INTEGRATED NUTRIENT MANAGEMENT FOR ENHANCING PRODUCTIVITY OF SPRING MAIZE (*Zea mays* L.) IN RICE AND MAIZE BASED CROPPING SYSTEMS

Dissertation

Submitted to the Punjab Agricultural University
in partial fulfilment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY
in
AGRONOMY
(Minor Subject: Soil Science)

By

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CERTIFICATE-I

This is to certify that the dissertation entitled, **“Integrated nutrient management for enhancing productivity of spring maize (*Zea mays* L.) in rice and maize based cropping systems”** submitted for the degree of **Doctor of Philosophy**, in the subject of **Agronomy** (Minor subject: **Soil Science**) of the Punjab Agricultural University, Ludhiana, is a bonafide research work carried out by **Priyanka Sahoo (L-2017-A-07-D)** under my supervision and that no part of this dissertation has been submitted for any other degree.

The assistance and help received during the course of investigation have been fully acknowledged.

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CERTIFICATE-II

This is to certify that the dissertation entitled **"Integrated nutrient management for enhancing productivity of spring maize (*Zea mays* L.) in rice and maize based cropping systems"** submitted by **Priyanka Sahoo (L-2017-A-07-D)** to the Punjab Agricultural University, Ludhiana, in partial fulfillment of the requirements for the degree of **Ph.D.** in the subject of **Agronomy** (Minor subject: **Soil Science**) has been approved by the Student's Advisory Committee along with External Examiner after an oral examination on the same.

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Date: ***(Priyanka Sahoo)***

Place:

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ABSTRACT

The study entitled "Integrated nutrient management for enhancing productivity of spring maize (*Zea mays* L.) in rice and maize based cropping systems" was carried out at the Student's Research Farm, Department of Agronomy, Punjab Agricultural University, Ludhiana, during the year 2018-19 and 2019-20 in split plot design. The soil of the experimental field was loamy sand, low in available N and high in available P and medium in available K. In first experiment, two crops *viz.*, rice and potato were kept in main plots with four treatment combinations were applied to 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 and each main plot was divided into six sub plots to allocate different nutrient levels (75%, 100% and 125% NPK) to single row and double rows on bed. In second experiment, two crops *viz*., *kharif* maize and pea were kept in main plots with four treatment combinations *viz*., 100 % NPK to maize + 100 % NPK to pea, 100 % NPK to maize + 100 % NPK + FYM @ 20 t ha^{-1} to pea, 100 % NPK+ FYM @ 15 t ha^{-1} to maize + 100 % NPK to pea and 100 % NPK + FYM @ 15 t ha^{-1} to maize + 100 % NPK + FYM @ 20 t ha^{-1} to pea and each main plot was divided into six sub plots to allocate different nutrient levels (75%, 100% and 125% NPK) to single row and double rows on bed. The results showed that in rice-potato-spring maize cropping system, combined application of straw incorporation + 100 % NPK+ FYM @ 50 t ha^{-1} to potato resulted in significantly higher growth, yield attributes, grain yield (80.1 and 83.6 q ha^{-1}), SMEY (257.6 and 267.4 q ha^{-1}), system productivity (82.9 and 89.1 kg ha^{-1}day^{-1}) and net returns (259.9 and 300.2 × 10^3 Rs ha^{-1}) during both years. Similarly in *kharif* maize-pea-spring maize cropping system, significantly higher growth, yield attributes, grain yield (81.1 and 84.3 q ha^{-1}), SMEY (227.4 and 229.3 q ha^{-1}), system productivity (67.5 and 67.5 kg ha^{-1} day^{-1}) and net returns (240.9 and 269.7 × 10^3 Rs ha^{-1}) were obtained with application of 100% NPK + FYM @15 t ha^{-1} to maize and 100% NPK + FYM @ 20 t ha^{-1} to pea during 2019 and 2020. Among nutrient levels applied to spring maize in sub plots under both the experiments, significantly higher growth, yield attributes and protein content were resulted with 125% NPK applied to single row on bed, whereas LAI, PAR interception and number of cobs per hectare were significantly higher with 125% NPK applied to double row on bed. Application of 125% NPK to double row on bed resulted in significantly higher grain yield of spring maize, SMEY, system productivity, net returns and profitability. Among the two cropping systems *viz*., rice-potato-spring maize and *kharif* maize-pea-spring maize, the rice based cropping system was more economically feasible and viable with 4.7% and 10.3% higher net returns during 2019 and 2020, respectively as compared to maize based cropping system.

Keywords: Spring maize, integrated nutrient management, straw incorporation, nutrient levels, spring maize equivalent yield, system productivity, economic returns, quality parameters

Signature of Major Advisor **Signature of the Student**

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ਸਾਰ ਅੰਸ਼

"ਝੋਨੇ ਅਤੇ ਮੱਕੀ ਆਧਾਰਿਤ ਫ਼ਸਲੀ ਚੱਕਰਾਂ ਵਿੱਚ ਬਹਾਰ ਰੁੱਤ ਦੀ ਮੱਕੀ (*ਜ਼ੀਆ ਮੇਜ਼* ਐੱਲ.) ਦੀ ਉਤਪਾਦਕਤਾ ਵਧਾਉਣ ਲਈ ਸੰਯੁਕਤ ਖਾਦ ਪ੍ਰਬੰਧ" ਸਿਰਲੇਖ ਵਾਲਾ ਅਧਿਐਨ ਪੰਜਾਬ ਖੇਤੀਬਾੜੀ ਯੂਨੀਵਰਸਿਟੀ, ਲੁਧਿਆਣਾ ਦੇ ਫ਼ਸਲ ਵਿਗਿਆਨ ਵਿਭਾਗ ਦੇ ਵਿਦਿਆਰਥੀ ਖੋਜ ਫਾਰਮ ਵਿਖੇ 2018-2019 ਅਤੇ 2019-2020 ਦੌਰਾਨ ਸਪਲਿੱਟ ਪਲਾਟ ਡਿਜ਼ਾਇਨ ਵਿਧੀ ਤਹਿਤ ਕੀਤਾ ਗਿਆ ਸੀ। ਤਜ਼ਰਬਾ ਖੇਤਰ ਦੀ ਮਿੱਟੀ ਮੈਰਾ ਰੇਤਲੀ, ਉਪਲਬਧ ਨਾਈਟ੍ਰੋਜਨ ਵਿੱਚ ਘੱਟ, ਉਪਲਬਧ ਫ਼ਾਸਫ਼ੋਰਸ ਵਿੱਚ ਵੱਧ ਅਤੇ ਉਪਲਬਧ ਪੋਟਾਸ਼ ਵਿੱਚ ਦਰਮਿਆਨੀ ਸੀ। ਪਹਿਲੇ ਤਜ਼ਰਬੇ ਵਿੱਚ ਦੋ ਫਸਲਾਂ-ਝੋਨਾ ਅਤੇ ਆਲੂ ਨੂੰ ਮੁੱਖ ਪਲਾਟਾਂ ਵਿੱਚ ਰੱਖਿਆ ਗਿਆ ਸੀ, ਜਿਸ ਵਿੱਚ ਆਲੂਆਂ ਤੇ ਚਾਰ ਉਪਚਾਰ ਲਾਗੂ ਕੀਤੇ ਗਏ ਸਨ ਜਿਵੇਂ ਕਿ ਪਰਾਲੀ ਨੂੰ ਬਾਹਰ ਕੱਢਣਾ + 100% ਐੱਨ.ਪੀ.ਕੇ. + ਰੂੜੀ 50 ਟਨ ਪ੍ਰਤੀ ਹੈਕਟੇਅਰ, ਪਰਾਲੀ ਨੂੰ ਬਾਹਰ ਕੱਢਣਾ + 150% ਐੱਨ.ਪੀ.ਕੇ., ਪਰਾਲੀ ਨੂੰ ਖੇਤ ਵਿੱਚ ਦੱਬਣਾ + 100 ਐੱਨ.ਪੀ.ਕੇ. + ਰੂੜੀ 50 ਟਨ ਪ੍ਰਤੀ ਹੈਕਟੇਅਰ ਅਤੇ ਪਰਾਲੀ ਨੂੰ ਖੇਤ ਵਿੱਚ ਦੱਬਣਾ + 150% ਐੱਨ.ਪੀ.ਕੇ. ਅਤੇ ਹਰੇਕ ਮੁੱਖ ਪਲਾਟ ਨੂੰ ਛੇ ਉੱਪ ਪਲਾਟਾਂ ਵਿੱਚ ਵੰਡਿਆ ਗਿਆ ਸੀ, ਜਿਸ ਵਿੱਚ ਵੱਖਰੇ ਖ਼ੁਰਾਕੀ ਤੱਤ (75%, 100% ਅਤੇ 125% ਐੱਨ.ਪੀ.ਕੇ.) ਇਕਹਿਰੀ ਕਤਾਰ ਅਤੇ ਦੋਹਰੀ ਕਤਾਰਾਂ ਵਾਲੇ ਬੈੱਡ ਉੱਪਰ ਦਿੱਤੇ ਗਏ ਸਨ। ਦੂਜੇ ਤਜ਼ਰਬੇ ਵਿੱਚ ਦੋ ਫ਼ਸਲਾਂ-ਸਾਉਣੀ ਦੀ ਮੱਕੀ ਅਤੇ ਮਟਰਾਂ ਨੂੰ ਮੁੱਖ ਪਲਾਟਾਂ ਵਿੱਚ ਚਾਰ ਉਪਚਾਰਾਂ ਨਾਲ ਰੱਖਿਆ ਗਿਆ ਸੀ, ਜਿਵੇਂ ਕਿ ਮੱਕੀ ਨੂੰ 100% ਐੱਨ.ਪੀ.ਕੇ. + ਮਟਰਾਂ ਨੂੰ 100% ਐੱਨ.ਪੀ.ਕੇ., ਮੱਕੀ ਨੂੰ 100% ਐੱਨ.ਪੀ.ਕੇ. + ਮਟਰਾਂ ਨੂੰ 100% ਐੱਨ.ਪੀ.ਕੇ. + ਰੂੜੀ 20 ਟਨ ਪ੍ਰਤੀ ਹੈਕਟੇਅਰ, ਮੱਕੀ ਨੂੰ 100% ਐੱਨ.ਪੀ.ਕੇ. + ਰੂੜੀ 15 ਟਨ ਪ੍ਰਤੀ ਹੈਕਟੇਅਰ + ਮਟਰਾਂ ਨੂੰ 100% ਐੱਨ.ਪੀ.ਕੇ. ਅਤੇ ਮੱਕੀ ਨੂੰ 100% ਐੱਨ.ਪੀ.ਕੇ. + ਰੂੜੀ 15 ਟਨ ਪ੍ਰਤੀ ਹੈਕਟੇਅਰ + ਮਟਰਾਂ ਨੂੰ 100% ਐੱਨ.ਪੀ.ਕੇ. + ਰੂੜੀ 20 ਟਨ ਪ੍ਰਤੀ ਹੈਕਟੇਅਰ ਅਤੇ ਹਰੇਕ ਮੁੱਖ ਪਲਾਟ ਨੂੰ ਛੇ ਉੱਪ ਪਲਾਟਾਂ ਵਿੱਚ ਵੰਡਿਆ ਗਿਆ ਸੀ, ਜਿਸ ਵਿੱਚ ਵੱਖਰੇ ਖ਼ੁਰਾਕੀ ਤੱਤ (75%, 100% ਅਤੇ 125% ਐੱਨ.ਪੀ.ਕੇ.) ਇਕਹਿਰੀ ਕਤਾਰ ਅਤੇ ਦੋਹਰੀ ਕਤਾਰਾਂ ਵਾਲੇ ਬੈੱਡ ਉੱਪਰ ਦਿੱਤੇ ਗਏ ਸਨ। ਨਤੀਜਿਆਂ ਨੇ ਦਿਖਾਇਆ ਕਿ ਦੋ ਸਾਲਾਂ ਦੌਰਾਨ ਝੋਨਾ-ਆਲੂ-ਬਹਾਰ ਰੁੱਤ ਦੀ ਮੱਕੀ ਦੇ ਫ਼ਸਲੀ ਚੱਕਰ ਵਿੱਚ ਆਲੂ ਬੀਜਣ ਤੋਂ ਪਹਿਲਾਂ ਪਰਾਲੀ ਨੂੰ ਖੇਤ ਵਿੱਚ ਦੱਬਣਾ + 100% ਐੱਨ.ਪੀ.ਕੇ. + ਰੂੜੀ 50 ਟਨ ਪ੍ਰਤੀ ਹੈਕਟੇਅਰ ਨਾਲ ਫ਼ਸਲ ਦੇ ਵਾਧੇ, ਝਾੜ ਦੇ ਪੈਰਾਮੀਟਰ, ਦਾਣਿਆਂ ਦਾ ਝਾੜ (80.1 ਅਤੇ 83.6 ਕੁਇੰਟਲ ਪ੍ਰਤੀ ਹੈਕਟੇਅਰ), ਬਹਾਰ ਰੁੱਤ ਦੀ ਮੱਕੀ ਦੇ ਬਰਾਬਰ ਝਾੜ (257.6 ਅਤੇ 267.4 ਕੁਇੰਟਲ ਪ੍ਰਤੀ ਹੈਕਟੇਅਰ), ਪ੍ਰਣਾਲੀ ਉਤਪਾਦਿਕਤਾ (82.9 ਅਤੇ 89.1 ਕਿੱਲੋ ਪ੍ਰਤੀ ਹੈਕਟੇਅਰ ਪ੍ਰਤੀ ਦਿਨ) ਅਤੇ ਮੁਨਾਫ਼ੇ (259.9 ਅਤੇ 300.2 ਹਜ਼ਾਰ ਰੁਪਏ ਪ੍ਰਤੀ ਹੈਕਟੇਅਰ) ਤੇ ਅਰਥਪੂਰਨ ਵਾਧਾ ਹੋਇਆ। ਇਸੇ ਤਰ੍ਹਾਂ ਦੇ ਨਤੀਜੇ ਸਾਉਣੀ ਦੀ ਮੱਕੀ-ਮਟਰ-ਬਹਾਰ ਰੁੱਤ ਦੀ ਮੱਕੀ ਦੇ ਫ਼ਸਲੀ ਚੱਕਰ ਵਿੱਚ ਮੱਕੀ ਨੂੰ 100% ਐੱਨ.ਪੀ.ਕੇ.+ਰੂੜੀ 15 ਟਨ ਪ੍ਰਤੀ ਹੈਕਟੇਅਰ + ਮਟਰਾਂ ਨੂੰ 100% ਐੱਨ.ਪੀ.ਕੇ. + ਰੂੜੀ 20 ਟਨ ਪ੍ਰਤੀ ਹੈਕਟੇਅਰ ਪਾਉਣ ਨਾਲ ਫ਼ਸਲ ਦੇ ਵਾਧੇ, ਝਾੜ ਦੇ ਪੈਰਾਮੀਟਰ, ਦਾਣਿਆਂ ਦਾ ਝਾੜ (81.1 ਅਤੇ 84.3 ਕੁਇੰਟਲ ਪ੍ਰਤੀ ਹੈਕਟੇਅਰ), ਬਹਾਰ ਰੁੱਤ ਦੀ ਮੱਕੀ ਦੇ ਬਰਾਬਰ ਝਾੜ (227.4 ਅਤੇ 229.3 ਕੁਇੰਟਲ ਪ੍ਰਤੀ ਹੈਕਟੇਅਰ), ਪ੍ਰਣਾਲੀ ਉਤਪਾਦਿਕਤਾ (67.5 ਅਤੇ 67.5 ਕਿੱਲੋ ਪ੍ਰਤੀ ਹੈਕਟੇਅਰ ਪ੍ਰਤੀ ਦਿਨ) ਅਤੇ ਮੁਨਾਫੇ (240.9 ਅਤੇ 269.7 ਹਜ਼ਾਰ ਰੁਪਏ ਪ੍ਰਤੀ ਹੈਕਟੇਅਰ) ਵਿੱਚ ਅਰਥਪੂਰਨ ਵਾਧਾ ਦੋਵੇਂ ਸਾਲਾਂ ਵਿੱਚ ਪ੍ਰਾਪਤ ਹੋਇਆ। ਜੋ ਖ਼ੁਰਾਕੀ ਤੱਤ ਬਹਾਰ ਰੁੱਤ ਦੀ ਮੱਕੀ ਨੂੰ ਉੱਪ ਪਲਾਟਾਂ ਵਿੱਚ ਦੋਹੇਂ ਤਜ਼ਰਬਿਆਂ ਵਿੱਚ ਦਿੱਤੇ ਸਨ, ਉਸ ਵਿੱਚ 125% ਐੱਨ.ਪੀ.ਕੇ. ਇਕਹਿਰੀ ਕਤਾਰ ਵਿੱਚ ਪਾਉਣ ਨਾਲ ਫ਼ਸਲ ਦੇ ਵਾਧੇ, ਝਾੜ ਦੇ ਪੈਰਾਮੀਟਰ ਅਤੇ ਪ੍ਰੋਟੀਨ ਦੀ ਮਾਤਰਾ ਵਧੇਰੇ ਪਾਈ ਗਈ, ਜਦਕਿ ਪੱਤਾ ਖੇਤਰ ਅੰਕ (ਐੱਲ.ਏ.ਆਈ.), ਸੂਰਜੀ ਵਿਕਿਰਨਾ ਦਾ ਸੋਖਣ ਅਤੇ ਛੱਲੀਆਂ ਦੀ ਗਿਣਤੀ ਪ੍ਰਤੀ ਹੈਕਟੇਅਰ ਦੋਹਰੀ ਕਤਾਰਾਂ ਵਾਲੇ ਬੈੱਡਾਂ ਵਿੱਚ 125% ਐੱਨ.ਪੀ.ਕੇ. ਪਾਉਣ ਨਾਲ ਵਧੇਰੇ ਪਾਈ ਗਈ ਸੀ। ਬੈੱਡ ਉੱਪਰ ਦੂਹਰੀ ਕਤਾਰ ਲਗਾਕੇ 125% ਐੱਨ.ਪੀ.ਕੇ. ਪਾਉਣ ਨਾਲ ਬਹਾਰ ਰੁੱਤ ਦੀ ਮੱਕੀ ਦੇ ਦਾਣਿਆਂ ਦਾ ਝਾੜ, ਬਹਾਰ ਰੁੱਤ ਦੀ ਮੱਕੀ ਦੇ ਬਰਾਬਰ ਝਾੜ, ਪ੍ਰਣਾਲੀ ਉਤਪਾਦਿਕਤਾ, ਸ਼ੁੱਧ ਆਮਦਨ ਅਤੇ ਮੁਨਾਫ਼ੇ ਵਿੱਚ ਅਰਥਪੂਰਨ ਵਾਧਾ ਹੋਇਆ। ਦੋਵੇਂ ਫ਼ਸਲੀ ਚੱਕਰ ਝੋਨਾ-ਆਲੂ-ਬਹਾਰ ਰੁੱਤ ਦੀ ਮੱਕੀ ਅਤੇ ਸਾਉਣੀ ਰੁੱਤ ਦੀ ਮੱਕੀ-ਮਟਰ-ਬਹਾਰ ਰੁੱਤ ਦੀ ਮੱਕੀ ਵਿੱਚੋਂ ਝੋਨਾ ਆਧਾਰਿਤ ਫ਼ਸਲੀ ਚੱਕਰ ਜ਼ਿਆਦਾ ਆਰਥਿਕ ਸੰਭਾਵਨਾ ਵਾਲਾ ਅਤੇ ਵਿਹਾਰਕ ਸੀ, ਇਸ ਨੇ ਮੱਕੀ ਆਧਾਰਿਤ ਫ਼ਸਲੀ ਚੱਕਰ ਨਾਲੋਂ ਸਾਲ 2019 ਅਤੇ 2020 ਵਿੱਚ ਕ੍ਰਮਵਾਰ 4.7 ਅਤੇ 10.3 ਪ੍ਰਤੀਸ਼ਤ ਜ਼ਿਆਦਾ ਮੁਨਾਫ਼ਾ ਦਿੱਤਾ ।

ਮੁੱਖ ਸ਼ਬਦ: ਬਹਾਰ ਰੁੱਤ ਦੀ ਮੱਕੀ, ਸੰਯੁਕਤ ਖਾਦ ਪ੍ਰਬੰਧ, ਪਰਾਲੀ ਨੂੰ ਖੇਤ ਵਿੱਚ ਦੱਬਣਾ, ਖ਼ੁਰਾਕੀ ਤੱਤਾਂ ਦਾ ਪੱਧਰ, ਬਹਾਰ ਰੁੱਤ ਦੀ ਮੱਕੀ ਦੇ ਬਰਾਬਰ ਝਾੜ, ਪ੍ਰਣਾਲੀ ਉਤਪਾਦਿਕਤਾ, ਆਰਥਿਕ ਮੁਨਾਫ਼ਾ, ਗੁਣਵੱਤਾ ਮਾਪਦੰਡ ।

ਮੁੱਖ ਸਲਾਹਕਾਰ ਦੇ ਹਸਤਾਖਰ **ਵਿੱਦਿਆਰਥੀ ਦੇ ਹਸਤਾਖਰ**

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CHAPTER I

INTRODUCTION

In India, rice-wheat is the predominant cropping system occupying 12.3 million hectares of area and around 85 per cent of this area falls under Indo Gangetic Plains (Bhatt *et al* 2021), which contributes more than 70 per cent of total cereal production in the country (Saharawat *et al* 2010). Traditionally, the farmers were following maize-wheat or cotton-wheat cropping system, but during last 4-5 decades they have shifted to rice-wheat cropping system. During green revolution, there was a rapid increase in production of rice-wheat cropping system due to increase in area and yield, resulted from the progress in development of extraordinary fertilizer responsive wheat and rice varieties, enlargement in irrigation facilities, upgraded management practices and government support price for wheat and rice (Nawaz *et al* 2019). Continuous practicing of this rotation has brought a number of ecological and environmental issues such as severe depletion of ground water (Bhatt *et al* 2020a), low nutrient use efficiency, emergence of new insect-pests, diseases and weeds, reduction in productivity (Busari *et al* 2015, Saini and Bhatt 2020) and fertility status of the soil (Das *et al* 2014). Beside this, rice-wheat cropping system consumes about 11,650 m^3 ha^{-1} water, out of which near about 7650 m^3 ha^{-1} is consumed by transplanted rice. Therefore, the ground water table in many pockets is declining at an alarming rate (Bhatt *et al* 2016a). Other than the above mentioned issues, constant and imbalance application of chemical fertilizers also lead to decrease and stagnation in yield, owing to deficiency of both macro and micronutrients (Shambhavi *et al* 2017). This increased concern about detrimental impact of uncontrolled use of synthetic fertilizers on soil fertility enforced a re-evaluation of agricultural nutrient management practices and changes in cropping system to upgrade the soil health status. These issues had given a major thrust to upgrade resource management system, choice of crops and cropping systems, which are environment friendly and productive in nature (Aulakh *et al* 2012).

Modern concepts in crop production such as crop diversification, conservation agriculture, integrated nutrient management, residue management, precision farming and different farming techniques has been developed to solve these issues and increase the production level, without hampering the natural resources (Singh 2015). Singh *et al* (2019) explained that crop diversification in agriculture can be regarded as the re-allocation of current crops/cropping systems/farm enterprises to some alternative crops/cropping systems/farm enterprises, while keeping a natural balance in meeting food, fodder and fuel need and side by side enhancing soil health and productivity of the agro-ecosystems of the region. In context to diversify the existing rice-wheat cropping system, rice-potato-spring maize and maize-pea-spring maize are two important cropping systems that can be practiced in Punjab region to obtain higher yield and sustainable productivity. Returns obtained from any crop in different cropping systems are enormously affected by the preceding crops and the nutrients applied therein. Accordingly, a greater emphasis should be focused on the cropping system as a whole instead of individual crop in a sequence (Singh *et al* 2008).

Maize (*Zea mays* L.) is an important cereal crop in the world after rice and wheat in terms of area and production. It holds an important position in Indian agriculture with highest genetic yield potential and wider adaptability under diverse soil and climatic conditions making it known as "queen of cereals" or "miracle crop". At world level, it was cultivated on 185.7 million hectares land and recorded a production of 1075.3 million tonnes of grains with an average yield of 5.8 t ha^{-1} and India had produced 31.5 million tonnes of maize grains from 9.6 million hectares of area with average productivity of 3.0 t ha^{-1} during 2020-21 (Anonymous 2021a). In Punjab, area occupied by maize was 144.6 thousand hectares with production of 410.5 thousand tonnes and average productivity was 35.8 q ha^{-1} during 2020-21 (Anonymous 2021b). Parihar *et al* (2011) gave the utilization pattern for maize in India, which includes poultry feed (49%), human food (25%), animal feed (12.5%), starch (11.5%), seed (1%) and brewery (1%). Maize has been successfully grown under varying climatic conditions throughout the country especially during *kharif, rabi* and spring seasons in Peninsular India, *kharif* and spring seasons in Indo-Gangetic Plains and only *kharif* season in the hilly regions. Cultivation of spring maize is becoming popular among the farmers of Punjab because of its short duration and higher yield and it is also used for diversifying some area from cereal based cropping system of the state. Spring maize may also be more profitable as it helps in meeting the green cob demand during early summer.

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 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).

Pea (*Pisum sativum* L.) is a major temperate grain legume widely cultivated worldwide. Pea is commonly used in human diet throughout the world and it is rich in protein

(21-25 %), carbohydrates, vitamin A and C, calcium, phosphorous and has high levels of amino acids "lysine" and "tryptophan" (Bhat *et al* 2013). Cultivation of green pea maintains soil fertility through biological nitrogen fixation while being in association with symbiotic *Rhizobium* which is present in its root nodules. Thus the crop plays a vital role in fostering sustainable agriculture (Fernandez *et al* 2021). Legumes are popular components in diversification strategies, as they provide ecological services to other crops, as well as to the environment. Inclusion of legume will promotes the interaction of soil microorganism for legumes to acquire and use efficiently nitrogen and phosphorus, which will reduce the use of mineral-based fertilizers and increase carbon-dioxide sequestration. Because of the high protein content of their seeds, legumes are used both for food and feed. Legumes fix atmospheric N into the soil and increase grain yield of subsequent crop and consequently total SOC in legumes-cereals rotations (Shah *et al* 2011).

Efficient nutrient management in India had played an outstanding role in achieving huge increase in food grain production from 52 million tonnes in 1951-52 to 280 million tonnes during 2020-21 (Anonymous 2021c). However, application of imbalance and/or excessive nutrients led to decline in nutrient-use efficiency, making fertilizer consumption uneconomical, produce adverse effects on atmosphere (Lamessa 2016), groundwater quality (Adimalla 2018) causing health hazards and global climate change. Chemical fertilizer cannot be avoided completely since they are the potential sources of large amount of primary and secondary nutrients in easily available forms. Most of the agricultural crops respond rapidly to chemical fertilizers and give higher yield. But, steady application of chemical fertilizers solely is not advantageous, as it has been reported to degenerate soil health (Basnet *et al* 2021). Contrarily, organic manures outplay in maintaining soil fertility status but have lower potential to achieve higher productivity (Sharma *et al* 2019). 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 (Mengistu *et al* 2017, Mahapatra *et al* 2018 and Bhatt *et al* 2020b). 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 (Wakene *et al* 2007). 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 (Khatri *et al* 2019, Kumar *et al* 2017 and Meena *et al* 2019). The basic concept of INM is to maintain availability of both macronutrients and micronutrients in an optimum range to achieve a given level of crop production by optimizing benefits from all possible plant nutrients sources in an integrated way and should be suitable to each cropping system and farming situations (Sharma *et al* 2019). So, adoption of integrated nutrient management is necessary for achieving sustainable crop yield, enhancement in soil fertility, input use efficiency and nutritional security in Indian agriculture (Dwivedi *et al* 2016).

Among the fertilizers, nitrogen is very important because it is responsible for major activities in growth and development of crops (Adhikari *et al* 2021). It is the primary nutrient and has a decisive role in the improvement of crop production (Szulc *et al* 2016). Hence, effective management of nitrogen fertilization is a leading challenge for enhancing maize productivity and environmental sustainability. N deficiency delays both vegetative and reproductive phenological development, reduces leaf emergence rate and grain yield (Srivastava *et al* 2018). On the other hand, higher rate of nitrogen combined with low nitrogen use efficiency will have adverse effect on the environment such as soil acidification, environmental pollution and decreased soil microbial activity (Zhu *et al* 2016). Hence, optimum N dose and improved N use efficiency are essential for the sustainable production of maize. Therefore, for sustainability of agro-ecosystem, both the crop yield and nitrogen use efficiency need to be balanced (Jin *et al* 2012).

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). These residues have enormous potential to be recycled in the crop production systems, because they contain a lot of macro and micro nutrients. Management of crop residues for a better C sequestration and the amount of crop residue application coupled with optimum use of N fertilizer is necessary for increasing productivity and promoting soil organic matter. In India, the estimated cereal crop residues production is 361 x 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 residue, farmers burning the stubble to make the field free for sowing of next crop. Residue burning is not advantegous act because it leads to air pollution, loss nutrients from soil, destruction in soil structure, serious health hazards in human being and global warming. 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. This accelerates the nutrient use efficiency and prevents nutrient losses through leaching or volatilization (Sarkar *et al* 2020). Bimbraw (2019) revealed that addition of organic manures and crop residues into soil on long run resulted in increased C sequestration and reduced the nitrogen requirement. Incorporation of crop residues increases soil organic matter (SOM), soil NPK contents and enhance the productivity (Turmel *et al* 2015, Singh and Benbi 2016, Bhatt *et al* 2020b). Residue incorporation in winter season crops like potato, wheat and rapeseed resulted in higher yield due to better soil health status (Sharma *et al* 2010).

Plant density is one of the most important cultural practices determining grain yield. It affects the plant architecture, alters growth and developmental pattern and influences carbohydrate partitioning (Xu *et al* 2017). Maize is more sensitive to variation in plant density and nitrogen levels than other members of grass family. At low densities, many modern maize hybrids quite often produce only one ear per plant (Fathy *et al* 2019). On the other hand, the use of high populations enhances interplant competition for light, water and nutrients. This may be detrimental to final yield because it stimulates apical dominance, induce barrenness, and ultimately decrease the number of ears produced per plant and kernels set per cob (Lashkari *et al* 2011, El-Kholy *et al* 2015). But, increasing plant density with increased nitrogen dose and organic manure application will resulted in higher grain yield (Kandil *et al* 2017, Fathy *et al* 2019). Therefore, there is an urgent need to understand the relationship between increasing yields, management of planting density and N in a sustainable manner.

Keeping in view the importance of INM, nitrogen levels, residue incorporation and plant density, the present study entitled "Integrated nutrient management for enhancing productivity of spring maize (*Zea mays* L.) in rice and maize based cropping systems" was conducted with following objectives:

- To study the effect of integrated nutrient management on growth, yield and quality of different crops under rice-potato-spring maize and maize-pea-spring maize cropping systems.
- To study soil properties, system productivity and economic viability of rice-potato-spring maize and maize-pea-spring maize cropping systems.

CHAPTER II

REVIEW OF LITERATURE

A resume of work done in India and abroad relevant to the present study entitled **"Integrated nutrient management for enhancing productivity of spring maize (*Zea mays* L.) in rice and maize based cropping systems"** has been reviewed and presented in this chapter under the following headings:

2.1 Effect of integrated nutrient management

2.1.1 Growth attributes

2.1.2 Yield and yield attributes

2.1.3 Soil health

2.2 Effect of residue incorporation

2.2.1 Growth, yield and yield attributes

2.2.2 Soil health

2.3 Effect of different levels of nitrogen

2.3.1 Growth, yield and yield attributes

2.3.2 Soil health

2.1 Effect of integrated nutrient management

Research on nutrient management in various agricultural crops has a long history in Indian agriculture but the early experiments were primarily restricted to single crop. The nutrient management strategies adopted in one crop often influence the fertilizer needs of the succeeding crops due to the carryover effect of nutrients and incorporation of crop residues. Accordingly, the research on crop nutrient management has started to consider the whole cropping system in formulating the fertilizer schedules.

2.2.1 Growth attributes

Sigaye *et al* (2021) studied the influence of organic and inorganic fertilizers on growth and yield attributes of maize and to determine economically optimum organic and inorganic fertilizer combinations for maize production. They reported that plant height, ear height and cob length of maize were significantly affected by the application of integrated use of organic and inorganic fertilizers. The longest plant height (236.5 cm), ear height (139.9 cm) and cob length (15.2 cm) of maize were recorded with the application of 50% of recommended NP + 50% of vermicompost as compared to 100% recommended NP fertilizer.

Basnet *et al* (2021) conducted a field experiment in the research field of Midwest Academy and Research Institute College of Live Sciences, Tulsipur to investigate the effect of integrated nutrient management on growth and yield of radish. The results from the experiment revealed that application of 50% recommended N through chemical fertilizer + 50% N through poultry manure recorded with highest germination percentage (77.0 %), plant height (13.3 cm), root length (16.9 cm), root diameter (3.01 cm) and yield (16.6 t ha^{-1}) and this treatment was found to be significantly superior than application of 100% recommended N through chemical fertilizer. Prabhavathi *et al* (2021) studied the effect of INM on growth and physiological parameters of maize in maize-groundnut cropping system and reported that growth parameters of maize like plant height, dry matter accumulation and chlorophyll content at tasselling were recorded significantly higher with integrated application of 125% RDF + FYM @ 10 t ha^{-1} as compared to sole application of mineral fertilizer and was at par with the 125% RDF + poultry manure @ 5 t ha^{-1}.

Bhatt *et al* (2020b) carried a field experiment during the spring season at research farm of National Maize Research Programme (NARC), Rampur, Chitwan to evaluate the effect of sole and combined application of different organic and inorganic fertilizers on growth, yield and profitability of maize crop. They concluded that growth attributes such as plant height, leaf area index and dry matter accumulation were found to be higher with combined application of organic and inorganic fertilizers as compared to sole application of inorganic fertilizers. Likewise, days to tasseling (62.5 days), days to silking (68.0 days) and anthesis-silking interval (3.5 days) were also found to be earlier with combined application of organic and inorganic fertilizers.

Mahato *et al* (2020) conducted a field experiment at Instructional Farm, Jaguli, BCKV, West Bengal to study the effect of integrated nutrient management on growth, yield and economics in hybrid maize. Application of 75% RDF + vermicompost @ 2 t ha^{-1} + foliar application of $ZnSO_4$ @ 0.5% recorded with tallest maize plant (250.9 cm), LAI (4.58) and dry matter accumulation (1680.4 g m^{-2}) followed by 75% RDF + vermicompost @ 2 t ha^{-1} + soil application of $ZnSO_4$ @ 25 kg ha^{-1} (249.5 cm, 4.43 and 1582.3 g m^{-2}). Both the treatments remained statistically at par to each other, while the shortest plant height, LAI and DMA (240.4 cm, 3.64 and 1219.2 g m^{-2}) was recorded under application of 100% RDF. A field experiment was conducted by Biswasi *et al* (2020) at research farm of Regional Research and Technology Transfer Sub-station, Kirei, Sundergarh, Odisha and the results showed that integrated application of 75% recommended dose of nitrogen + 25 % N through vermicompost resulted with significantly better plant height (220.8 cm) at harvest, leaf area index (5.15) at 60 days after sowing and dry matter accumulation at harvest (1745 g m^{-2}) as compared to sole application of inorganic fertilizers.

Snehaa *et al* (2019) observed that application of recommended dose of inorganic fertilizer (150:60:40 kg ha^{-1} NPK) recorded the higher values of plant height (61.4 and 64.7cm), LAI (3.6 and 4.1), DMA (850.3 and 920.7 kg ha^{-1}) and CCI (16.0 and 16.8) of maize planted in summer and *kharif* seasons, which was statistically at par with vermicompost @ 5 t ha^{-1} that recorded values of growth attributes viz., plant height (59.6 and 62.2 cm), LAI (3.5 and 3.8), DMA (812.3 and 893.5 kg ha^{-1}) and CCI (15.5 and 16.3). Iniya Ponmozhi *et al*

(2019) conducted a field experiment at Agricultural Research Farm, School of Agriculture, Suresh Gyan Vihar University, Jaipur to study the effect of integrated nutrient management on growth and yield of maize *(Zea mays* L). The maximum plant height, total dry matter accumulation and crop growth rate (CGR) were recorded with application of 100% RDF + 25% Vermicompost + 25% FYM + 25 kg $ZnSO_4$ and it was at statistically par with the treatments 100% RDF + 50% Vermicompost + 50% FYM and 50% RDF + 25% Vermicompost + 25% FYM + 25 kg $ZnSO_4$ and significantly superior to rest of the treatments. To study the effect of farm yard manure (FYM) and nitrogen application on growth and productivity of wheat, an experiment was conducted by Kavinder *et al* (2019) and they reported that plant height, dry matter accumulation and number of tillers m^{-2} were recorded significantly higher with application of 120 kg N ha^{-1} + FYM 15 t ha^{-1} as compared to sole application of 120 kg N ha^{-1}.

Ghosh *et al* (2018) carried an experiment to investigate the continuous effect of inorganic fertilizers and organic manures on growth and productivity of maize. They concluded that the treatment receiving recommended dose of NPKS + FYM + bio fertilizer + lime recorded maximum plant height at 43, 55 and 100 days after sowing as well as root density of maize and the minimum was found in control. So, the results on integrated nutrient management in maize showed that all growth parameters including plant height, root density, chlorophyll content and nutrient concentration in leaves increased to a satisfactory level by the combined application of organics, inorganics, microbial inoculants and lime. A field experiment was conducted by Rathod *et al* (2018) at Navsari Agricultural University, Gujurat, to study the influence of spacing and integrated nutrient management on sweet corn (*Zea mays* L. *saccharata*). The results revealed that application of *Azotobacter* + PSB + KMB biofertilizer recorded significantly higher plant height (210.9 cm), number of leaves $plant^{-1}$ (13.3), stem girth (2.10 cm), cob length with husk (26.4 cm) and without husk (18.1cm), cob girth with husk (14.5 cm) and without husk (10.5 cm) and protein content in grain (6.85%) as compared to no bio fertilizer application.

