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Research Article

Effect of Residue Incorporation and Integrated Nutrient Management on Tuber Grading, Yield and Yield Attributes of Potato

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ABSTRACT

A field experiment on integrated nutrient management was conducted in loamy sand soil of Indo-Gangetic Plain during 2018-19 and 2019-20 at Student's Research Farm, Department of Agronomy, PAU, Ludhiana (India) with four treatment combinations randomized in potato *viz.,* straw removal + 100 % NPK + FYM @ 50 t ha^{-1}, straw removal + 150 % NPK, straw incorporation + 100 % NPK + FYM @ 50 t ha^{-1} and straw incorporation + 150 % NPK. The experiment was conducted in randomized complete block design with three replications. Yield attributes *viz.,* number of tillers per plant, number of tubers per plant and tuber weight per plant were significantly higher under residue incorporated plots along with application of 100% NPK + FYM @ 50 t ha^{-1} during both the years. Application of 100% NPK + FYM @ 50 t ha^{-1} along with rice residue incorporation increase the number and weight of medium sized tuber by 81.4 and 74.5%, 98.0% and 90.3% and resulted in significantly higher tuber yield (366.3 and 375.4 q ha^{-1}), gross returns (166.3 and 202.7 × 10^3 Rs ha^{-1}) and net returns (76.0 and 104.8 × 10^3 Rs ha^{-1}) as compared to residue removal + 150% NPK during 2018-19 and 2019-20, respectively. Combined use of 100% NPK + FYM @ 50 t ha^{-1} + residue incorporation to potato recorded significant increase in yield attributes, tuber yield and B:C as compared to residue removal + 150% NPK.

Key words: Integrated nutrient management, residue incorporation, tuber grading and tuber yield

Introduction

Potato (*Solanum tuberosum* L.) is an important crop among all vegetables and has an important role in our daily diet. It is a balanced food containing less energy but nutritionally high quality protein, essential vitamins and minerals including trace elements (Kaundal *et al.,* 2018). It is known as poor man's friend because it supplies high nutrition and low cost energy to people. Potato protein is superior to that of cereals and rich in essential amino acid 'lysine' and vitamin C. In addition, its varieties that contain high levels of starch are utilized as raw materials in the production of flour, starch and alcohol (Arioglu *et al.,* 2014). Cropping systems involving potato crop has special significance in developing countries as it has high production potential per unit area and time, and has high nutritional value to sustain burgeoning population and to overcome malnutrition and hunger (Jatav *et al.,* 2017). Considering the starvation and malnutrition problems of millions of human beings, the Food and Agriculture Organization of the United Nations declared 2008 as the "*International Year of Potato*" (Arioglu and Gulluoglu, 2014).

Integrated nutrient management (INM) is defined as the use of inorganic, organic and biological

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nutrient sources in optimum condition to achieve and sustain optimum yield without harming the soil ecosystem and environment. Integration of organic manure along with synthetic fertilizers in agricultural crop production systems assist to improve soil structure, soil moisture conservation and soil microbial activity which, helps to increase the production and productivity of the crops and may increase mineralization and mobilization of nutrients (Mahapatra *et al.,* 2018). Therefore, the sources of nutrients are to be chosen and managed carefully for sustainable crop production, particularly in maize based cropping system (Zerihun *et al.,* 2013). These include inorganic fertilizers, organic manures and inclusion of legumes crops in cereal based cropping system. Organic sources of plant nutrients offer the twin benefits of increase in organic matter content and improvement in physical, chemical and biological properties of the soil while meeting a part of nutrients need of crops (Meena *et al*., 2019).

Crop residues are the plants parts left in the agricultural field after crops have been harvested and threshed. A huge amount of rice-straw has been produced annually in the rice growing countries (Ghimire *et al*., 2017). Moreover, the adoption of mechanized farming techniques has resulted in leaving a large amount of residue in the field after harvesting the crops (Chen *et al*., 2019). In India, the estimated cereal crop residues production is 361 $\times 10^6$ kg yr^{-1}, of which wheat residue contribute about 33 % and rice residue contribute about 53 % (Rathod *et al*., 2019). Due to production of large amount of residues farmers are burning the stubble to make the field free for sowing of next crop. Residue burning is not an advantageous act because it leads to air pollution, loss nutrients from soil, destruction in soil structure, serious health hazards in human being and global warming (Sidhu *et al*., 2020). Thus, there is an urgent need for residue management of different crops for stability and sustainability of the production system. Ploughing is the most efficient residue incorporation method into the soil. The advantage of crop residue incorporation is that the soil microorganisms temporarily immobilize the nutrients that are released into the soil from residues and conserve the nutrients as slowly available forms, therefore, plants cannot take up all of the nutrients at one time, but the nutrients may become available throughout the crops life or in the subsequent crop (Rani *et al*., 2019). This accelerates the nutrient use efficiency and prevents nutrient losses through leaching or volatilization (Sarkar *et al*., 2020).

