 3 Root growth of potato crop at harvest in different treatments

Table 5: Effect of organic and inorganic fertilizers placement methods on number of tubers, weight of tubers per plant and root dry mass

| Treatments | Number of tubers | Weight of tubers, g | Roots dry mass, g |
|---|---|---|---|
| **$T_1$** | 11 | 1098 | 0.63 |
| **$T_2$** | 9 | 941 | 0.56 |
| **$T_3$** | 10 | 1163 | 0.41 |
| **$T_4$** | 9 | 1021 | 0.55 |
| **$T_5$** | 12 | 1605 | 0.74 |
| **$T_6$** | 9 | 1421 | 0.70 |
| **$T_7$** | 10 | 1045 | 0.33 |
| **$T_8$** | 10 | 1528 | 0.68 |
| **$T_9$** | 10 | 1263 | 0.40 |
| **S. Em.±** | **1.29** | **108.78** | **0.11** |
| **C. D. at 5%** | **3.87** | **326.09** | **0.33** |
| **C.V.** | **22.43** | **15.29** | **34.75** |

Table 6: Potato tuber grades and total yield in different treatments

| Treatments | Tubers grade wise yield, t/ha | | | | Total tuber yield, t/ha |
|---|---|---|---|---|---|
| | A | B | C | D | |
| **$T_1$** | 24.06 | 7.31 | 5.17 | 2.58 | 39.12 |
| **$T_2$** | 18.83 | 8.85 | 4.74 | 1.66 | 34.08 |
| **$T_3$** | 26.37 | 10.80 | 6.14 | 2.53 | 45.84 |
| **$T_4$** | 21.42 | 8.91 | 3.89 | 1.39 | 35.61 |
| **$T_5$** | 30.91 | 12.30 | 5.87 | 2.06 | 51.16 |
| **$T_6$** | 28.20 | 11.31 | 5.50 | 3.09 | 48.10 |

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| | | | | | |
|---|---|---|---|---|---|
| $T_7$ | 25.74 | 11.52 | 5.42 | 1.63 | 44.31 |
| $T_8$ | 27.42 | 12.46 | 5.89 | 2.14 | 47.91 |
| $T_9$ | 24.86 | 14.82 | 5.36 | 1.65 | 46.69 |
| **S. Em.±** | **2.20** | **1.00** | **1.11** | **0.53** | **2.81** |
| **C. D. at 5%** | **6.61** | **3.00** | **3.33** | **1.59** | **8.42** |
| **C.V.** | **15.08** | **15.87** | **36.13** | **44.30** | **11.16** |

The tuber yield in treatment $T_5$ (i.e. 80% inorganic fertilizer placed at 250 mm depth and 20% inorganic fertilizer placed at 350 mm depth) was found significantly maximum as 51.16 t/ha in comparison to treatments $T_1$ (39.12 t/ha), $T_2$ (34.08 t/ha) and $T_4$ (35.61 t/ha). The tuber yield in treatment $T_5$ was approximately 23.53 %, 33.39 % and 30.40 % higher than treatments $T_1$, $T_2$ and $T_4$, respectively. This clearly indicates that incase of treatment $T_5$, where the soil was thoroughly disturbed upto 350 mm depth, had reduced the very high initial bulk density (1.82-2.0 $Mg/m^3$) with corresponding increase in porosity and hydraulic conductivity of soil. This provided a greater volume of soil to be utilized by the plants by developing relatively large, deep and extensive root system during vegetative growth of the crop. Better soil loosening helps to increase the tuber size by minimizing the soil stresses and a well developed root system could increase the water and nutrient utilization efficiency by the crop which ultimately is reflected in terms of increased yield. The lowest yield response in control treatment ($T_1$) i.e. mixing of fertilizers in top 150 mm depth clearly indicates that the plants were unable to utilize the water and nutrient reserve due to compaction (bulk density ~1.82 $Mg/m^3$) of soil beyond 150 mm depth. It must be understood that the potato roots penetrate beyond 1.4 m depth with maximum concentration of roots in the top 30 cm of soil. Therefore, proper loosening of soil atleast upto 30 cm depth is essential. It could be further emphasized that in conventional practice the full dose of P & K and 50% of N is mixed during field preparation and beds are formed upto a height of about 15 cm after planting of tubers. Also, the irrigation in furrows is recommended only upto a half of the ridge height, hence the top 50% of the ridge remains dry for most of the cropping period. As P & K are immobilized and remain in the top dry portion of the ridge, they are available only when irrigation water is applied. This shows that the efficiency of utilization of P & K is very low in conventional practice but could be improved substantially when P & K are placed below the ridge in furrows which remain moist for most part of the cropping period. Band placement further improves the utilization efficiency which is in agreement with the research findings in the past. It is evident from the results that in treatments $T_5$ and $T_6$ the average yield increased by 23.53% and 18.67%, respectively than that of conventional method ($T_1$). These findings are in line with McEwen and Johnston (1979) who reported that mixing of P and K in subsoil increased the potato yield by over 16%.