A field study was carried out by Jadav *et al* (2018) at Jorapura Farm of Livestock Research Station, Sardarkrushinagar to evaluate the effect of integrated nutrient management on growth and yield of *rabi* forage maize (*Zea mays* L.). The results revealed that maximum plant height (175.8 cm), number of leaves per plant (13.5), and length of internodes (12.7 cm) were recorded from plot fertilized with treatment combination of 100 % RDF + *Azotobacter* + PSB. Application of 100 % RDF + *Azotobacter* + PSB registered maximum stem girth of 3^{rd} internode (9.28 cm), leaf area $plant^{-1}$ (4000 cm^2) and leaf:stem ratio (0.37) over other treatments. Kumar *et al* (2017) conducted a field experiment at Zonal Research Station, Birsa Agricultural University, Jharkhand, to study the effect of integrated nutrient management on productivity and profitability of maize. The maximum plant height (201.9 cm), dry matter accumulation (213.5 g), number of cobs plant^{-1} (1.40), number of grains cob^{-1} (393.8) and test weight (223.3 g) were recorded in treatment T_3 (150 % RDF) followed by treatment T_5 (RDF + 5 tons FYM ha^{-1}) which recorded plant height, dry matter accumulation, number of cobs plant^{-1}, number of grains cob^{-1} and test weight of 200.3 cm, 212.9 g, 1.40, 391.9 and 223.2 g, respectively. The results also revealed that treatment T_5 was found to be at par with treatment T_3 with regards to above mentioned parameters. Shambhavi *et al* (2017) examined that with application of 100 % NPK + FYM resulted with higher root mass density (4.08 kg m^{-3}), root volume density (10.84 m^3 m^{-3} x 10^{-3}), root length density (2.60 m m^{-3} x 10^{-4}), root surface area (204.12 m^2 x 10^{-4}) and root cation exchange capacity (8.37 c mol kg^{-1}) as compared to 100% NPK fertilizer.

An experiment was conducted by Singh *et al* (2017) during *rabi* season at Research Farm of the Department of Agriculture, Mata Gujri College, Fatehgarh Sahib to study the effect of integrated nutrient management on growth and yield attributes of maize (*Zea mays* L.) under winter season. The results revealed that application of 75% RDF + vermicompost (5 t ha^{-1}) + FYM (5 t ha^{-1}) + *Azotobacter* recorded with maximum plant height, DMA and LAI of maize at 60, 90 DAS and at harvest, but minimum growth attributes were recorded with sole application of inorganic fertilizers. Application of 100% RDF gave best results on growth parameters (plant height, LAI and dry matter) at 30 DAS because utilization and availability of fertilizer by the plants is usually higher. A field experiment was conducted by Hashim *et al* (2015) at New Delhi, to evaluate the effect of integrated nutrient management on growth, yield attributes, yield and economics of maize (*Zea mays* L.*)*-wheat (*Triticum aestivum*) cropping system. The results showed that application of 50% recommended dose of fertilizer (RDF) through synthetic fertilizers + 50% recommended dose of nitrogen (RDN) through crop residue mixed farmyard manure recorded maximum values of growth attributes in maize. The highest values of plant height, dry matter accumulation and leaf-area index were registered with application of 50% RDF + 50% RDN through crop residue mixed FYM, which were significantly higher than the control.

Priya *et al* (2014) investigated that maximum plant height at harvest (237.3 cm), dry matter accumulation in maize plants at 30 DAS (22.3 g plant^{-1}), 45 DAS (61.4 g plant^{-1}) and 60 DAS (107.2 g plant^{-1}), CGR between 30-45 DAS (21.7 g m^{-2}day^{-1}) and 45-60 DAS (25.42 g m^{-2} day^{-1}), LAI at 45 DAS (3.29) and 60 DAS (3.94) and RGR between 30-45 DAS (0.067 g g^{-1}day^{-1}) and between 45-60 DAS (0.037 g g^{-1}day^{-1}) were recorded with 100% NPK + FYM @ 10 t ha^{-1} which was statistically at par with 150% NPK but significantly superior to all other treatments. A field experiment was conducted by Kalhapure *et al* (2013) to evaluate most efficient and economic combination of different organic and inorganic sources of nutrients to increase the productivity of hybrid maize (*Zea mays* L.) without deteriorating the soil qualities. They investigated that significantly better plant height, total plant dry matter, number of cobs plant^{-1}, grains cob^{-1} and weight of 100 grains of maize were recorded with application of 25% RDF + biofertilizers (*Azotobacter* + PSB) + green manuring (sunhemp) + compost than other treatments. Kannan *et al* (2013) carried out a field study at Vanavarayar Institute of Agriculture, Manakkadavu, to study the effect of INM on soil fertility and productivity on maize (*Zea mays* L.). The results showed that combined application of vermicompost + NPK and FYM + NPK to maize resulted in significantly higher leaf area and plant height as compared to application of chemical fertilizer alone.

Haque *et al* (2012) conducted a field experiment during *kharif* to study the performance of maize cultivars as influenced by integrated nutrient management under Terai region of West Bengal. The results revealed that 75% RDF + vermicompost @ 2 t ha^{-1} recorded with tallest plant (2.40 and 2.19 m) as compared to other treatments. The leaf area index, dry matter production, days to 50 and 100% tasseling and silking, and number of cobs plant^{-1} were found to be highest under combined use of 75% RDF + vermicompost. Malligawad (2010) concluded that application of FYM @ 7.5 t ha^{-1} in groundnut during *kharif* season produced higher dry matter (3510 kg ha^{-1}) as compared to application of recommended dose of NPK fertilizer (2970 kg ha^{-1}). Patidar and Mali (2002) reported that plant height of wheat at harvest was significantly higher owing to the integrated nutrient management in sorghum in preceding season.

2.1.2 Yield and yield attributes

Sigaye *et al* (2021) studied the effect of organic and inorganic fertilizers on maize yield and reported highest maize grain yield (7494.3 kg ha^{-1}) and above-ground biomass yield (18718.0 kg ha^{-1}) with the application of 50% recommended NP fertilizer + 50% vermicompost than sole application of recommended NP fertilizers. Ejigu *et al* (2021) conducted an experiment to study the combined effect of compost and mineral fertilizer on maize yield in North-Western Ethiopia. The results showed that plots amended with 10 t ha^{-1} compost + 100/100 kg ha^{-1} Urea/Nitrogen + Phosphorus + Sulphur + Boron (NPSB) blended mixture provided the highest maize dry biomass (18.6 t ha^{-1}) and grain yield (6.07 t ha^{-1}) while the lowest biomass (5.70 t ha^{-1}) and grain (1.17 t ha^{-1}) yields were obtained from the control treatment. Chahal *et al* (2019) concluded that grain and stover yield of both crops in maize-wheat cropping system increased significantly with the incorporation of 100% NPK + FYM 10 t ha^{-1} over control. The highest maize grain yield of 4033 kg ha^{-1}, 4053 kg ha^{-1} and stover yield of 5290 kg ha^{-1}, 5320 kg ha^{-1} were recorded with application of 100% NPK + FYM 10 t ha^{-1} during 2014-15 and 2015-16, respectively. Similarly, the highest wheat grain yield of 4939 kg ha^{-1}, 5107 kg ha^{-1} and straw yield of 7217 kg ha^{-1}, 7270 kg ha^{-1} were recorded under 100% NPK + FYM 10 t ha^{-1} treatment during both years.

Biswas and Dutta (2020) reported that application of 100% RDF along with supplementation of either vermicompost or yeast vinasse @ 2 t ha^{-1} enhanced nutrient uptake such as N (144.6 kg ha^{-1} and 138.9 kg ha^{-1}), P (18.3 kg ha^{-1} and 16.8 kg ha^{-1}) and K (130.2 kg ha^{-1} and 134.8 kg ha^{-1}), tuber yield (27.29 t ha^{-1} and 26.97 t ha^{-1}), dry matter yield (6.75 t ha^{-1} and 6.66 t ha^{-1}) and quality parameters such as carbohydrate (74.7% and 74.9%) and protein (1.23% and 1.22%) of potato over sole application of 100% RDF through chemical sources during both the years. Biswasi *et al* (2020) evaluated that the number of grains cob^{-1} (466.49), grain weight cob^{-1} (102.7 g), test weight (220.3 g), length of cob (24.3 cm), girth of cob (18.0 cm), number of cobs plant^{-1} (1.07), grain yield (6.79 t ha^{-1}), stover yield (10.9 t ha^{-1}), harvest index (0.39), gross returns (88,318 Rs ha^{-1}), net returns (52,099 Rs ha^{-1}) and returns per rupee invested (2.44) of maize were recorded to be significantly higher under 75% Recommended DFN + 25 % N through vermicompost as compared to sole use of inorganic fertilizers.

Mahato *et al* (2020) observed maximum number of cobs per plant (1.11), 100-grain weight (28.8 g), grains per cob (402.6), N uptake (200.5 kg ha^{-1}) and P uptake (66.5 kg ha^{-1}) with the application of 75% RDF + vermicompost @ 2 t ha^{-1}+ foliar application of $ZnSO_4$ @ 0.5% to maize, while minimum number of cobs per plant (1.03), 100-grain weight (28.4 g), grains per cob (326.6), N uptake (136.5 kg ha^{-1}) and P uptake (45.3 kg ha^{-1}) were recorded with application of 100% RDF. Bhatt *et al* (2020b) carried a field experiment to evaluate the effect of sole and combined applications of different organic and inorganic fertilizers on growth parameters and profitability in maize. The results showed that biological yield (10.1 t ha^{-1}) and B: C ratio (1.58) were comparatively superior with application of 60 kg N ha^{-1} as urea + 60 kg N ha^{-1} as poultry manure as compared to application of inorganic fertilizers alone. Therefore, they concluded that application of 120 kg N through combination of 60 kg N ha^{-1} as urea + 60 kg N ha^{-1} as poultry manure was found as best combination of fertilizers for higher returns in Terai region of Nepal.

Meena *et al* (2019) reported that maize grain yield was significantly higher with soil test crop response (STCR) based INM practices i.e. 75% NPK of STCR + FYM @ 5 Mg ha^{-1} followed by integration of 75% NPK + poultry manure @ 1 Mg ha^{-1} as compared to general recommended dose (GRD) and 100% NPK alone. Further, maize on STCR based INM practice 75% NPK + FYM showed significant increase of 5.39%, 15.28%, 29.82%, 29.35% and 24.5% in grain yield over GRD during 2012-13, 2013-14, 2014-15, 2015-16 and 2016-17, respectively. Snehaa *et al* (2019) concluded that application of NPK @ 150:60:40 kg ha^{-1} recorded highest values of yield attributes *viz.,* number of cobs, cob length, cob girth, cob weight, cob yield and fodder yield of maize for summer and *kharif* seasons this treatment was at par with vermicompost @ 5 t ha^{-1}. Iniya Ponmozhi *et al* (2019) observed that highest grain yield (71.3 q ha^{-1}) was obtained with the application of 100% RDF + 25% vermicompost + 25% FYM + 25kg $ZnSO_4$ which was statistically at par with 100% RDF + 50% vermicompost + 50% FYM, 50% RDF + 25% vermicompost + 25% FYM + 25kg $ZnSO_4$ and significantly superior to other treatments. There was an increase of 30% more yield in treatment 100%

RDF + 25% vermicompost + 25% FYM + 25kg $ZnSO_4$ as compared to that of 50% RDF which recorded the lowest grain yield (31.4 q ha^{-1}). Jadav *et al* (2018) carried out a field study to evaluate the effect of integrated nutrient management on growth and yield of *rabi* forage maize (*Zea mays* L.). Maximum green forage (557 q ha^{-1}) and dry fodder (116 q ha^{-1}) yield of crop were registered when crop fertilized with 100 % RDF + *Azotobacter* + PSB followed by 75 % RDF + *Azotobacter* + PSB. Both the treatments were found significantly superior over rest of all other treatment combinations for green forage and dry fodder yield.

Ghosh *et al* (2018) evaluated that yield parameters like cob length (18.5 cm) and cob diameter (15 cm), volume of cob (862.8 cm^3), number of rows cob^{-1} (15), grains cob^{-1} (570), test weight (326) and grain yield (7 t ha^{-1}) of maize were found to be highest with combined application of soil test dose + vermicompost + biofertilizer + lime as compared to control and sole application of inorganic fertilizers. The relative agronomic efficiency, uptake of nutrients and the apparent recovery of N (78%) and P (46.4%) were also found to be highest in this treatment. Rathod *et al* (2018) recorded significantly higher cob weight with and without husk (201.5 g and 145.1 g), numbers of grains per row (37.7), grains per cob (458.9), fresh weight of grains per cob (116.1 g), green cob yield (86.6 q ha^{-1}) and green fodder yield (299.7 q ha^{-1}) with application of bio fertilizers i.e. *Azotobacter* + PSB + KMB. Whereas, the lowest values of above mentioned parameters were found under no bio fertilizers application. A field study was conducted on sorghum by Dhonde *et al* (2018) and they concluded that among organic nutrient levels the crop supplied with 100% N (50% N through FYM + 50% N through VC) produced significantly higher grain yields of 3242, 3622 and 3432 kg ha^{-1} during 2015-16, 2016-17 and 2017-18 and the per cent increase in grain yield were 39.20, 43.04 and 41.17 over application of 50% N through organic manure. The protein and total sugar content of sorghum were recorded to be significantly higher with application of 50% N through FYM + 50% N through VC as compared to other treatments. Singh *et al* (2017) reported that all the yield attributes of maize *viz.* number of cobs per plant, number of grains per row, cob length, shelling %, seed index, seed yield and stubble yield were recorded significantly higher with application of 75% RDF + vermicompost (5 t ha^{-1}) + FYM (5 t ha^{-1}) + *Azotobacter* than control and was statistically at par with treatment consisting of 100% RDF and 75% RDF + vermicompost (5 t ha^{-1}). Kumar *et al* (2017) evaluated that the maximum grain yield (52.1 q ha^{-1}) and stover yield (140.7 q ha^{-1}) was recorded in treatment T_3 (150 % RDF) followed by treatment T_5 (RDF + FYM @ 5 t ha^{-1}) which recorded grain yield and stover yield of 51.7 q ha^{-1} and 140.1 q ha^{-1}, respectively. A close examine of the data also revealed that treatment T_5 was found to be at par with treatment T_3 with regards to grain yield and stover yield while minimum yield was recorded in T_8 (Control).

Bhatt *et al* (2016b) studied long-term effect of chemical fertilizers and farmyard manure (FYM) in rice (*Oryza sativa*)-wheat (*Triticum aestivum*) cropping system for two consecutive years after 38 and 39 years on productivity and soil biological properties of Mollisols. The mean grain and straw yields of rice and wheat crops after 38^{th} and 39^{th} years were highest with treatment 100% NPK + FYM 15 t ha^{-1}. This treatment produced significantly higher mean grain and straw yields of rice (37.6% and 24.5%) and wheat (34.5% and 20.7%, respectively) over 100% NPK application. Similarly, an experiment was conducted at Almora by Bhattacharyya *et al* (2016) and they concluded that plots supplied with 100 % NPK + FYM had maximum mean maize (5.00 Mg ha^{-1}) and wheat (2.61 Mg ha^{-1}) yields that were significantly higher than yields observed under other treatments. The greater yield in NPK + FYM (7.61 Mg ha^{-1}, total of maize + wheat) compared with NPK plots (5.49 Mg ha^{-1}) could be due to a number of factors, including greater total nutrient inputs and the combination of organic and inorganic sources of nutrients under NPK + FYM. Singh *et al* (2016) conducted an experiment at student's research farm, Department of Agriculture, Khalsa College, Amritsar to study the effect of integrated nutrient management on yield and quality parameters of Baby corn (*Zea mays* L.). They observed that yield parameters of baby corn like number cobs per plant, cob length, cob girth, green cob weight, corn yield, stover yield and quality parameters like protein content and total soluble sugar were significantly higher with application of 100% of recommended N which was statistically at par with application of FYM 10 t ha^{-1} + inorganic N 75 kg ha^{-1}.

Elayarajan *et al* (2015) reported that highest maize grain yield of 9906 kg ha^{-1} and straw yield of 12681 kg ha^{-1} was recorded with integrated application of 100% NPK along with FYM @ 12.5 t ha^{-1} (INM practice) over 100% NPK. The INM practice proved its superiority by recording 10.4 % increases in grain yield of maize hybrid over 100% NPK. Total uptake of NPK was also found to be higher in INM practice. Gundlur *et al* (2015) reported significant higher maize yield and chickpea yield from the plot which received RDF with bio fertilizer in maize-chickpea crop sequence. Sohu *et al* (2015) found that application of organic farmyard manure and poultry manure in combination with inorganic NPK fertilizers to chickpea resulted in a positive effect on yield and yield attributes of succeeding chickpea crop in rice-chickpea cropping system. Hashim *et al* (2015) examined that yield attributes like cob length, 1000-grain weight, grains per cob, seed yield and stover yield were significantly increased with the application of different combinations of crop residue + FYM and fertilizer over the control treatment. The maximum values of yield and yield attributes were recorded owing to combined application of 50% RDF + 50% RDN followed by application of 75% RDF + 25% RDN and these were significantly higher than the control. In maize, highest system productivity was recorded under treatment 50% RDF + 50% RDN, followed by 75% RDF + 25% RDN as compared to inorganic fertilizer application.

Rajasingh and Lourduraj (2014) investigated that application of 100 % RDF with FYM 12.5 t ha^{-1} to maize and application of 100 % RDF to succeeding cowpea crop can be recommended for enhancing the growth parameters, grain and haulm yield in the succeeding cowpea. Sheetal *et al* (2014) observed that maximum pod and haulm yield (20.9 and 37.9 q ha^{-1}) of groundnut was recorded with 150 @ % RDF which was at par with integrated use of FYM @ 5 t ha^{-1} + 50 % RDF + neem cake 500 kg ha^{-1} + bio fertilizers (18.8 and 37.0 q ha^{-1}). Rani *et al* (2014) studied integrated use of organic manures and inorganic fertilizers for maize + spinach intercropping system. They found that application of 75% RDF + 25% through vermi-compost recorded significantly higher grain yield (52.4 q ha^{-1}) and stover yield (60.8 q ha^{-1}) in maize. A study was carried out by Dunjana *et al* (2014) to determine the effects of cattle manure and inorganic N-fertilizer application on the hydraulic properties of soil and maize yield. They observed that soil hydraulic properties which included steady state infiltration rate, moisture retention under low suction and maize grain yield were significantly improved with application of 25 t ha^{-1} cattle manure + 100 kg ha^{-1} N as compared to the control.

Priya *et al* (2014) conducted an experiment at Udaipur, to assess effect of application of plant nutrients through organic and inorganic sources and its combination on crop growth and productivity of maize. The results of the investigation reflected that application of integrated nutrient as 100% NPK+ FYM 10 t ha^{-1} in maize recorded maximum grain yield (4.03 t ha^{-1}) and stover yield (6.04 t ha^{-1}) with a per cent increase of 203 and 169.6 over control. Kalhapure *et al* (2013) conducted a field experiment at breeder seed production farm of Mahatma Phule Krishi Vidyapeeth, Rahuri to find out most efficient and economic combination of organic and inorganic source of nutrients to increase the productivity of hybrid maize (*Zea mays* L.) without deteriorating the soil health. They reported that with combined use of organic and inorganic fertilizers, maize grain yield was increased by 252.4% over control and 147.6% over 100% RDF. Maximum B:C ratio (1.30) was also observed in jointly use of 25% RDF, compost, biofertilizers and green manuring and it was followed by application of 100% RDF (1.26) which was responsible for deterioration of nutrient status of soil.

Kannan *et al* (2013) carried out a field study at Vanavarayar Institute of Agriculture, Manakkadavu to study the effect of INM on soil fertility and productivity on maize (*Zea mays*). Number of grains per cob and cob weight were recorded significantly higher with treatment consisted of NPK + FYM than control and sole application of inorganic fertilizers. The 1000-seed weight and seed yield were recorded significantly higher with application of vermicompost + NPK followed by NPK + FYM. Haque *et al* (2012) conducted a field experiment in *kharif* season to study the performance of maize cultivars as affected by integrated nutrient management under Terai region of West Bengal. Numbers of effective cobs per plant was found to be significantly higher (1.25 and 0.98) under 75% recommended dose of fertilizer + vermicompost @ 2 t ha^{-1} in both the years of investigation, which ultimately resulted into production of maximum (74667 and 58733) number of cobs ha^{-1}. The treatment receiving 75 % recommended dose of fertilizer + vermicompost @ 2 t ha^{-1} fetched highest benefit:cost ratio of (2.82) as compared to 100 % recommended dose of chemical fertilizer.

Verma *et al* (2012) found that incorporation of 100% NPK along with FYM @ 10 t ha^{-1} resulted in highest yield of both the crops in maize-wheat intensive cropping system. Rahman *et al* (2012) observed that integrated use of inorganic fertilizers and manure produced comparable higher seed yield of maize as compared to chemical fertilizers alone in maize-mungbean cropping system. Karforma *et al* (2012) reported that the experimental area receiving 50% RDN (30 kg ha^{-1} N) through organic manures and remaining 50 % RDF through chemical fertilizers along with *Azotobacter* to preceding maize had a significant residual effect on most of the yield components and yield of succeeding rapeseed. A study was carried out by Farhad *et al* (2011) at the Agronomic Research Area, University of Agriculture, Faisalabad on effectiveness of different levels of poultry manure (PM) on the yield and quality of spring maize (*Zea mays* L.). They found that the grain yield (7.33 t ha^{-1}), biomass (20.22 t ha^{-1}), harvest index (36.3%) and seed protein (8.52%) were recorded significantly higher with the application of recommended NPK, which was statistically at par with application of 12 t ha^{-1} of poultry manure. However, marginal analysis showed that application of PM 12 t ha^{-1} gave highest marginal rate of return (470.7%) against the minimum (109%) with recommended NPK due to high cost of synthetic fertilizers.

Lingaraju *et al* (2010) reported that the experimental plot which received 7.5 t ha^{-1} FYM along with 100 % RDF recorded with significantly higher maize and bengal gram yield in maize-bengal gram cropping system. Veeral (2008) observed that application of press mud @ 12.5 t ha^{-1} with lignite fly-ash @ 5 t ha^{-1} proved to be superior in growth, yield and yield attributes of maize under various maize based cropping systems.

A field experiment was conducted by Ghosh *et al* (2004) on deep vertisols of Bhopal, to evaluate the manurial potential of three organic manures: farmyard manure (FYM), poultry manure (PM), phospho-compost (PC) vis-a-vis 0%, 75% and 100% recommended dose of fertilizer NPK. The results of the above experiment revealed that application of 75% NPK in combination with PM or FYM or PC to preceding rainy season crops (soybean and sorghum) and 75% NPK to wheat produced significantly higher grain yield of wheat than those in inorganics and control indicating noticeable residual effect on the succeeding wheat crop and saving of 25% fertilizer-NPK. The total system productivity of both the cropping systems was recorded to be significantly higher in the treatment receiving FYM and PM than other treatments. Samui *et al* (2004) conducted a field experiment at Kalyani, West Bengal to evaluate the performance of rice based crop sequences. They reported that rice-potato-groundnut gave the highest gross returns, net returns and B:C followed by rice-cabbage-rice,

rice- potato-rice and rice-potato-sesame. Rice equivalent yield, production efficiency was highest in rice-potato-groundnut sequence which indicates that this sequence having potato and groundnut crops has good effect on subsequent rice crop.

Dey (2003) observed that grain yield of maize at 50 % recommended NP with black gram rotation was significantly higher than that of sole maize at 100 % recommended NP but was statistically at par with sole maize at 150% recommended NP. Mosa *et al* (2003) found that application of 100% recommended NPK with compost 4 t ha^{-1} or 6 t ha^{-1} of FYM resulted in maximum plant height, dry matter accumulation and higher pod yield of groundnut under maize-groundnut cropping system. Pathak *et al* (2002) reported that yield attributes, *viz.*, cobs per plant, cob length, cob girth, 1000-grain weight and seed yield of maize were recorded maximum in the treatment which received 75 % of the recommended dose of NPK in inorganic forms and 25 % N from organic manures i.e FYM. Whereas, all yield attributing parameters of wheat were recorded maximum from the treatment received 50 % of NPK through inorganic fertilizers and 50 % from FYM in the preceding crop and getting 100 % recommended NPK in wheat. Palled *et al* (2000) conducted an experiment on red soils of Karnataka and observed that grain yield of maize and pod yield of groundnut were significantly higher by 8.84 % and 9.18 % respectively, from the plot receiving recommended dose of fertilizer along with green manure over the recommended dose alone.

2.1.3 Soil health

Sigaye *et al* (2021) studied the influence of organic and inorganic fertilizers on soil fertility. They observed that the maximum soil organic carbon content (3.5%), total nitrogen (0.41%), available phosphorus (19.5 g kg^{-1}) and CEC (40.1 c mol kg^{-1}) of soil were obtained from the combined application of 50% vermicompost + 50% recommended NP fertilizer than sole application of recommended NP fertilizers. Ejigu *et al* (2021) concluded that combined application of compost and mineral fertilizer (10 t ha^{-1} compost + 100/100 kg ha^{-1} urea/NPSB) significantly increased soil pH (5.65), organic carbon (1.96 %), total nitrogen (0.22 %), available phosphorus (10.90 mg kg^{-1}), available sulphur (11.58 mg kg^{-1}) and cation exchange capacity (33.07 Cmol kg^{-1}) as compared to sole mineral fertilizer application and control treatment. However, there was significant decrease in soil bulk density (1.24 g cm^{-1}) with combined application of compost and mineral fertilizer. Kumawat *et al* (2019) concluded that the organic carbon in treatment RDF + FYM 5 t ha^{-1} + *Rhizobium* + PSB was significantly higher than RDF. The application of RDF + 5 t FYM ha^{-1} + *Rhizobium* + PSB significantly enhanced the available N and P content in soil. This treatment was found statistically at par with RDF + 1 g $(NH_4)_2MoO_4$ kg $seed^{-1}$ + *Rhizobium* + PSB and significantly better than RDF.

Meena *et al* (2019) reported that the highest SOC (6.30 g kg^{-1}) was recorded with application of exclusive organic manure (FYM at 20 Mg ha^{-1} $year^{-1}$) followed by 75% NPK+ 5 Mg ha^{-1} FYM (6.17 g kg^{-1}) and the increases in SOC was 31.4, 26.8% and 60.4, 54.8% in

FYM @ 20 Mg ha^{-1} year^{-1} and 75% NPK+ 5 Mg ha^{-1} FYM as compared to GRD and control treatments, respectively. The highest carbon sequestration (213.1 kg ha^{-1} year^{-1}) was recorded with the application of organic manures at FYM 20 Mg ha^{-1} year^{-1} followed by 75% NPK + FYM @ 5 Mg ha^{-1} (203.6 kg ha^{-1} year^{-1}). The increase in dehydrogenase activity (DHA), alkaline phosphates (Alk-P) and fluorescein diacetate (FDA) by 73.3, 30.9 and 63.2% under continuous applied of FYM at 20 Mg ha^{-1}as compared to GRD and 227.1, 49.2 and 92.9% over the unfertilized plot, respectively. The soil BD was significantly lower under the integration of 75% NPK with FYM/poultry manure/urban compost and application of pure organic manures due to the addition of higher organic matter. While, in contrast, significantly increase in soil porosity was recorded with application of FYM (20 Mg ha^{-1}) every year than unfertilized plots and 100% NPK alone.

A study was carried out by Joshi *et al* (2018) during *kharif* season at the Instructional Dairy Farm, Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, Uttarakhand to study soil nutrient status under different integrated nutrient management treatments. The study revealed that highest available nitrogen and potassium, apparent nitrogen and potassium balance, soil organic carbon and bacterial population were estimated with application of 100% NPK + *Azotobacter* + *Azospirillum* as compared to sole application of inorganic fertilizer. Bhatt *et al* (2016b) studied long-term effects of chemical fertilizers and farmyard manure (FYM) in rice (*Oryza sativa*)-wheat (*Triticum aestivum*) cropping system on productivity and soil biological properties of Mollisols. The experimental results indicated that the soil microbial biomass, C (410.0 and 407.5 μg g^{-1}) and N (44.53 and 48.30 μg g^{-1}) after rice and wheat, respectively, were highest with application of 100% NPK + 15 t FYM ha^{-1}, which were significantly higher over sole use of inorganic fertilizers. Application of 100% NPK + 15 t FYM ha^{-1} recorded highest population of bacteria (24.8 and 29.8 cfu × 106 g^{-1}), fungi (25.4 and 25.9 cfu × 104 g^{-1}) and actinomycetes (40.1 and 41.9 cfu × 105 g^{-1}) after rice and wheat crops, respectively. Continuous use of FYM over the years in combination with optimum chemical fertilizers supplied large amount of readily available carbon in soil resulting into more microbial population as compared to application of chemical fertilizers alone. Shambhavi *et al* (2017) concluded that conjoint use of FYM + 100% NPK substantially improved the organic carbon status by 4.95 g kg^{-1} as well as available P, K and S by 154.1, 14.5 and 12.5 kg ha^{-1}, respectively in soil over its initial values, thereby indicating significant contribution towards sustaining the soil health.

Bhattacharyya *et al* (2016) concluded that soil supplied with NPK + FYM, FYM and 1/2 NPK + FYM plots resulted in larger total SOC content than all other treatments in the surface (0-15 cm) layer. The NPK + FYM plots increased total SOC by nearly 36 % over NPK in the 0-30 cm soil layer. Thus, soil C retention potential data indicate that plots under NPK + FYM had the highest CO_2 sequestration potential in the 0-30 cm soil layer, was significantly higher than all other treatments. Xin *et al* (2016) observed that compost application (OM, 1/2OM1/2NPK) decrease the soil bulk density and increase total porosity significantly in comparison with that in the unfertilized control plots. Compost application increased the total amount of water-stable macro-aggregates (>0.25 mm). The compost and mineral fertilizer treated soil had 34.6–91.7% higher volume of macropores than the control plots. The hydraulic conductivity in the balanced fertilization plots (OM, 1/2OM1/2NPK, NPK) tended to be higher than in the unbalanced fertilization treatments (NP, PK, and NK) and control.

A field experiment was conducted by Brar *et al* (2015) at Punjab Agricultural University, Ludhiana to assess the effects of inorganic fertilizers and farmyard manure (FYM) on soil organic carbon (SOC), soil physical properties and crop yields in a maize (*Zea mays*)-wheat (*Triticum aestivum*) rotation. The results showed that the cumulative infiltration, infiltration rate and aggregate MWD were greater with integrated use of FYM along with 100% NPK compared to non-treated control. The SOC pool was the lowest in control at 7.3 Mg ha^{-1} and increased to 69 % (11.6 Mg ha^{-1}) with application of 100% NPK + FYM. Elayarajan *et al* (2015) conducted experiment to investigate the effect of continuous application of inorganic fertilizers and organic manures on yield, uptake and soil fertility of maize at Tamil Nadu Agricultural University. They found that continuous application of 100% NPK along with FYM @ 12.5 t ha^{-1} resulted in the highest organic carbon (0.70%), available nitrogen (216 kg ha^{-1}) and potassium (920 kg ha^{-1}) as compared to sole use of inorganic fertilizers. Yang *et al* (2015) reported that average soil organic carbon (SOC) and total nitrogen (TN) contents were 38.0 and 17.3%, 14.2 and 6.7%, and 12.9 and 6.1% higher, respectively, for NM, NPK and NS in maize-wheat cropping system. In addition, the SOC contents with the five treatments N, NGM, NS, NPK and NM was increased by 25.5, 33.1, 42.1, 69.7 and 145.6%, respectively, for TN they increased by 6.6, 17.8, 23.2, 35.5 and 57.5%, respectively.

Sarkar *et al* (2014) reported that soil analysis done after harvesting of rice showed decrease in soil organic carbon content and a significant increase in total N, mineralisable N, P and K from integrated use of green manure along with inorganic fertilizer in rice-pea cropping system. Somashekharappa *et al* (2014) observed that application of 100% recommended N, P_2O_5 and K_2O + poultry manure resulted in a significantly higher soil organic carbon and available NPK content followed by 100% recommended N, P_2O_5 and K_2O + recommended FYM.

A field study was carried out by Kannan *et al* (2013) at Vanavarayar Institute of Agriculture, Manakkadavu, to study the effect of INM on soil fertility and productivity on maize (*Zea mays* L.). With application of NPK + FYM there was change in soil physical and chemical properties and resulted in higher available nitrogen, phosphorus and potassium, higher soil organic carbon, low bulk density and decreased soil pH as compared to sole application of NPK fertilizers. Kalhapure *et al* (2013) observed that application of 25% recommended dose of fertilizers (RDF) in combination with biofertilizers (*Azotobacter chroococcum* + phosphate solubilizing bacteria), green manuring with sunhemp and incorporation of compost @ 10 t ha^{-1} improved soil physic-chemical properties (viz. decrease in alkaline pH by 0.4, bulk density by 0.04 g cm^{-3} and increase in infiltration rate by 0.65 cm hr^{-1}). This was also responsible for improving the nutrient status of soil in respect of organic carbon, available N and available P_2O_5 which were increased by 0.14%, 4.4 kg ha^{-1} and 11.7 kg ha^{-1}, respectively over the initial nutrient status of soil. Brar *et al* (2013) observed positive impact of INM in rice-wheat cropping system at soil depth of 0-15 cm. The soil organic carbon (SOC) was significantly increased from 4.11 g kg^{-1} with 100 % NPK to 4.55 g kg^{-1} with 100 % NPK + FYM.

Verma *et al* (2012) estimated that available N and P was increased significantly in the experimental plot which received 150 % NPK and 100 % NPK + FYM @ 10 t ha^{-1} as compared to 100 % NPK and control treatment in maize-wheat intensive cropping system. Akbari *et al* (2011) reported that integrated use of inorganic and organic fertilizers enhanced the yield of groundnut and wheat as well as sustained the soil fertility. Satish *et al* (2011) observed that organic sources of nutrients in combination with inorganic fertilizers showed improvement in organic carbon content from 0.68 % to 0.73 %, available phosphorus from 12.3 kg ha^{-1} to 22.0 kg ha^{-1} and maintained available potassium content in soil as compared to sole application of inorganic fertilizers.

A field experiment was conducted by Walia *et al* (2010) at Ludhiana to study the long-term effect of integrated nutrient management on physic-chemical and biological properties of soil after 23 cycles of a rice-wheat cropping system. They observed that the integrated nutrient management technique resulted in a positive influx of nutrients by increasing organic carbon content, available nitrogen, phosphorus and potassium varying from 0.390 to 0.543%, 171.7 to 219.3 kg ha^{-1}, 20.5 to 43.3 kg ha^{-1} and 124.6 to 148.9 kg ha^{-1}, respectively. Also, NO_3-N and NH_4-N and DTPA-extractable Zn, Cu, Fe, and Mn content showed significant improvement in the soil with the addition of FYM, wheat cut straw (WCS) and GM.

Antil and Singh (2007) observed that continuous application of organic manures alone or in conjunction with NP fertilizer for 10 years decreased the soil pH. The organic carbon content of the soil has approached to 0.99% in plot receiving 15 Mg FYM ha^{-1} + 150 kg N ha^{-1} + 30 kg P_2O_5 ha^{-1}. The application of organic manures with or without NP fertilizers could not sustain the original level of N. However, their application increased the available P, K and DTPA extractable Zn, Fe, Mn and Cu content of soil. Rasool *et al* (2007) evaluated that the addition of both FYM and $N_{120}P_{30}K_{30}$ increased the organic carbon by 44 and 37%, respectively in rice. The total porosity of soil increased by 25% in 0-15 cm soil depth with the application of FYM + $N_{120}P_{30}K_{30}$ as compared to control plots. The average water holding capacity (WHC) was 16 and 11% higher with FYM and $N_{120}P_{30}K_{30}$ application from that in control plots. The total porosity and water holding capacity (WHC) improved with the application of balanced application of fertilizers.

2.2 Effect of residue incorporation

Recycling of crop residues by incorporation into soil is a sustainable way of their management. Crop residues are the significant source of organic matter that can be reverted back to soil for nutrient recycling and to improve soil physical, chemical and biological properties of soil. When crop residues are incorporated, several organic acids are released due to their decomposition, which helps to improve the availability of nutrients and increase the productivity of crops in the next season. Incorporation of residues has a number of positive effects like improved nutrient availability, better soil structure, improved water retention and less risk of soil erosion.

2.2.1 Growth, yield and yield attributes

Ku *et al* (2019) conducted an experiment to evaluate the effect of continuous rice straw incorporation on grain yield of rice. The results revealed that rice straw (RS) and rice straw compost (RSC) incorporation increased grain yields by 9.2 % (1,757 kg ha^{-1}) and 11.2 % (1,783 kg ha^{-1}) respectively compared with the control (1,610 kg ha^{-1}). Kumari *et al* (2018) studied the effect of crop residue incorporation on yield and soil physical properties of rice-wheat cropping system and observed that highest grain and straw yields of both rice (4.52 and 7.22 t ha^{-1}, respectively) and wheat (4.55 and 6.51 t ha^{-1}, respectively) were recorded with 100 % incorporation of crop residues with starter dose of Zn @ 10 kg ha^{-1} as compared to 0, 25 and 50 % crop residue incorporation. Memon *et al* (2018) reported maximum grain yield of rice with the incorporation of wheat residues in soil under reduced tillage. The highest average grain yield was recorded in 60 % straw incorporation with reduced tillage (8274 kg ha^{-1}) and the lowest was found in residue removal with conventional tillage (7172 kg ha^{-1}).

Ali *et al* (2018) reported that the highest pearl millet equivalent yield (13,306 kg ha^{-1}) was observed under residue incorporation which was 16 % higher over no residue incorporation. Meena *et al* (2018) carried out a field experiment to study the effect of residue retention practices on wheat yield in north-western plains of India and reported that incorporation of rice residue @ 2.5 t ha^{-1} resulted with significantly higher grain yield (5.73 t ha^{-1}) and biomass yield (12.9 t ha^{-1}) of wheat as compared to no residue retention practice. Chen *et al* (2018) observed that straw incorporation significantly increased the average grain yields of rice and wheat by 11.6 % and 11.1 %, respectively, compared with those of the straw removal treatments at the Jiangyan and Guangde site of south-eastern China.

A field experiment was conducted by Almaz *et al* (2017) at Malaysia, to evaluate the effect of incorporation of crop residues with supplemental inorganic fertilizers on yield and quality of maize crop. The results showed that the application of soybean residue with supplemental phosphorus and potassium fertilizer gave maize yield (37,290 kg ha^{-1}) similar to that of the complete inorganic fertilizer treatment (36,500 kg ha^{-1}). Kesarwani *et al* (2017) studied the effect of in-situ rice residue management under rice-wheat cropping system and their influence on wheat productivity in Uttar Pradesh. They concluded that productivity of succeeding wheat crop was enhanced with incorporation of rice residues in rice-wheat cropping system as compared to residue removal and burning. Grain and straw yield of 60.5 and 75.2 q ha^{-1} was obtained from surface retention of residues integrated with application of 150 kg N ha^{-1}.