Materials and Methods

The present investigation was carried out at Students' Research Farm, Department of Agronomy, Punjab Agricultural University, Ludhiana (India). The experiment was established during *rabi* seasons of 2018-19 and 2019-20. The experimental soil of Ludhiana is loamy sand and was low in organic carbon and available nitrogen, medium in available potassium and high in available phosphorus. However, the EC and pH of soil were found to be in normal range. The field experiment was conducted in randomized complete block design (RCBD) which was replicated thrice. Four treatment combinations were randomized in potato crop *viz.,* straw removal + 100 % NPK + FYM @ 50 t ha^{-1}, straw removal + 150 % NPK, straw incorporation + 100 % NPK + FYM @ 50 t ha^{-1} and straw incorporation + 150 % NPK. The experiment consist of two crops i.e. rice-potato during 2018-19 and 2019-20. Initially rice crop was transplanted in the field and after the harvesting of rice crop potato was planted and the residue generated from rice crop was utilized in potato field. Total straw yield recorded after harvesting of rice crop was 13.6 and 12.9 t ha^{-1} during 2018-19 and 2019-20, respectively and 100% of the straw yield was incorporated into soil before planting of potato crop during both the years. The recommended fertilizer dose applied to potato crop was 187.5:62.5:62.5 kg ha^{-1} $N:P_2O_5:K_2O$ during both the season. Full dose of P and K and half dose of N was applied at sowing and the remaining half N at the time of earthing-up. A tractor mounted ridger was used for preparation of 60 cm wide ridges. Planting of potato tubers was done manually by keeping plant to plant distance 20 cm.

The experimental site i.e. Ludhiana is situated at $30^0 54'$ N latitude and $75^0 48'$ E longitude with an altitude of 274 meters above the mean sea level, is placed in the central plain region of Punjab under Trans Gangetic agro-climatic zone of India. It represents sub-tropical and semi-arid climate with very hot and dry summer from April to June, hot and humid conditions from July to September, cold winters from November to January and mild climate during February to March. Ludhiana receive average annual rainfall of 755 mm and major portion (> 75 per cent) of the rainfall is received as summer monsoon from July to September. During winter, the rainfall is scanty but a few showers of cyclonic rains are received during December-January or late spring due to western disturbances. *Rabi* season is marked with lower temperature during the sowing of *rabi* crops and bright sunshine hours during the flowering or maturity period.

The weekly mean maximum air temperature during the potato growing period ranged from 17.2-30.6°C and 10.4-30.4°C, while weekly mean minimum temperature ranged from 2.79-16.0°C and 4.91-16.2°C during 2018-19 and 2019-20, respectively. The maximum and minimum weekly mean temperature of 30.6°C, 30.5°C and 2.79°C, 4.91°C were recorded during 43rd, 43rd and 52nd, 6th week of crop season of 2018-19 and 2019-20. The maximum 75.3 and 83.9 per cent weekly mean relative humidity were recorded during 6th and 51st week of crop season of 2018-19 and 2019-20, respectively. The minimum 59.3 and 59.9 per cent weekly mean relative humidity were recorded during 47th and 45th week of crop season of 2018-19 and 2019-20, respectively. Total rainfall, sunshine hours and evapo-transpiration of 137.1, 121.8 mm, 550.8, 496.3 hrs and 186.3, 153.3 mm were recorded during 2018-19 and 2019-20 (Fig. 1 and 2).

For tuber grading, number of tubers from each plot were recorded and categorized into three grades *viz.,* small sized (<50 g), medium sized (50-100 g) and large sized (>100 g). For grade wise tuber weight above graded tubers *viz.,* small sized (<50 g), medium sized (50-100 g) and large sized (>100 g) were weighed separately from each plot. Fresh weight of tubers was recorded and expressed in q ha^{-1}. The tuber yield of potato was recorded from net plot area and converted into q ha^{-1} under different treatments. Gross return is the total amount of income or returns from each crop. Gross returns are obtained by multiplying the quantity of output with prevailing local market price. Net return was calculated by subtracting the total cost of cultivation from gross returns of the system. B:C was calculated to access the feasibility of the treatments and it is the ratio between net returns obtained from the system and the total cost of cultivation. The economics was calculated as per