*3.9 Potato grades and yield*

The data obtained on yield of potato in different grades A, B, C and D out of the total yield are presented in Table 6. The maximum tuber yield under grade A was found to be significantly higher in treatment $T_5$ (30.91 t/ha) followed by treatments $T_1$ (24.06 t/ha), $T_4$ (21.42 t/ha) and $T_2$ (18.83 t/ha) which was at par with treatments $T_3$ (26.37 t/ha), $T_6$ (28.20 t/ha), $T_7$ (25.74 t/ha), $T_8$ (27.82 t/ha) and $T_9$ (24.86 t/ha). Similarly, the maximum tuber yield under grade B was found to be significantly higher in treatment $T_5$ (12.30 t/ha) followed by treatments $T_4$ (8.91 t/ha), $T_2$ (8.85 t/ha) and $T_1$ (7.31 t/ha) which was at par with treatments $T_3$ (10.80 t/ha), $T_6$ (11.31 t/ha), $T_7$ (11.52 t/ha), $T_8$ (12.46 t/ha) and $T_9$ (14.82 t/ha). This is because of the fact that in deep and differential rate placement of P and K, the time needed for the roots to reach to the available nutrients is comparatively high than other treatments. Trehan (2003) also reported that nitrogen enhanced tuber yield by increasing both number and size of tubers, however, increase in size of tubers contributed more to yield than number of tubers.

In case of grade C, tuber yield was noted non-significantly highest in treatment $T_3$ (6.14 t/ha) followed by the treatments $T_1$ (5.17 t/ha), $T_2$ (4.74 t/ha), $T_4$ (3.89 t/ha), $T_5$ (5.87 t/ha), $T_6$ (5.50 t/ha), $T_7$ (5.42 t/ha), $T_8$ (5.89 t/ha) and $T_9$ (5.36 t/ha). Similarly in the grade D, the highest tuber yield was found in treatment $T_6$ (3.09 t/ha) followed by the treatments $T_1$ (2.58 t/ha), $T_3$ (2.53 t/ha), $T_8$ (2.14 t/ha), $T_5$ (2.06 t/ha), $T_2$ (1.66 t/ha), $T_9$ (1.65 t/ha), $T_7$ (1.63 t/ha) and $T_4$ (1.39 t/ha), respectively but found to be statistically non- significant. The results in relation to various grades of tubers in different treatments are also illustrated in Fig. 4.


Fig.4. A view of harvested potato tuber grades in different treatments

## V. Conclusion

There was no significant difference found in respect of emergence, height of plants and number of shoots per plant amongst different treatments. The number of leaves per plant in treatment $T_5$ (80% (inorganic) placed at 250 mm and 20% (inorganic) placed at 350 mm depths) was found maximum at all the stages of plant growth which was found to be significantly higher than conventional method $T_1$ (100% (inorganic) + Mixing in 150 mm depth).

The numbers of tubers per plant were found to vary non-significantly among treatments with maximum of 12 tubers in $T_5$. The variation in tubers weight per plant among the treatments was found significant. The maximum average value was obtained in treatment $T_5$ (1605g) which was par at with treatments $T_6$ (1421g) and $T_8$ (1528 g). However, the variation in tubers weight per plant was found significant in treatments $T_2$ (941g), $T_4$ (1021g), $T_7$ (1045g), $T_1$ (1098g), $T_3$ (1163g) and $T_9$ (1263g).

Deep soil loosening and placement of fertilizers in the root zone helped to increase root length and dry matter accumulation of root. Dry matter accumulation in root and root length was highest in deep and differential rate placement method in comparison to conventional method.

The deep and differential rate fertilizer placement method ($T_5$) gave the maximum potato yield of 51.16 t/ha followed at par with the method of 50% N (inorganic) placed at 250 mm and the remaining 50% N (organic) basal dose placed at 350 mm depth ($T_6$) with 48.10 t/ha of average yield. The conventional method of mixing basal dose of 100% P & K and 50% N (inorganic) in top 150 mm depth ($T_1$) before ridge formation gave 39.12 t/ha tuber yield which indicated approximately 23.53% higher yield in deep and differential rate placement method over conventional practice. Maximum yield of Grade-A (>75g) potato was found in treatment $T_5$ (30.91 t/ha) followed by $T_6$ (28.20 t/ha) which was 22.16% and 14.68% higher than conventional method ($T_1$) with 24.06 t/ha potato yield, respectively.

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