Meena *et al* (2015) studied the effect of tillage and residue management practices on yield and yield attributes in summer mungbean and concluded that maximum yield was obtained from conventional tillage with residue incorporation as compared to other treatments. Wei *et al* (2015) concluded that higher yields coupled with higher nutrient contents were achieved with high level: 9000 kg ha^{-1}, medium level: 6000 kg ha^{-1}, and low level: 3000 kg ha^{-1} of straw incorporation as compared with control, where these treatments increased the crop yields by 26.75%, 21.51%, and 7.15%, respectively. Dhar *et al* (2014) studied the residual effect of crop residues along with green manure, microbial culture and inorganic fertilizer on yield and soil properties of wheat grown after rice and concluded that maximum plant height, tillers m^{-2}, straw and grain yield of wheat were increased significantly with treatment consisting of straw @ 5 t ha^{-1} + GM @ 5 t ha^{-1} as compared to other treatments. Verma and Pandey (2013) conducted an experiment to study the effect of varying rice residue management practices on growth, yield of wheat and soil organic carbon in rice-wheat sequence. They reported that higher number of effective tillers m^{-2}, ear head length , number of spikelet $spike^{-1}$ and 1000-grain weight from plots receiving rice residue incorporation including 30% additional NPK application + recommended NPK, whereas the lowest values were observed in application of only recommended NPK without any incorporation of rice residue. Davari *et al* (2012) conducted field experiments at Indian Agricultural Research Institute, New Delhi to study the effects of rice-wheat (RWCS) and rice-wheat-mungbean (RWMCS) cropping systems and crop residue incorporation on the productivity, protein yield, energy output and chemical-physical and biological properties of soil. The results revealed that RWMCS with residue incorporation had significantly higher productivity and protein yield than RWCS.

Mohammad *et al* (2012) in an experiment in Peshawar, Pakistan reported that the grain yield was significantly highest in residue retained treatment under no-tillage as compared to tillage treatment. No-tillage + residue retained treatment produced 520 kg ha^{-1} more grain yield than residues removal treatment. Zhu *et al* (2010) conducted an experiment in China and found that average sweet potato and rapeseed yields were 10-20 % higher with rice straw incorporation than application of fertilizers alone in sweet potato-rapeseed rotation. Sharma *et al* (2010) conducted a field experiment on crop diversification and residue incorporation. They observed that the rice yield was significantly higher in rice-potato-mungbean cropping system with residue incorporation than that rice-wheat cropping system without any residue incorporation. Singh *et al* (2010) reported that incorporation of crop residues has improved the mean rice equivalent yields of system by 7.86 per cent as compared to their removal. Incorporation of crop residue in soil recorded higher grain yield of maize and maize grain equivalent yield (Singh *et al* 2010, Kaleeswari *et al* 2007). Sharma and Prasad (2008) observed that incorporation of wheat straw along with 60 and 120 kg N ha^{-1} lead to increase in grain yield of rice by 0.3-0.8 and 0.8-1.3 Mg ha^{-1}, respectively in rice-wheat cropping system. Mandal *et al* (2004) reported that maximum wheat yield was obtained from plots receiving straw incorporation and FYM application as compared to control in rice-wheat cropping system. Surekha *et al* (2003) observed that grain yields of rice was increased significantly in plots treated with 100 % straw incorporation over 50 % straw incorporation and control.

2.2.2 Soil health

Crop residue management is widely used term in agriculture land conservation practices. It provides various amounts of soil nutrients for increasing the production of crop. In addition to improving soil physical, chemical and biological properties, it also affects the movement of water, infiltration rate and runoff of water. Residue influences the temperature of soil by insulating the soil surface from the sun’s radiant energy and reduces evaporation losses. Residue increases organic matter content by covering soils surface than the bare soil.

Hizrel *et al* (2020) studied the response of maize to different residue levels and reported that previous crop species and residue level affected some nutrients concentrations in grain, plant and soil chemical properties. Maize grain Ca content was positively affected by canola residue level. Bai *et al* (2020) observed that the proportion of soil macro aggregates in top layer and deep layer of soil significantly increased by 25-26 and 48-67%, respectively under the continuous straw/biochar return in comparison to the control. The nitrate N ($NO3^-$ -N), ammonium N ($NH4^+$-N), available P, SOC contents and CEC increased significantly with straw/biochar incorporation in both 0-20 cm and 20-40 cm soil layer than control. Zhao *et al* (2019) investigated the effect of straw incorporation on fertility status of the soil and reported that straw incorporation resulted with significant increase in total N, P and available N, P and K in soil by 24, 16, 64, 28 and 64%, respectively at 0-20 cm soil depth. There was also a marked increase in SOC and CEC by 8 % and 22 % in straw incorporation plot at 0-20 cm soil depth as compared straw removal plots.

Carlesso *et al* (2019) reported that application of crop residues obtained from ryegrass and straw residues as well as mixed litter can significantly improve the soil porosity, water-holding capacity, soil EC, CEC and pH, and can ultimately make the soil more productive. Application of crop residues with conservation tillage was reported to improve the soil aggregate and carbon storage in rice-based cropping systems (Wang *et al* 2019). Chen *et al* (2018) conducted a field experiment to assess the effects of straw incorporation on total organic carbon (TOC) and labile organic carbon (LOC) fractions at 0-0.4 m depths and on crop yields in rice-wheat cropping system at two sites. The study revealed that the TOC at 0-0.2 m was 13.8-22.3% higher under straw incorporation than under straw removal at the Jiangyan site, whereas 32.2% higher value was found at 0-0.1 m at the Guangde site. Dissolved organic C, microbial biomass C and easily oxidizable C at 0-0.1 m and particulate organic C at 0-0.2 m were greater under straw incorporation than under straw removal treatments at both sites.

Kumari *et al* (2018) reported that bulk density decreased significantly with increasing levels of Zn from 0 to 2.5 kg ha^{-1} and crop residue incorporation from 0 to 100%. Sharma *et al* (2010) observed that there was increase in N uptake in rice by 16-28 kg ha^{-1} with incorporation of *Sesbania* green manure and mungbean residues over control, whereas without incorporation of *Sesbania* green manure and mungbean residues the N uptake in rice was increased only up to 3-11 kg ha^{-1}. Shen *et al* (2018) reported higher water holding capacity, infiltration rate and moisture content in no tillage residue retained plots as compared to residue removal plots. Kumari *et al* (2018) reported that maximum water holding capacity and lowest bulk density were obtained with 100% incorporation of crop residues with starter dose of Zn at 10 kg ha^{-1} as compared to 0, 25 and 50 % residue retention.

Chaudhary *et al* (2017) conducted a long-term fertilizer experiment in rice-wheat cropping system at Ludhiana, on sandy loam soil and reported that the incorporation of straw + NPK increased total soil porosity (46.3%) and decreased the bulk density (1.42 Mg m^{-3}) upto 0-15 cm when compared to 100% NPK treated plots (43.1% and 1.51 Mg m^{-3}). An experiment was conducted by Salahin *et al* (2017) to evaluate the effect of tillage system and residue retention on soil physical properties, SOC content and crop yields under wheat-mungbean-rice cropping system. The results revealed that the highest soil moisture content was found in plots where residues of all three crops were retained followed by residues of two crops retained plots and residues of single crop retained plots. The lowest moisture content was found in no crop residues retained plots. Lowest bulk density (1.38 g cm^{-3}) and highest porosity (43.2 %) was observed with incorporation of residues of all the three crops in to soil. Zhang *et al* (2016) reported that total N and available N, P and SOC of soil at 0-40 cm depth increased by 10.8, 27.5, 5.2, 16.6 and 9.8%, respectively under straw incorporation treatment as compared to the straw removal treatment.

Banerjee *et al* (2016) reported that maximum N, P and K removal (146.2, 30.4 and

95.2 kg ha^{-1}, respectively) was recorded when potato crop receive 100% RDF + residue incorporation + bio-fertilizers, while the least removal of N, P and K (60.1, 18.5 and 54.1 kg ha^{-1}, respectively) was recorded under sole application of 75% RDF. The same trend was observed by Rathod *et al* (2019) and Deepika and Devi (2017). Zhang *et al* (2016) carried out a field study to determine the effect of residue incorporation on soil health, soil nutrients and enzyme activity. They reported that the mean weight diameter (MWD), geometric mean diameter (GMD), soil aggregate stability and SOC were significantly increased with residue incorporation as compared to control. Meena *et al* (2015) reported that residue incorporation improved the N-uptake by the crop, decrease bulk density of soil and increase the soil organic carbon content in maize based cropping system. Wei *et al* (2015) conducted an experiment to determine the effect of wheat straw incorporation on the arid soil nutrient levels of crop land cultivated with winter wheat after different straw incorporation levels. Three wheat straw incorporation levels were tested (High: 9000 kg hm^{-2}, Medium: 6000 kg hm^{-2}, and Low: 3000 kg hm^{-2}) and no straw incorporation was used as the control. The results showed that variable straw amounts had significant effect on the soil fertility indices, where treatment H had the greatest effect. Compared with control, the average soil available N, available P, available K, SOC, LOC, urease, phosphatase and invertase levels were higher in the 0-40 cm soil layers after straw incorporation treatments, i.e., 9.1-30.5%, 9.8-69.5%, 10.3-27.3%, 0.7-23.4%, 44.4-49.4%, 24.4-31.3%, 9.9-36.4% and 42.9-65.3%, respectively.

Dhar *et al* (2014) reported that a significant increase in soil organic carbon content and decrease in soil pH was observed with incorporation of wheat straw (5 t ha^{-1}) + green manure (5 t ha^{-1}) in alluvial soil. This is due to the production of organic acids during decomposition. Electrical conductivity of the soils was not significantly influenced by the incorporation of wheat straw and green manures. Chaudhary *et al* (2014) observed an increase of 15.6 % in total water stable aggregates of top soil with incorporation of residue as compared to residue removal plots. Kabirinejad *et al* (2014) carried out a field study at Iran to evaluate the effect of incorporation of crop residues into soil on chemical properties of the soil. The results of the experiment showed that incorporation of crop residues significantly decreased the soil pH, whereas electrical conductivity (EC), concentration of dissolved organic carbon (DOC) and DTPA extractable Cu in soil were significantly increased.

Experiment conducted by Heydari *et al* (2013) resulted in increased soil organic matter (22.2 %), saturated hydraulic conductivity (51.9 %), porosity (3.7 %), mean weight diameter (MWD) of the aggregates (5.4 %) and field capacity (5.8 %) but reduced the bulk density (3.7 %) with application of crop residue in to soil. Whereas, burning of crop residues decreased soil organic matter (31.8 %), saturated hydraulic conductivity (36.6 %), porosity (0.5 %), mean weight diameter (MWD) of the aggregates (5.1 %) and field capacity (4.1 %) but increased the soil bulk density (0.1 %). Verma and Pandey (2013) concluded that a significantly higher organic carbon content was recorded with rice residue incorporation + 30 % additional NPK + recommended NPK and rice residue incorporation + 15 % additional NPK + recommended NPK in wheat as compared to without incorporation of rice residue + recommended NPK. Mousavi *et al* (2012) conducted a field experiment to evaluate the effect of rice residue incorporation on soil physical properties. They observed that higher soil moisture content and lower bulk density was obtained from rice residue incorporation plots. Highest moisture content of 44.7 % and lower bulk density of 1.03 g cm^{-3} were measured in rice residues incorporations plots. Davari *et al* (2012) concluded that there was a significant increase in numbers of bacteria, fungi, and actinomycetes under rice-wheat-maize cropping system (RWMCS) with residue incorporation.

Singh *et al* (2011) reported that higher soil moisture was obtained in plots mulched with rice residues, which led to higher grain yield of wheat. Sharma *et al* (2010) conducted an experiment to study the effect of residue incorporation in rice based cropping systems and observed that incorporation of crop residue significantly increased organic C, total N, extractable P and extractable K content in soil in all 3 study years as compared to residue removal treatment. The increase in organic C, total N, extractable P and extractable K in residue incorporation was 5.92-6.50 g kg^{-1}, 848-948 mg kg^{-1}, 8.2-9.8 mg kg^{-1} and 182-193 mg kg^{-1} in soil as compared to residue removal treatment. Brar and Walia (2010) conducted an experiment at Punjab Agricultural University, Ludhiana with five residue management treatments and evaluated that lowest bulk density (1.48 g cm^{-3} in 0-15 cm soil layer) and soil strength (9.86 deci MPa in 0-15 cm soil layer) were obtained in rice residue incorporated plots as compared to surface retention of residue and no rice residue treatments. Sharma *et al* (2010) studied that incorporation of crop residues recycled plant nutrients and increased the soil organic matter content in rice cultivation. Mandal *et al* (2004) concluded that soil physical properties were improved as a result of incorporation of rice straw at 5 t ha^{-1} and FYM in rice. Rice straw + FYM treated plots recorded higher percentage of water stable aggregates (>0.25 mm diameter), greater mean weight diameter, higher porosity, lower bulk density, higher available water capacity and higher hydraulic conductivity of saturated soil. Surekha *et al* (2003) showed that the bulk density decreased significantly (1.25 g cc^{-1}) in 100 % straw incorporated plot as compared to burning (1.42 g cc^{-1}) and control (1.41 g cc^{-1}) treatment in rice.

2.3 Effect of different levels of nitrogen

2.3.1 Growth, yield and yield attributes

An experiment was conducted by Adhikari *et al* (2021) to determine the effect of different levels of nitrogen and varieties on growth and yield of hybrid maize in Dang, Nepal. They concluded that hybrid maize should be planted under N level 220 kg ha^{-1} to ensure maximum economic grain yield. The application of nitrogen @ 220 kg N ha^{-1} recorded to produce highest grain yield (10.1 t ha^{-1}), cob length (16.3 cm), number of rows cob^{-1} (14.9), no of grains row^{-1} (33.4), cob diameter (4.54), thousand grain weight (276.8 g), stover yield (12.9 t ha^{-1}), biological yield (23.0 t ha^{-1}), harvest index (43.8), gross returns (Rs 208940 ha^{-1}), net returns (Rs 104488 ha^{-1}) and B:C ratio (2.01) as compared to lower levels of nitrogen. Raj *et al* (2021) conducted a field experiment to determine the effect of different doses of nitrogen and zinc on growth and yield of baby corn. The findings of the experiment showed that maximum plant height (145.8 cm), number of cob $plant^{-1}$ (2.60), cob yield (973.3 kg ha^{-1}), stover yield (1633.3 kg ha^{-1}), net returns (Rs 178301.5 ha^{-1}) and B:C (3.74) were recorded with application of 160 kg N ha^{-1} + 25 kg Zinc ha^{-1} as compared to control treatment.

Golla *et al* (2020) studied the effect of nitrogen rates and intra-row spacings on yield and yield components of maize. They reported that highest number of ear $plant^{-1}$ (1.38), ear length (18.6 cm), number of kernel rows ear^{-1} (15.4), number of kernels ear^{-1} (621.6), 1000-seed weight (353.6 g), harvest index (38.9) and grain yield (26.8 q ha^{-1}) were recorded with application of 115 kg N ha^{-1} and it was significantly better than lower dose of nitrogen i.e 23, 46, 69, and 92 kg ha^{-1} and control. Worku *et al* (2020) concluded that grain and stover yields of maize were significantly affected by nitrogen levels and planting density and there were consistently increase in yield and yield attributes with increasing nitrogen levels from 120 kg ha^{-1} to 360 kg ha^{-1}. The maximum grain (13.9 t ha^{-1}) and stover yield (17.6 t ha^{-1}) were recorded with the application of 360 kg N ha^{-1} and minimum grain (8.70 t ha^{-1}) and stover yield (10.1 t ha^{-1}) were recorded at 120 kg N ha^{-1} nitrogen level.

Srivastava *et al* (2018) conducted an experiment to investigate the effect of sowing date and nitrogen application rates on maize dry matter yield, grain yield and nitrogen use efficiency under rainfed and irrigated condition. Grain yield for N_{100}, N_{80}, and N_{60} were 292%, 249% and 149% higher than that of N_0 under the rainfed maize, respectively. Grain yield for N_{125}, N_{100}, and N_{75} were 340%, 271% and 204% higher than that of N_0 under irrigated maize. A field study was conducted by Shahid *et al* (2016) to evaluate the impact of different tillage regimes and nitrogen levels on yield and yield components of maize (*Zea mays* L.) at University of Agriculture, Faisalabad. They observed that the maximum number of grain rows cob^{-1} (17.7), number of grains row^{-1} (34.3), number of grains cob^{-1} (678.6), cob weight (187.5 g), 1000-grain weight (275.5 g), biological yield (15.7 t ha^{-1}), grain yield (6.16 t ha^{-1}) and dried stalk yield (9.91 t ha^{-1}) were recorded in deep tillage at 200 kg ha^{-1} nitrogen application. Imran *et al* (2015) conducted a field experiment to study the effect of nitrogen levels and plant population on yield and yield components of maize. They reported that maximum plant height (202 cm), leaf area $plant^{-1}$ (2757 cm^2), leaf area index (2.16), ear length (18.0 cm), ear weight (150 g), grains ear^{-1} (548), 1000 grain weight (258 g) and grain yield (2673 kg ha^{-1}) were obtained with application of 210 kg N ha^{-1} which was statistically similar to 180 and 150 kg N ha^{-1} and significantly better than control.

Gul *et al* (2015) reported that fertilizer levels F_3 (90: 60: 40) and F_2 (75: 50:30) were statistically at par with one another and recorded significant increase in growth and yield characters, namely, plant height, leaf area index, dry matter production, cob length, number of cobs plant^{-1}, number of grains cob^{-1} and 100-seed weight over F_1 (60:40:20). Significantly higher grain yield was recorded with fertilizer level F_3 (90:60:40) being at par with F_2 (75:50:30) and showed significant increase over F_1 (60:40:20) with superiority of 5.4 and 5.7% during 2011 and 2012, respectively. Singh (2010) observed that application of 150 and 175 kg N ha^{-1} being statistically at par with each other and gave significantly higher grain yield over 125 and 100 kg N ha^{-1}. Similar trend was also observed for growth and yield attributing characters viz; plant height, number of leaves plant^{-1}, LAI, DMA, leaf chlorophyll content, root density, number of grains cob^{-1}, test weight, cob length etc. Quality parameters such as oil, starch and total sugar content (%) remained unaffected under different nitrogen levels. Whereas, protein content was increased with each increment in nitrogen levels. Crop took more number of days to attain dough stage and physiological maturity under higher nitrogen levels in comparison to lower nitrogen levels.

Onasanya *et al* (2009) studied the growth and yield response of maize (*Zea mays* L.) to different rates of nitrogen and phosphorus fertilizers in southern Nigeria. They observed that application of 120 kg N ha^{-1} + 20 kg P ha^{-1} and 120 kg N ha^{-1} + 40 kg P ha^{-1} significantly increased the growth and yield attributes of maize. Whereas, application of 120 kg N ha^{-1} + 40 kg P ha^{-1} resulted in significantly higher growth attributes like stem girth and LAI while yield attributes like ear length, ear girth, number of seed ear^{-1}, weight of seed ear^{-1}, 1000-seed weight and seed yield of maize were statistically at par with application of 120 kg N ha^{-1} + 20 kg P ha^{-1}. Kumar (2009) conducted a field experiment at New Delhi on sandy loam soil testing low in available nitrogen and reported that increasing nitrogen levels produced taller plants with increased plant dry weight, number of cobs ha^{-1}, number of kernels cob^{-1}, 1000-kernel weight, green cob weight and kernel recovery of maize, which consequently improved the yield and net returns. While, barrenness declined with increasing nitrogen levels.

Siam *et al* (2008) recorded that the highest values of growth attributes like plant height, fresh and dry weight of plant, yield components like ear weight, 100-grain weight, yield, N, P, K uptake and quality parameters of maize like protein, oil, starch and sugar with the application of 140 kg N ha^{-1} as ammonia gas fertilizer, while lowest values were obtained when the plant received 100 kg N ha^{-1} as urea. Mehta (2009) conducted an experiment at Ludhiana and reported that biometrical parameters viz., plant height, leaf area, root shoot ratio, crop growth rate, relative growth rate and root density were significantly higher under 250 and 275 kg N ha^{-1} as compared to 0, 175, 200 and 225 kg N ha^{-1}. Similar results were found by Bindhani *et al* (2007) and Kar *et al* (2007). Namakka *et al* (2008) at Kadawa in Sudan Savanna of Nigeria found that application of nitrogen up to 80 kg ha^{-1} significantly increased the cob length, cob diameter, cob weight and grain yield while further application of nitrogen (120 kg ha^{-1}) did not show any sifnificant influence on cob diameter and grain yield. Amanullah *et al* (2007) reported that specific leaf area (SLA), leaf area index (LAI) and leaf area ratio (LAR) of maize enhanced at the rate 0.152 cm^2 g^{-1}, 0.0065 and 0.023 cm^2 g^{-1}, respectively with one kg increase in N rate. The highest SLA (324.8 cm^2 g^{-1}), LAI (4.59) and LAR (63.0 cm^2 g^{-1}) was recorded in those plots to which N was applied in five splits with greater proportion at later stages, while the minimum SLA (275.7 cm^2 g^{-1}), LAI (3.66) and LAR (53.5 cm^2 g^{-1}) were recorded in the plots which received N only in three splits with greater proportion at the sowing time. Parlawar *et al* (2003) observed that application of 120 kg N ha^{-1} was found to give maximum and significantly higher grain yield of maize (27.2 q ha^{-1}) than control, 40 and 80 kg N ha^{-1}. The increase in grain yield might have come through increased grains cob^{-1} and grain weight plant^{-1}.

Ayub *et al* (2002) revealed that growth characteristics like plant height, number of leaves plant^{-1}, stem diameter, leaf area plant^{-1}, green fodder yield and dry matter yield were significantly influenced by the application of nitrogen and phosphorus. Maximum green fodder yield was obtained when nitrogen and phosphorus were applied at the rate of 200-80 kg ha^{-1} but it is statistically at par with NP application of 200:60 kg ha^{-1}. Quality parameters like crude protein, crude fibre and ash content were also significantly influenced by application of NP fertilizer. Randhawa *et al* (2002) studied the effect of nitrogen application on grain quality parameters of August sown maize at different nitrogen levels (0, 100, 150 and 200 kg N ha^{-1}) at Faisalabad, Pakistan. They reported that among all the treatments, application of 200 kg N ha^{-1} produced highest grain starch (68.92%) and protein (7.71%) while the maximum oil (3.71%) was observed at 100 kg N ha^{-1}.

Sepehri *et al* (2002) reported that by decreasing nitrogen levels from 200 kg N ha^{-1}, there was decrease in biological yield and this reduction was about 1858 kg ha^{-1} in maize. Mahmood *et al* (2001) studied the effect of different levels of N and intra-row plant spacing on yield and yield components of maize at the University of Agriculture, Faisalabad. They reported that maximum grain yield of 5.7 t ha^{-1}, 1000-grain weight (262.4 g) and harvest index (34.9 %) was obtained with the application of 180 kg N ha^{-1} followed by 140 kg ha^{-1} which were significantly higher than 100 kg N ha^{-1} and control. Shivay and Singh (2000) reported that the growth parameters i.e. plant height, leaf area index and dry matter accumulation of maize increased significantly with successive increase in nitrogen levels from 0 to 120 kg ha^{-1} on silty clay loam soil testing medium in available nitrogen. Similar findings were reported by Singh *et al* (2000) and Parmar and Sharma (2001). Gupta and Gautam (1994) at Pantnagar observed that the grain yield of maize, number of cobs plant^{-1}, number of grains cob^{-1}, 1000-grain weight and shelling percentage were significantly higher with application of 120 kg N ha^{-1} as compared to 60 kg N ha^{-1} on a silty clay loam soil testing low in organic carbon.

2.3.2 Soil health

Kumar (2009) conducted a field experiment at New Delhi on sandy loam soil testing low in available nitrogen and reported that increasing nitrogen levels up to 120 kg ha^{-1} resulted in higher protein content, total available nitrogen and actual residual soil nitrogen content as compared to its lower dose and control. Nitrogen uptake in maize was enhanced with each increased dose of nitrogen up to 120 kg N ha^{-1}. Similar finding were reported by Kumar (2008). Bindhani *et al* (2008) also found the increased nitrogen uptake at higher nitrogen level up to 120 kg ha^{-1} under rainfed conditions of Bhubaneswar on sandy loam soil having low available nitrogen. Ramu and Reddy (2007) conducted a field experiment at Tirupati (Andhra Pradesh) on sandy loam soil with low available nitrogen and observed that total nitrogen uptake by maize was increased with each increment of nitrogen level up to 240 kg ha^{-1} but it was at par with 180 kg ha^{-1} Al- Kaisi and Yin (2003) from the experiment conducted at Yuma on sandy loam soil observed that nitrogen uptake was maximum with nitrogen application at 360 kg ha^{-1} which was statistically at par with 250 and 140 kg N ha^{-1} and significantly higher than 30 kg N ha^{-1}. Brar *et al* (2001) at Ludhiana observed that N, P and K uptake by maize increased significantly with nitrogen application of 100 kg ha^{-1} on sandy loam soil. Further application of 150 kg N ha^{-1} of nitrogen did not show any significant increase in nutrient uptake.

CHAPTER III

MATERIALS AND METHODS

The present study entitled, **"Integrated nutrient management for enhancing productivity of spring maize (*Zea mays* L.) in rice and maize based cropping systems"** was carried out for 2 years at Student's Research Farm, Department of Agronomy, Punjab Agricultural University, Ludhiana during 2018-19 and 2019-20. The detail of the materials used and the methods followed are presented in this chapter.

3.1 Location and climate

Ludhiana, 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. Spring season is marked with mild temperature during the sowing of spring crops and bright sunshine hours during the flowering or maturity period.

3.2 Weather during crop season

Mean weekly meteorological data was recorded at meteorological observatory of Punjab Agricultural University, Ludhiana. During the rice growing period the weekly mean maximum air temperature ranged from 29.8-35.5^0C and 30.2-34.7^0C, while weekly mean minimum temperature ranged from 18.6-28.1^0C and 18.5-27.7^0C during 2018 and 2019, respectively. The maximum and minimum weekly mean temperature of 35.5^0C, 34.7^0C and 18.6^0C, 18.5^0C were recorded during 28^{th}, 36^{th} and 41^{st}, 42^{nd} week of crop season of 2018 and 2019, respectively. The maximum 76.6 and 80.7 per cent weekly mean relative humidity were recorded during 29^{th} and 33^{rd} week of crop season during 2018 and 2019. The minimum 40.1 and 66.0 per cent weekly mean relative humidity were recorded during 41^{st} and 42^{nd} week of crop season of 2018 and 2019, respectively. Total rainfall, sunshine hours and evapo-transpiration of 738.1, 800.2 mm, 708.1, 617.8 hrs and 437.5, 409.6 mm were recorded during rice growing season of 2018 and 2019 (Fig. 3.1 and 3.2).

Weekly mean maximum air temperature during *kharif* maize ranged between 29.8 to 38.3^0C during 2018 and 30.2 to 39.6^0C during 2019. While weekly mean minimum temperature ranged from 20.5 to 28.1^0C during 2018 and 20.5 to 28.9^0C during 2019. The weekly mean maximum temperature of 38.3^0C and weekly mean minimum temperature of

20.5^{0}C were recorded during 25th and 40th week of crop season during 2018, which are 4.5^{0}C higher and 5.2^{0}C lower than respective mean maximum and minimum temperature of crop season. The weekly mean maximum temperature of 39.6^{0}C and weekly mean minimum temperature of 20.5^{0}C were recorded during 26th and 40th week of crop season during 2019 which are 5.8^{0}C higher and 5.5^{0}C lower than respective mean maximum and minimum temperature of crop season. The maximum value 80.4 and 83.2 percent of weekly mean relative humidity was recorded during 29th and 39th week of crop season during 2018 and 2019, respectively. The minimum value 48.5 and 46.4 percent of weekly mean relative humidity was recorded during 25th and 26th week of crop season during 2018 and 2019, respectively. The total rainfall, sunshine hours and evapo-transpiration of 738.2, 814.6 mm, 713.0, 628.0 hrs and 496.3, 490.8 mm were recorded during *kharif* maize growing season of 2018 and 2019 (Fig. 3.3 and 3.4).

During the potato growing period the weekly mean maximum air temperature ranged from 17.2-30.6^{0}C and 10.4-30.4^{0}C, while weekly mean minimum temperature ranged from 2.79-16.0^{0}C and 4.91-16.2^{0}C during 2018-19 and 2019-20, respectively. The maximum and minimum weekly mean temperature of 30.6^{0}C, 30.5^{0}C and 2.79^{0}C, 4.91^{0}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. 3.5 and 3.6).

Weekly mean maximum air temperature during pea ranged between 17.2-31.7^{0}C during 2018-19 and 10.4-30.5^{0}C during 2019-20. While weekly mean minimum temperature ranged from 2.79-16.2^{0}C during 2018-19 and 4.91-16.2^{0}C during 2019-20. The weekly mean maximum temperature of 31.7^{0}C and weekly mean minimum temperature of 2.79^{0}C were recorded during 42nd and 52nd week of crop season during 2018-19 which are 8.76^{0}C higher and 6.2^{0}C lower than respective mean maximum and minimum temperature of crop season. The weekly mean maximum temperature of 30.5^{0}C and weekly mean minimum temperature of 4.91^{0}C were recorded during 43rd and 6th week of crop season during 2019-20 which are 9.9^{0}C higher and 4.5^{0}C lower than respective mean maximum and minimum temperature of crop season. The minimum value 59.3 and 59.9 percent of weekly mean relative humidity was recorded during 47th and 45th week of crop season during 2018-19 and 2019-20 respectively. The total rainfall, sunshine hours and evapo-transpiration of 144.3, 127.9 mm, 687.0, 613.4 hrs and 218.3, 184.7 mm were recorded during 2018-19 and 2019-20 (Fig. 3.7 and 3.8).