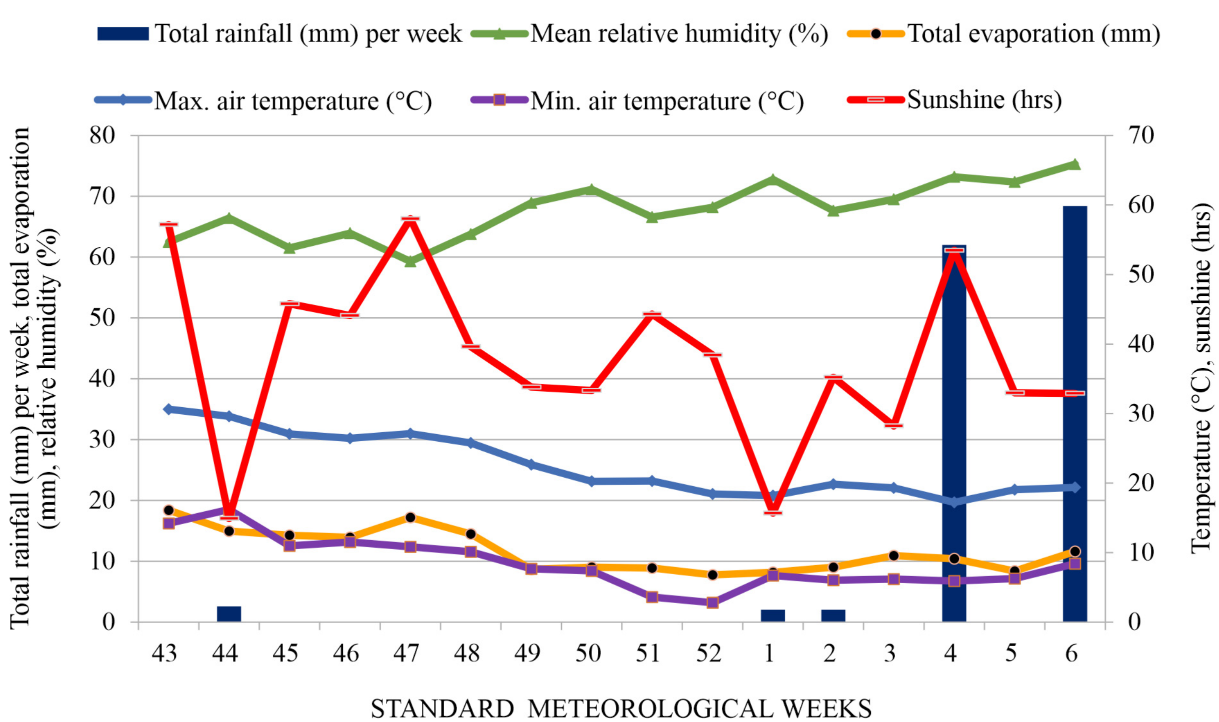

Fig. 1. Standard meteorological weather data for potato 2018-19

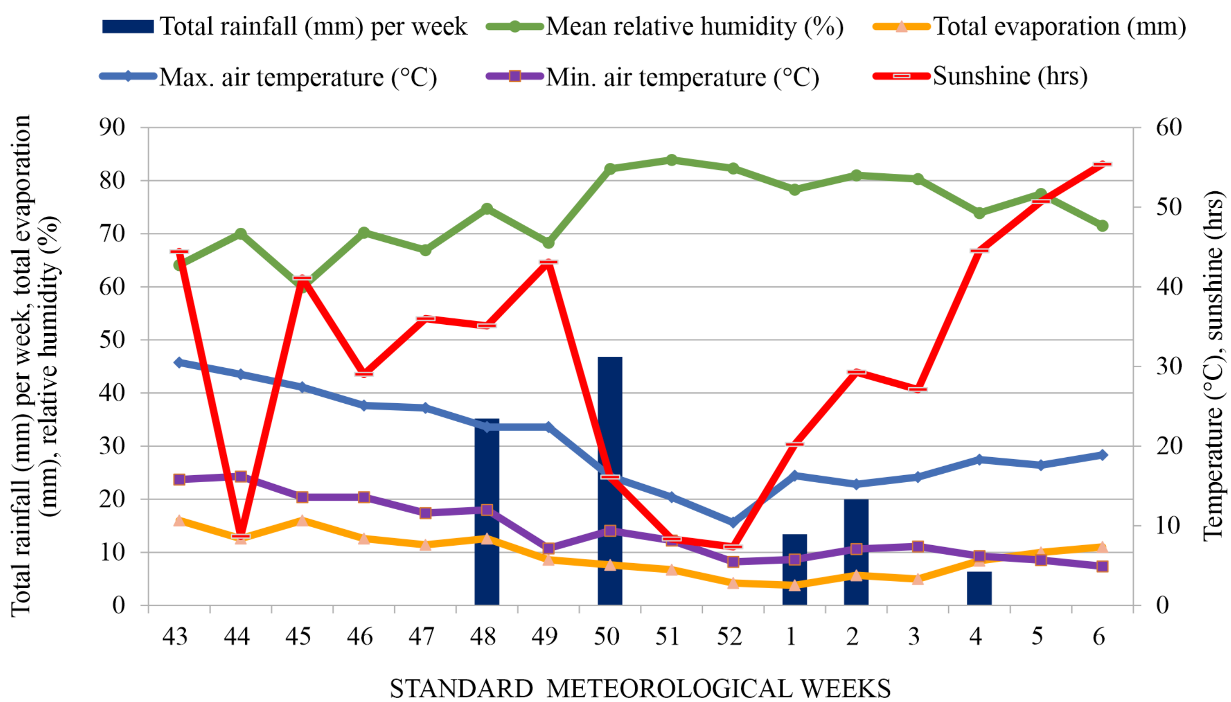

Fig. 2. Standard meteorological weather data for potato 2019-20

input cost and economic value of different crop produce in respective year of research in the local market. The local market price was taken as (454 and 540 Rs q^{-1}) for potato crop during 2018-19 and 2019-20 in respect to economic produce.

Analysis of variance was performed using Proc GLM procedure of SAS version 9.4 (SAS Institute, Inc., Cary, NC, USA) for all the parameters. The difference was compared with Fisher's protected least significant difference (LSD) test at 5 per cent probability level.

Results and Discussion

Yield attributes of potato

Number of tillers per plant

The data in respect of number of tillers per plant are presented in Table 1. Number of tillers per plant was significantly varied with different treatments during 2018-19 and it was recorded to be non-significant during 2019-20. Highest number of tillers (3.33) during haulm cutting was recorded in residue incorporation + 100% NPK + FYM @ 50 t ha^{-1} which was statistically at par with residue removed + 100% NPK + FYM @ 50 t ha^{-1} and significantly higher than all other treatments. Lowest number of tillers (2.50) was recorded with application of 150% NPK in residue removal treatment. Integrated use of organic and inorganic nutrients had a positive effect over growth and development of the crop. Better water nutrient and water availability leads to better vegetative growth of plants. The application of organic manures undergoes slow decomposition might have helped in release of macro and micro nutrients in soil slowly throughout the crop growth period which improved growth parameters of potato crop. Yadav and Meena (2014) also reported better growth of plant with application of FYM along with chemical fertilizers. Patel *et al.* (2013) also recorded maximum number of shoots per plant in potato with combined application of organic and inorganic source of nutrients.

Number of tubers per plant

Number of tubers per plant is important parameters which directly relates to tuber yield. More number of tubers per plant leads to higher yield. Data recorded for tuber number per plant are presented in Table 1. Plots where rice residue was incorporated

Table 1. Effect of rice residue incorporation and nutrient application on number of tillers per plant, number of tubers per plant and tuber yield per plant in potato

Treatment	Number of tillers $plant^{-1}$		Number of tubers per plant		Tuber yield per plant (g)	
	2018-19	2019-20	2018-19	2019-20	2018-19	2019-20
Straw removal + 100 % NPK+FYM @ 50 t ha^{-1}	3.06^{ab}	4.73^{ns}	12.5^{b}	15.7^{ab}	739.7^{a}	751.3^{abc}
Straw removal + 150 % NPK	2.50^{c}	4.47	10.5^{c}	12.7^{c}	537.3^{b}	622.3^{c}
Straw incorporation + 100 %NPK+ FYM @ 50 t ha^{-1}	3.33^{a}	4.87	15.0^{a}	16.8^{a}	821.3^{a}	863.7^{a}
Straw incorporation + 150 %NPK	2.74^{bc}	4.33	11.3^{bc}	14.6^{bc}	594.7^{b}	644.3^{bc}

with application of 100% NPK + FYM @ 50 t ha^{-1} recorded maximum number of tubers and plant (15.0 and 16.8) during both the years and it was and significantly higher than rest of the treatments. Number of tubers recorded under residue removed plot + 100% NPK + FYM @ 50 t ha^{-1} was statistically at par with residue incorporation + 150% NPK. Minimum number of tubers (10.5 and 12.7) was recorded in plots with application of 150% NPK where rice residues were removed. The probable reason for higher number of tubers with combined use of organic and inorganic fertilizer with straw incorporation may be attributed to better tuber formation and growth due to good physical condition of the soil. Straw incorporation in the soil decreases the compactness of soil and provides proper space for stolon development and also it act as mulch by reducing the loss of water from soil. The possible reason for the increment in tuber number was due to increase in stolon numbers in response to an increased rate of nutrients supplied from the combined sources. Nitrogen and phosphorus are known to influence the rate of gibberellin acid biosynthesis in potato. The involvement of gibberellin in regulating stolon number through stolon initiation was reported by Kandil *et al.* (2011). Combined application of synthetic and organic fertilizer has positive effect on tuber growth due to better availability of nutrients and water to the plants. Similar findings were reported by Jadhav (2012) and Babu (2019).