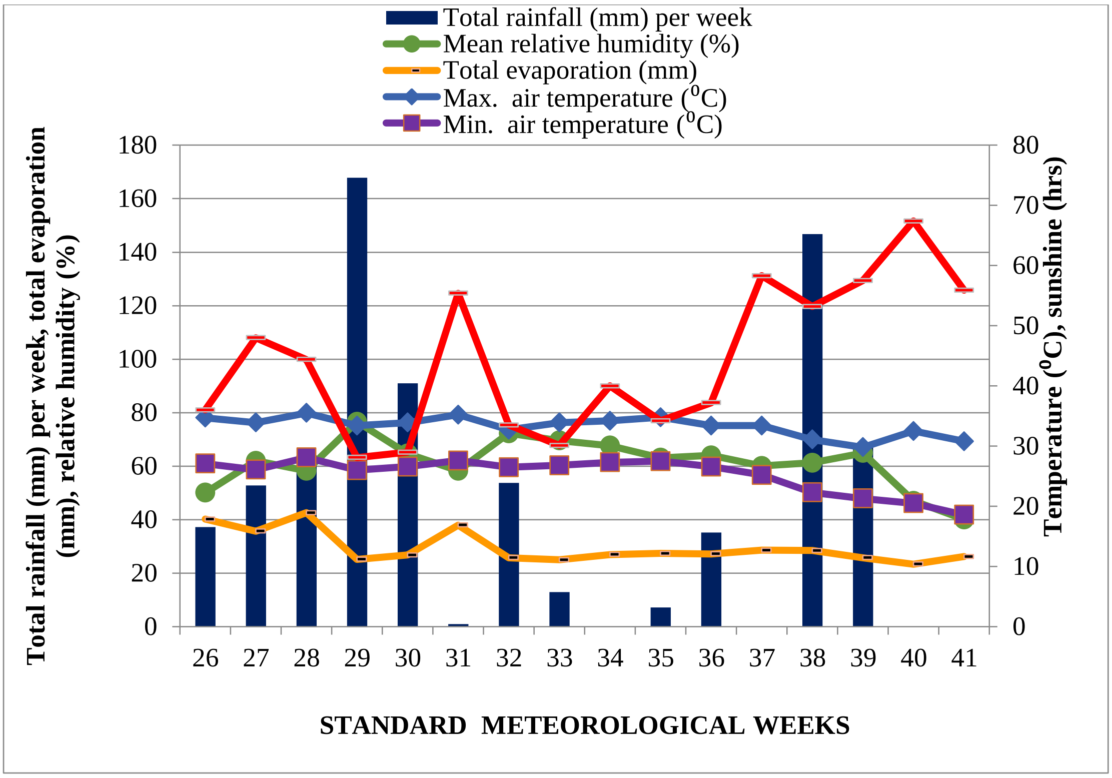


Fig. 3.1: Standard meteorological weather data for rice 2018

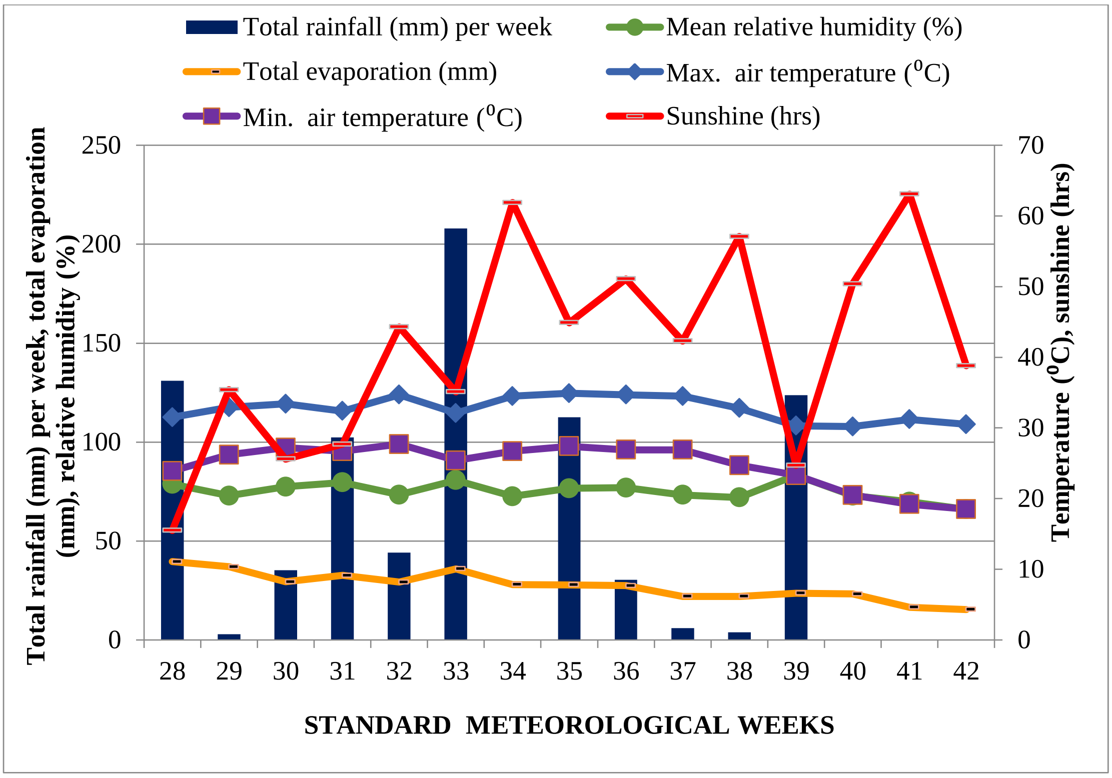


Fig. 3.2: Standard meteorological weather data for rice 2019

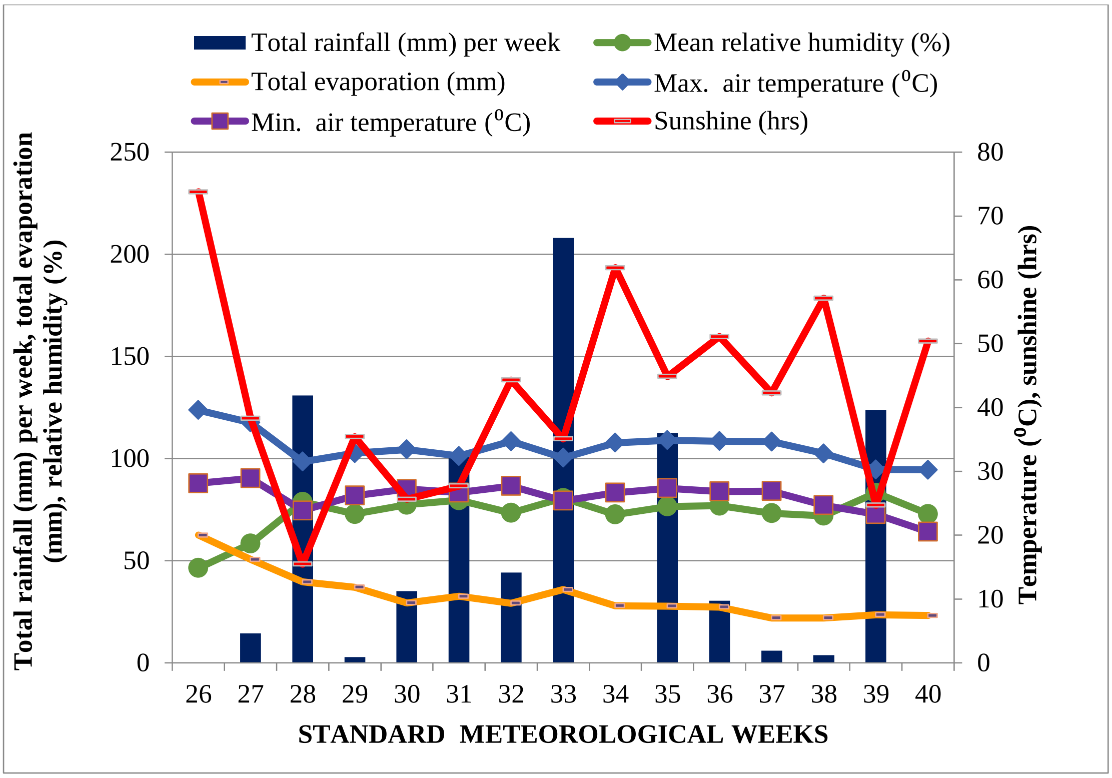


Fig. 3.3: Standard meteorological weather data for *kharif* maize 2018

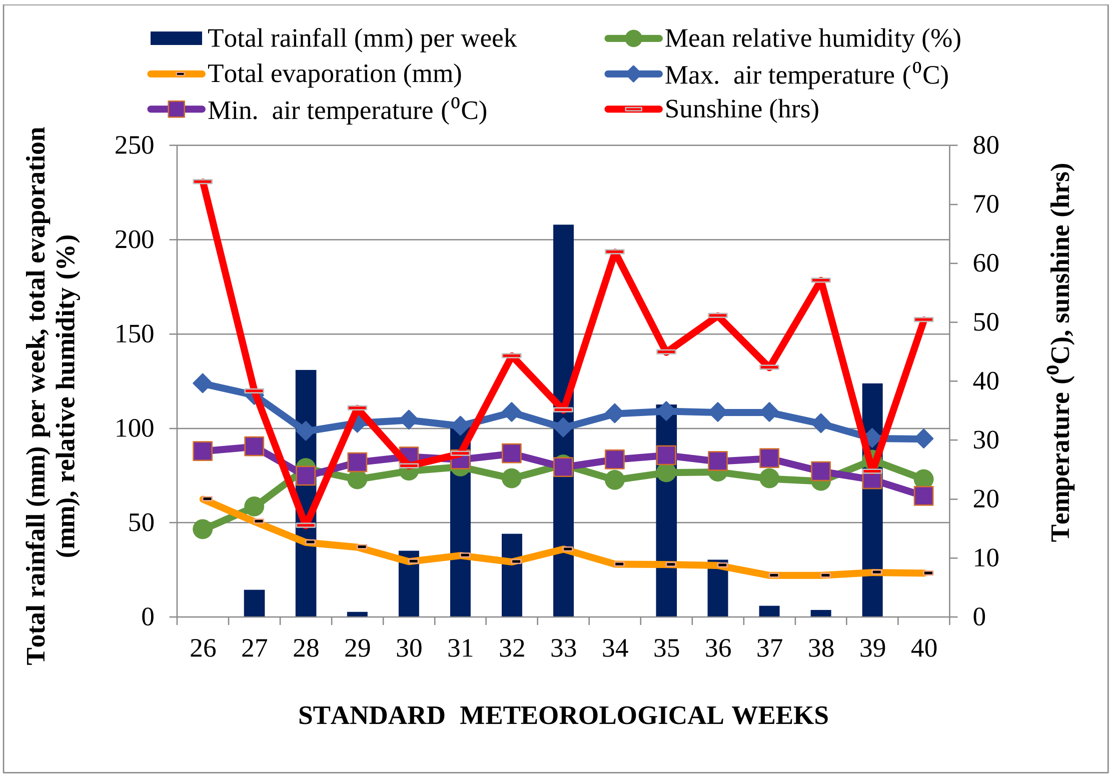


Fig. 3.4: Standard meteorological weather data for *kharif* maize 2019

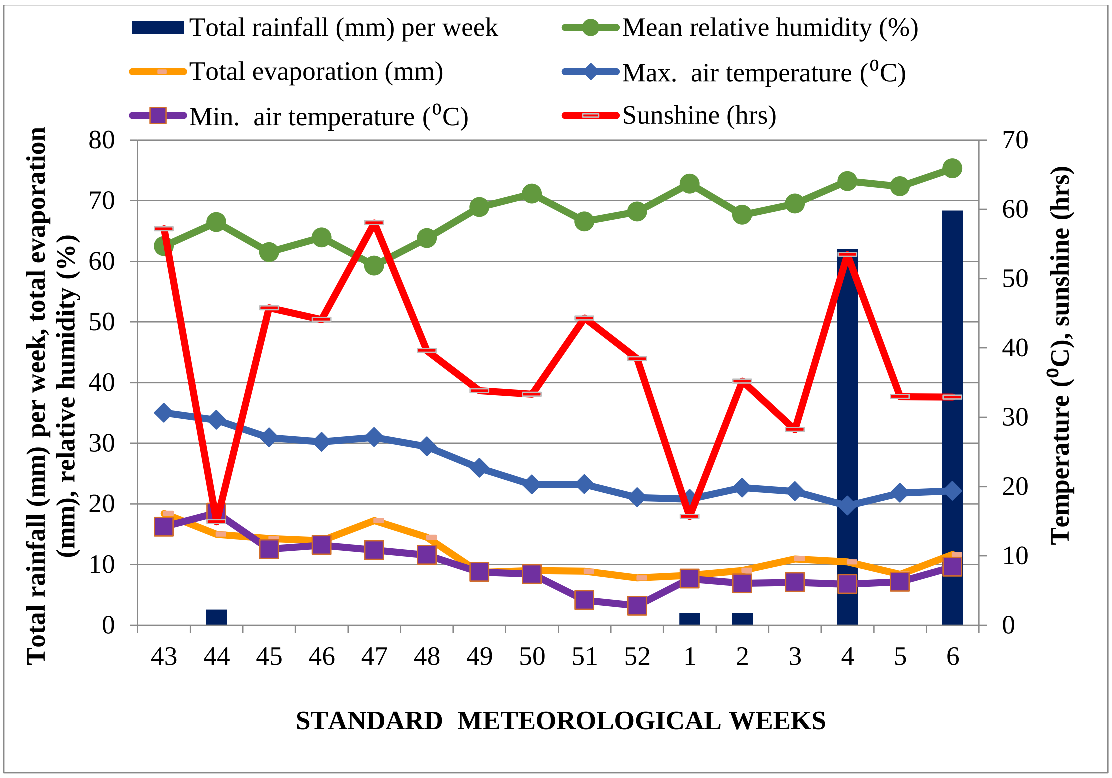


Fig. 3.5: Standard meteorological weather data for potato 2018-19

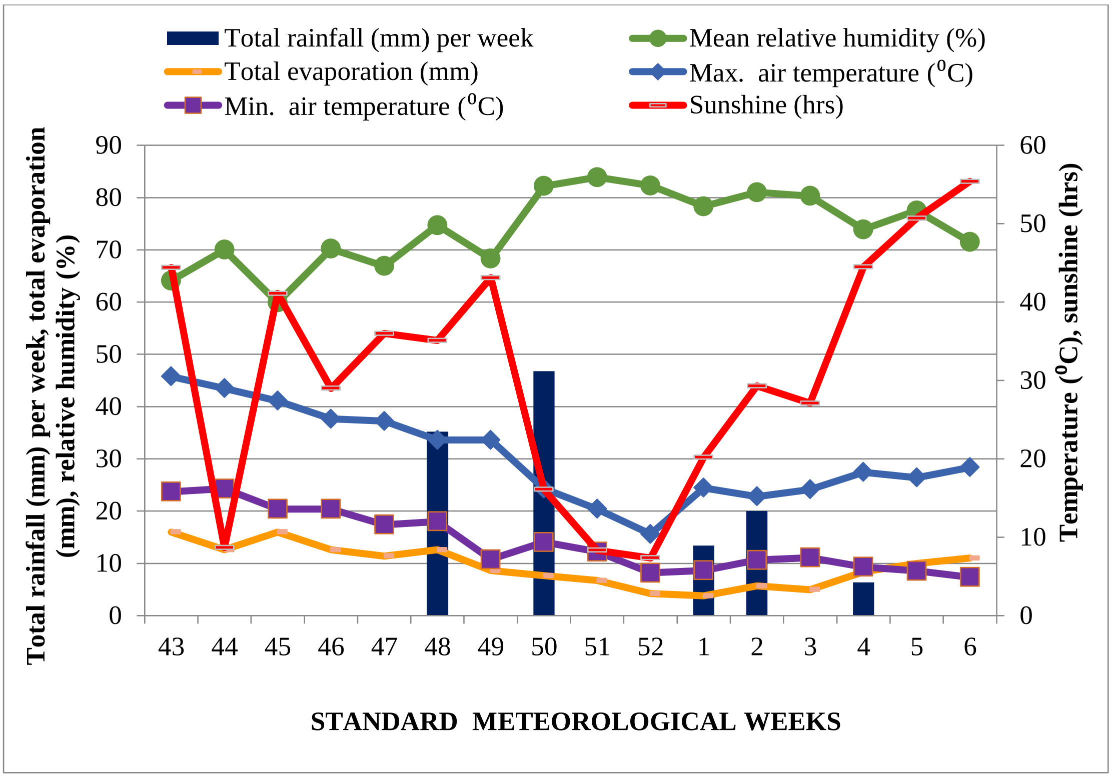


Fig. 3.6: Standard meteorological weather data for potato 2019-20

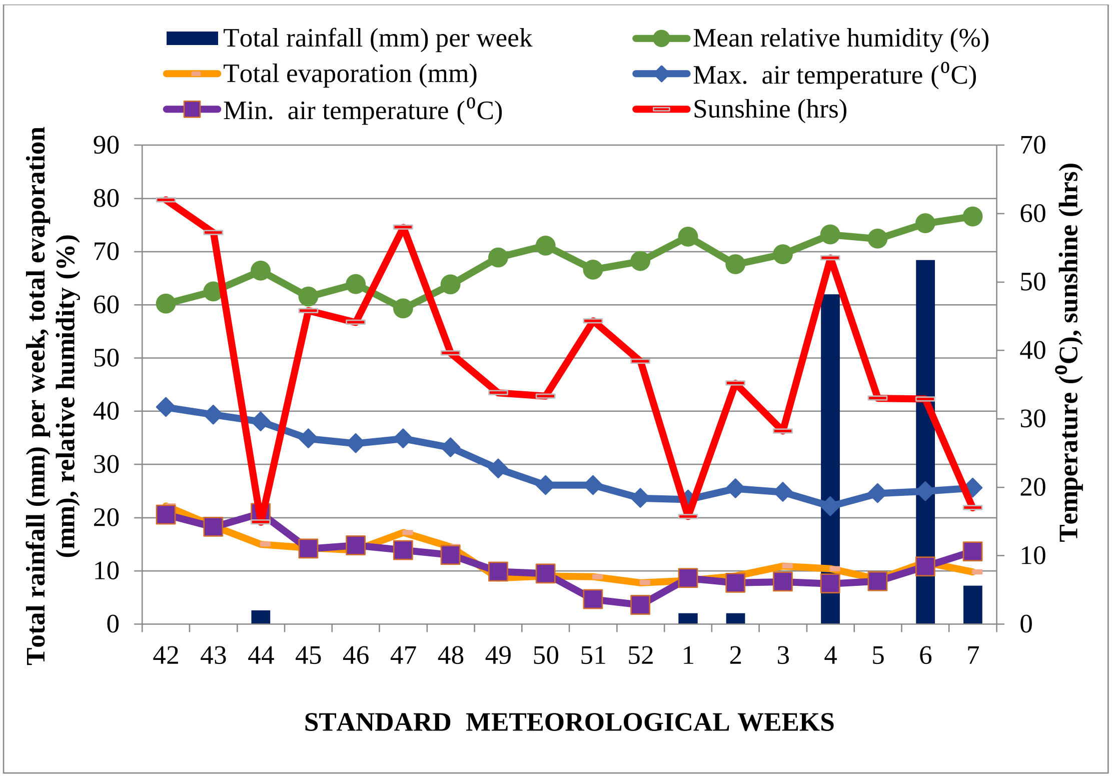


Fig. 3.7: Standard meteorological weather data for pea 2018-19

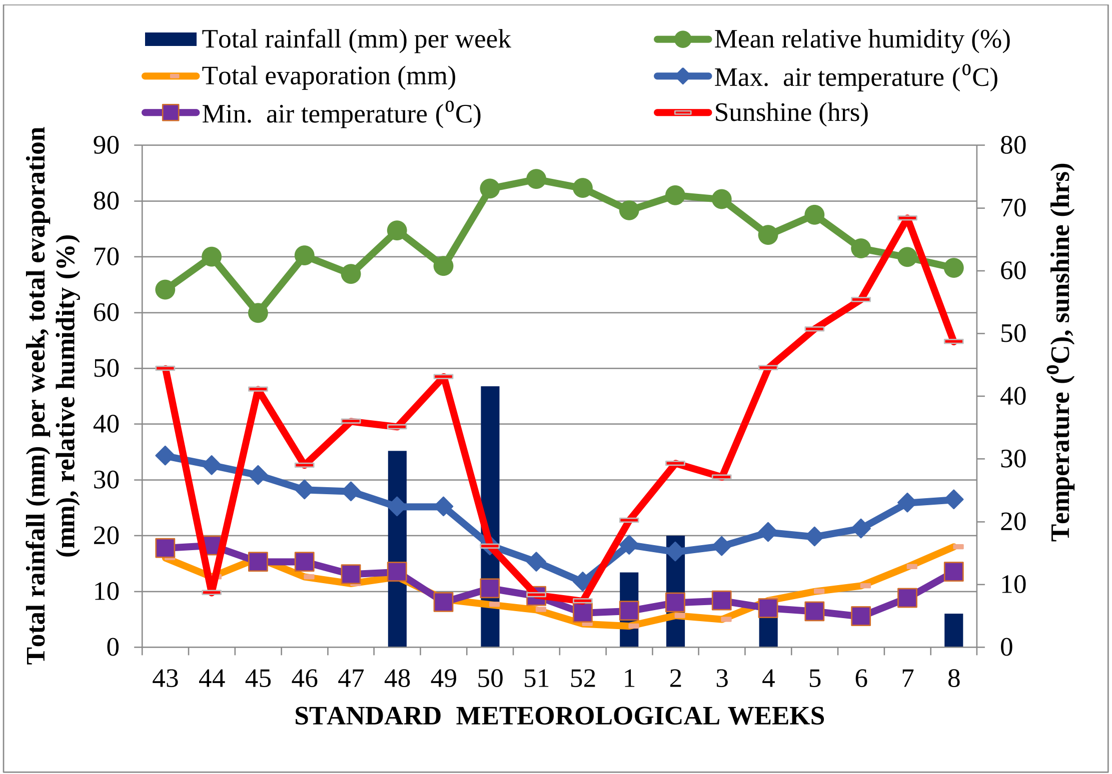


Fig. 3.8: Standard meteorological weather data for pea 2019-20

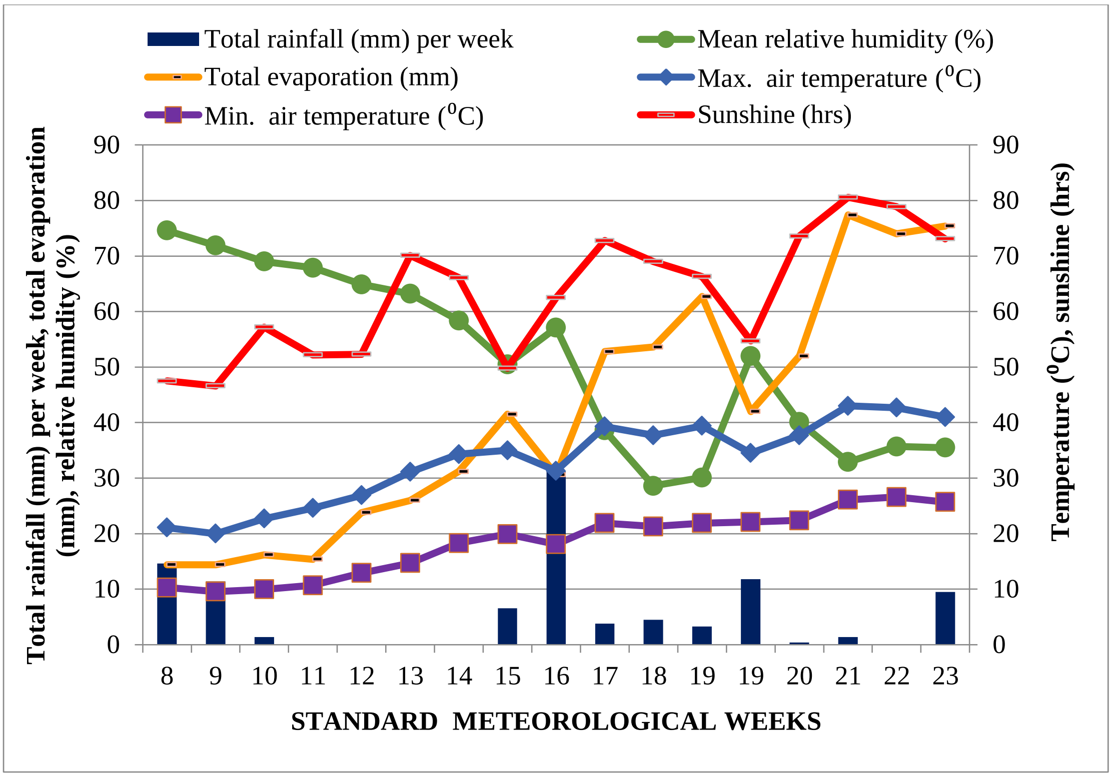


Fig. 3.9: Standard meteorological weather data for spring maize 2019

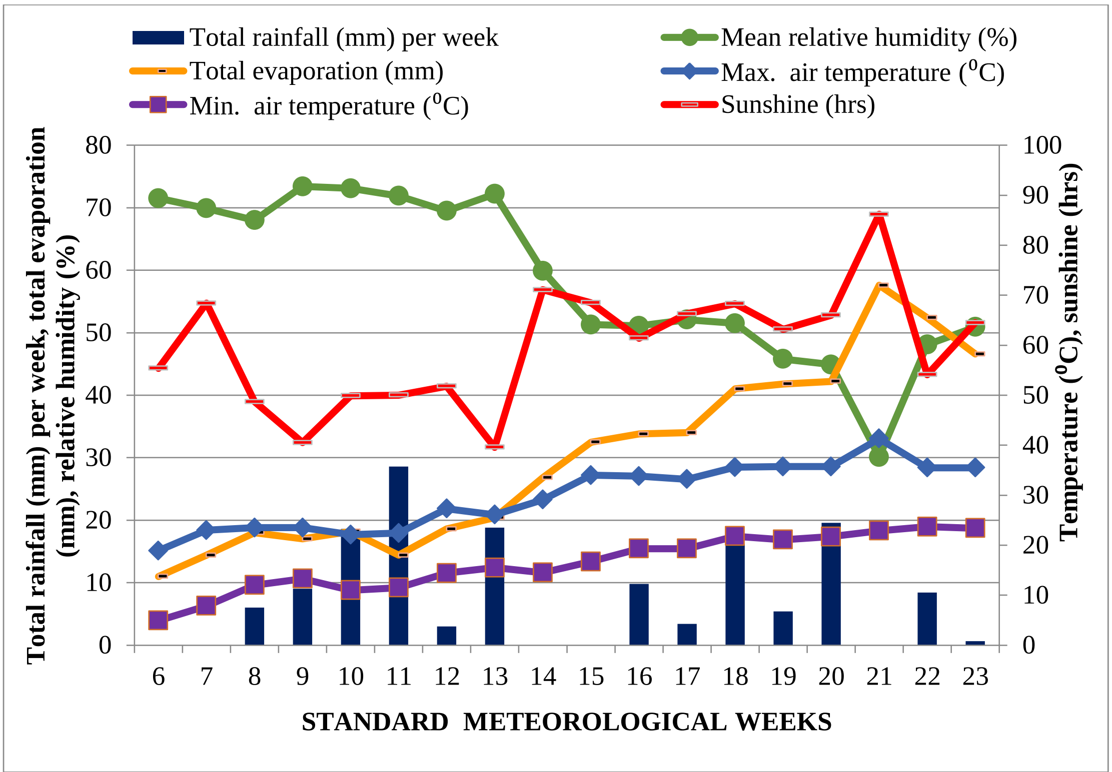


Fig. 3.10: Standard meteorological weather data for spring maize 2020

During the spring maize (for both the experiments) growing period the weekly mean maximum air temperature ranged from 20.0-43.0^{0}C and 18.9-41.3^{0}C, while weekly mean minimum temperature ranged from 9.57-26.6^{0}C and 4.91-23.7^{0}C during 2019 and 2020, respectively. The maximum and minimum weekly mean temperature of 43.0^{0}C, 41.3^{0}C and 9.57^{0}C, 4.91^{0}C were recorded during 22nd, 21st and 9th, 6th week of crop season of 2019 and 2020. The maximum 74.6 and 73.4 per cent weekly mean relative humidity was recorded during 8th and 9th week of crop season of 2019 and 2020. The minimum 28.6 and 30.1 per cent weekly mean relative humidity was recorded during 18th and 21st week of crop season of 2019 and 2020. The total rainfall, sunshine hours and evapo-transpiration of 100.0, 147.6 mm, 1073.2, 1073.9 hrs and 703.4, 540.8 mm were recorded during 2019 and 2020, respectively (Fig. 3.9 and 3.10).

3.3 Soil sampling and analysis

Composite soil samples were taken from randomly selected sites in the experimental field from 0-15 and 15-30 cm of soil depth before planting of the experimental crop. The samples were dried in shade, ground and sieved through 2 mm sieve and analyzed for physical and chemical properties of soil.

3.3.1 Mechanical analysis

The proportion of sand, silt and clay was determined by International Pipette Method (Piper 1966). The soil of the experimental field was categorized as loamy sand in texture (Table 3.1).

Table 3.1: Physico-mechanical properties of the experimental field

Soil depth (cm)	Sand (%)	Silt (%)	Clay (%)	Textural classes
0-15	79.7	11.7	8.6	Loamy sand
15-30	80.5	11.6	7.9	Loamy sand
Method used	**International Pipette Method (Piper 1966)**			

3.3.2 Chemical analysis

The composite soil samples from 0-15 and 15-30 cm profile were collected before sowing from randomly selected sites and analyzed for initial soil reaction, electrical conductivity and fertility status. The data presented in (Table 3.2) indicated that initially the soil 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.

Table 3.2: Chemical properties of the soil

Chemical property	2019	2020	Rating	Method used
pH	7.2	6.9	Normal	Beckman's glass electrode meter (Jackson 1967)
EC (dS m^{-1})	0.244	0.265	Normal	Solu bridge conductivity meter (Jackson 1967)
OC (%)	0.36	0.38	Low	Walkley and Black's rapid titration method (Jackson 1967)
Available N (kg ha^{-1})	188.2	175.6	Low	Alkaline potassium permanganate method (Subbiah and Asija 1956)
Available P (kg ha^{-1})	23.4	22.6	High	0.5 N Sodium bicarbonate extractant method (Olsen *et al* 1954)
Available K (kg ha^{-1})	193.2	181.4	Medium	1N Ammonium acetate extractable method (Muhr 1965)

3.4 Cropping history

The experimental field was under following cropping systems (Table 3.3) for the last two years:

Table 3.3: Cropping history of experimental field (Experiment I and II)

Year	Crop rotation		
	Kharif	***Rabi***	**Spring**
2016-17	Maize	Wheat	-
2017-18	Rice	Wheat	-
2018-19	Rice/Maize (Expt. Crops)	Potato/Peas (Expt. Crops)	Spring maize (Expt. crop)
2019-20	Rice/Maize (Expt. Crops)	Potato/Peas (Expt. Crops)	Spring maize (Expt. crop)

3.5 Experimental details

3.5.1 Experiment-I

i. Name of the experiment: Integrated nutrient management for enhancing productivity of rice-potato-spring maize cropping system.

ii. Location/place of work: The experiment was conducted during 2018-19 and 2019-20 at Student's Research Farm, Department of Agronomy, Punjab Agricultural University, Ludhiana.

iii. Treatments

Main plot: Rice and potato (4)

A. Rice - 1: Rice straw incorporation

2: Rice straw removal

B. Potato - 1: 100 % NPK + FYM @ 50 tonnes ha^{-1}

2: 150 % NPK

Sub plot: Spring maize (6)

1. Bed planting (single row) + 75 % NPK
2. Bed planting (double row) + 75 % NPK
3. Bed planting (single row) + 100 % NPK
4. Bed planting (double row) + 100 % NPK
5. Bed planting (single row) + 125 % NPK
6. Bed planting (double row) + 125 % NPK

iv. Methodology

- Number of treatments : 24
- Replications : 3
- Total number of plots : 24 x 3= 72
- Design : Split plot

Each main plot was divided into six sub plots to allocate the treatments.

3.5.2 Experiment-II

i. Name of the experiment: Integrated nutrient management for enhancing productivity of maize-pea-spring maize cropping system.

ii. Location/place of work: The experiment was conducted during 2018-19 and 2019-20 at Student's Research Farm, Department of Agronomy, Punjab Agricultural University, Ludhiana.

iii. Treatments

Main plot: *Kharif* maize and pea (4)

A. Maize- 1: 100 % NPK

2: 100 % NPK + FYM @ 15 tonnes ha^{-1}

B. Pea- 1: 100 % NPK

2: 100 % NPK + FYM @ 20 tonnes ha^{-1}

Sub plot: spring maize (6)

1. Bed planting (single row) + 75 % NPK
2. Bed planting (double row) + 75 % NPK
3. Bed planting (single row) + 100 % NPK
4. Bed planting (double row) + 100 % NPK
5. Bed planting (single row) + 125 % NPK
6. Bed planting (double row) + 125 % NPK

iv. Methodology

- Number of treatments : 24
- Replications : 3
- Total number of plots : 24 x 3 = 72
- Design : Split plot

There were 4 main plots and each main plot was divided into six sub plots for allocation of treatments.

3.6 Experimental details (Experiment-I)

The field experiment was conducted in split plot design (SPD) keeping 4 treatment combinations in main plots (M_1- Rice$_{\text{straw incorporation}}$ + Potato$_{\text{100\% NPK + FYM}}$, M_2- Rice$_{\text{starw incorporation}}$ + Potato$_{\text{150\% NPK}}$, M_3- Rice$_{\text{straw removal}}$ + Potato$_{\text{100\% NPK + FYM}}$ and M_4- Rice$_{\text{straw removal}}$ + Potato$_{\text{150\% NPK}}$) and 6 treatments were applied to bed planted spring maize in sub plots (S_1- Spring maize$_{\text{75\% NPK + single line}}$, S_2- Spring maize$_{\text{75\% NPK + double line}}$, S_3- Spring maize$_{\text{100\% NPK + single line}}$, S_4- Spring maize$_{\text{100\% NPK + double line}}$, S_5- Spring maize$_{\text{125\% NPK + single line}}$ and S_6- Spring maize$_{\text{125\% NPK + double line}}$) during 2018-19 and 2019-20 as presented in table 3.4. The gross size of experimental plot was 7.0 m x 3.375m. In each plot beds were made at spacing of 67.5 cm and plant to plant spacing was maintained at 18 cm for single row on bed and 24 cm for double row on bed (150% plant population).

3.7 Experimental details (Experiment-II)

The field experiment was conducted in split plot design (SPD) keeping 4 treatment combinations in main plot (M_1- *Kharif* maize$_{\text{100\% NPK}}$ + Pea$_{\text{100\% NPK}}$, M_2- *Kharif* maize$_{\text{100\% NPK}}$ + Pea$_{\text{100\% NPK + FYM}}$, M_3- *Kharif* maize$_{\text{100\% NPK + FYM}}$ + Pea$_{\text{100\% NPK}}$ and M_4- *Kharif* maize$_{\text{100\% NPK + FYM}}$ + Pea$_{\text{100\% NPK + FYM}}$) and 6 treatments were applied to bed planted spring maize in sub plot (S_1- Spring maize$_{\text{75\% NPK + single line}}$, S_2- Spring maize$_{\text{75\% NPK + double line}}$, S_3- Spring maize$_{\text{100\% NPK + single line}}$, S_4- Spring maize$_{\text{100\% NPK + double line}}$, S_5- Spring maize$_{\text{125\% NPK + single line}}$ and S_6- Spring maize$_{\text{125\% NPK + double line}}$) during 2018-19 and 2019-20 as presented in table 3.5. The gross size of experimental plot was 7.0 m x 3.375m. In each plot beds were made at spacing of 67.5 cm and plant to plant spacing was maintained at 18 cm for single row on bed and 24 cm for double row on bed (150% plant population).

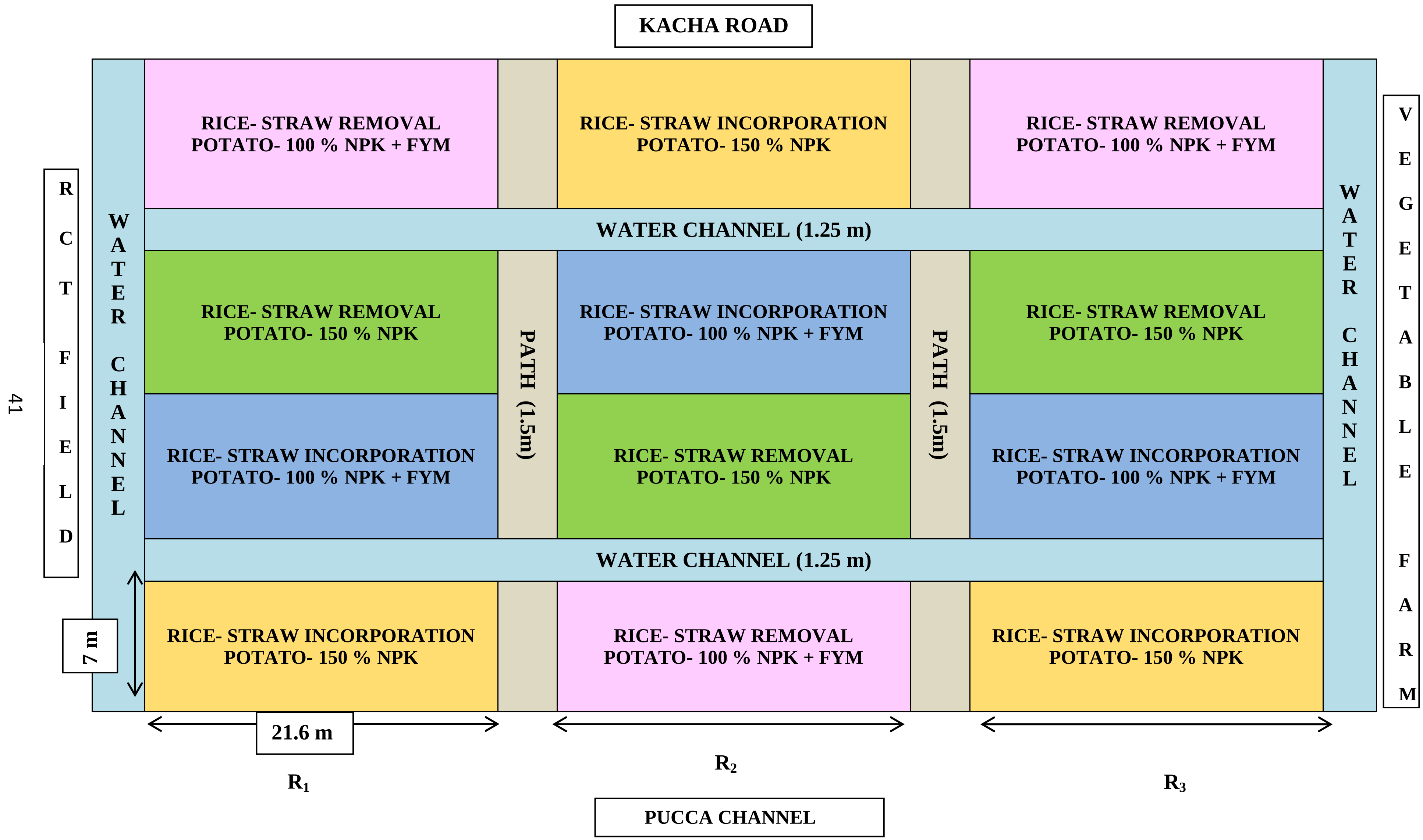


Fig. 3.11 : Layout of experiment 1 (Potato)

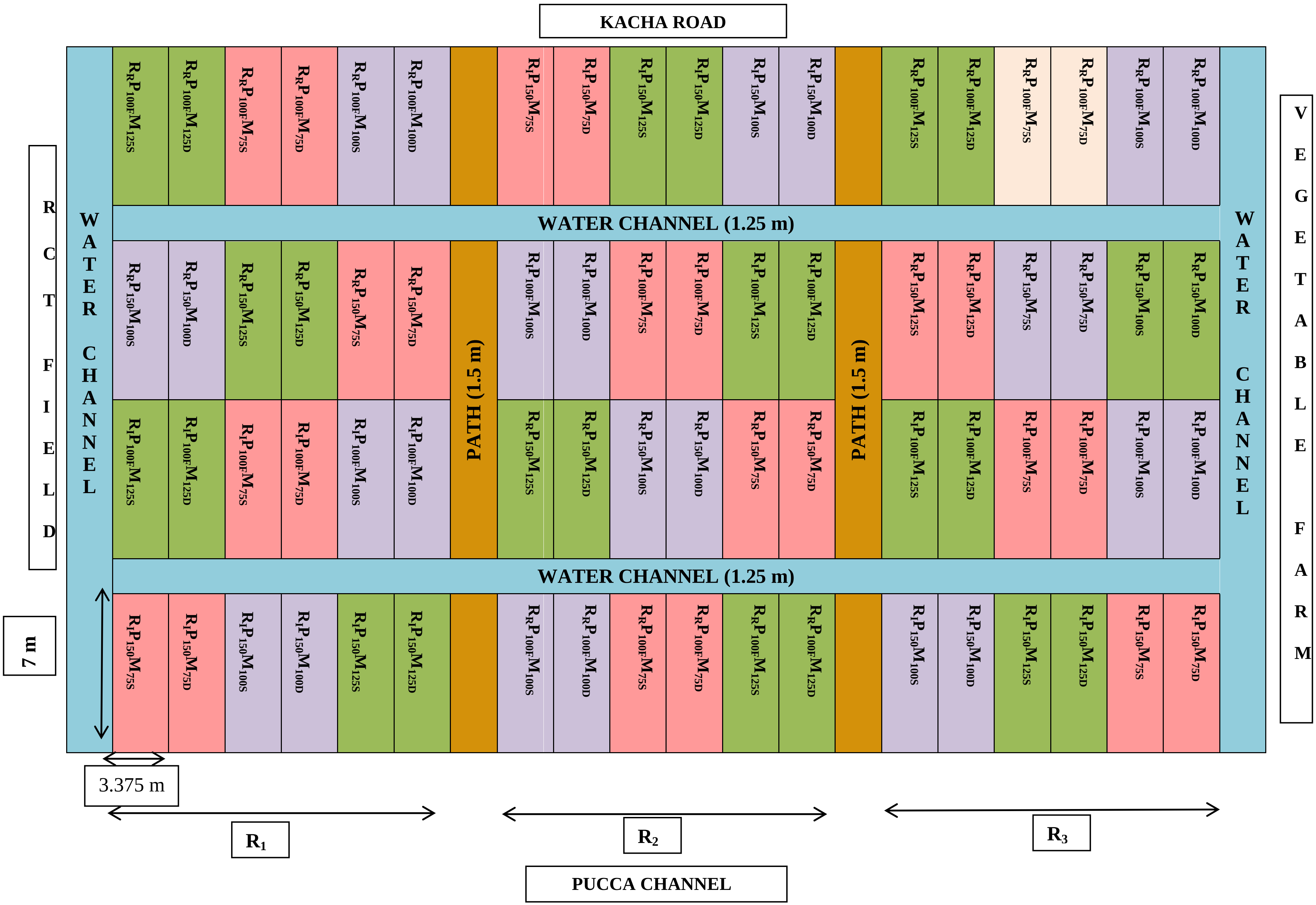


Fig. 3.12 : Layout of experiment I (Spring Maize)

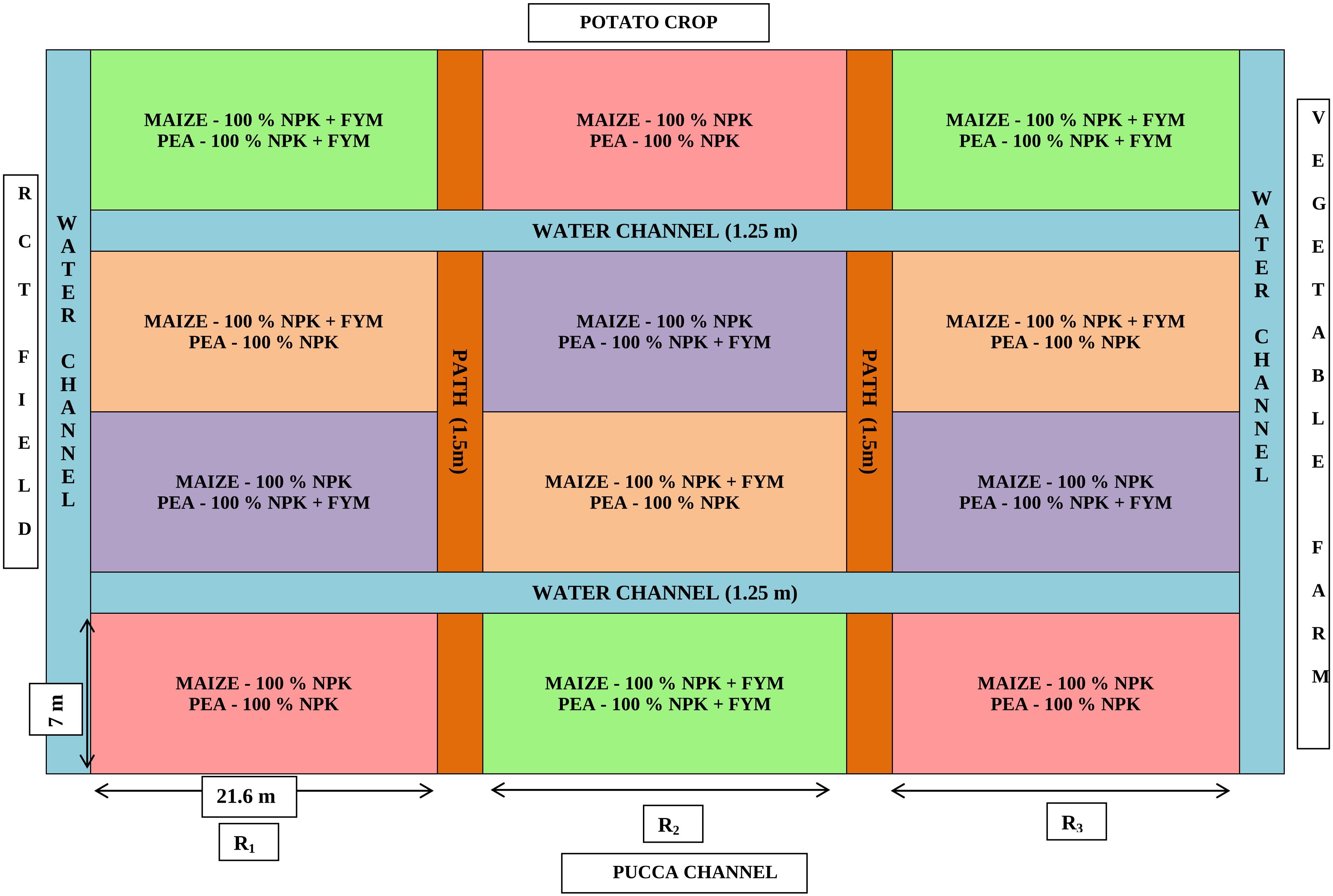


Fig. 3.13 : Layout of experiment II (Pea)