Tuber yield per plant

Tubers yield per plant serves as a reliable criterion to assess crop yield. It has direct relation to tuber yield. A scrutiny of the mean data presented in Table 1 indicated that application of inorganic fertilizers coupled with FYM and rice residue incorporation had a profound effect on tuber yield per plant. Application of 100% NPK + FYM @ 50 t ha^{-1} with rice residue incorporation resulted in significantly higher tuber yield per plant (821.3 and 863.7 g) which was statistically at par with treatment which include application of 100% NPK + FYM @ 50 t ha^{-1} without straw incorporation (739.7 and 751.3 g) during 2018-19 and 2019-20, respectively and straw incorporation with 150% NPK kg ha^{-1} during 2019-20. Lowest per plant (537.3 and 622.3 g) was recorded under treatment that involves residue removal + 150% NPK during 2018-19 and 2019-20, respectively. Chang *et al.* (2016) found higher percentage of tubers collected in mulched plot compared with un-mulched plot. The increase in tuber weight could be attributed to the favorable impact on the plant height, leaf area, dry matter production and its partitioning within plant especially tubers, thereby increasing its weight and size. Organic fertilizer supplies both micro and macronutrients to the plant for a long period of time in a sufficient quantity during critical stages resulted with better nutrient uptake, improved plant vigour and superior growth attributes. Jadhav (2012) and Babu (2019) also reported higher weight of tubers per plant under integrated use of organic manures and inorganic fertilizers.

Tuber grading

Grade wise number of tubers

Grade wise distribution of tubers is an important attribute for marketing purpose. The number of tubers

Table 2. Effect of rice residue incorporation and nutrient application on grade wise number of tubers in potato

Treatment	Grade wise number of tubers ('000 ha^{-1})					
	Small		Medium		Large	
	2018-19	2019-20	2018-19	2019-20	2018-19	2019-20
Straw removal + 100 % NPK+ FYM @ 50 t ha^{-1}	219.0^{b}	260.1^{b}	279.2^{a}	277.4^{a}	136.3^{ab}	139.9^{a}
Straw removal + 150 % NPK	322.0^{a}	386.3^{a}	165.3^{b}	177.4^{b}	107.1^{c}	118.0^{b}
Straw incorporation + 100 %NPK+ FYM @ 50 t ha^{-1}	209.1^{b}	222.3^{b}	299.9^{a}	309.6^{a}	144.2^{a}	141.5^{a}
Straw incorporation+150% NPK	301.6^{a}	360.1^{a}	175.8^{b}	197.3^{b}	118.4^{b}	136.5^{a}

Small: <50g, Medium: 50-100g and Large: > 100g

is directly related to tuber yield. The grading was done into three categories i.e. small (<50g), medium (50-100g) and large (>100g). The data pertaining to grade wise number of tubers are presented in Table 2. The scrutiny of data manifested that number of tubers under different grades were significantly influenced by integrated use of organic and inorganic sources of nutrients. Number of small size tubers (322.0 and 386.3 thousand ha^{-1}) were significantly higher under the sole application of inorganic fertilizer i.e. residue removal + 150% NPK which was statistically at par with residue incorporation + 150% NPK treatment during both the years. The number of small size tubers decreased with integrated application of organic and inorganic source of nutrients. Minimum number of small sized tubers (209.1 and 222.3 thousand ha^{-1}) were found under treatment consisting of residue incorporation + 100% NPK + FYM @ 50 t ha^{-1} which was statistically at par with residue removal + 100% NPK + FYM @ 50 t ha^{-1} during both the years. A significantly higher number of medium sized tubers (299.9 and 309.6 thousand ha^{-1}) were recorded with residue incorporation + 100% NPK + FYM @ 50 t ha^{-1} during both the years which was significantly better than residue incorporation + 150% NPK and residue removal + 150% NPK treatments, but was statistically at par with treatment involving residue removal + 100% NPK + FYM @ 50 t ha^{-1}. Minimum number of medium sized tubers (165.3 and 177.4 thousand ha^{-1}) were found under sole application of synthetic fertilizer i.e. residue removal + 150% NPK during both the years. Inclusion of FYM and residue incorporation marked a significant influence on number of medium sized tubers. Application of 100% NPK + FYM @ 50 t ha^{-1} along with rice residue incorporation increase the number of medium sized tubers by 81.4 and 74.5% as compared to sole application of synthetic fertilizers i.e. residue removal + 150% NPK. Treatment consisting of both organic and inorganic nutrient sources along with straw incorporation (100% NPK + FYM @ 50 t ha^{-1} + residue incorporation) was found significantly better than other treatments with respect to number of large size tubers (144.2 and 141.5 thousand ha^{-1}) during both the years. FYM and rice residue incorporation had a positive effect on number of large size tubers. Minimum number of tubers (107.1 and 118.0 thousand ha^{-1}) under this category was recorded with application of 150% NPK in residue removal plots. It was clearly observed that conjoint application of organic manures and inorganic fertilizer increases the number of medium and large sized tubers as compared to sole application of inorganic fertilizer. The increase in tubers number under this category might be attributed to higher number of stolon with increased nutrient supply due to combined application organic and inorganic sources of nutrients. Integrated nutrient management in the system provide adequate amount of macro and micronutrients to the plant resulted with more assimilation of photosynthates at the sink. Translocation of sugars from source to sink would ultimately leads to increase medium and large size tubers. The tuber development was improved by good physical and biological properties of the soil. The current experiment findings agree with those of (Ayalew and Dejene, 2011), which indicated that an increase in average tubers with the use of both organic and inorganic fertiliser may be attributable to increased photosynthetic activity and the translocation of photosynthate to the root, which may have assisted in the initiation of more stolons in potatoes. Tuber number is also determined by the