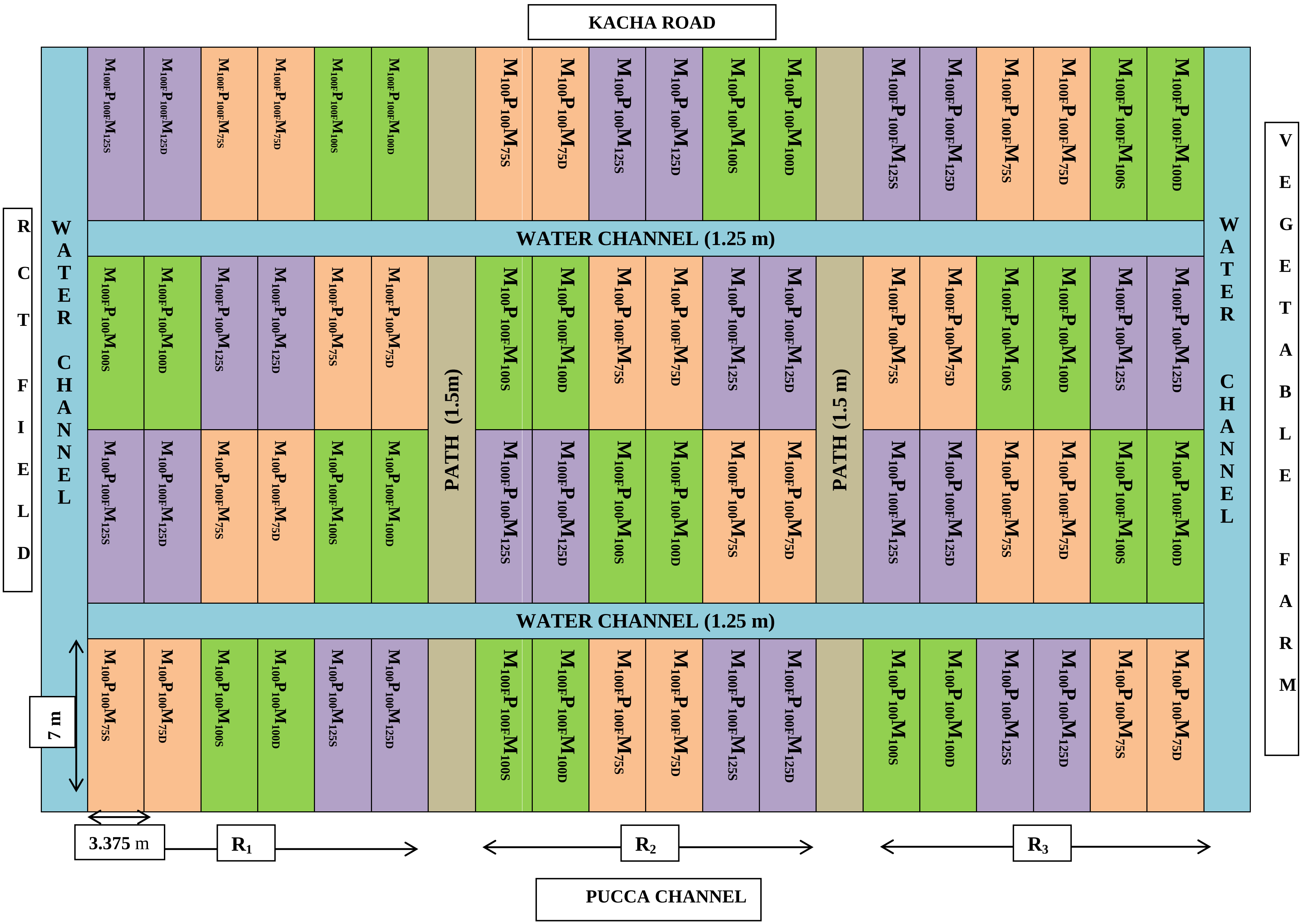


Fig. 3.14 : Layout of experiment II (Spring Maize)

Table 3.4: Details of treatments in the Experiment-I

Symbol	Treatment combinations
$R_IP_{100F}M_{75S}$	**Rice**$_{\text{straw incorporation}}$ + **Potato**$_{\text{100 \% NPK + FYM @ 50 t/ha}}$ + **Spring maize** $_{\text{75\% NPK + single line}}$
$R_IP_{100F}M_{75D}$	**Rice**$_{\text{straw incorporation}}$ + **Potato**$_{\text{100 \% NPK + FYM@ 50 t/ha}}$ + **Spring maize** $_{\text{75\% NPK + double line}}$
$R_IP_{100F}M_{100S}$	**Rice**$_{\text{straw incorporation}}$ + **Potato**$_{\text{100 \% NPK + FYM @ 50 t/ha}}$ + **Spring maize** $_{\text{100\% NPK + single line}}$
$R_IP_{100F}M_{100D}$	**Rice**$_{\text{straw incorporation}}$ + **Potato**$_{\text{100 \% NPK + FYM @ 50 t/ha}}$+ **Spring maize** $_{\text{100\% NPK + double line}}$
$R_IP_{100F}M_{125S}$	**Rice**$_{\text{straw incorporation}}$ + **Potato**$_{\text{100 \% NPK + FYM @ 50 t/ha}}$ + **Spring maize** $_{\text{125\% NPK + single line}}$
$R_IP_{100F}M_{125D}$	**Rice**$_{\text{straw incorporation}}$ + **Potato**$_{\text{100 \% NPK + FYM@ 50 t/ha}}$ + **Spring maize** $_{\text{125\% NPK + double line}}$
$R_IP_{150}M_{75S}$	**Rice**$_{\text{straw incorporation}}$ + **Potato**$_{\text{150 \% NPK}}$ + **Spring maize** $_{\text{75\% NPK + single line}}$
$R_IP_{150}M_{75D}$	**Rice**$_{\text{straw incorporation}}$ + **Potato**$_{\text{150 \% NPK}}$ + **Spring maize** $_{\text{75\% NPK + double line}}$
$R_IP_{150}M_{100S}$	**Rice**$_{\text{straw incorporation}}$ + **Potato**$_{\text{150 \% NPK}}$ + **Spring maize** $_{\text{100\% NPK + single line}}$
$R_IP_{150}M_{100D}$	**Rice**$_{\text{straw incorporation}}$ + **Potato**$_{\text{150 \% NPK}}$ + **Spring maize** $_{\text{100\% NPK + double line}}$
$R_IP_{150}M_{125S}$	**Rice**$_{\text{straw incorporation}}$ + **Potato**$_{\text{150 \% NPK}}$ + **Spring maize** $_{\text{125\% NPK + single line}}$
$R_IP_{150}M_{125D}$	**Rice**$_{\text{straw incorporation}}$ + **Potato**$_{\text{150 \% NPK}}$ + **Spring maize** $_{\text{125\% NPK + double line}}$
$R_RP_{100F}M_{75S}$	**Rice**$_{\text{straw removal}}$ + **Potato**$_{\text{100 \% NPK + FYM @ 50 t/ha}}$ + **Spring maize** $_{\text{75\% NPK + single line}}$
$R_RP_{100F}M_{75D}$	**Rice**$_{\text{straw removal}}$+ **Potato**$_{\text{100 \% NPK + FYM @ 50t/ha}}$ + **Spring maize** $_{\text{75\% NPK + double line}}$
$R_RP_{100F}M_{100S}$	**Rice**$_{\text{straw removal}}$ + **Potato**$_{\text{100 \% NPK + FYM @ 50t/ha}}$ + **Spring maize** $_{\text{100\% NPK + single line}}$
$R_RP_{100F}M_{100D}$	**Rice**$_{\text{straw removal}}$+ **Potato**$_{\text{100 \% NPK + FYM @ 50t/ha}}$ + **Spring maize** $_{\text{100\% NPK + double line}}$
$R_RP_{100F}M_{125S}$	**Rice**$_{\text{straw removal}}$ + **Potato**$_{\text{100 \% NPK + FYM @ 50t/ha}}$ + **Spring maize** $_{\text{125\% NPK + single line}}$
$R_RP_{100F}M_{125D}$	**Rice**$_{\text{straw removal}}$ + **Potato**$_{\text{100 \% NPK + FYM @ 50t/ha}}$ + **Spring maize** $_{\text{125\% NPK + double line}}$
$R_RP_{150}M_{75S}$	**Rice**$_{\text{straw removal}}$ + **Potato**$_{\text{150 \% NPK}}$ + **Spring maize** $_{\text{75\% NPK + single line}}$
$R_RP_{150}M_{75D}$	**Rice**$_{\text{straw removal}}$ + **Potato**$_{\text{150 \% NPK}}$ + **Spring maize** $_{\text{75\% NPK + double line}}$
$R_RP_{150}M_{100S}$	**Rice**$_{\text{straw removal}}$ + **Potato**$_{\text{150 \% NPK}}$ + **Spring maize** $_{\text{100\% NPK + single line}}$
$R_RP_{150}M_{100D}$	**Rice**$_{\text{straw removal}}$ + **Potato**$_{\text{150 \% NPK}}$ + **Spring maize** $_{\text{100\% NPK + double line}}$
$R_RP_{150}M_{125S}$	**Rice**$_{\text{straw removal}}$ + **Potato**$_{\text{150 \% NPK}}$ + **Spring maize** $_{\text{125\% NPK + single line}}$
$R_RP_{150}M_{125D}$	**Rice**$_{\text{straw removal}}$ + **Potato**$_{\text{150 \% NPK}}$ + **Spring maize** $_{\text{125\% NPK + double line}}$

Table 3.5: Details of treatments in the Experiment-II

Symbols	**Treatment combinations**
$M_{100}P_{100}M_{75S}$	***Kharif*** **maize**$_{\text{100\% NPK}}$ + **Pea**$_{\text{100\% NPK}}$ + **Spring maize** $_{\text{75\%NPK + single line}}$
$M_{100}P_{100}M_{75D}$	***Kharif*** **maize**$_{\text{100\% NPK}}$ + **Pea**$_{\text{100\% NPK}}$ + **Spring maize** $_{\text{75\%NPK + double line}}$
$M_{100}P_{100}M_{100S}$	***Kharif*** **maize**$_{\text{100\% NPK}}$ + **Pea**$_{\text{100\% NPK}}$ + **Spring maize** $_{\text{100\%NPK + single line}}$
$M_{100}P_{100}M_{100D}$	***Kharif*** **maize**$_{\text{100\% NPK}}$ + **Pea**$_{\text{100\% NPK}}$ + **Spring maize** $_{\text{100\%NPK + double line}}$
$M_{100}P_{100}M_{125S}$	***Kharif*** **maize**$_{\text{100\% NPK}}$ + **Pea**$_{\text{100\% NPK}}$ + **Spring maize** $_{\text{125\%NPK + single line}}$
$M_{100}P_{100}M_{125D}$	***Kharif*** **maize**$_{\text{100\% NPK}}$ + **Pea**$_{\text{100\% NPK}}$ + **Spring maize** $_{\text{125\%NPK + double line}}$
$M_{100}P_{100F}M_{75S}$	***Kharif*** **maize**$_{\text{100\% NPK}}$ + **Pea**$_{\text{100\% NPK + FYM @ 20 t/ha}}$ + **Spring maize** $_{\text{75\%NPK + single line}}$
$M_{100}P_{100F}M_{75D}$	***Kharif*** **maize**$_{\text{100\% NPK}}$ + **Pea**$_{\text{100\% NPK + FYM @ 20 t/ha}}$ + **Spring maize** $_{\text{75\%NPK + double line}}$
$M_{100}P_{100F}M_{100S}$	***Kharif*** **maize**$_{\text{100\% NPK}}$ + **Pea**$_{\text{100\% NPK + FYM @ 20 t/ha}}$ + **Spring maize** $_{\text{100\%NPK + single line}}$
$M_{100}P_{100F}M_{100D}$	***Kharif*** **maize**$_{\text{100\% NPK}}$ + **Pea**$_{\text{100\% NPK + FYM @ 20 t/ha}}$ + **Spring maize** $_{\text{100\%NPK + double line}}$
$M_{100}P_{100F}M_{125S}$	***Kharif*** **maize**$_{\text{100\% NPK}}$ + **Pea**$_{\text{100\% NPK + FYM @ 20 t/ha}}$ + **Spring maize** $_{\text{125\%NPK + single line}}$
$M_{100}P_{100F}M_{125D}$	***Kharif*** **maize**$_{\text{100\% NPK}}$ + **Pea**$_{\text{100\% NPK +FYM @ 20 t/ha}}$ + **Spring maize** $_{\text{125\%NPK + double line}}$
$M_{100F}P_{100}M_{75S}$	***Kharif*** **maize**$_{\text{100\% NPK + FYM @ 15 t/ha}}$+ **Pea**$_{\text{100\% NPK}}$ + **Spring maize** $_{\text{75\%NPK + single line}}$
$M_{100F}P_{100}M_{75D}$	***Kharif*** **maize**$_{\text{100\% NPK + FYM @ 15 t/ha}}$ + **Pea**$_{\text{100\% NPK}}$ + **Spring maize** $_{\text{75\%NPK + double line}}$
$M_{100F}P_{100}M_{100S}$	***Kharif*** **maize**$_{\text{100\% NPK + FYM @ 15 t/ha}}$ + **Pea**$_{\text{100\% NPK}}$ + **Spring maize** $_{\text{100\%NPK + single line}}$
$M_{100F}P_{100}M_{100D}$	***Kharif*** **maize**$_{\text{100\% NPK + FYM @ 15 t/ha}}$ + **Pea**$_{\text{100\% NPK}}$ + **Spring maize** $_{\text{100\%NPK + double line}}$
$M_{100F}P_{100}M_{125S}$	***Kharif*** **maize**$_{\text{100\% NPK +FYM @ 15 t/ha}}$ + **Pea**$_{\text{100\% NPK}}$ + **Spring maize** $_{\text{125\%NPK + single line}}$
$M_{100F}P_{100}M_{125D}$	***Kharif*** **maize**$_{\text{100\% NPK + FYM @ 15 t/ha}}$ + **Pea**$_{\text{100\% NPK}}$ + **Spring maize** $_{\text{125\%NPK + double line}}$
$M_{100F}P_{100F}M_{75S}$	***Kharif*** **maize**$_{\text{100\% NPK+FYM @ 15 t/ha}}$ + **Pea**$_{\text{100\% NPK + FYM@ 20 t/ha}}$ + **Spring maize** $_{\text{75\%NPK+single line}}$
$M_{100F}P_{100F}M_{75D}$	***Kharif*** **maize**$_{\text{100\% NPK+FYM @ 15 t/ha}}$ + **Pea**$_{\text{100\% NPK+FYM @ 20 t/ha}}$ + **Spring maize** $_{\text{75\%NPK+double line}}$
$M_{100F}P_{100F}M_{100S}$	***Kharif*** **maize**$_{\text{100\% NPK+FYM @ 15 t/ha}}$ + **Pea**$_{\text{100\% NPK+FYM @ 20 t/ha}}$ + **Spring maize** $_{\text{100\%NPK+single line}}$
$M_{100F}P_{100F}M_{100D}$	***Kharif*** **maize**$_{\text{100\% NPK+FYM @ 15 t/ha}}$ + **Pea**$_{\text{100\% NPK+FYM @ 20 t/ha}}$ + **Spring maize** $_{\text{100\%NPK+double line}}$
$M_{100F}P_{100F}M_{125S}$	***Kharif*** **maize**$_{\text{100\% NPK+FYM @ 15 t/ha}}$ + **Pea**$_{\text{100\% NPK+FYM @ 20 t/ha}}$ + **Spring maize** $_{\text{125\%NPK+ ingle line}}$
$M_{100F}P_{100F}M_{125D}$	***Kharif*** **maize**$_{\text{100\% NPK+FYM @ 15 t/ha}}$ + **Pea**$_{\text{100\% NPK+FYM @ 20 t/ha}}$ + **Spring maize** $_{\text{125\%NPK+double line}}$

3.8 Agronomic practices

3.8.1 Pre-sowing irrigation

A heavy pre-sowing irrigation (10 cm) was applied after dividing the field in small borders so as to ensure even distribution of moisture in soil profile of the field. It was applied to ensure adequate moisture in the soil at the time of sowing. Pre-sowing irrigation was given 10 days before sowing of the experimental crop.

3.8.2 Seed bed preparation

The field was ploughed twice with disc harrow and a fine seed bed was prepared by giving two cultivations with tractor drawn cultivator followed by planking. Beds were made by tractor mounted bed planter at 67.5 cm apart in north-south direction for *kharif* maize and spring maize. Furrows and ridges were prepared by tractor mounted ridger for potato.

3.8.3 Fertilizer application

In both the experiments nitrogen was applied to spring maize as per treatment in each experimental unit by taking the recommended dose of nitrogen as 125 kg N ha^{-1}. Rate of nitrogen application was worked out as 93.8, 125 and 156.3 kg N ha^{-1} for treatments of 75, 100 and 125% of recommended nitrogen dose, respectively. Rate of phosphorus application was worked out as 45, 60 and 75 kg P_2O_5 ha^{-1} for treatments of 75, 100 and 125 per cent of recommended phosphorus dose, respectively. Rate of potassium application was worked out as 22.5, 30 and 37.5 kg K_2O ha^{-1} for treatments of 75, 100 and 125% of recommended potassium dose, respectively. Urea, Di-ammonium phosphate and Muriate of potash are the source for N, P and K, respectively. Entire quantity of P and K along with $1/3^{rd}$ of N was applied at sowing and remaining N was applied in two equal splits i.e. at knee high and at pre-tasselling stages of crop growth for spring maize and *kharif* maize. All the fertilizers were broadcasted before the formation of beds by tractor operated bed planter. For rice full dose of P and K and $1/3^{rd}$ dose of N was applied before transplanting, remaining $2/3^{rd}$ dose of N were applied in 2 equal splits at 21 and 35 days after transplanting, respectively. For potato crop full dose of P and K and half dose of N was applied at sowing and the remaining N at the time of earthing-up. For pea full dose of NP was applied before sowing as basal application.

Table 3.6: Recommended fertilizer dose

Crops	N (kg ha^{-1})	P_2O_5 (kg ha^{-1})	K_2O (kg ha^{-1})
Rice	105	30	30
Kharif maize	125	60	30
Potato	187.5	62.5	62.5
Pea	50	62.5	-
Spring maize	125	60	30

3.8.4 Seed treatment

Seed was treated with 6 ml Gaucho 600 FS (imidacloprid) per kg seed before planting for protection against attack of maize shoot fly and with Bavistin (carbendazim) @ 3 g per kg seed for protection against various fungal diseases. Potato tubers were treated with Monoceren 250 SL @ 625 ml in 250 litre of water to control black scarf disease. Pea seeds were inoculated with bacterial culture (*Rhizobium leguminosarum*) to ensure nodule formation and quick growth. Rice seed were treated with Sprint 75 WS @ 3 g kg seed in 10-12 ml water before sowing.

3.8.5 Method of sowing

The spring maize hybrid PMH 10 was sown in both the experiments on 23rd and 8th February during the year 2019 and 2020, respectively. Seed was sown at optimum soil moisture using 25 kg seed per hectare. Wheat bed planter was used for 67.5 cm spaced bed preparation (bed top width was 37.5 cm and furrow width was 30 cm). In both the experiments, sowing was done on beds by dibbling method by keeping bed to bed distance of 67.5 cm and plant to plant distance of 18 cm in single row on bed and 24 cm in double row on bed. A tractor mounted ridger was used for preparation of 60 cm wide ridges. Planting of *kharif* maize and potato tubers was done manually by keeping plant to plant distance 20 cm. Pea was sown with hand operated seed drill by keeping plant to plant distance 10 cm.

Table 3.7: Sowing date of different crops is listed below

Crops	2018-19	2019-20
Rice	28th June, 2018	13th July,2019
Kharif maize	22nd June, 2018	29th June, 2019
Potato	23rd October, 2018	28th October, 2019
Pea	16th October, 2018	22nd October, 2019
Spring maize	23rd February, 2019	08th February, 2020

3.8.6 Weed control

Herbicide Atrataf 50 WP (atrazine) was applied as pre-emergence @ 2 kg ha^{-1} using 500 litre of water with knap sack sprayer using flat fan nozzle for controlling the weeds in maize field. One hand weeding was also done at 45 days after planting. Stomp 30 EC (pendimethalin) @ 2.5 litre ha^{-1} was sprayed within 2 days after sowing in pea for control of *rabi* weeds. Gramaxone 24 SL (paraquat) @ 1.25 litre ha^{-1} was sprayed after emergence of 5-10% of potato crop to control annual weeds. The left over weeds in potato and pea field were removed by hand weeding after one month of planting. For weed control in rice nominee gold (bispyribac) @ 250 ml ha^{-1} was sprayed as post-emergence application.

3.8.7 Thinning and gap filling

Thinning and gap filling of *kharif* and spring maize was done after one month of sowing by keeping one plant per hill to maintain optimum plant population in the entire experimental area.

3.8.8 Irrigation

Schedule of irrigation application to different crops is mentioned in table 3.8 which was according to crop requirement for both research experiments.

Table 3.8: Irrigation applied to experiment-I and experiment-II

Rice					
2018			**2019**		
Irrigation	**DAS**	**Date**	**Irrigation**	**DAS**	**Date**
1	2	29th June, 2018	1	3	16th July, 2019
2	8	6th July, 2018	2	7	20th July, 2019
3	12	11th July, 2018	3	12	25th July, 2018
4	18	16th July, 2018	4	17	30th July, 2019
5	23	21st July, 2018	5	25	6th Aug, 2019
6	27	25th July, 2018	6	29	10th Aug, 2019
7	36	4th Aug, 2018	7	33	14th Aug, 2019
8	42	10th Aug, 2018	8	37	20th Aug, 2019
9	48	16th Aug, 2018	9	42	26th Aug, 2019
10	57	25th Aug, 2018	10	50	3rd Sept, 2019
11	65	2nd Sept, 2018	11	55	8th Sept, 2019
12	74	11th Sept, 2018	12	61	14th Sept, 2019
13	82	19th Sept, 2018	13	69	19th Sept, 2019
			14	85	5th Oct, 2019
***Kharif* maize**					
1	18	10th July, 2018	1	24	23rd July, 2019
2	43	4th Aug, 2018	2	44	12th Aug, 2019
3	60	21st Aug, 2018	3	59	27th Aug, 2018
4	81	12th Sept, 2018	4	76	13th Sept, 2019
Potato					
2018-19			**2019-20**		
1	2	25th oct, 2018	1	25	22nd Nov, 2019
2	28	20th Nov, 2018	2	51	18th Dec, 2019
3	66	27th Dec, 2018	3	77	15th Jan, 2020
Pea					
1	17	2nd Nov, 2018	1	18	9th Nov, 2019
2	56	11th Dec, 2018	2	45	16th Dec, 2019
3	88	13th Jan, 2018	3	80	21st Jan, 2019
Spring maize					
2019			**2020**		
1	14	9th March, 2019	1	7	15th Feb, 2020
2	28	23rd March, 2019	2	17	25th Feb, 2020
3	35	30th March, 2019	3	43	22nd march, 2020
4	43	6th April, 2019	4	58	6th April, 2020
5	50	13th April, 2019	5	72	20th April, 2020
6	65	29th April, 2019	6	86	4th May, 2020
7	74	8th May, 2019	7	101	19th May, 2020
8	82	16th May, 2019			
9	90	24th May, 2019			
10	96	30th May, 2019			

Table 3.9: Details of the varieties used, seed rates, row spacing, fertilizer doses, sowing and harvesting dates of different crops

Crop	Variety	Spacing (cm)	Seed rate	Fertilizer			Date of sowing		Date of harvesting	
				N (kg ha^{-1})	P_2O_5 (kg ha^{-1})	K_2O (kg ha^{-1})	2018-19	2019-20	2018-19	2019-20
Rice	PR 126	20 x 15	20 kg ha^{-1}	105	30	30	28th June, 2018	13th July, 2019	8th Oct, 2018	18th Oct, 2019
Kharif Maize	PMH 1	60 x 20	20 kg ha^{-1}	125	60	30	22nd June, 2018	29th June, 2019	6th Oct, 2018	7th Oct, 2019
Potato	Kufri Pukhraj	60 x 20	32.5 q ha^{-1}	187.5	62.5	62.5	23rd Oct, 2018	28th Oct, 2019	6th Feb, 2019	6th Feb, 2020
Pea	Punjab 89	30 x 10	75 kg ha^{-1}	50	62.5	-	16th Oct, 2018	22nd Oct, 2019	16th Jan - 14th Feb, 2019	21st Jan- 23rd Feb, 2020
Spring maize	PMH 10	67.5 x 18 and 67.5 x 24	25 kg ha^{-1} and 37.5 kg ha^{-1}	125	60	30	23rd Feb, 2019	8th (Expt-I) and 25th (Expt-II) Feb, 2020	13th June, 2019	9th (Expt-I) and 16th (Expt-II) June, 2020

3.8.9 Plant protection

Spring maize and *kharif* maize was sprayed with Decis 2.8 EC (deltamethrin) @ 200 ml ha^{-1} to control maize borer (*Chilo partellus*). Rice was sprayed with Fame 480 EC (flubendiamide) @ 50 ml ha^{-1} to control rice stem borer. Fungicide Tilt 25 EC @ 500 ml ha^{-1} in 200 litre of water (against sheath blight) was applied to rice crop. Potato was sprayed with Indofil M-45 (kavach) @ 1.25 kg ha^{-1} for protection against infestation of late blight (*Phytophthora infestans*) disease. Pea was sprayed with Bavistin @ 2 g l^{-1} to control wilt disease during both the years.

3.8.10 Harvesting

Spring maize was harvested manually on 13thJune, 2019 during first year trial and 9th June, 2020 (expt-I) and 16th June, 2020 (expt-II) during second year trial in both the experiments. The net plot size harvested was 5m x 2.025m = 10.125m^2 during 1st year trial and 6.64m x 2.025m = 13.446m^2 during 2nd year trial. Rice was harvested with combine harvester after taking the samples from 10 m^2 area. In potato crop, after 5 days of de-haulming, digging of potato tubers was done manually. Pods were harvested manually in vegetable pea by 4 pickings at nearly 7-10 days interval.

3.8.11 Threshing

The cobs were de-husked manually after harvesting and were allowed to dry for 3-4 days and thereafter the threshing was done using maize thresher. The maize grain yield was converted to q ha^{-1}.

3.9 Observations recorded for rice

3.9.1 Yield and yield attributes

3.9.1.1 Number of tillers

The numbers of tillers were counted from one meter square area at maturity.

3.9.1.2 Panicle length

Five representative panicles were randomly selected from each plot and their length from neck node to the apex was measured in centimeters.

3.9.1.3 Number of grains panicle^{-1}

The representative five panicles were threshed manually to count the number of grains and then mean value was calculated to represent number of grains panicle^{-1}.

3.9.1.4 1000-grain weight

One thousand grains were counted and their weight was recorded using electronic balance and expressed in grams. The sample was collected after the threshed product had sufficiently been dried and brought to moisture content of 14 per cent.

3.9.1.5 Grain yield

The total produce of samples was weighed in bundles after harvesting and threshed manually by beating against the hard surface. After threshing grains obtained from each plot was used to calculate grain yield in q ha^{-1}.

3.9.1.6 Straw yield

Straw yield was computed after deducting the weight of grains from total bundle weight and expressed as q ha^{-1}.

3.9.1.7 Biological yield

Biological yield was calculated by adding grain and straw yield per plot and expressed as q ha^{-1}.

3.10 Potato

3.10.1 Growth attributes

3.10.1.1 Plant height

Periodic plant height of five tagged plants from each plot was recorded at 30, 60 DAS and at haulm cutting. The mean plant height of five tagged plants taken from the base of main stem to the base of last unfolded leaf was computed.

3.10.1.2 Dry matter accumulation

Dry matter accumulation of haulms was determined at 30, 60 DAS and at haulm cutting stage by cutting the haulms near the soil surface from sampling row. The haulms were oven dried at 60^0 C after sun drying and expressed in g $plant^{-1}$.

3.10.1.3 Chlorophyll index

Reading of chlorophyll index was taken at 30, 60 DAS and at haulm cutting. Chlorophyll index of leaves was recorded with SPAD meter. Top 3^{rd} fully opened leaf was selected for observation. Five readings were taken from each plot with care so that mid rib of leaf should not come under eye of instrument and mean value was worked out.

3.10.1.4 Leaf area Index

Leaf area index was recorded at 30, 60 DAS and at haulm cutting using the Sun Scan Canopy Analyzer, Model: Sun scan SSI, manufactured by Delta-T Devices, Cambridge, England.

3.10.2 Yield and yield attributes

3.10.2.1 Number of tillers per plant

Branches from the five tagged plants were counted and mean value was worked out which represented in terms of tillers $plant^{-1}$.

3.10.2.2 Number of tubers per plant

Five tagged plants from the plot were carefully dug out without disturbing the tubers and their total number was counted. The tubers average was worked out and expressed as number of tubers $hill^{-1}$.

3.10.2.3 Tuber yield per plant

Tubers harvested from the tagged plants from each treatment were cleaned thoroughly to remove soil and weighed to get the fresh weight of tubers in g $plant^{-1}$. The tubers harvested from the tagged plants used for counting the number of tubers per plant were also used for recording the fresh weight of tuber in g plant^{-1}.

3.10.2.4 Grade wise number of tubers

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).

3.10.2.5 Grade wise weight of tubers

The 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}.

3.10.2.6 Grade wise length of tubers

Five representative tubers from each grade were taken and their length was measured with the help of scale. The average tuber length was worked out and expressed in centimeter.

3.10.2.6 Grade wise girth of tubers

Tubers which were collected for measurement of length are also used for measuring girth with the help of scale. The mean value was worked out to represent girth of tuber in centimeter.

3.10.2.7 Tuber yield

Yield of tubers from each plot was recorded separately by excluding the borders from all side for the computation of yield per hectare.

3.10.2.8 Haulm yield

Haulms per plot were harvested separately five days before potato digging close to the ground and dried for one week in sun for computation of yield per hectare.

3.11 Pea

3.11.1 Growth attributes

3.11.1.1 Plant height

Randomly five representative plants from each plot were tagged for recording plant height. Height of tagged plants from each plot was measured from base level to top of the fully opened new leaf at 30, 60 DAS and at maturity.

3.11.1.2 Dry matter accumulation

Three representative plants from each plot were taken randomly for periodically recording dry matter accumulation at 30, 60 DAS and at maturity. The above ground portion was oven dried at 60^0 C after sun drying to attain a constant weight. The average dry matter accumulation was worked out and expressed as g plant^{-1}.

3.11.1.3 Chlorophyll index

The periodic chlorophyll index was recorded with SPAD meter at 30, 60 DAS and at maturity. The fully opened 3rd leaf from the top was selected for recording the observation. From each plot five reading were taken carefully and mean value was worked out. Care should be taken so that the mid rib of the leaf should not come under eye of the instrument.

3.11.1.4 Leaf area Index

The periodic leaf area index was recorded with Sun Scan Canopy Analyzer, Model: Sun scan SSI, manufactured by Delta-T Devices, Cambridge, England at 30, 60 DAS and at maturity.

3.11.2 Yield and yield attributes

3.11.2.1 Number of pods per plant

Number of pods were picked and counted from tagged plants for each picking and at the end of season, the average was expressed as number of pods per plant.

3.11.2.2 Pod length

Ten pods from each plot were selected randomly during pickings and length of each pod was measured with measuring scale. The average pod length was worked out and expressed in centimeter.

3.11.2.3 Number of seeds per pod

Total number of seeds of ten randomly selected pods from each plot was taken and average was expressed as number of seeds per pod.

3.11.2.4 100-seed weight

Seed taken for number of seeds per pod were used for 100 seed-weight on fresh weight basis and average 100-seed weight was worked out for each treatment by subtracting the moisture content.

3.11.2.5 Pod yield

The pods per plot were harvested separately and after final picking pods yield per plot was worked out and total yield q ha^{-1} was calculated.

3.11.2.6 Stover yield

Stover obtained from each plot after separating the pods was sun dried for a week and weight was recorded and expressed as q ha^{-1}.

3.12 Observations recorded for *kharif* maize and spring maize

3.12.1 Growth attributes

3.12.1.1 Plant height

Plant height was recorded at 30, 60, 90 days after sowing (DAS) and at harvest from five randomly tagged plants in central rows of each experimental unit and average value was calculated for reporting. The plant height was measured from the ground level to the top of the fully opened new leaf before tasseling stage. After tasseling the plant height was measured from the ground level to base of the tassel**.**

3.12.1.2 Dry matter accumulation

Three representative randomly selected plants were harvested each time at 30, 60, 90 DAS and at harvest from each plot and plants were sun dried and oven dried at 60^0C to a constant weight for recording dry matter accumulation (DMA) which was then expressed as g $plant^{-1}$.

3.12.1.3 Leaf area index

Leaf area index was recorded at 30, 60, 90 DAS and at harvest using the Sun Scan Canopy Analyzer, Model: Sun scan SSI, manufactured by Delta-T Devices, Cambridge, England.

3.12.2 Microclimatic Observations

3.12.2.1 Photosynthetically active radiation (PAR) interception

Line quantum sensor (LI COR Photometer model LI-191-84) which measure quantum (photon) response through wavelength range of 400-700 nm for Photosynthetic Photon Flux Density (PPDF) was used for PAR measurements. Penetration of PAR in the range of 400-700 nm was measured between 2.00 pm to 3.00 pm at top to measure incidence radiation, at base to measure transmittance and at the top with inverting sensor for measuring reflectance within the crop canopy at 60, 90 DAS and at harvest. The data which recorded were used for calculating PAR interception by the crop as under:

$$\text{PAR interception (\%)} = \frac{\text{PAR(Incidence)} - \text{PAR (Transmittance)} - \text{PAR (Reflectance)}}{\text{PAR (Incidence)}} \text{ x } 100$$

3.12.3 Crop phenology

3.12.3.1 Days taken to 50 per cent tasseling

Days taken to tasseling were recorded as the number of days taken from planting to the date when the tassels had emerged on fifty per cent of plants in the plot.

3.12.3.2 Days taken to 50 per cent silking

It was recorded as the number of days from planting to the date when silk emergence was noticed on fifty per cent of plants in the plot.

3.12.3.3 Days taken to 50 per cent dough stage

The date was recorded when fifty per cent of plants in the plot had whitish yellow to yellow kernels and fingernail impression was retained on them.

3.12.3.4 Days taken to physiological maturity

Number of days taken to physiological maturity was recorded from the date of planting to the date when fifty per cent plants showed browning or drying of cob husk.

3.12.4 Yield and yield attributes

3.12.4.1 Average number of cobs per plant

Total number of plants and total number of cobs obtained from each net harvested plot were counted. Numbers of cobs were divided by total number of plants to calculate number of cobs per plant.

$$\text{Number of cobs per plant} = \frac{\text{Total number of cobs per plot}}{\text{Total number of plants per plot}}$$

3.12.4.2 Cob length

Length of three representative cobs from each plot was measured with the scale and then average value was worked out in cm.

3.12.4.3 Cob girth

Cob diameter of the three representative randomly selected cobs was measured with the help of vernier caliper from the base, centre and the top and mean value was multiplied with the value of 3.14 to get average cob girth.

3.12.4.4 Number of grain rows per cob

Grain rows of three representative cobs were counted and the average number of rows was worked out by taking the mean value of three cobs.

3.12.4.5 Number of grains per row

The number of grains per row of three representative cobs were counted and average was worked out by taking the mean value of the three cobs.

3.12.4.6 Number of grains per cob

Grains from the three representative cobs used for measuring length and girth were counted and expressed as number of grains per cob.

3.12.4.7 1000-grain weight

One thousand grains were counted from produce of each plot and then weighed in grams to represent 1000-grain weight.

3.12.4.8 Grain weight per cob

Total number of cobs per plot was counted at harvest and total grain weight from each plot was recorded. Grain weight per plot was divided by number of cobs per plot to calculate average grain weight per cob.

$$\text{Average grain weight per cob (g)} = \frac{\text{Grain weight per plot (g)}}{\text{Number of cobs per plot}}$$

3.12.4.9 Grain yield

All the cobs from each plot were sun dried and shelled. Moisture content of grains from each plot was determined. The grain yield was adjusted to 15% of moisture level and expressed as q ha^{-1}.

3.12.4.10 Stover yield

Cobs were picked and the remaining plant material including husk was sun dried, weighed and expressed as stover yield (q ha^{-1}).

3.12.4.11 Harvest index

Grain yield expressed as percentage of total biomass yield was taken as harvest index.

$$\text{Harvest index (\%)} = \frac{\text{Grain yield (q ha}^{-1}\text{)}}{\text{Biological yield (q ha}^{-1}\text{)}} \text{x } 100$$

3.12.5 Quality characteristics

3.12.5.1 Protein content, starch content and oil content in maize grain

Non-destructive method was used for determination of protein, starch and oil content in grain with FOSS INFRATEC^{TM} 1241 Grain Analyzer instrument.

3.12.5.2 Estimation of total sugar in grain

Maize grain sample (100 g) was grinded and 0.1 g of sample was taken in glass bottles, then 10 ml of alcohol (70%) was added to it and kept for 24 hours. After this the content was heated on hot plate by adding distilled water in it, to make it free from alcohol. After heating, final volume was made to 100 ml by adding distilled water. In a small test tube 0.5 ml of extract was taken and 1 ml of phenol (5 per cent) and 5 ml of concentrated sulphuric acid were added to it. Content in test tube was mixed mechanically. After half an hour, reading of absorbance was recorded at 490 nm wavelength on spectrophotometer. Concentration of total sugars (glucose) was calculated from glucose standards (10-100 µg) run simultaneously (Dubois *et al* 1956).

3.13 Plant analysis

Plant samples were collected at harvesting stage from different crops as per treatment. These samples were firstly sun dried then kept in oven for few days for complete loss of moisture. Samples were then finely ground using electric grinder.

3.13.1 N, P and K content in seed and stalk

3.13.1.1 Nitrogen

The nitrogen content in plant samples was estimated by micro Kjeldahl's distillation method, as given by Piper (1966). Sample of 0.5 gram was taken and digested with sulphuric acid. The solution that prepared after digestion was then placed in distillation for absorption of ammonia in presence of boric acid. After distillation the solution that contains absorbed ammonia was titrated against sulphuric acid.

3.13.1.2 Phosphorus

The phosphorus content in seed and stalk samples were determined by vanado-phospho-molybdate yellow color method by digesting the samples with di-acid. The intensity of yellow colour was determined using spectrophotometer at 470 nm, as given by Piper (1966). A sample of 0.5 gram was taken in digestion tube and sample digested with di-acid. After digestion, volume was made by mixing vanado- phospho-molybdate yellow colour solution and distilled water. The solution kept undisturbed for half an hour for development of colour. Then intensity of colour was determined using spectrophotometer at 420 nm.