Table 3. Effect of rice residue incorporation and nutrient application on grade wise weight of tubers in potato

Treatment	Grade wise weight of tubers (q ha^{-1})					
	Small		Medium		Large	
	2018-19	2019-20	2018-19	2019-20	2018-19	2019-20
Straw removal + 100 % NPK+ FYM @ 50 t ha^{-1}	59.1^{b}	70.2^{b}	167.5^{a}	166.5^{a}	122.7^{ab}	125.6^{ns}
Straw removal + 150 % NPK	86.9^{a}	96.6^{a}	90.9^{b}	97.6^{b}	99.6^{c}	109.8
Straw incorporation + 100 % NPK+ FYM @ 50 t ha^{-1}	56.5^{b}	62.2^{b}	180.0^{a}	185.8^{a}	129.8^{a}	127.4
Straw incorporation +150% NPK	81.4^{a}	90.0^{a}	96.7^{b}	108.5^{b}	110.0^{bc}	122.9

Small: <50g, Medium: 50-100g and Large: > 100g

number of stems produced which in turn depends up on the tuber size and variety as reported by (Sood 2007). Babu (2019) also reported similar findings. Residue incorporation also improved grain production by increasing porosity and decreasing bulk density of soil.

Grade wise weight of tubers

Data presented in Table 3 depicts the effect of rice residue and nutrient application in potato on grade wise weight of potato tubers. A quick glance at data revealed that there was noticeable difference among various treatments. Weight of small sized tubers was significantly higher in residue removal plots with application of 150% NPK (86.9 and 96.6 q ha^{-1}) than all other treatments during both the years. Weight of tubers under this category was decreased with combined application of both organic and inorganic source of nutrients. Under small sized tuber category the lowest weight was recorded with incorporation of rice residue + 100% NPK + FYM @ 50 t ha^{-1} (56.5 and 62.2 q ha^{-1}) which was statistically at par with residue removal + 100% NPK + FYM @ 50 t ha^{-1}. Maximum weight of medium sized tubers (180.0 and 185.8 q ha^{-1}) was found where 100% NPK + FYM @ 50 t ha^{-1} was applied along with residue incorporation which was superior to other treatments and followed by treatment involving residue removal + 100% NPK + FYM @ 50 t ha^{-1}. The per cent increase in medium sized tubers yield in residue incorporation + 100% NPK + FYM @ 50 t ha^{-1} treatment was 98.0% and 90.3% as compared to residue removal treatment with 150% NPK application during both the years. Lowest yield of medium sized tubers (90.9 and 97.6 q ha^{-1}) was recorded with sole application of inorganic fertilizers i.e. residue removal + 150% NPK, which was statistically at par with 150% NPK along with residue incorporation during both the years of study. The effect of rice residue and nutrient application on weight of large sized tubers was significant during 2018-19 and it was recorded to be non-significant during 2019-20. Maximum weight of large sized tubers (129.8 q ha^{-1}) was noticed in 100% NPK + FYM @ 50 t ha^{-1} along with residue incorporated plots, which was statistically similar to treatment where residue was removed with application of 100% NPK + FYM @ 50 t ha^{-1} during 2018-19 and significantly better than all other treatments. The lowest weight of large sized tubers (99.6 q ha^{-1}) was recorded with application of 150% NPK in residue removed plots during 2018-19. The per cent increase in weight of large size tubers was 30.3% with application of 100% NPK + FYM @ 50 t ha^{-1} along with residue incorporation as compared to residue removal + 150% NPK during 2018-2019.