3.13.1.3 Potassium

The potassium content in plant samples was estimated by using flame photometer as described by Muhr *et al* (1965). The sample that digested with di-acid was taken in volumetric flask and volume was made by adding distilled water to it. The potassium content was determined by using flame photometer.

3.13.2 N, P and K uptake in seed and stalk

3.13.2.1 Nitrogen uptake

The nitrogen uptake in seed and stalk samples were determined by multiplying nitrogen content with seed and stalk yield, respectively. The nitrogen content in plant sample was estimated by adopting modified Kjeldahl's method given by Piper (1966).

3.13.2.2 Phosphorus uptake

The phosphorus content in seed and stalk samples were determined by Vanado-molybdate phosphoric yellow colour method in nitric acid medium described by Piper (1966) and intensity of yellow colour was determined by using Spectronic-20 photoelectric colorimeter at 470 µm wavelength. The phosphorus uptake of seed and stalk samples were determined by multiplying phosphorus content with seed and stalk yield, respectively.

3.13.2.3 Potassium uptake

The digested material used in phosphorus determination was used for potassium determination. Potassium content was determined by using Flame photometer (Muhr *et al* 1965). The reading of the Flame photometer was compared with standard curve to get K content in percentage. The potassium uptake of seed and stalk were calculated by multiplying potassium content with seed and stalk yield, respectively.

3.14 Soil chemical properties

3.14.1 Soil pH

The soil pH was determined in 1:2 soil-water suspensions using an Beeckman's glass electrode pH meter (Jackson 1967).

3.14.2 Electrical conductivity

Electrical conductivity of the soil samples was determined in 1:2 soil-water suspension equilibrated for 24 hour using a solu-bridge.

3.14.3 Organic carbon

The organic carbon was determined by Walkley and Black's rapid titration method as detailed by Jackson 1967.

3.14.4 Available nitrogen

The total available nitrogen of the soil was determined by Alkaline Potassium Permanganate Method given by Subbiah and Asija (1956). Soil was treated with an excess of alkaline-$KMnO_4$ and the ammonia thus evolved was absorbed in a standard acid. The excess of acid was titrated with standard alkali by using methyl red indicator. From the volume of standard acid used for absorption of ammonia, the amount of nitrogen in the soil sample was calculated.

3.14.5 Available phosphorus

Available phosphorus was determined by 0.5 M $NaHCO_3$ method suggested by Olsen *et al* (1954). Soil was shaken with bicarbonate extractant for half an hour with the help of electric shaker. Then the clear filtered soil extract was treated with ammonium molybdate, complexing agent. In the presence of reducing agent (ascorbic acid) the soil extract gave blue colour. The intensity of the blue colour was measured with a colorimeter at a wavelength of 760 mµ using red filter. From the standard curve the amount of phosphorus present in soil was calculated.

3.14.6 Available potassium

The available potassium of the soil was determined by the method given by Muhr *et al* (1965). The index of potassium availability is the sum of exchangeable and water soluble potassium. The extraction of potassium was determined by using neutral normal ammonium acetate solution as extracting agent. The extract, thus obtained was tested for its content of potassium with the help of flame photometer.

3.15 Economic analysis

3.15.1 Spring maize equivalent yield (SMEY)

Yield of various crops in the system were converted to spring maize equivalent yield (SMEY) on basis of market price of crops (Anjaneyulu *et al* 1982).

$$\text{SMEY (q ha}^{-1}) = \text{Grain yield of spring maize} + \frac{\text{Grain yield of rice}/kharif\text{ maize x price of rice}/kharif\text{ maize}}{\text{price of spring maize}} + \frac{\text{Yield of potato/pea x price of potato/pea}}{\text{price spring maize}}$$

3.15.2 System productivity

System productivity was calculated by dividing the spring maize equivalent yield with duration of the system. It was calculated by using following formula:

$$\text{System productivity(kg ha}^{-1}\text{ day}^{-1}) = \frac{\text{Spring maize equivalent yield of the system (q ha}^{-1})}{\text{Duration of the system (days)}}$$

3.15.3 Gross returns

It is the total amount of income or returns from each crop in the system. Gross returns are obtained by multiplying the quantity of output and market price.

3.15.4 Net returns

Net return was calculated by subtracting the total cost of cultivation from gross returns of the system.

Net returns = Gross returns – Total cost of cultivation

3.15.5. Benefit cost ratio

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 that is incurred for obtaining the said gross returns. Total cost of cultivation includes variable cost of inputs like land preparation cost, seed and seed treatment cost, cost of irrigation, fertilizer, weedicides, pesticides, human labour and tractor charges, market charges etc. It was calculated by using the formula given below:

$$\text{Benefit : Cost} = \frac{\text{Net returns (Rs ha}^{-1})}{\text{Total cost of cultivation (Rs ha}^{-1})}$$

3.15.6 Profitability

The profitability of the system was calculated by dividing net returns of the system by 365 days and expressed as Rs $ha^{-1}day^{-1}$.

3.16 Statistical analysis

Analysis of variance was performed using procedure proposed by Cochran and Cox (1967). For analysis of data, statistical package CPCS-I, software was used which was developed by the Department of Mathematics and Statistics, PAU, Ludhiana. Treatment comparisons were made at 5 per cent level of significance.

Experiment I

Integrated nutrient management for enhancing productivity of rice-potato-spring maize cropping system.

Experimental design: Split plot design

Table 3.10: Analysis of variance of experiment-I

Sources of variation	Degree of freedom
Replications	2
Rice residue and nutrient application in potato (a)	3
Error (a)	6
Nutrient application in spring maize (b)	5
Rice residue and nutrient application in potato × nutrient application in spring maize (ab)	15
Error (b)	40
Total	**71**

Experiment II

Integrated nutrient management for enhancing productivity of *kharif* maize-pea-spring maize cropping system.

Experimental design: Split plot design

Table 3.11: Analysis of variance of experiment-II

Sources of variation	Degree of freedom
Replications	2
Nutrient application in *kharif* maize and pea (a)	3
Error (a)	6
Nutrient application in spring maize (b)	5
Nutrient application in *kharif* maize and pea × nutrient application in spring maize (ab)	15
Error (b)	40
Total	**71**

CHAPTER IV

RESULTS AND DISCUSSION

The data recorded with respect to various parameters, results obtained and the supporting explanation with regard to the two years study entitled "Integrated nutrient management for enhancing productivity of spring maize (*Zea mays* L.) in rice and maize based cropping systems" are presented in this chapter. The results obtained and its possible scientific explanations of integrated nutrient management for enhancing productivity of rice-potato-spring maize cropping system are presented under experiment I and integrated nutrient management for enhancing productivity of *kharif* maize-pea-spring maize cropping system under experiment II.

4.1 EXPERIMENT I

The experiment entitled "Integrated nutrient management for enhancing productivity of rice-potato-spring maize cropping system" was conducted in a split plot design, which was replicated thrice during 2018-19 and 2019-20. The experiment was randomized with 24 treatment combinations, which involves rice and potato in the main plots and spring maize treatments in the sub plots.

4.1.1 RICE

Rice was grown as a general crop by following package of practices recommended by Punjab Agricultural University, Ludhiana during both the years. After harvesting rice, potato was cultivated by randomizing four treatments into it. Data pertaining to yield and yield attributes of rice were recorded at maturity during 2018 and 2019 are presented in table 4.1.

Table 4.1 Yield and yield attributes of rice at maturity during 2018 and 2019

Sr. No.	Character	2018	2019
1	Plant height (cm)	114.5	112.6
3	No. of tillers m^{-2}	554.0	512.8
4	Panicle length (cm)	24.2	22.4
5	1000 seed weight (g)	21.4	20.6
6	No. of grains per panicle	218.6	198.0
7	Biological yield (q ha^{-1})	218.2	206.1
8	Grain yield (q ha^{-1})	82.5	77.5
9	Straw yield (q ha^{-1})	135.7	128.6

Plate 1: Agronomic operations in rice field

The data given in table 4.1 showed that plant height of 114.5 and 112.6 cm, number of tillers per m^2 of 554.0 and 512.8, panicle length of 24.2 and 22.4 cm, number of grains per panicle of 218.6 and 198.0 and test weight of 21.4 and 20.6 g were recorded in rice at maturity during 2018 and 2019, respectively. The grain yield of 82.5 and 77.5 q ha^{-1}, biological yield of 218.2 and 206.1 q ha^{-1} and straw yield of 135.7 and 128.6 q $ha^{-1}$was recorded at the end of the season during 2018 and 2019, respectively. After the harvesting of rice crop, the straw was used in the succeeding potato crop for further study.

4.1.2 POTATO

4.1.2.1 Pre harvest studies

4.1.2.1.1 Plant height

Plant height is an index of growth and development representing the infrastructure build-up over a period of time which depend upon genetic constitution of a particular cultivar and may also vary due to different agronomic intervention, which may alter the soil and above ground conditions for better growth and development. A taller plant can support more number of leaves, leading to better photosynthesis which ultimately resulted with a higher crop yield. The data on plant height was recorded at 30, 60 DAS and at haulm cutting are presented in table 4.2 and fig. 4.1. Analysis of data revealed that plant height differed significantly for different treatments applied there in. The effect of rice residue and nutrient application to potato on plant height was non-significant at 30 DAS, whereas it had a significant effect at 60 DAS and at haulm cutting during both the years of study. Among various treatments, maximum plant height at 60 DAS and at haulm cutting (38.1, 43.5 cm and 46.0, 51.8 cm) was recorded where rice residue was incorporated along with application of 100% NPK + FYM @ 50 t ha^{-1} to potato and this treatment was significantly better than treatments involving residue incorporation + 150% NPK and residue removal + 150% NPK but was statistically at par with rice residue removal + 100% NPK + FYM @ 50 t ha^{-1} during 2018-19 and 2019-20, respectively. The lowest plant height at 60 DAS and haulm cutting (32.2, 35.6 cm and 39.2, 43.8 cm) was recorded under rice residue removed plot + 150% NPK application during 2018-19 and 2019-20, respectively. Incorporation of residue with combined application of organic and inorganic fertilizers resulted in taller plant height might be due to better nutrient availability to the plant for their growth. Verma and Pandey (2013) and Kaur and Kumar (2018) also reported taller plant height in residue retained plot as compared to residue removal plot. Begum and Saikia (2014) reported better potato growth with residue retention in the field as compared to without residue retention. Combined application of organic and inorganic fertilizers leads to higher growth of the plant due to adequate availability of nutrient and water for longer period of time, which will be available to plant during its peak demand period as reported by Mengistu and Mekonnen (2012). Organic manures provide essential nutrients and improve the physical condition of soil and also provide better microclimatic conditions for plant growth. Habib *et al* (2012), Joshi *et al* (2013), Mahato *et al* (2020) and Sigaye *et al* (2021) reported higher growth of plant with combined application of organic and inorganic nutrient sources as compared to sole application of chemical fertilizers.

Table 4.2: Effect of rice residue incorporation and nutrient application on plant height (cm) of potato

Treatment	30 DAS		60 DAS		At haulm cutting	
	2018-19	**2019-20**	**2018-19**	**2019-20**	**2018-19**	**2019-20**
Straw removal + 100 % NPK+ FYM @ 50 t ha^{-1}	19.3	24.0	35.5	40.5	43.8	47.8
Straw removal + 150 % NPK	17.3	21.8	32.2	35.6	39.2	43.8
Straw incorporation + 100 % NPK+ FYM @ 50 t ha^{-1}	21.0	23.6	38.1	43.5	46.0	51.8
Straw incorporation + 150 % NPK	18.7	22.1	33.9	39.7	40.7	45.3
CD (p=0.05)	NS	NS	3.88	3.58	4.21	4.00

4.1.2.1.2 Dry matter accumulation

Dry matter accumulation (DMA) is an important feature showing the growth and metabolic efficiency of plants which ultimately affects the yield of crop. Optimum accumulation of dry matter followed by adequate partitioning of assimilates to the sink leads to higher grain yield. The data with respect to DMA are presented in table 4.3 and fig. 4.2 which revealed that DMA was not significantly influenced by various treatments at 30 DAS but it differed significantly at 60 DAS and haulm cutting during both the years. The maximum DMA was recorded at 60 DAS and haulm cutting (36.0, 40.8 g $plant^{-1}$ and 54.6, 67.4 g $plant^{-1}$) in rice residue incorporated plots supplied with 100% NPK + FYM @ 50 t ha^{-1} which was significantly better than the treatments consist of residue incorporation + 150% NPK and residue removal + 150% NPK during 2018-19 and 2019-2020, respectively, but it was statistically at par with residue removed plots + 100% NPK + FYM @ 50 t ha^{-1} during 2018-19 at 60 DAS. The minimum DMA was recorded where rice residues were removed and 150% NPK was applied (6.02, 6.73 g $plant^{-1}$, 29.1, 32.1 g $plant^{-1}$ and 43.8, 59.8 g $plant^{-1}$) at 30, 60 DAS and at haulm cutting during 2018-19 and 2019-20, respectively.

Incorporation of residue in to soil have beneficial effect on soil physical, chemical and biological properties which favours better root growth and nutrient uptake thereby increasing plant growth and photosynthates translocation and assimilation leading to higher dry matter accumulation. Singh *et al* (2005), Khurshid *et al* (2006), Sidhu *et al* (2007) and Khatri *et al* (2019) reported higher growth and photosynthates accumulation in residue retained plots.

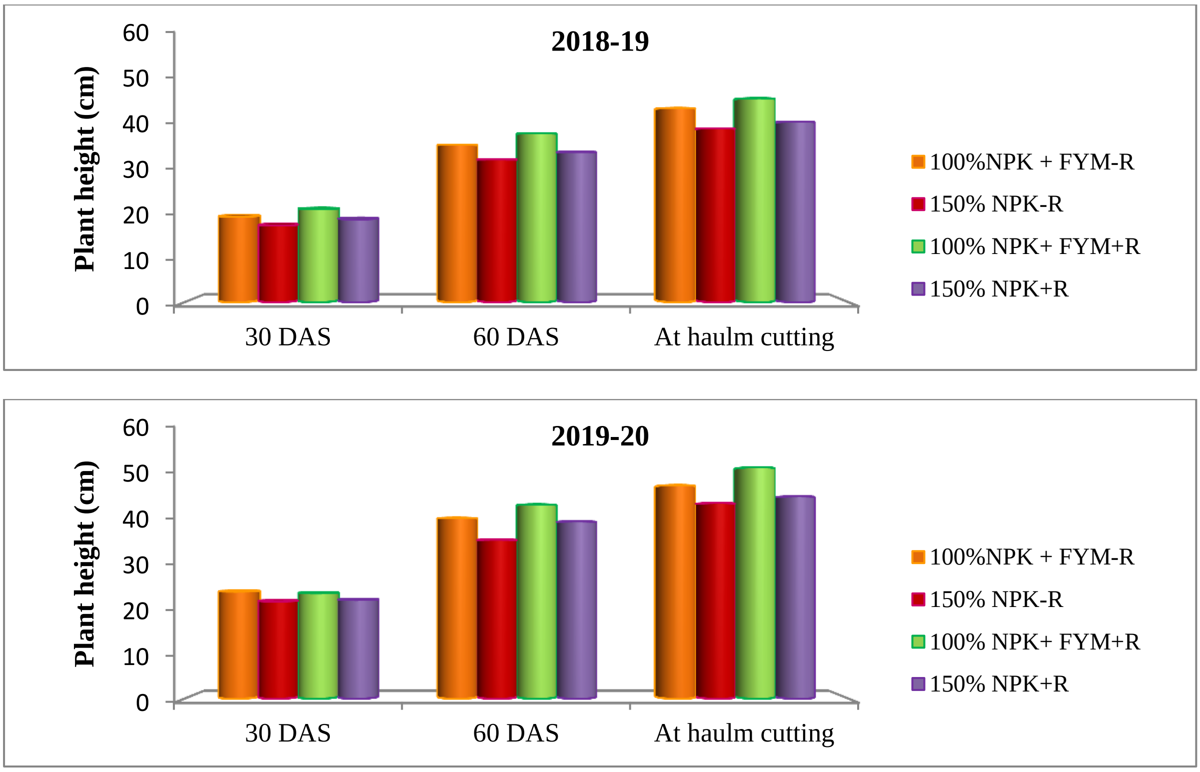


Fig. 4.1: Effect of rice residue incorporation and nutrient application on plant height of potato

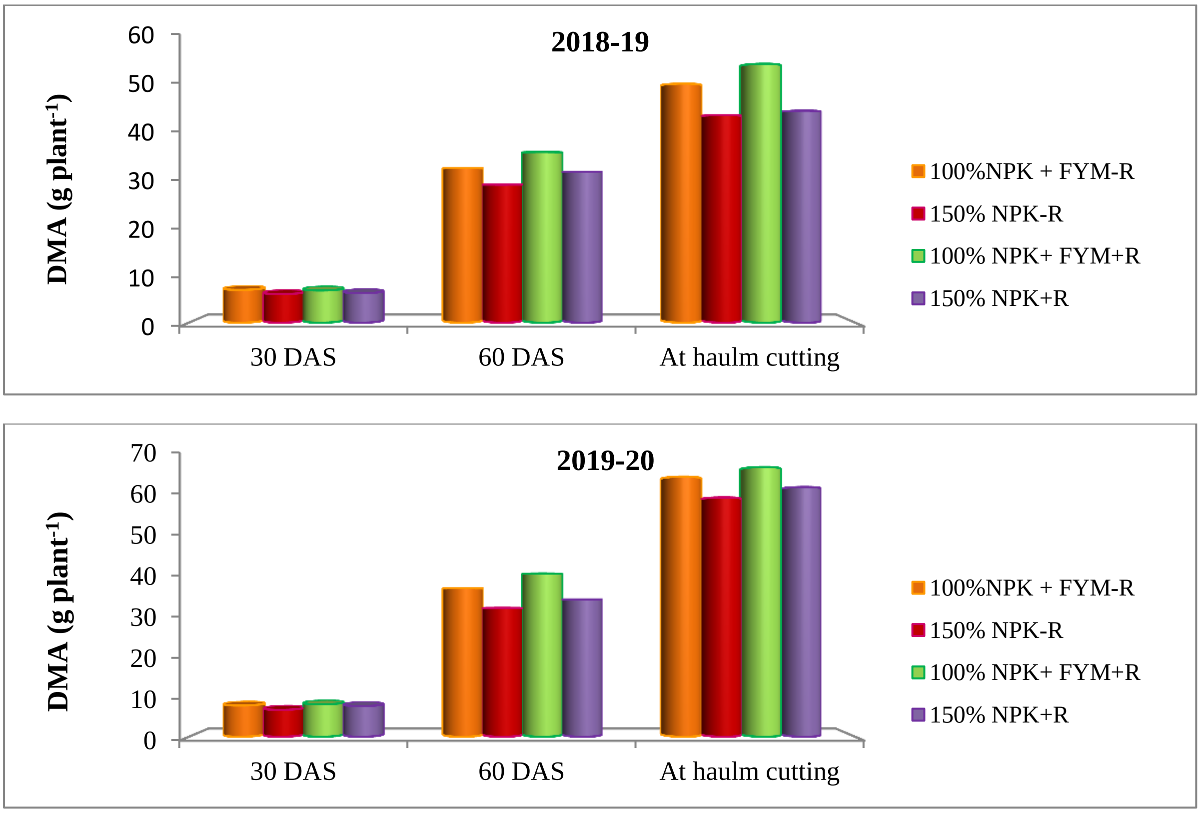


Fig. 4.2: Effect of rice residue incorporation and nutrient application on DMA of potato

Integrated application of organic and synthetic fertilizers significantly increases the growth attributes as compared to use of inorganic fertilizer alone. This might be due to better availability of nutrient from both organic and inorganic sources that enhances vegetative growth. Similar results were observed by Kushwah *et al* (2005) and Babu (2019).

Table 4.3: Effect of rice residue incorporation and nutrient application on dry matter accumulation (g plant^{-1}) of potato

Treatment	30 DAS		60 DAS		At haulm cutting	
	2018-19	**2019-20**	**2018-19**	**2019-20**	**2018-19**	**2019-20**
Straw removal + 100 % NPK+ FYM @ 50 t ha^{-1}	6.92	7.80	32.6	37.1	50.4	65.0
Straw removal + 150 % NPK	6.02	6.73	29.1	32.1	43.8	59.8
Straw incorporation + 100 % NPK+ FYM @ 50 t ha^{-1}	6.80	8.09	36.0	40.8	54.6	67.4
Straw incorporation + 150 % NPK	6.22	7.66	31.8	34.3	44.7	62.4
CD (p=0.05)	NS	NS	3.0	4.2	5.7	NS

4.1.2.1.3 Leaf area index

Leaf area index (LAI) is an important index to judge the production potential of a crop. It is an indicator of source size and dictates the efficiency of photosynthetic surface. It influences the interception of solar radiation, photosynthesis and ultimately the total biomass production. LAI signifies the ground area covered by plant area. More tillers and taller plants result in higher leaf area index. Data pertaining to LAI are presented in table 4.4 and fig 4.3 and it revealed that LAI of the crop responded significantly to application of different treatments except at 30 DAS during 2018-19. LAI increased with advancement of crop age up to 60 DAS and it declined thereafter when crop advanced towards maturity due to senescence of lower leaves. At 30 DAS during 2019-20 and at 60 DAS and haulm cutting during 2018-19 and 2019-20, LAI recorded was highest (0.55), (313, 3.14 and 0.92, 0.93) respectively when potato crop applied with 100% NPK + FYM @ 50 t ha^{-1} in residue incorporated plots. Data recorded for LAI under residue removal + 100% NPK + FYM @ 50 t ha^{-1} was statistically at par with residue incorporation + 100% NPK + FYM 50 t ha^{-1} at all stages except at 60 DAS during 2019-20. Minimum value for LAI was recorded where rice residue was removed with application of 150% NPK at 30 DAS (0.30) during 2019-20, at 60 DAS (2.70, 2.72) and haulm cutting (0.70, 0.64) during 2018-19 and 2019-20. Higher leaf are index in combined application of organic and inorganic nutrient plot might be due to more N availability for longer period of time leading to more plant height and higher number of tillers. Snehaa *et al* (2019), Mahato *et al* (2020) and Sigaye *et al* (2021) recorded higher plant height, DMA and

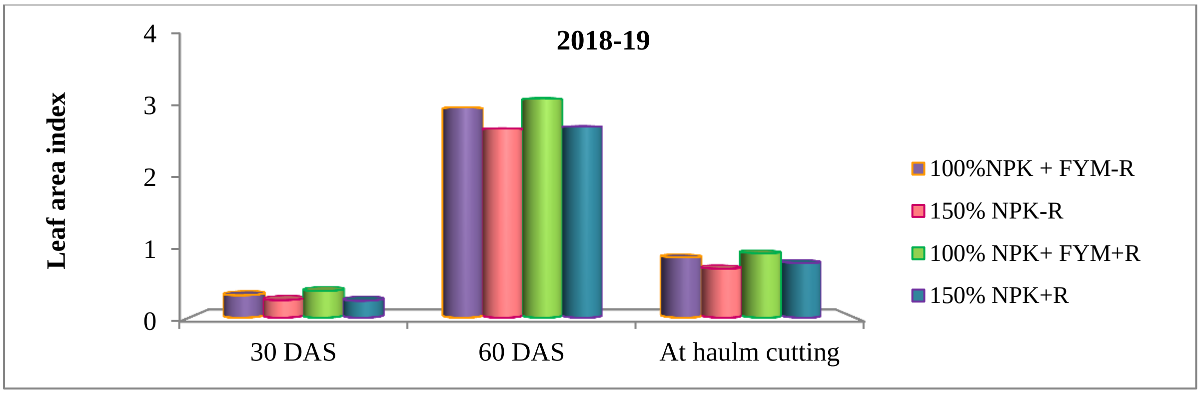
LAI in combined application of organic and inorganic source of nutrient. Organic manures enhances soil organic carbon content (SOC) and has direct and indirect effect on soil properties, particularly N, conducive for plant growth resulted in better growth and leaf area as compared to sole application of inorganic fertilizers. Incorporation of straw creates a better microclimatic environment leading to better growth of the crop leads to higher leaf area index. Sarwar *et al* (2013) also reported that integration of FYM along with inorganic fertilizers resulted in higher LAI as compared to sole application of inorganic fertilizers.

Table 4.4: Effect of rice residue incorporation and nutrient application on LAI of potato

Treatment	30 DAS		60 DAS		At haulm cutting	
	2018-19	2019-20	2018-19	2019-20	2018-19	2019-20
Straw removal + 100 % NPK+ FYM @ 50 t ha^{-1}	0.32	0.40	3.00	2.88	0.86	0.77
Straw removal + 150 % NPK	0.25	0.30	2.70	2.72	0.70	0.64
Straw incorporation + 100 % NPK+ FYM @ 50 t ha^{-1}	0.38	0.55	3.13	3.14	0.92	0.93
Straw incorporation + 150 % NPK	0.24	0.36	2.73	2.87	0.78	0.74
CD (p=0.05)	NS	0.15	0.29	0.24	0.11	0.18

4.1.2.1.4 Chlorophyll index

Chlorophyll index indicates chlorophyll content of the plant leaves. Higher chlorophyll index indicates more greenness of foliage. Greenness enhances better photosynthesis which ultimately leads to accumulation of photosynthates at the sink. Scrutiny of data pertaining to chlorophyll index revealed that it differed significantly with application of different treatments. Data collected for chlorophyll index are presented in table 4.5 and fig. 4.4 which revealed that highest values of chlorophyll index was recorded with application of 150% NPK in rice residue incorporated treatment during both the years at 30 DAS (18.1 and 20.6), 60 DAS (34.3 and 39.0) and at haulm cutting (6.00 and 7.30) and it was statistically at par with residue removed treatment + 150% NPK application at 30 DAS and 60 DAS during 2018-19 and at haulm cutting stage during 2019-20 and significantly higher than all other treatments. Numerically lowest CCI value was recorded with application of 100% NPK + FYM @ 50 t ha^{-1} where residue was removed during both the years at all growth stages which was statistically at par with treatment consist of residue incorporation + 100% NPK + FYM @ 50 t ha^{-1} at all growth stages during 2018-19 and 2019-20.



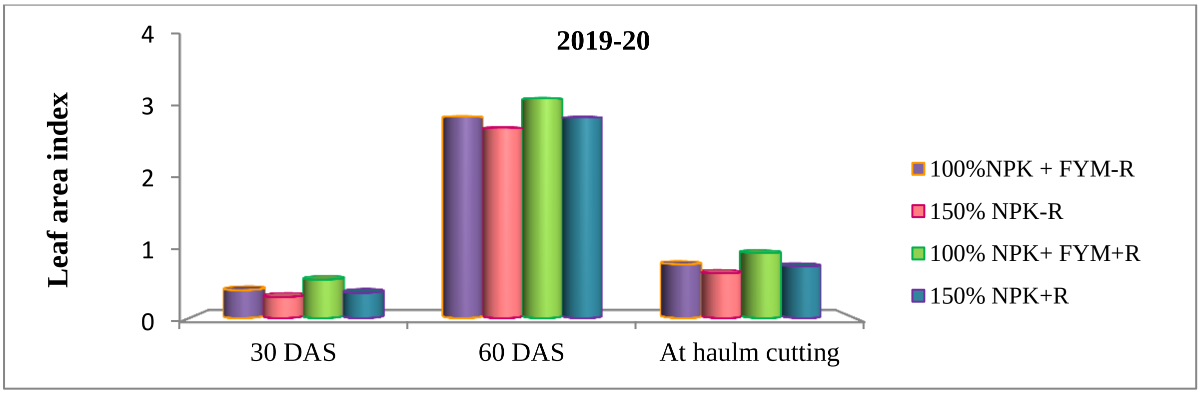
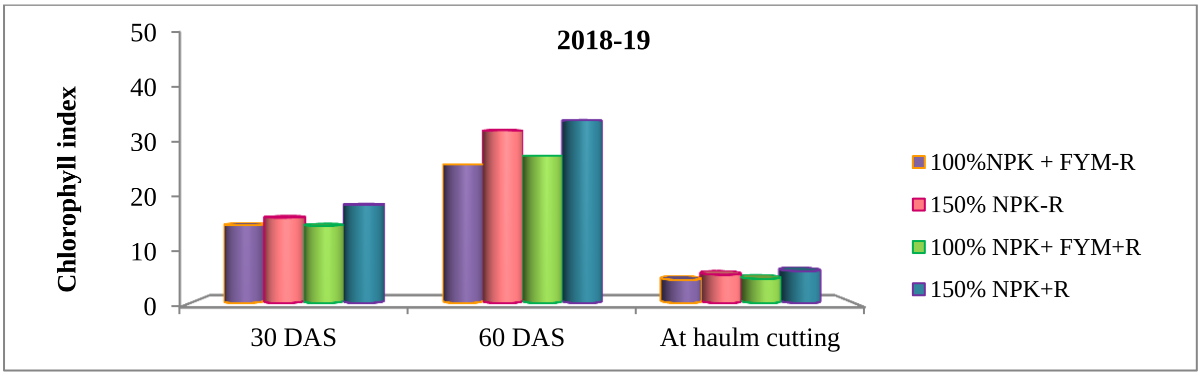


Fig. 4.3: **Effect of rice residue incorporation and nutrient application on LAI of potato**



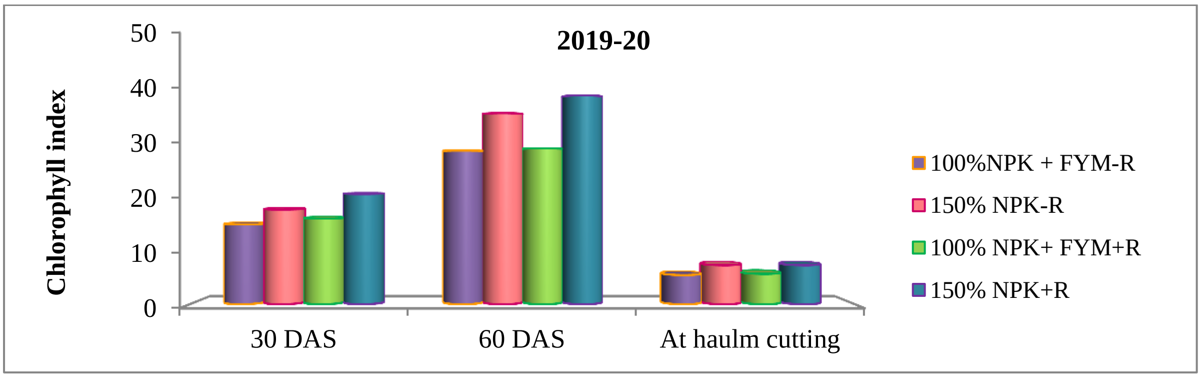


Fig. 4.4: Effect of rice residue and nutrient application on chlorophyll index of potato

Table 4.5: Effect of rice residue and nutrient application on chlorophyll index of potato

Treatment	30 DAS		60 DAS		At haulm cutting	
	2018-19	**2019-20**	**2018-19**	**2019-20**	**2018-19**	**2019-20**
Straw removal + 100 % NPK+ FYM @ 50 t ha^{-1}	14.6	14.9	26.0	28.7	4.34	5.46
Straw removal + 150 % NPK	16.0	17.7	32.4	35.7	5.33	7.30
Straw incorporation + 100 % NPK+ FYM @ 50 t ha^{-1}	14.5	16.0	27.6	29.1	4.56	5.68
Straw incorporation + 150 % NPK	18.4	20.6	34.3	39.0	6.00	7.30
CD (p=0.05)	2.4	2.3	5.6	5.5	0.64	1.17

Higher dose of synthetic fertilizers increase the chlorophyll index of the plant and makes the foliage looks darker as compared to combined application of organic and inorganic fertilizers. With increased dose of nitrogen chlorophyll index was also increased (Hokmalipour and Darbandi 2011).

4.1.2.2 Post harvest studies

4.1.2.2.1 Number of tillers per plant

The data in respect of number of tillers per plant are presented in table 4.6. 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 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. Bahadhur *et al* (2013) also reported better growth of plant with application of FYM along with chemical fertilizers. Banjara (2019) and Patel *et al* (2013) also recorded maximum number of shoots per plant in potato with combined application of organic and inorganic source of nutrients.

4.1.2.2.2 Number of tubers per plant

Number of tubers per plant is an 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 4.6 and fig. 4.5. Plots where rice residue was incorporated with application of 100% NPK + FYM @ 50 t ha^{-1} recorded maximum number of tubers per 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 Guler (2009), Jadhav (2012) and Babu (2019).

Table 4.6: 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	4.73	12.5	15.7	739.7	751.3
Straw removal + 150 % NPK	2.50	4.47	10.5	12.7	537.3	622.3
Straw incorporation + 100 % NPK+ FYM @ 50 t ha^{-1}	3.33	4.87	15.0	16.8	821.3	863.7
Straw incorporation + 150 % NPK	2.74	4.33	11.3	14.6	594.7	644.3
CD (p=0.05)	0.42	NS	1.8	1.9	108.9	133.5

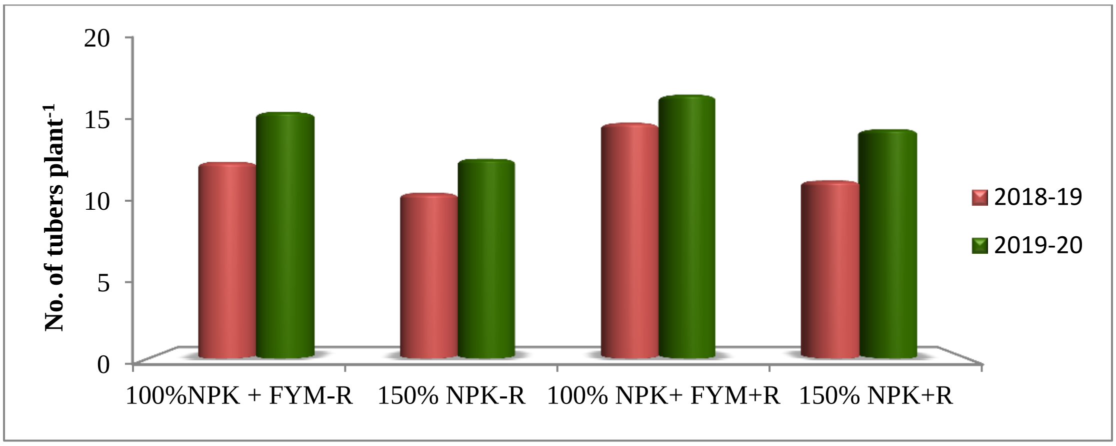


Fig. 4.5: Effect of rice residue and nutrient application on number of tubers per plant of potato

4.1.2.2.3 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 4.6 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) as compared to rest of the treatments during both the years. Straw removal with application of 100% NPK + FYM @ 50 t ha^{-1} also resulted with higher tubers weight and was statistically at par with residue incorporation + 150% NPK application during both the years. A lowest tuber weight per plant (537.3 and 622.3 g) was recorded under treatment that involves residue removal + 150% NPK during 2018-19 and 2019-20. 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.

4.1.2.2.4 Grade wise number of tubers

Grade wise distribution of tubers is an important attribute for marketing purpose. The number of tubers 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 4.7. 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. Charan (2002), Sood (2007) and Babu (2019) also reported similar findings.

Table 4.7: 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	260.1	279.2	277.4	136.3	139.9
Straw removal + 150 % NPK	322.0	386.3	165.3	177.4	107.1	118.0
Straw incorporation + 100 % NPK+ FYM @ 50 t ha^{-1}	209.1	222.3	299.9	309.6	144.2	141.5
Straw incorporation + 150 % NPK	301.6	360.1	175.8	197.3	118.4	136.5
CD (p=0.05)	42.3	42.1	37.9	36.9	19.6	16.4

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

4.1.2.2.5 Grade wise weight of tubers

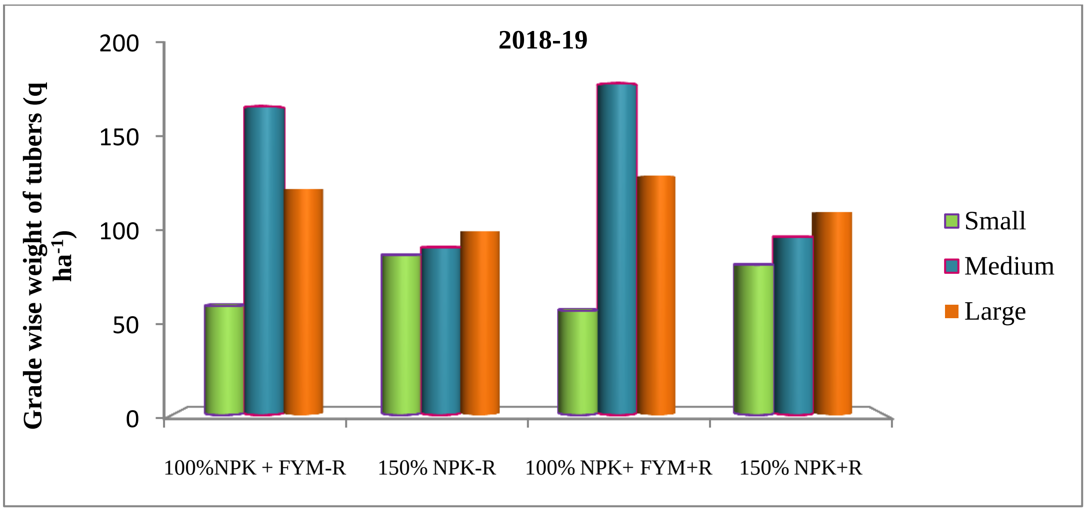
Data presented in table 4.8 and fig. 4.6 depicts the effect of rice residue and nutrient application in potato on grade wise weight of potato tubers. A quick glance at data revealed that there was noticeable difference among various treatments. Weight of small sized tubers was significantly higher in 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 2018-19. 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 provide space for tuberization.