From the above mentioned data it was clearly observed that FYM and rice residue incorporation significantly increased the weight of medium and large sized tubers, where as sole application of inorganic fertilizers recorded with maximum weight of small sized tubers. The increase in weight of medium and large sized tubers was due to cumulative effect of organic and inorganic source of nutrients on growth and yield attributes of potato. Rice straw incorporation and FYM provides proper aeration to plant roots, improves the soil physical properties of soil *viz.,* water holding capacity of soil, reduces bulk density and improves soil porosity, which may provide space for better tuberization. FYM supplies both macro and micronutrient for a long period of time. So, nutrient uptake by plant was higher which ultimately leads to more photosynthate accumulation at sink. Dan and Thind (2005) observed that combined application of organic and inorganic nutrients resulted in higher weight of large sized tubers due to reduction in soil strength which provide better microclimatic environment for tuber development. Similar results were reported by Jadhav (2012) and Babu (2019). According to Taye (2011) combination of organic and inorganic inputs resulted in a significant increase in tuber yield. It is possible that this is because of higher nutrient availability and uptake with higher rates of both fertilizer and increased availability of plant nutrients (Kundu *et al*., 2007). The result clearly revealed that the total yield and marketable yield of potato could be increased by the interaction of organic and inorganic fertilize.

Tuber yield

Data presented in table 4 the effect of rice residue and nutrient application on tuber yield of potato. A cursory glance at data revealed that combined use of organic and inorganic source of nutrients with residue incorporation resulted in higher tuber yield as compared to other treatments especially sole application of inorganic fertilizer. Application of 100% NPK + FYM @ 50 t ha^{-1} with residue incorporation resulted in significantly higher tuber yield (366.3 and 375.4 q ha^{-1}) as compared to residue removal + 150% NPK application and application 150% NPK along with residue incorporation during both the years, but it was statistically at par with residue removal along with application of 100% NPK + FYM @ 50 t ha^{-1}. Application of 100% NPK + FYM @ 50 t ha^{-1} along with residue incorporation recorded 32.0 and 23.4% higher tuber yield than residue removal + 150% NPK during 2018-19 and 2019-20, respectively. The minimum tuber yield of 277.4 and 304.4 q ha^{-1} was recorded during both the years when residue was removed and the crop was applied with 150% NPK. Higher tuber yield in case of straw incorporated plots was due to better aeration and penetration of roots for water and nutrient uptake. It act as mulch and reduce the water loss from soil and decrease bulk density of soil which provide proper space for tuber development. Prasad *et al.* (2016) reported the similar results in their studies. Integrated use of organic and inorganic fertilizers i.e. residue incorporation + 100% NPK + FYM @ 50 t ha^{-1} resulted in higher potato yield as compared to residue removal + 150% NPK. Application of fertilizer along with residue incorporation resulted in significantly higher potato yield as compared to fertilizer treatments without residue incorporation might be due better physical, chemical and biological properties of soil and supplies adequate nutrition to the plant for its growth and development. Begum and Saikia (2014) reported higher tuber yield under residue retained plot as mulch as compared to residue removed plot. Kumar *et al.* (2012) showed that 50% of the recommended dose of NPK through inorganic + 50% recommended dose of nitrogen (RDN) through organic manures (FYM, PM or VC) influenced the tuber yield, nutrient uptake, soil fertility and higher returns as compared sole application of synthetic fertilizer. The results of (Sood, 2007) who noticed a higher potato tuber yield under integrated usage of organic (FYM) and inorganic source were supported by the trend of yields growing steadily with increased application of farmyard manure. This indicated that the application of higher rates of farmyard manure is required to get the highest tuber yield provided that the ease of use of highly decomposed farm yard manure material and other prevailing conditions The present finding is supported by (Taye, 2011) who found that combination of FYM and mineral fertilizers resulted in a tuber yield increase of 61%

Table 4. Effect of rice residue incorporation and nutrient application on tuber yield of potato

Treatment	Tuber yield (q ha^{-1})		Haulm yield (q ha^{-1})	
	2018-19	2019-20	2018-19	2019-20
Straw removal + 100 % NPK+ FYM @ 50 t ha^{-1}	349.3^{ab}	362.5^{a}	102.2^{a}	111.4^{a}
Straw removal + 150 % NPK	277.4^{c}	304.0^{c}	73.1^{bc}	97.6^{bc}
Straw incorporation + 100 % NPK+ FYM @ 50 t ha^{-1}	366.3^{a}	375.4^{a}	107.1^{a}	115.3^{a}
Straw incorporation + 150 % NPK	288.3^{bc}	321.4^{bc}	71.1^{c}	95.9^{c}

when compared to the yield obtained using only mineral fertilisers. Furthermore, according to (Ayalew and Dejene, 2011), the enhanced crop yield recorded by application of FYM was attributed to significantly higher yield components.