Table 4.8: 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	70.2	167.5	166.5	122.7	125.6
Straw removal + 150 % NPK	86.9	96.6	90.9	97.6	99.6	109.8
Straw incorporation + 100 % NPK+ FYM @ 50 t ha^{-1}	56.5	62.2	180.0	185.8	129.8	127.4
Straw incorporation + 150 % NPK	81.4	90.0	96.7	108.5	110.0	122.9
CD (p=0.05)	13.6	12.3	26.8	22.8	16.3	NS

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



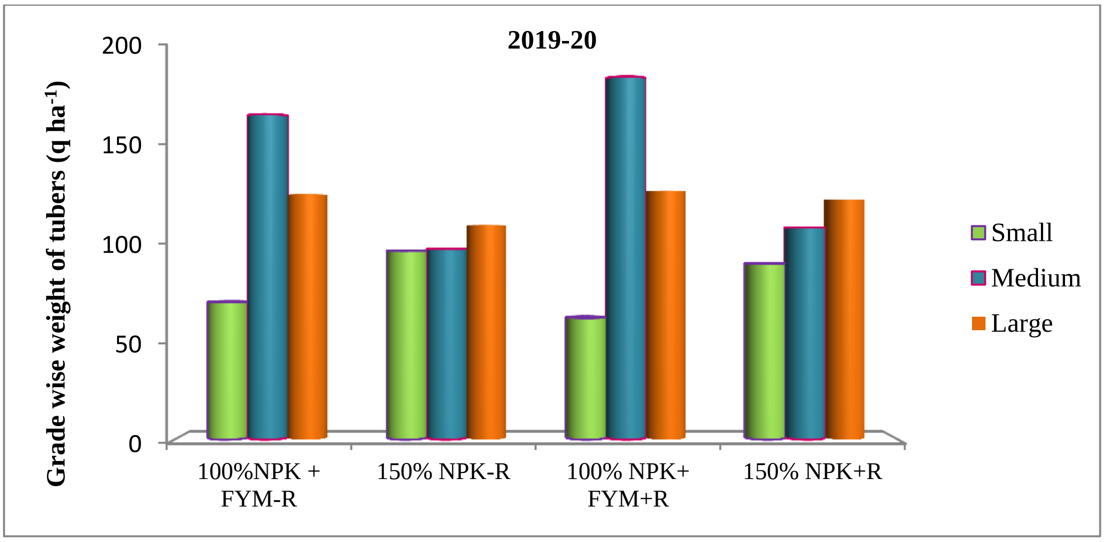


Fig. 4.6: Effect of rice residue incorporation and nutrient application on grade wise weight of tubers of potato

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).

4.1.2.2.6 Grade wise length of tubers

A close scrutiny of data presented in table 4.9 depicted that the length of different grades of tubers was varied with application of different treatments. In both small and medium sized tubers, larger length of tubers was recorded (6.10, 6.30 cm and 7.85, 7.80 cm, respectively) when combined application of organic and inorganic fertilizer (residue incorporation + 100% NPK + FYM @ 50 t ha^{-1}) was done with straw incorporation during both the years. While the smallest length of tubers (5.00, 5.07 cm and 6.68, 6.79 cm) were recorded with residue removed + application of 150% NPK during both the years. In case of large sized tubers, maximum length of tubers was recorded in residue incorporation + 150% NPK applied plot and the minimum length was recorded with application of 100% NPK + FYM @ 50 t ha^{-1} along with residue incorporation during 2019-20. The effect of treatments over length of large sized tubers was found to be non-significant during 2018-19. Larger length of tubers was due to higher availability of nutrients. Better physical properties of soil provide better microclimatic condition for tuberizaion leads to larger sized tubers. A smaller size tuber in case of sole application of inorganic fertilizer was due to improper tuber development and more nitrate accumulation in tubers. The results are corroborated with the findings of Charan (2002) and Babu (2019).

Table 4.9: Effect of rice residue incorporation and nutrient application on grade wise length of potato tubers

Treatment	**Grade wise length of tubers (cm)**					
	Small		**Medium**		**Large**	
	2018-19	**2019-20**	**2018-19**	**2019-20**	**2018-19**	**2019-20**
Straw removal + 100 % NPK+ FYM @ 50 t ha^{-1}	5.60	5.88	7.44	7.55	8.99	9.00
Straw removal + 150 % NPK	5.00	5.07	6.68	6.79	9.29	9.56
Straw incorporation + 100 % NPK+ FYM @ 50 t ha^{-1}	6.10	6.30	7.85	7.80	9.11	9.16
Straw incorporation + 150 % NPK	5.12	5.50	7.10	7.30	9.83	10.4
CD (p=0.05)	0.42	0.72	0.66	0.66	NS	0.58

4.1.2.2.7 Grade wise girth of tubers

The effect of rice residue and nutrient application in potato on grade wise girth of potato is conferred in table 4.10. From the close analysis of data revealed that the girth of tubers was increased with combined application of organic manures and synthetic fertilizers with straw incorporation as compared to sole application of synthetic fertilizers. Larger girth of tubers was recorded (12.6, 13.2 cm and 16.5, 16.9 cm) in both small and medium grade tubers when residue was incorporated along with application of 100% NPK + FYM @ 50 t ha^{-1} to the crop during both the years. The smallest girth of 11.6, 11.5 cm and 15.0, 15.4 cm was recorded with application of 150% NPK when residue was removed. In case of large sized grade tubers, maximum girth of potato tubers (19.7 and 20.6 cm) was resulted from application of 150% NPK along with residue incorporation and smallest girth of tubers (18.2 and 19.1 cm) was recorded when residue was removed with application of 100% NPK + FYM @ 50 t ha^{-1} during both the years. Larger girth of tubers in conjoint application of FYM and RDF with straw incorporation was due to better tuberization in soil. It provides adequate nutrient and water to plants for better photosynthesis and translocation of sugars towards sink. Smaller girth in sole application of inorganic fertilizer was due to lack of aeration and compactness of soil which did not allow the tuber to enlarge its size (Babu 2019).

Table 4.10: Effect of rice residue and nutrient application on grade wise girth of potato tubers

Treatment	Grade wise girth of tubers (cm)					
	Small		**Medium**		**Large**	
	2018-19	**2019-20**	**2018-19**	**2019-20**	**2018-19**	**2019-20**
Straw removal + 100 % NPK+ FYM @ 50 t ha^{-1}	12.4	12.7	16.3	16.3	18.2	19.1
Straw removal + 150 % NPK	11.6	11.5	15.0	15.4	18.9	19.6
Straw incorporation + 100 % NPK+ FYM @ 50 t ha^{-1}	12.6	13.2	16.5	16.9	18.5	19.2
Straw incorporation + 150 % NPK	11.9	12.5	16.0	15.7	19.7	20.6
CD (p=0.05)	0.42	0.47	0.82	0.93	0.98	0.53

4.1.2.2.8 Tuber yield

Data presented in table 4.11 and fig. 4.7 depicts 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), Larney *et al* (2016) and Khakbazan *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. Sadawarti *et al* (2013) and Begum and Saikia (2014) reported higher tuber yield under residue retained plot as mulch as compared to residue removed plot.

4.1.2.2.9 Haulm yield

Data pertaining to haulm yield of potato presented in table 4.11 and fig. 4.8 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. Habib *et al* (2012) and Joshi *et al* (2013) also reported higher growth of the plant with combined application of organic fertilizers and chemical fertilizers as compared to sole application of chemical fertilizers.

Table 4.11: 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	362.5	102.2	111.4
Straw removal + 150 % NPK	277.4	304.0	73.1	97.6
Straw incorporation + 100 % NPK+ FYM @ 50 t ha^{-1}	366.3	375.4	107.1	115.3
Straw incorporation + 150 % NPK	288.3	321.4	71.1	95.9
CD (p=0.05)	63.6	33.9	20.1	13.7

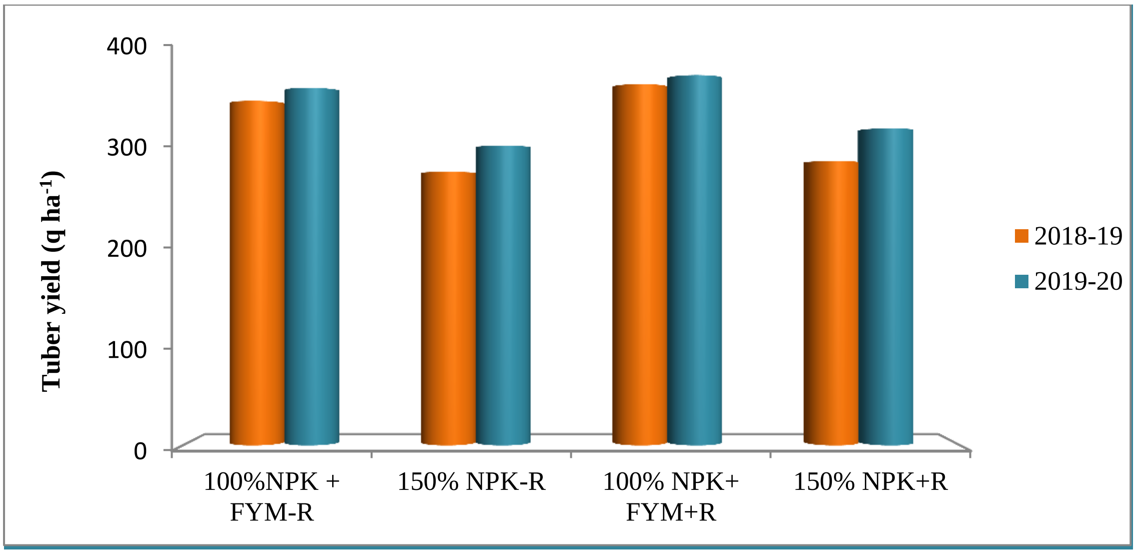


Fig. 4.7: Effect of rice residue incorporation and nutrient application on tuber yield of potato

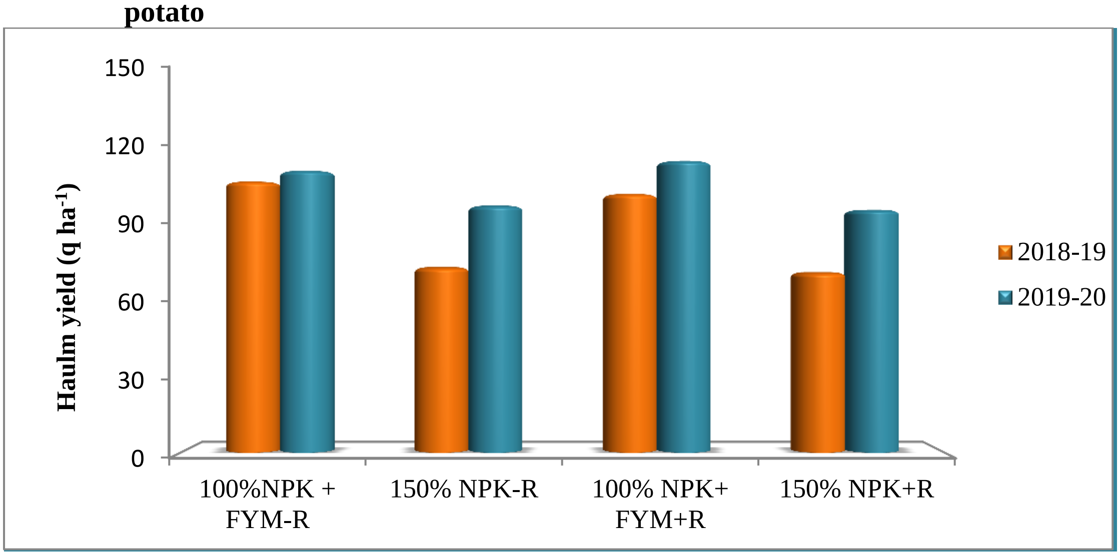


Fig. 4.8: Effect of rice residue incorporation and nutrient application on haulm yield of potato

Plate 2: Agronomic operations in Potato field

Plate 3: Treatments randomized in potato crop

4.1.3 SPRING MAIZE

4.1.3.1 Biometric observations

4.1.3.1.1 Plant height

The growth and development of a plant can be determined by recording the plant height, as the plant height indicates strength and vigor of plant to the existing environmental conditions. It is an important physiological parameter related to growth and development of the crop. The plant height of spring maize was recorded at 30, 60, 90 DAS and at maturity and the data are presented in table 4.12 and fig. 4.9.

Table 4.12: Effect of rice residue and nutrient application to preceding potato and nutrient levels to spring maize on plant height (cm) in spring maize

Treatment	30 DAS		60 DAS		90 DAS		At maturity	
	2019	**2020**	**2019**	**2020**	**2019**	**2020**	**2019**	**2020**
Rice residue and nutrient application to preceding potato								
Straw removal + 100 % NPK+ FYM @ 50 t ha^{-1}	23.4	23.3	119.3	123.0	224.3	228.1	234.3	239.8
Straw removal + 150 % NPK	22.6	23.0	113.1	115.2	215.5	219.7	227.5	231.0
Straw incorporation + 100 % NPK+ FYM @ 50 t ha^{-1}	23.8	24.1	122.6	125.7	228.8	232.1	240.7	242.1
Straw incorporation + 150 % NPK	23.1	23.3	117.9	119.9	221.9	224.6	234.0	237.8
CD (p=0.05)	NS	NS	5.8	6.4	7.8	7.6	7.1	6.8
Nutrient levels in spring maize								
75 % NPK with single row on bed	22.8	23.3	116.2	119.1	219.3	224.5	230.6	236.9
75 % NPK with double row on bed	20.5	22.6	102.8	111.0	206.1	217.0	218.0	225.2
100% NPK with single row on bed	23.1	23.6	126.8	125.6	229.2	230.7	241.1	241.8
100 % NPK with double row on bed	22.7	23.0	109.8	116.9	218.8	221.8	229.9	234.6
125 % NPK with single row on bed	26.0	24.8	132.0	129.5	235.6	236.6	246.8	247.7
125 % NPK with double row on bed	24.2	23.7	121.8	123.7	227.1	226.0	238.2	239.7
CD (p=0.05)	2.3	1.3	6.5	5.2	8.7	7.4	8.8	10.6
Interaction	NS	NS	NS	NS	NS	NS	NS	NS

The scrutiny of data revealed that plant height of spring maize was significantly affected by rice residue and nutrition applied to preceding potato and nutrition applied to spring maize during both the years. Plant height was increased successively with passage of time and the increase was maximum between 60-90 days after sowing. At 30 DAS plant height did not differ significantly under rice residue incorporation and nutrition application to preceding potato during both the years. At 60, 90 DAS and at maturity maximum plant height of spring maize (122.6,125.7 cm, 228.8, 232.1 cm and 240.7, 242.1 cm) was observed under treatment rice straw incorporation plots + application of 100% NPK + FYM @ 50 t ha^{-1} to the preceding crop, which was recorded to be at par with treatment involving rice residue removal + 100% NPK + FYM @ 50 t ha^{-1} and residue incorporation + 150% NPK application to potato crop, but was significantly better than residue removal + 150% NPK application during 2019 and 2020, respectively. The minimum plant height was noticed under residue removal + 150% NPK application at all growth stages, however this treatment was statistically at par with application of 150% NPK along with straw incorporation during both the years. The higher plant height under residue incorporated plots along with integrated application of organic and inorganic nutrient sources might be due to better root development which helped in better soil and nutrient extraction and maintained plant vigour due to better N availability for their growth. Singh (2011) and Verma and Pandey (2013) also reported taller plant height in residue retained plots as compared to residue removed plots. Integrated application of organic manure and synthetic fertilizers provides better environment for plant growth also improves the available nutrient status of the soil that ultimately leads to higher crop growth and yield. Joshi *et al* (2013), Mahato *et al* (2020) and Sigaye *et al* (2021) also reported similar findings.

A perusal of the data given in table 4.12 showed that different nutrition applied in spring maize significantly affected the plant height at 60, 90 DAS and at maturity during both the years. The results on plant height under different nutrition levels were observed to be non-significant at 30 DAS during both the years. At 60, 90 DAS and at maturity, application of 125% NPK to single row bed planted spring maize resulted in significantly higher plant height (132.0, 129.5 cm, 235.6, 236.6 cm and 246.8, 247.7 cm) during 2019 and 2020, respectively. However it was statistically at par with 100% NPK applied to single row bed planted spring maize at 60 DAS during both the years and 125% NPK applied to double row bed planted spring maize at 90 DAS during 2019 and at maturity during both the years. Lowest plant height was recorded with application of 75% NPK to double row bed planted spring maize at all growth stages during both the years. The improvement in plant height with increase in nitrogen might be attributed to the fact that nitrogen is an integral part of proteins, the building blocks of plant and it also helps in maintaining higher auxin level which might have resulted in better plant height (Singh *et al* 2000).

Fig. 4.9: Effect of rice residue and nutrient application to preceding potato and nutrient levels to spring maize on plant height in spring maize

Similar results were also reported by Kumar (2009) and Kaur and Kumar (2018). With increase in plant stand of spring maize i.e. double row bed planted maize the plant height decreased as compared to single row bed planted maize might be due to sparsely populated plants receiving sufficient amount of light and nutrients as compared to dense populated plants. Pandey *et al* (2000) also observed that plant height of maize increased greatly when the seeds were planted sparsely and sufficient amount of N was applied.

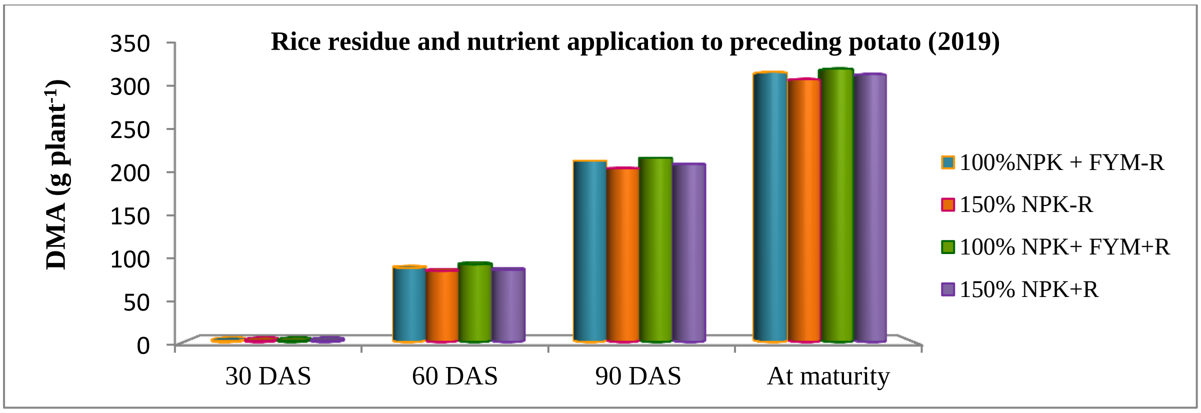
4.1.3.1.2 Dry matter accumulation

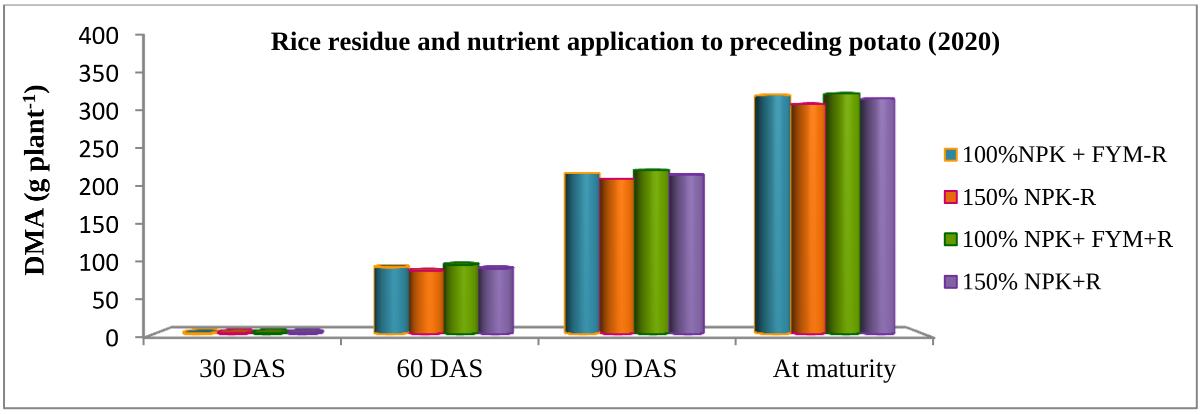
Dry matter accumulation (DMA) is an important feature showing the growth and metabolic efficiency of plants which ultimately affect the yield of the crop. DMA signify the amount of photosynthates produced and allocated in the crop plant. Optimum accumulation of dry matter followed by adequate partitioning of assimilates to the sink leads to higher grain yield. DMA is important determinants of grain yield in cereals, the higher the biomass the greater the amount of photosynthates that can be translocated to the grain during its filling. DMA was progressively increased with advancement of crop age and its maximum values were recorded at maturity of the crop. The data on periodic DMA are presented in table 4.13 and fig. 4.10. The perusal of data showed that rice residue and nutrient application to preceding potato significantly affected the dry matter accumulation of spring maize at 60, 90 DAS and at maturity during both the years however, the differences were not significant at 30 DAS. Residue incorporation + 100% NPK + FYM @ 50 t ha^{-1} maintained its superiority on DMA to the other treatments at 60, 90 DAS and at maturity by recording significantly higher DMA (91.9, 93.9 g, 218.1, 222.4 g and 323.7, 326.1g) over residue removal + 150% NPK respectively, during both the years. Whereas, this treatment was recorded to be statistically at par with residue removal + 100% NPK + FYM @ 50 t ha^{-1} at 60, 90 DAS and at maturity and with residue incorporation + 150% NPK at 90 DAS and at maturity. Minimum DMA was resulted from treatment involving residue removal + 150% NPK and it was statistically at par with residue incorporation + 150% NPK at 60, 90 DAS and at maturity during both the years. Higher dry matter accumulation with rice residue incorporation may be due to increased availability of nutrients and water to plants resulted from better root penetration for better growth, more plant height and improved photosynthetic rate. Plant height and dry matter production increased significantly with incorporation of straw over its removal (Jahan *et al* 2014). Li *et al* (2013) reported significantly higher leaf area, leaf area index and dry matter accumulation with application of straw mulch as compared to residue removal treatments in maize. Besides this increased nutrient availability, improved soil physical conditions due to combined use of organic and inorganic nutrients have probably improved the growth of the plant and dry matter production. Habib *et al* (2012), Kaur and Kumar (2018) and Mahato *et al* (2020) also recorded higher dry matter accumulation under combined use of organic manures and synthetic fertilizers as compared to use of synthetic fertilizers alone.

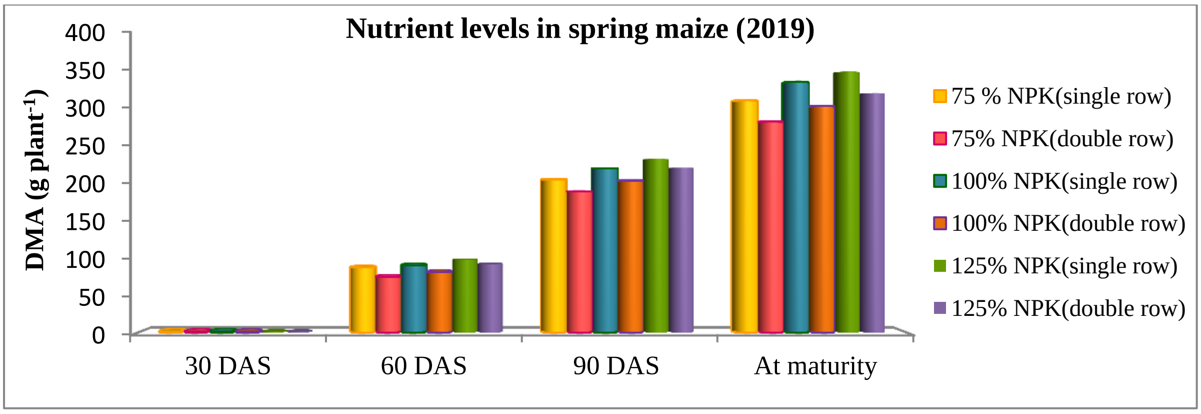
Table 4.13: Effect of rice residue and nutrient application to preceding potato and nutrient levels to spring maize on dry matter accumulation (g plant^{-1}) in spring maize

Treatment	30 DAS		60 DAS		90 DAS		At maturity	
	2019	**2020**	**2019**	**2020**	**2019**	**2020**	**2019**	**2020**
Rice residue and nutrient application to preceding potato								
Straw removal + 100 % NPK+ FYM @ 50 t ha^{-1}	1.09	1.07	88.0	90.5	214.7	218.1	319.6	324.1
Straw removal + 150 % NPK	1.11	1.09	84.0	85.6	206.0	210.4	311.3	311.9
Straw incorporation + 100 % NPK+ FYM @ 50 t ha^{-1}	1.10	1.11	91.9	93.9	218.1	222.4	323.7	326.1
Straw incorporation + 150 % NPK	1.08	1.06	85.3	88.7	210.8	216.2	317.2	319.2
CD (p=0.05)	NS	NS	5.4	5.1	7.8	7.7	8.0	8.4
Nutrient levels in spring maize								
75 % NPK with single row on bed	1.08	1.11	87.6	88.3	205.8	212.3	311.7	311.7
75 % NPK with double row on bed	0.99	1.05	74.8	79.0	189.6	197.2	283.3	291.1
100% NPK with single row on bed	1.22	1.09	90.4	93.1	220.6	221.9	336.6	334.1
100 % NPK with double row on bed	0.99	1.00	81.2	85.0	204.2	210.9	304.2	310.6
125 % NPK with single row on bed	1.18	1.14	97.7	99.0	233.0	234.7	350.3	352.7
125 % NPK with double row on bed	1.10	1.11	92.1	93.7	221.3	223.5	321.5	321.7
CD (p=0.05)	NS	NS	3.8	4.5	6.4	6.8	7.9	8.7
Interaction	NS	NS	NS	NS	NS	NS	NS	NS

Among nutrient application in spring maize, there is no significant difference in DMA at 30 DAS during both the years. At 60, 90 DAS and at maturity, single row bed planted spring maize applied with 125% NPK recorded significantly higher DMA (97.4, 99.0 g, 233.0, 234.7 g and 350.3, 352.7 g) than all other treatments during 2019 and 2020, respectively. It was followed by treatment consisting of 125% NPK application to double row bed planted spring maize which was statistically at par with 100% NPK with single row on bed at all the growth stages. Lowest DMA was recorded under 75% NPK application to double row on bed at all growth stages during both the years. Higher amount of dry matter accumulated with increase in N levels was due to cumulative effect of higher plant height, number of leaves per plant and leaf area index as compared to the lower levels of nitrogen. Higher leaves and LAI paved the way for more production of photosynthetic dry matter. Similar results have also been reported by Sarwargaonkar *et al* (2008) and Gul *et al* (2015).







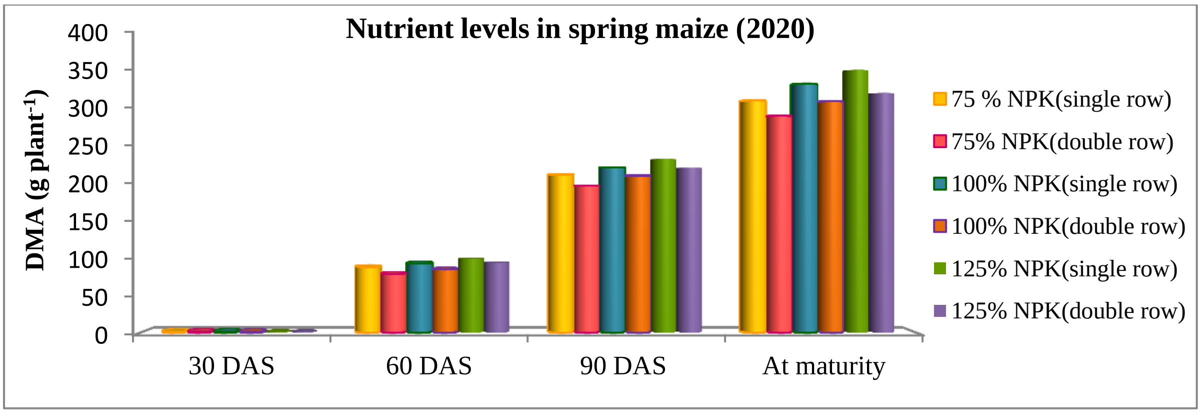


Fig. 4.10: Effect of rice residue and nutrient application to preceding potato and nutrient levels to spring maize on dry matter accumulation in spring maize

Higher DMA per plant was recorded under lower population density with higher nitrogen dose which might be due to sufficient nutrient availability to plants for better photosynthesis as compared to higher population density. The results were corroborated with findings of Pandey *et al* (2000) and Tajul *et al* (2013) who also reported that sparsely populated plants accumulates more dry matter as compared to densely populated plants.

4.1.3.1.3 Leaf area index

Leaf area index is an important index to judge the production potential and has marked influence on plant growth and yield of crop. It is the indicator of source size and dictates the efficiency of photosynthetic surface. It signifies the plant cover to ground area ratio. More profuse canopy and taller plants results in higher LAI. The data pertaining to LAI at 30, 60, 90 DAS and at maturity are presented in table 4.14 and fig. 4.11. LAI increased successively with advancement in age of crop and its maximum value was attained at 90 DAS and thereafter LAI decreased due to senescence of leaves. LAI was not significantly influenced by various treatments at 30 DAS during both the years. At 60, 90 DAS and at maturity, LAI was significantly higher (3.10 and 3.16, 3.83 and 3.87 and 2.30 and 2.67) in treatment involving residue incorporation + 100% NPK + FYM @ 50 t ha^{-1} as compared to other treatments but it was statistically at par with treatment consisting of residue removal +100% NPK + FYM @ 50 t ha^{-1} during both the years. The higher LAI in straw incorporated and combined application of organic and inorganic fertilizers treatments might be due to better physical condition of soil leading to more nutrient availability for a longer period of time that resulted in taller plants which increased the leaf load, better accumulation of photosynthates and ultimately higher LAI. Bahadur *et al* (2013), Snehaa *et al* (2019) and Mahato *et al* (2020) also reported better growth with application of FYM along with chemical fertilizers. Minimum LAI was recorded when residue was removed and crop was applied with 150% NPK, however, it was at par with residue removal + 100% NPK + FYM @ 50 t ha^{-1} at 60 DAS and with residue incorporation + 150% NPK at all growth stages during both the years.

Among nutrients applied to spring maize with varied population density, LAI differ significantly at all growth stages except at 30 DAS during both the years. Maximum values for LAI (3.45 and 3.50, 4.24 and 4.40 and 2.74 and 2.92) were recorded with application of 125% NPK to double row bed planted spring maize at 60, 90 DAS and at maturity during both the years as compared to all other treatment combinations. However, the analysis also depicted that it was statistically at par with 100% NPK applied to double row bed planted spring maize at 60 and 90 DAS during both years. Minimum LAI was recorded under 75% NPK application to double row bed planted spring maize. The increase in LAI with increasing nitrogen levels and plant density was due to more number of leaves per plant, lesser senescence and longer leaf retention period. Shivay and Singh (2000) and Gul *et al* (2015) found improvement in LAI with increasing dose of nitrogen. Plot with thicker plant density and higher nitrogen dose gave higher LAI as compared to lower plant density. Amanullah *et al* (2007) also reported higher LAI with increase in plant density and nitrogen rates.

Table 4.14: Effect of rice residue and nutrient application to preceding potato and nutrient levels to spring maize on leaf area index in spring maize

Treatment	30 DAS		60 DAS		90 DAS		At maturity	
	2019	**2020**	**2019**	**2020**	**2019**	**2020**	**2019**	**2020**
Rice residue and nutrient application to preceding potato								
Straw removal + 100 % NPK+ FYM @ 50 t ha^{-1}	0.17	0.20	2.97	2.99	3.71	3.77	2.26	2.47
Straw removal + 150 % NPK	0.16	0.19	2.75	2.82	3.46	3.49	1.92	2.17
Straw incorporation + 100 % NPK+ FYM @ 50 t ha^{-1}	0.20	0.20	3.10	3.16	3.83	3.87	2.30	2.67
Straw incorporation + 150 % NPK	0.19	0.20	2.83	2.90	3.55	3.63	2.00	2.26
CD (p=0.05)	NS	NS	0.24	0.17	0.17	0.16	0.10	0.20
Nutrient levels in spring maize								
75 % NPK with single row on bed	0.17	0.20	2.31	2.46	2.88	2.90	1.60	1.91
75 % NPK with double row on bed	0.18	0.19	3.10	3.15	3.94	3.97	2.22	2.55
100% NPK with single row on bed	0.18	0.20	2.54	2.55	3.15	3.15	1.75	2.11
100 % NPK with double row on bed	0.17	0.20	3.33	3.36	4.21	4.25	2.55	2.70
125 % NPK with single row on bed	0.18	0.17	2.74	2.79	3.39	3.47	1.82	2.17
125 % NPK with double row on bed	0.19	0.21	3.45	3.50	4.24	4.40	2.74	2.92
CD (p=0.05)	NS	NS	0.19	0.17	0.18	0.20	0.17	0.17
Interaction	NS	NS	NS	NS	NS	NS	NS	NS

4.1.3.1.4 Chlorophyll index of spring maize

The chlorophyll index indicates the chlorophyll content in the plant leaves. A higher chlorophyll index indicates more greenness of the plant. More greenness of leaves will harvest more solar radiation leads to higher photosynthesis and photosynthates production and its translocation to sink. Data on the periodic chlorophyll index of spring maize were recorded and presented in table 4.15. Chlorophyll index of spring maize was significantly affected by rice residue and nutrient applied to preceding potato at all growth stages except at 30 DAS during both the years.

Maximum values of chlorophyll index (25.2 and 24.7, 34.6 and 33.7 and 19.0 and 18.9) at 60, 90 DAS and at maturity, respectively during 2019 and 2020, were recorded under straw incorporated plots along with 100% NPK + FYM @ 50 t ha^{-1} application to the preceding crop which remained statistically at par with residue removal + 100% NPK + FYM @ 50 t ha^{-1} at 60 DAS and at maturity. Chlorophyll index with application of 100% NPK + FYM @ 50 t ha^{-1} to the preceding crop without residue remained statistically at par with 150% NPK along with straw incorporation at 60, 90 DAS and at maturity. Lowest values of chlorophyll index were observed under residue removal plots along with 150% NPK application to the preceding crop at all growth stages. With combined application of organic manure and inorganic fertilizers there was better availability of nitrogen in the soil and more uptake by the plants that resulted in higher greenness of leaves and ultimately higher chlorophyll index value. Snehaa *et al* (2019) and Prabhavathi *et al* (2021) observed higher SPAD values in maize crop with application of nutrients from both organic and inorganic sources.

Table 4.15: Effect of rice residue and nutrient application to preceding potato and nutrient levels to spring maize on chlorophyll index in spring maize

Treatment	**30 DAS**		**60 DAS**		**90 DAS**		**At maturity**	
	2019	**2020**	**2019**	**2020**	**2019**	**2020**	**2019**	**2020**
Rice residue and nutrient application to preceding potato								
Straw removal + 100 % NPK+ FYM @ 50 t ha^{-1}	17.8	18.2	23.9	23.1	33.3	32.1	18.1	18.1
Straw removal + 150 % NPK	16.9	18.2	22.2	21.9	30.7	29.5	16.7	17.1
Straw incorporation + 100 % NPK+ FYM @ 50 t ha^{-1}	17.8	18.9	25.2	24.7	34.6	33.7	19.0	18.7
Straw incorporation + 150 % NPK	16.5	18.2	23.2	22.3	32.0	30.8	18.1	17.1
CD (p=0.05)	NS	NS	1.1	1.6	1.8	1.8	1.4	1.1
Nutrient levels in spring maize								
75 % NPK with single row on bed	17.4	18.3	23.7	23.8	32.4	30.0	17.9	18.0
75 % NPK with double row on bed	15.4	17.3	21.3	18.1	26.4	25.0	15.8	16.1
100% NPK with single row on bed	18.3	18.4	24.4	25.0	35.6	33.4	19.1	18.4
100 % NPK with double row on bed	15.8	17.7	23.3	21.8	30.1	29.6	16.9	16.4
125 % NPK with single row on bed	18.7	19.7	25.6	26.7	37.2	38.0	21.0	19.6
125 % NPK with double row on bed	17.8	19.1	23.3	22.6	34.1	33.4	17.2	18.0
CD (p=0.05)	1.2	1.0	1.4	1.3	2.4	1.9	1.4	1.2
Interaction	NS	NS	NS	NS	NS	NS	NS	NS

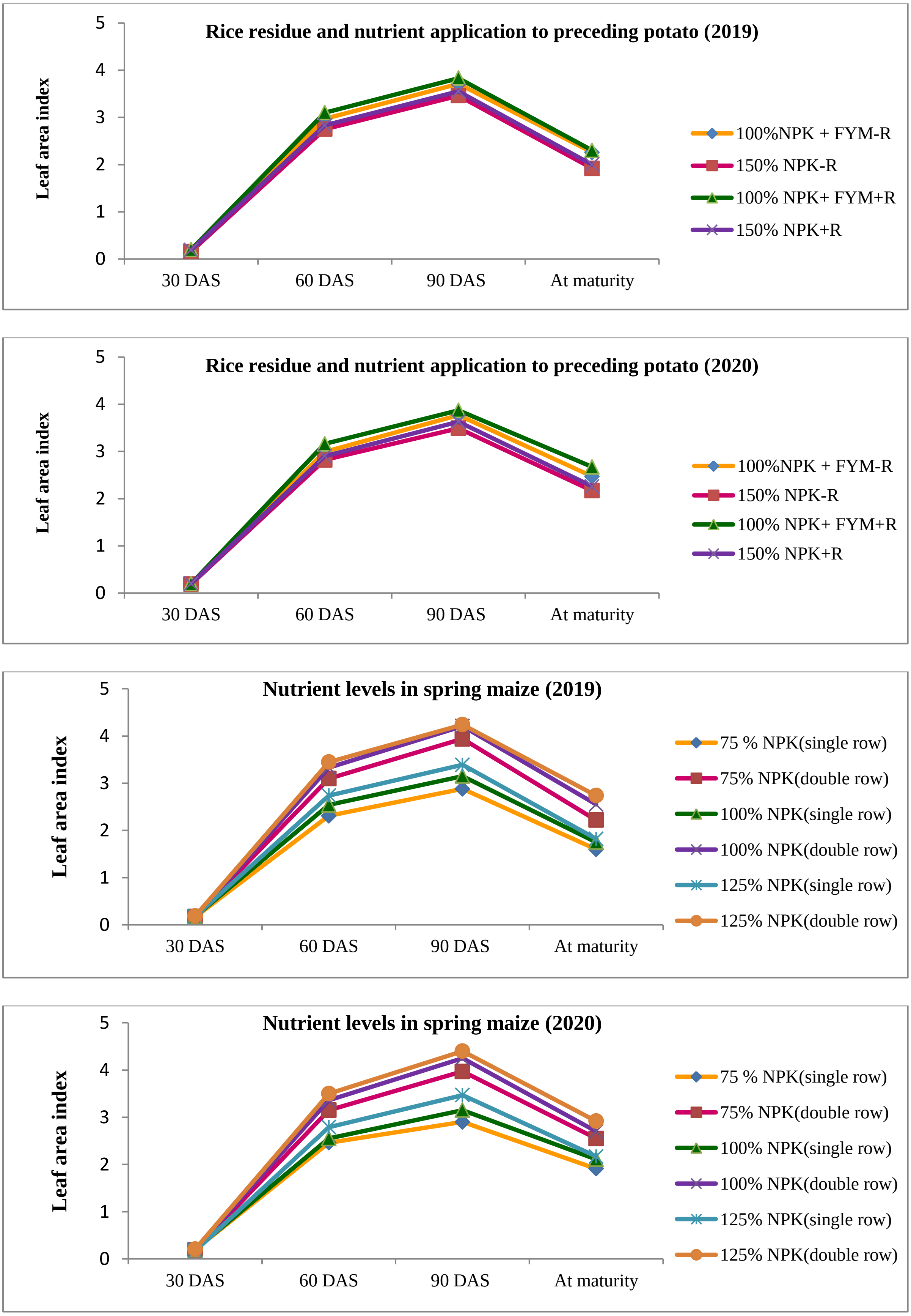


Fig. 4.11: **Effect of rice residue and nutrient application to preceding potato and nutrient levels to spring maize on leaf area index in spring maize**

Chlorophyll index values differed significantly with different levels of nutrients applied to spring maize at all the growth stages during both the years. Significantly higher chlorophyll index values were recorded (18.7 and 19.7, 25.6 and 26.7, 37.2 and 38.0 and 21.0 and 19.6) when 125% NPK was applied to single row bed planted spring maize at 30, 60, 90 DAS and at maturity during 2019 and 2020, respectively, whereas this treatment remained at par with 100% NPK applied to single row on bed at all the growth stages during 2019 and significantly better than all other treatments during both the years. Lowest values of chlorophyll index was observed when 75% NPK was applied to double row bed planted spring maize at all growth stages during 2019 and 2020. Basically different nitrogen levels applied to single row on bed resulted in higher chlorophyll index as compared to double row bed on bed. This might be due more competition among the plants in high population density for available nutrients resulted in lower chlorophyll index of spring maize. With increased in nitrogen dose chlorophyll index values were also increased. Singh (2010) reported that increase in nitrogen dose from 100 to 150 kg ha^{-1} was effective to bring significant increase in SPAD values in maize.