Haulm yield

Data pertaining to haulm yield of potato presented in table 4 revealed that rice residue and nutrient application in potato significantly influenced the haulm yield of potato. Conjoint application of organic and synthetic fertilizer with residue incorporation i.e. 100% NPK + FYM @ 50 t ha^{-1} + residue incorporation resulted in significantly higher haulm yield (102.2 and 115.3 q ha^{-1}) as compared to residue removal + 150% NPK application but it was statistically at par with residue removed with 100% NPK + FYM @ 50 t ha^{-1} application during both the years. The per cent increase in haulm yield with residue incorporation + 100% NPK + FYM 50 t ha^{-1} was 39.8 and 18.1 % as compared to residue removal + 150% NPK during both the years. Lowest haulm yield of 73.1 and 97.6 q ha^{-1} was recorded from residue removed plots with application of 150% NPK during 2018-19 and 2019-20. Higher haulm yield in integrated nutrient management i.e. residue incorporation + 100% NPK + FYM 50 t ha^{-1} was attributed to better nutrient and water availability that leads to better plant height, dry matter accumulation and leaf area of the plant which ultimately resulted into higher haulm yield. This result is in conformity with the findings of (Nazm *et al.* 2010), which found that enhanced nitrogen application significantly increased the canopy dry matter production of potato. Similarly (Chowdahury *et al*., 2002) also reported that efficient use of inorganic fertilizer increased the above ground biomass. This rise in above-ground biomass with rising inorganic fertilizer rates may be a result of nitrogen influence on vegetative development. Similar outcomes were found for sweet potatoes by (Olika, 2002). Habib *et al.* (2012) also reported higher growth of the plant with combined application of organic fertilizers and chemical fertilizers as compared to sole application of chemical fertilizers.

Economic analysis

Data presented in Table 5 the effect of rice residue and nutrient application on economics analysis of potato. The data revealed that combined use of organic and inorganic source of nutrients with residue incorporation resulted in higher gross returns, net returns and B:C as compared to other treatments especially sole application of inorganic fertilizer. Application of 100% NPK + FYM @ 50 t ha^{-1} with residue incorporation resulted in maximum gross returns (166.3 and 202.7 × 10^3 Rs ha^{-1}), net returns (76.0 and 104.8 × 10^3 Rs ha^{-1}) and B:C (0.84 and 1.07) as compared to all other treatments. Application of 100% NPK + FYM @ 50 t ha^{-1} along with residue incorporation increase the gross returns and net returns up to a margin of 32.0% and 23.5%, 68.5% and 37.6% than residue removal + 150% NPK during 2018-19 and 2019-20, respectively. The minimum gross returns (125.9 and 164.1 ha^{-1} × 10^3 Rs ha^{-1}) and net returns (45.1 and 75.9 × 10^3 Rs ha^{-1}) was recorded during both the years when residue was removed and the crop was applied with 150% NPK. In accordance with Rajiv (2014), applying 75% NPK through chemical fertilizers with 20 t ha^{-1} nadepkaka (NADEP) compost yielded a maximum net return of Rs. 60,990/- ha^{-1}. The use of increasing the rate of NPK from 50% to 75% in conjunction with organic sources enhanced the net return. On the other hand,

Table 5. Effect of rice residue incorporation and nutrient application on economics of potato

Treatment	Gross returns (× 10^3 Rs ha^{-1})		Net returns (× 10^3 Rs ha^{-1})		B:C	
	2018-19	2019-20	2018-19	2019-20	2018-19	2019-20
Straw removal + 100 % NPK+ FYM @ 50 t ha^{-1}	158.6	195.8	69.3	98.8	0.78	1.02
Straw removal + 150 % NPK	125.9	164.1	45.1	75.9	0.56	0.86
Straw incorporation + 100 % NPK+ FYM @ 50 t ha^{-1}	166.3	202.7	76.0	104.8	0.84	1.07
Straw incorporation + 150 % NPK	130.9	173.6	49.0	84.3	0.60	0.95

a careful combination of organic and inorganic sources of nutrients might be helpful to obtain a good economic return of potato with strong soil health (Hensh *et al*., 2020). Integrated use of all sources of plant nutrients, including chemical fertilizer, organic manures and biofertilizer is important not only for increasing crop productivity but also for improving soil health, which is essential for sustaining the crop productivity over time.

Conclusion

Based on the finding of the investigation, it can be concluded that using farmyard manure (FYM) and crop residues in addition to applying 100% NPK @ 50 t ha^{-1} resulted in better yield characteristics and economic parameters as compared to sole application of synthetic fertilizer. The integrated use of organic and inorganic fertilizer with residue incorporation significantly improved various yield attributes. These improvements included a rise in the number of tillers, tubers and tuber yield per plant. A overall higher tuber yield was also achieved because to an apparent increase in the quantity and weight of medium-sized tubers. Additionally, the integrated treatment had positive benefits on economic parameters like benefit-to-cost (B:C) ratio, net returns and gross returns. Higher net returns as a result of the greater yield attributes indicate better profitability. Overall, the results indicate that 100% NPK + FYM @ 50 t ha^{-1} with residue incorporation can greatly enhance yield attributes, tuber yield and economic viability of potato cultivation. These results highlight the potential advantages of adopting integrated use of organic and inorganic inputs for profitable and sustainable potato cultivation.

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