4.1.3.2 Microclimatic observations

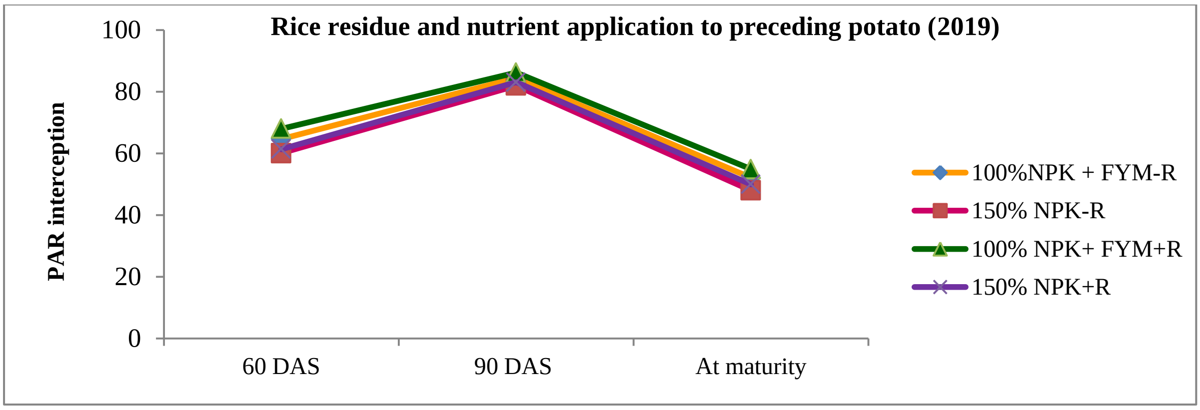
4.1.3.2.1 Photosynthetically active radiation (PAR) interception

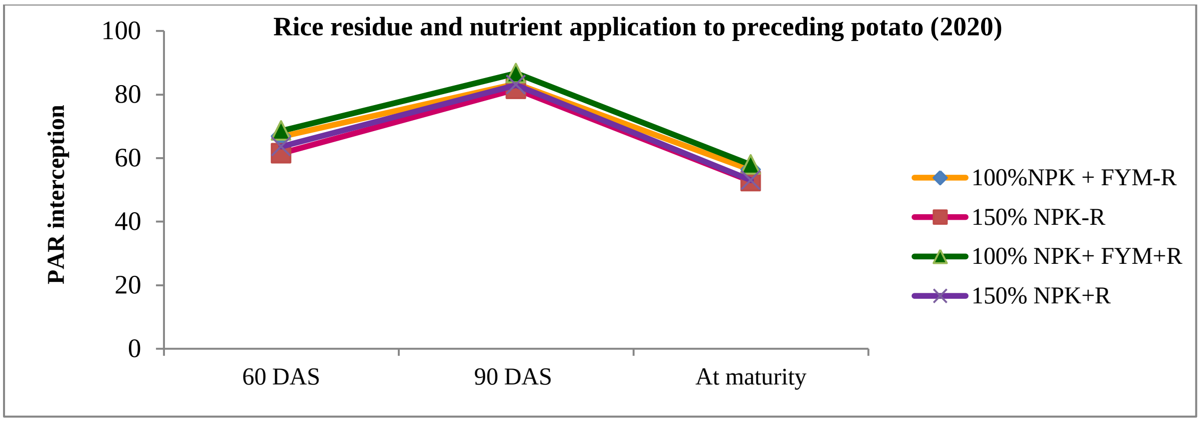
Distribution and interception of photosynthetic active radiation (PAR) within crop canopy are important factors which determine the photosynthetic capacity of the crop. Photosynthetic efficiency affects the dry matter production and accumulation of the crop, also affects yield of the crop. The PAR value increased with advancement of crop age up to 90 DAS and afterwards it decreased due to senescence of leaves. Data pertaining to PAR interception in spring maize was recorded and presented in table 4.16 and fig. 4.12. Rice residue and nutrient application to preceding potato had significant effect on PAR interception at 60, 90 DAS and at maturity during both the year of study. Application of 100% NPK + FYM @ 50 t ha^{-1} to the preceding crop along with residue incorporation resulted with significantly higher PAR values at all growth stages during 2019 and 2020 as compared to other treatments, but it was statistically at par with treatment consisting of residue removal + 100% NPK + FYM @ 50 t ha^{-1}. Application of 150% NPK without residue recorded lowest PAR values at all the growth stages. The per cent increase in PAR interception in residue incorporation + 100% NPK + FYM @ 50 t ha^{-1} was 13.1 and 11.5%, 5.12 and 6.11% and 14.3 and 9.86% as compared to 150% NPK application without residue at 60, 90 DAS and at maturity during 2019 and 2020, respectively. It may be due to the fact that integration of organic and inorganic fertilizer provided better microclimatic environment for plant growth and also corrected the deficiency of both macro and micronutrients to attain more growth. Habib *et al* (2012) and Joshi *et al* (2013) also reported higher growth with combined application of organic and chemical fertilizers as compared to sole application chemical fertilizers.

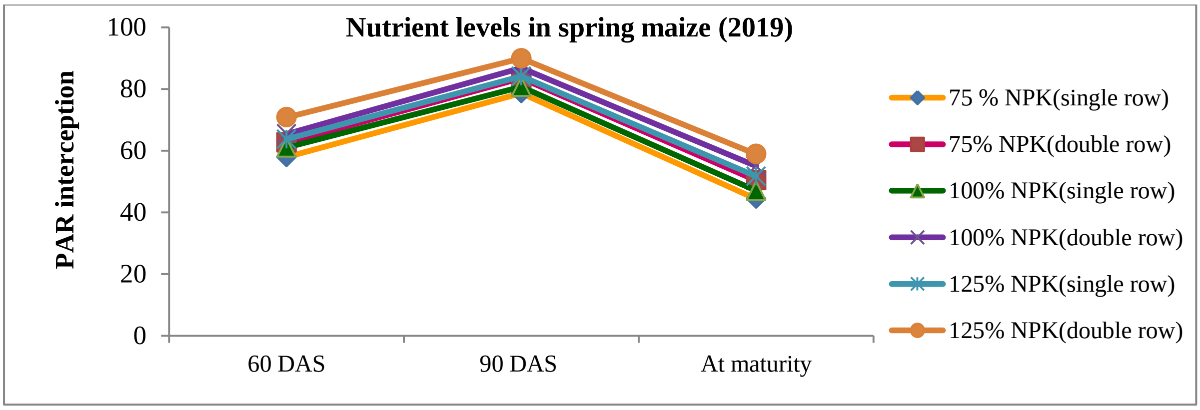
Table 4.16: Effect of rice residue and nutrient application to preceding potato and nutrient levels to spring maize on PAR interception (%) in spring maize

Treatment	60 DAS		90 DAS		At maturity	
	2019	**2020**	**2019**	**2020**	**2019**	**2020**
Rice residue and nutrient application to preceding potato						
Straw removal + 100 % NPK+ FYM @ 50 t ha^{-1}	64.7	66.8	84.5	83.4	52.1	56.3
Straw removal + 150 % NPK	60.1	61.5	82.0	81.7	48.0	52.7
Straw incorporation + 100 % NPK+ FYM @ 50 t ha^{-1}	68.0	68.6	86.2	86.7	54.9	57.9
Straw incorporation + 150 % NPK	61.4	63.6	83.1	83.0	50.0	53.0
CD (p=0.05)	3.6	3.4	2.8	3.0	2.9	3.9
Nutrient levels in spring maize						
75 % NPK with single row on bed	57.9	59.2	78.6	76.1	44.4	48.0
75 % NPK with double row on bed	62.6	63.7	83.5	83.6	50.4	52.9
100% NPK with single row on bed	61.0	61.6	80.7	82.0	47.0	50.7
100 % NPK with double row on bed	65.4	69.1	86.8	86.1	55.0	58.6
125 % NPK with single row on bed	63.7	65.0	84.1	83.9	51.7	56.8
125 % NPK with double row on bed	70.8	72.2	89.9	90.4	58.9	62.7
CD (p=0.05)	4.1	3.1	4.6	4.7	3.4	4.8
Interaction	NS	NS	NS	NS	NS	NS

PAR interception increased with increase in nitrogen level and plant density (Table 4.16). Among the nutrients applied to spring maize, PAR interception was recorded to be significantly higher (70.8 and 72.2%, 89.9 and 90.4% and 58.9 and 62.7%) in treatment consisted of 125% NPK applied to double row bed planted spring maize as compared to other treatments at all growth stages during 2019 and 2020, respectively. It remained at par with 100% NPK application to double row on bed at 90 DAS during both years. Least values for PAR interception were recorded when crop was applied with 75% NPK to single row on bed during both the years of study.







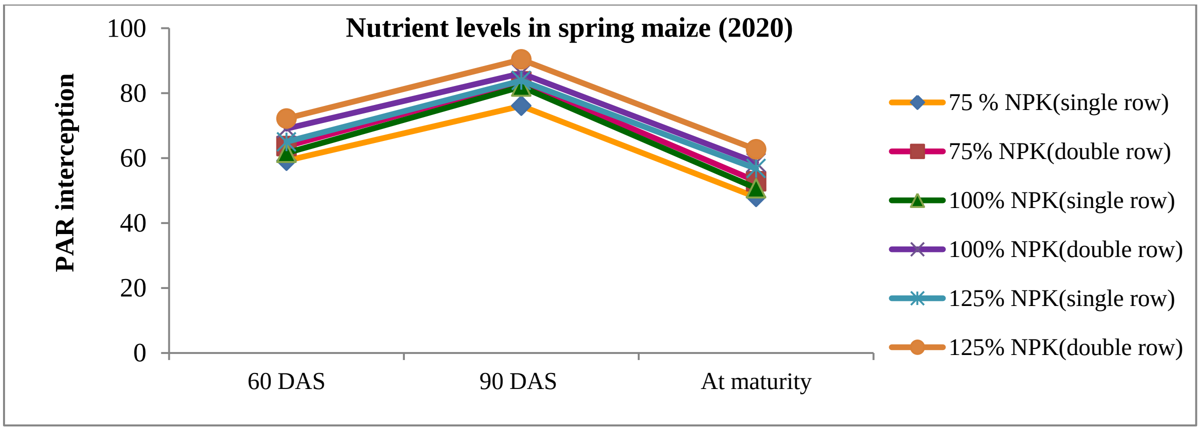


Fig. 4.12: Effect of rice residue and nutrient application to preceding potato and nutrient levels to spring maize on PAR interception in spring maize

The per cent increase in PAR interception under 125% NPK application to double row on bed was 16.0 and 17.2%, 11.4 and 10.2% and 20.3 and 23.7% as compared to 100% NPK application to single row on bed at 60, 90 DAS and at maturity during 2019 and 2020. Among single row on bed, 125% NPK application resulted in higher PAR interception as compared to 100% and 75% NPK at all growth stages. Increasing dose of nitrogen and plant population increase the PAR interception due to better growth and development of crop resulted from better nutrient availability. Singh (2010) also observed significant increase in PAR interception with increase in N dose from 100 to 150 kg ha^{-1} due to more number of leaves and higher LAI.

4.1.3.3 Crop phenology

4.1.3.3.1 Days taken to 50% tasseling

Time taken by the crop to reach 50% tasseling was not significantly influenced by rice residue and nutrient application to preceding potato but it differed significantly with nutrient applied to spring maize during both the years. In general, tasseling was early with the increase in nitrogen-level (Table 4.17). Days taken by the crop to reach 50% tasseling was significantly higher (74 and 78 days) under 75% NPK applied to double row bed planted spring maize as compared to all other treatments but it was statistically at par with 100% (73 and 78 days) and 125% NPK (72 and 76 days) applied to double row bed planted spring maize during both the years of study. Tasseling was 2 days earlier under 125% NPK as compared to 75% NPK in double row on bed during both the years. In case of single row on bed, application of 75% NPK took more days (71 and 76 days) to reach 50% tasseling as compared to 100% NPK (71 and 76 days) and 125% NPK (70 and 75 days) during both years. Tasseling was advanced by 1 day under 125% NPK over 75% NPK applied to single row on bed. The tasseling period of maize decreased with increased N doses. With increase in N dose the availability of nutrient in soil increased. This condition reduce intra specific competition pressure within the plant stand which may leads to uniform flowering, whereas lower N rate promote the competition of individual plants with different abilities to capture scarce resources eventually increase their tasseling period. These results are consistent with finding of Dawadi and Sah (2012) and Jassal *et al* (2017). Maize tasseling period increased with increase in plant density. This might be due to higher plant densities induce competition among crop plants for different resources such as light, nutrient, water and air. Competition for limiting resources might have slowed down the pace of phonological development which ultimately delayed the tasseling. Shrestha (2013) and Golla *et al* (2020) also reported that days taken to 50% tasseling were increased with increase in plant density.

4.1.3.3.2 Days taken to 50% silking

Number of days taken by the crop to reach 50% silking was not significantly affected by rice residue and nutrient application to the preceding crop but it was significantly influenced by nutrients applied to spring maize during both the years. Data with respect to phenology of spring maize are given in table 4.17. Generally increased fertilizer levels reduced the silking period of maize. Days taken to attain 50% silking was recorded to be higher (77 and 82 days) with application of 75% NPK to double row on bed, which was statistically at par to 100% NPK in both years and 125% NPK in 2019. As compared to single row on bed, double row on bed took more days to reach 50% silking. Application of 125% NPK to double row on bed advanced the silking by 1 and 2 days than under 75% NPK in 2019 and 2020, respectively. For single row on bed, application of 75% NPK took more days (74 and 79 days) to reach 50% silking and was at par with 100% NPK and 125% NPK during both the years. Silking was 1 day earlier under 125% NPK applied to single row on bed in 2019 and 2020 as compared to75% NPK. Reduction in number of days taken for anthesis with increasing levels of fertilizer may be attributed to higher growth attributes like LAI and DMA resulted in quick growth in plants which enhanced the tasseling stage. With increase in N dose the availability of nutrients to the plants increased which fasten the days to reach silking stage. Shrestha *et al* (2018) concluded that application of 200 kg N ha^{-1} takes 47 days to attain tasseling stage whereas application of 0 kg N ha^{-1} took 52 days to attain tasselling stage. Higher plant population takes more days to reach 50% silking than lower population density which might be due to more competition for available resources which slowed down the phenological development. Imran *et al* (2015) and Sharifi and Namvar (2016) also concluded that days taken to 50% silking was more under higher plant density as compared to lower plant density.

4.1.3.3.3 Days taken to 50% dough stage

Time taken by the crop to reach 50% dough stage was not significantly affected by rice residue and nutrient application to preceding potato but it was significantly affected with nutrients applied to spring maize during both the year. The analysis of data presented in table 4.17 revealed that increasing rates of fertilizer application significantly increased the number days taken to reach 50% dough stage. On the other hand, increased plant density significantly taken less days to reach 50% dough stage. Days taken by the crop to reach dough stage was significantly higher under 125% NPK (97 and 102 days) applied to single row on bed as compared to all other treatments but it was statistically at par with 100% NPK (97 and 102 days) during both years and 75% NPK during 2019. Application of 75% NPK took 1 and 2 days less to reach 50% dough stage as compared to 125% during 2019 and 2020, respectively. Application of 125% NPK in double row on bed took more days (95 and 100 days) to reach 50% dough stage, which was followed by 100% NPK (94 and 99 days) and 75% NPK (94 and 98 days) during both years. Application of 75% NPK took 1 and 2 days earlier to reach 50% dough stage over 125% NPK applied to double row on bed during 2019 and 2020, respectively. The increasing rates of fertilizer application significantly increased the number of days taken to reach 50% dough stage. This might be due to application of higher fertilizer dose that kept the foliage green for longer period of time, which resulted in longer maturity period. Increased plant density decreased the days taken to reach 50% dough stage which might be due to higher competition for limited resources that reduced the rate of phenological developments. These results are confirmed by the findings of Golla *et al* (2020).

4.1.3.3.4 Days taken to physiological maturity

The number of days taken by the crop to reach physiological maturity was not significantly influenced by rice residue and nutrient applied to the preceding crop but it was significantly affected by the nutrients applied to spring maize during both the years. The data given in table 4.17 showed that increasing rates of fertilizer application significantly increased the number of days taken to reach physiological maturity. Contrarily, increased plant density significantly takes fewer days to reach physiological maturity.

Table 4.17: Effect of rice residue and nutrient application to preceding potato and nutrient levels in spring maize on phenological stages in spring maize

Treatment	Days taken to 50% tasselling		Days taken to 50% silking		Days taken to 50% dough		Days taken to Physiological maturity	
	2019	2020	2019	2020	2019	2020	2019	2020
Rice residue and nutrient application to preceding potato								
Straw removal + 100 % NPK+ FYM @ 50 t ha^{-1}	70	76	74	79	96	102	111	115
Straw removal + 150 % NPK	74	78	77	82	93	99	108	113
Straw incorporation + 100 % NPK+ FYM @ 50 t ha^{-1}	70	76	73	78	98	102	113	115
Straw incorporation + 150 % NPK	73	77	76	81	95	99	110	114
CD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Nutrient levels in spring maize								
75 % NPK with single row on bed	71	76	74	79	96	100	111	114
75 % NPK with double row on bed	74	78	77	82	94	98	108	112
100% NPK with single row on bed	71	76	74	79	97	102	112	116
100 % NPK with double row on bed	73	78	77	82	94	99	109	114
125 % NPK with single row on bed	70	75	74	79	97	102	113	116
125 % NPK with double row on bed	72	76	76	80	95	100	110	114
CD (p=0.05)	2.3	2.0	2.1	1.9	2.1	2.0	2.3	1.9
Interaction	NS	NS	NS	NS	NS	NS	NS	NS

The maize crop took longer time to reach physiological maturity stage (113 and 116 days) when 125% NPK was applied to single row on bed as compared to all other treatments, but it was statistically at par to 100% NPK (112 and 116 days) in both years and 75% NPK in 2019. Application of 75% NPK advanced the physiological maturity by 2 days as compared to 125% NPK during 2019 and 2020. In case of double row on bed application of 125% NPK took more days (110 and 114 days) to reach physiological maturity, which was followed by 100% NPK (109 and 114 days) and 75% NPK (108 and 112 days) during both years. Application of 125% NPK delayed the physiological maturity by 2 days as compared to 75% NPK applied to double row on bed. The physiological maturity of maize was delayed with increased doses of fertilizers. Higher fertilizer dose delayed the senescence of leaves and plants remained greener which increased the days required to attain physiological maturity. Similar results have been recorded by Dawadi and Sah (2012) and Sharifi and Namvar (2016). Shrestha *et al* (2018) reported that the shortest period (130.4 days) to physiological maturity was observed under 0 kg N ha^{-1} and the longest period (133.7 days) to attain physiological maturity was observed under 200 kg N ha^{-1}. Increase in plant density decreased the days taken to reach physiological maturity. This may be due to competition among crop plants for different resources (light, moisture and nutrient) that reduced the phenological development that ultimately reduced maturity period. The results corroborated with the findings of Shrestha (2013) and Imran *et al* (2015).

4.1.3.4 Yield and yield attributes

4.1.3.4.1 Number of cobs per plant

The cob bearing capacity of maize plant is one of the most important yield attributing characters which affect yield. Basically it is the genetic character of the cultivar but some agronomic manipulations were expected to bring some improvement in its bearing ability. The data regarding the number of cobs per plant are presented in table 4.18. The analysis of data revealed that rice residue and nutrient application to preceding potato had no significant effect on number of cobs per plant.

Nutrient levels applied to spring maize had significant influence on number of cobs per plant. It was observed that with increase in nitrogen levels, the number of cobs per plant was increased and with increase in plant population number of cobs per plant were decreased. The maximum number of cobs per plant (1.17 and 1.17) were recorded with 125% NPK application to single row on bed, which was statistically at par with 100% NPK applied to single row on bed (1.13 and 1.11) but significantly better than all other treatments during 2019 and 2020. Lowest number of cobs per plant (0.97 and 0.97) was recorded from application of 75% NPK to double row on bed. Application of 125% NPK produced 11.4 and 12.5% higher number of cobs per plant over 75% NPK during 2019 and 2020, respectively in case of single row on bed. Whereas, under application of 125% NPK to double row on bed, the per cent increase was 10.3, 9.3% and 9.2, 7.1% over 75% NPK and 100% NPK during 2019 and 2020, respectively. The bearing ability i.e. number of cobs per plant constantly improved with increase in nitrogen levels and bearing ability decreased with increase in plant population. But increased dose of nitrogen with higher plant density out yielded lower plant density. Arif *et al* (2010) concluded that with increased nitrogen level, higher plant density resulted in higher number of cobs per plant. Raj *et al* (2021) concluded in their finding that higher nitrogen dose of 160 kg ha^{-1} enhanced number of cobs per plant as compared to lower fertilizer dose. All the interaction effects were non-significant.

4.1.3.4.2 Cob length

The data with respect to cob length are presented in table 4.18. Cob length is increased significantly with combined application of organic and inorganic fertilizer to the preceding crop along with residue incorporation as compared to sole application of synthetic fertilizer without residue incorporation. Maximum cob length (16.5 and 16.3 cm) was observed under 100% NPK + FYM @ 50 t ha^{-1} along with residue incorporation, followed by treatment consisting of residue removal + 100% NPK + FYM @ 50 t ha^{-1} and residue incorporation + 150% NPK. Minimum cob length (15.6 and 15.6 cm) was recorded from treatment involving residue removal + 150% NPK to the preceding crop. The per cent increase in cob length was 5.76 and 4.48% under residue incorporation + 100% NPK + FYM @ 50 t ha^{-1} over residue removal + 150% NPK during 2019 and 2020, respectively. This may be due to the fact that incorporation of residue releases several organic acids due to their decomposition, which helps to improve the availability of nutrients and increase the productivity of crops in the succeeding season. More cob length obtained from crop residue incorporated plot was due to efficient utilization of nutrients, which increases the rate of conversion of dry matter into economic yield. Similar results were reported by Almaz *et al* (2017). Combined application of organic and inorganic fertilizer enhances the root penetration for better nutrient and water uptake which had a positive effect on yield attributes of the plant. Snehaa *et al* (2019) and Biswasi *et al* (2020) observed higher cob length of maize under integrated application of organic and inorganic fertilizers.

The average cob length increased with increase in nitrogen level but it decreased with increase in plant density. Cob length was significantly higher (17.7 and 17.8 cm) under 125% NPK applied to single row on bed, but was statistically at par (17.1 and 17.2 cm) with 100% NPK application to single row on bed during 2019 and 2020, respectively. However, the cob length was statistically comparable under 125% NPK applied to double row on bed and 75% NPK to single row on bed but both treatments were significantly superior to 75% NPK to double row on bed during both the years of study. The cobs were 7.27 and 10.6% longer under 125% NPK to single row on bed as compared to 75% NPK during 2019 and 2020, respectively. In case of double row on bed the increase in cob length under 125% NPK was

8.78 and 8.72% over 100% NPK and 15.0 and 15.7% over 75% NPK during 2019 and 2020, respectively. The probable reason for highest cob length under higher dose of fertilizers could be due to optimum utilization of solar radiation, higher assimilate production and their conversion to starches resulted in higher ear length. Imran *et al* (2015) also reported higher cob length with application of higher dose of nitrogen as compared to its lower dose.

4.1.3.4.3 Cob girth

Data presented in table 4.18 on cob girth showed that cob girth increased significantly with combined application of organic and inorganic fertilizers in residue incorporated plots as compared to sole application of inorganic fertilizer. Higher cob girth (14.1 and 14.6 cm) was recorded under 100% NPK + FYM @ 50 t ha^{-1} applied to preceding potato crop along with residue incorporation as compared to sole application of inorganic fertilizer i.e. residue removal + 150% NPK. Minimum cob girth (13.1 and 14.0 cm) was observed under treatment

Table 4.18: Effect of rice residue and nutrient application to preceding potato and nutrient levels to spring maize on yield attributing characters in spring maize

Treatment	**Number of Cobs per plant**		**Cob length (cm)**		**Cob girth (cm)**		**Number of rows per cob**	
	2019	**2020**	**2019**	**2020**	**2019**	**2020**	**2019**	**2020**
Rice residue and nutrient application to preceding potato								
Straw removal + 100 % NPK+ FYM @ 50 t ha^{-1}	1.07	1.08	16.1	16.2	13.8	14.4	14.2	14.5
Straw removal + 150 % NPK	1.04	1.01	15.6	15.6	13.1	14.0	13.6	14.2
Straw incorporation + 100 % NPK+ FYM @ 50 t ha^{-1}	1.09	1.08	16.5	16.3	14.1	14.6	14.4	14.8
Straw incorporation + 150 % NPK	1.05	1.06	15.9	16.0	13.3	14.2	13.8	14.3
CD (p=0.05)	NS	NS	0.6	0.5	0.5	0.4	0.4	0.4
Nutrient levels in spring maize								
75 % NPK with single row on bed	1.05	1.04	16.5	16.1	13.6	14.3	14.1	14.6
75 % NPK with double row on bed	0.97	0.97	14.0	14.0	12.6	13.5	12.9	13.4
100% NPK with single row on bed	1.13	1.11	17.1	17.2	14.1	14.8	14.6	14.7
100 % NPK with double row on bed	0.98	0.99	14.8	14.9	12.8	13.7	13.3	14.0
125 % NPK with single row on bed	1.17	1.17	17.7	17.8	14.5	15.3	15.0	15.2
125 % NPK with double row on bed	1.07	1.06	16.1	16.2	13.8	14.3	14.0	14.5
CD (p=0.05)	0.04	0.06	0.7	0.6	0.5	0.5	0.6	0.6
Interaction	NS	NS	NS	NS	NS	NS	NS	NS

consisting of residue removal + 150% NPK to the preceding crop. The increase in cob girth was 7.7 and 4.3% under residue incorporation + 100% NPK + FYM @ 50 t ha^{-1} over residue removal + 150% NPK during 2019 and 2020, respectively. Application of organic manures in combination with inorganic fertilizers not only enhanced the nutrient and water supply for completing its vegetative and reproductive phase, but also alters the soil physical and chemical properties which favour better crop growth and yield. Higher yield and yield attributes of maize might be due to better interception, absorption and utilization of radiation energy leading to higher photosynthetic rate and more accumulation of photosynthates at sink. Mahato *et al* (2020) and Biswas and Dutta (2020) also reported that combined application of organic and inorganic source of nutrients improved the length and girth of cob.

Cob girth varied significantly under different nutrient levels applied to spring maize during both the years. Maximum cob girth (14.5 and 15.3 cm) was recorded under 125% NPK applied to single row on bed, which was statistically at par with 100% NPK and significantly better that 75 % NPK applied to single row on bed during both the years. Similar trend was followed in double row on bed in response to different nitrogen levels. Lowest cob girth was recorded under 75% NPK application to double row on bed during both the years. The percentage in cob girth was 6.61 and 7.0% under 125% NPK to single row planted maize over 75% NPK to single row planted maize and increase was 9.52 and 5.92% under 125% NPK applied to double row planted maize as compared to 75% NPK to double row planted maize during 2019 and 2020, respectively. This was due to the fact that maize is an exhaustive crop, it responds to high levels of nutrient application for better growth and development. At higher nutrient levels there was adequate availability of nutrient in soil which allowing the plant to accumulate more biomass. Gul *et al* (2015) and Golla *et al* (2020) also recorded higher cob girth with application of higher dose of nitrogen as compared to lower dose.

4.1.3.4.4 Number of grain rows per cob

Number of rows per cob is a genetic character of the cultivar, but it is expected that agronomic manipulations can improve the rows number per cob. Data recorded and analyzed for number of grain rows per cob are presented in table 4.18. Number of rows per cob was significantly affected by rice residue and nutrients applied to preceding potato during both the years. Significantly higher rows number was recorded under residue incorporated plots along with 100% NPK + FYM @ 50 t ha^{-1} to the preceding crop which was statistically at par with treatment which involves residue removal + 100% NPK + FYM @ 50 t ha^{-1} and it was significantly better than residue removal + 150% NPK application. Number of rows per cob was higher to a margin of 5.9 and 4.2% under 100% NPK + FYM @ 50 t ha^{-1} along with residue incorporation over residue removal + 150% NPK application during 2019 and 2020, respectively. Ghosh *et al* (2018) reported higher number of grain rows per cob under combined application of organic and inorganic fertilizers.

Number of rows increased with increase in fertilizer dose in spring maize during both the years. Among nutrients applied to spring maize, higher number of rows per cob was observed under 125% NPK application to single row on bed which is statistically at par with 100% NPK applied to single row on bed and statistically better than 75% NPK applied to single row on bed. Under double row bed planted spring maize, 125% NPK application resulted in higher number of rows per cob as compared to 75% NPK and 100% NPK but it was at par with 100% NPK application to single row on bed. The increase in number of rows per cob under 125% NPK applied to single row planted maize was 6.4 and 4.2% higher than 75% NPK application during 2019 and 2020, respectively. While in case of double row planted spring maize the increase under 125% NPK was up to a margin of 8.5 and 8.2% over 75% NPK and 5.2 and 3.6% over 100% NPK during 2019 and 2020, respectively. Higher fertilizer dose improves the nutrient availability results in high leaf area index, provides more assimilates to improves number of grain rows per cob. The results get support from the findings by Majid *et al* (2017) and Adhikari *et al* (2021) who reported higher number of rows per cob with increasing nitrogen level from 160 to 220 kg ha^{-1}.

4.1.3.4.5 Number of grains per row

The number of grains per row plays an important role in determining the final grain yield. Data pertaining to number of grains per row are presented in table 4.19. From the thorough scrutiny of data, it was revealed that maximum number of grains per row (30.5 and 30.7) was recorded under residue incorporated plots along with 100% NPK + FYM @ 50 t ha^{-1} application to the preceding potato, which was statistically at par with treatment involving residue removal + 100% NPK + FYM @ 50 t ha^{-1} during both the years. Lowest number of grains per row was recorded (27.9 and 28.8) form residue removal + 150% NPK applied plots which were at par with 150% NPK along with residue incorporation. Integrated application of organic and synthetic fertilizers enhances the grain filling ability of cob by accumulating higher biomass at sink due to higher photosynthesis rate. Singh *et al* (2017) and Rathod *et al* (2018) reported higher number of grains per row under integrated application of organic and inorganic fertilizers as compared to sole application of inorganic fertilizer.

Maximum number of grains per row (32.5 and 33.8) was recorded from 125% NPK applied to single row on bed which was statistically at par with 100% NPK only during 2019 and significantly better over 75% NPK during both year and over 100% NPK during 2020. In case of double row planted spring maize, 125% NPK application resulted in higher number of grains per row (28.6 and 29.0), which was at par with 100% NPK and significantly higher than 75% NPK application during both the years. The margin of increase in grains per row in single row planted spring maize was 9.4 and 9.7% under 125% NPK over 75% NPK during 2019 and 2020, respectively. However, in case of double row planted spring maize the increase was 16.2 and 14.2% in 125% NPK as compared to 75% NPK during 2019 and 2020.

An increase in number of grains per row under higher fertilizer levels might be due to lower competition for nutrients that allowing the plant to accumulate more biomass with a higher capacity to convert more photosynthesis towards sink. Sharifi and Namvar (2016) and Shahid *et al* (2016) also reported higher number of grains per row with application of higher dose of nitrogen over its lower dose.

4.1.3.4.6 Number of grains per cob

The data with respect to number of grains per cob are presented in table 4.19 and fig. 4.13. A perusal data revealed that total grains per cob was significantly higher (440.0 and 449.0) when residue was incorporated with application of 100% NPK + FYM @ 50 t ha^{-1} to the preceding crop which was followed by treatment consist of residue removal + 100% NPK + FYM @ 50 t ha^{-1}. Lowest grains per cob were recorded (376.7 and 409.8) form residue removal + 150% NPK applied plots which were at par with 150% NPK along with residue incorporation. Integrated application of organic and synthetic fertilizers enhanced the grain filling ability of cob. As mentioned above it improves the length, girth, number of rows per cob and grains per row which directly related to total number of grains per cob. The above mentioned results were corroborated with the findings of Snehaa *et al* (2019) and Biswasi *et al* (2020) who observed higher number of grains per cob with combined application of organic and inorganic nutrients.

In case of nutrients applied to spring maize, the number of grains per cob was increased with increase in fertilizer levels. A perusal data revealed that total grains per cob increased under various nutrient levels in the order of 125% NPK > 100% NPK > 75% NPK in both single and double row planted spring maize during both the years. Amongst all the treatments highest number of grains per cob was recorded in 125% NPK applied to single row on bed and lowest grains per cob was recorded under 75% NPK applied to double row on bed during both years of study. In single row planted spring maize the increase in number of grains per cob was 16.1, 10.4% and 8.5, 6.4% under 125% NPK over 75% NPK and 100% NPK during 2019 and 2020, respectively. Likewise, in double row bed planted spring maize the increase of grains per cob was up to a margin of 26.1, 23.4% and 10.1, 8.1% under 125% NPK as compared to 75% NPK and 100% NPK during 2019 and 2020. Higher grains number under higher nutrients level might be due to wide availability of nutrients throughout its growth period leading to more availability of photosynthates, metabolites and nutrients to develop reproductive structure. The increase in number of grains with increased nitrogen levels also reported by Shahid *et al* (2016), Golla *et al* (2020) and Adhikari *et al* (2021).

4.1.3.4.7 1000-grain weight

Data pertaining to 1000-grain weight was presented in table 4.19 and fig.4.13. Thousand grain weight was significantly higher under residue incorporation + 100% NPK + FYM @ 50 t ha^{-1} applied to preceding potato crop as compared to all other treatment combinations during 2019, however during 2020 it was recorded to be non-significant. The increase in 1000-grain weight under residue incorporation + 100% NPK + FYM @ 50 t ha^{-1} was 4.9% over sole application of synthetic fertilizer i.e. residue removal + 150% NPK during 2019. Integrated application of organic and inorganic fertilizer enhances 1000-grain weight by supplying nutrients in a balanced form which reflected on high photosynthetic efficiency and consequently translocation of assimilates towards reproductive part. Singh *et al* (2017), Biswas *et al* (2020) and Mahato *et al* (2020) reported higher 1000-grain weight under conjoint application of organic and inorganic fertilizers as compared to sole application of synthetic fertilizers.

Table 4.19: Effect of rice residue and nutrient application to preceding potato and nutrient levels to spring maize on yield attributing characters in spring maize

Treatment	Grain weight per cob (g)		Number of grains per row		Number of grains per cob		1000-grain weight (g)	
	2019	**2020**	**2019**	**2020**	**2019**	**2020**	**2019**	**2020**
Rice residue and nutrient application to preceding potato								
Straw removal + 100 % NPK+ FYM @ 50 t ha^{-1}	96.6	99.9	29.1	30.0	414.4	433.0	247.1	255.2
Straw removal + 150 % NPK	96.7	93.7	27.9	28.8	376.7	409.8	239.1	246.3
Straw incorporation + 100 % NPK+ FYM @ 50 t ha^{-1}	98.9	102.0	30.5	30.7	440.0	449.0	250.9	258.4
Straw incorporation + 150 % NPK	96.8	99.2	28.7	29.4	397.2	420.5	241.9	251.4
CD (p=0.05)	NS	NS	1.4	1.3	22.8	18.4	2.8	NS
Nutrient levels in spring maize								
75 % NPK with single row on bed	97.3	93.9	29.7	30.8	419.9	451.9	246.5	256.4
75 % NPK with double row on bed	86.8	80.1	24.6	25.4	317.4	340.4	234.8	235.2
100% NPK with single row on bed	104.8	115.2	30.8	31.9	449.4	468.6	249.8	260.2
100 % NPK with double row on bed	91.8	90.6	28.0	27.8	367.9	388.6	235.5	244.1
125 % NPK with single row on bed	108.4	117.5	32.5	33.8	487.4	498.8	259.6	269.0
125 % NPK with double row on bed	94.6	95.0	28.6	29.0	400.5	420.1	242.1	252.2
CD (p=0.05)	5.0	6.8	2.0	1.6	29.3	23.7	8.0	8.0
Interaction	NS	NS	NS	NS	NS	NS	NS	NS

Amongst nutrient applied to spring maize, maximum 1000-grain weight was observed under 125% NPK application to single row on bed which was significantly higher than 75% NPK and 100% NPK during both the years. The increase in 1000-grain weight was 5.3, 4.9% and 3.9, 3.4% under 125% NPK application as compared to 75% NPK and 100% NPK during 2019 and 2020, respectively. In case of double row planted maize, maximum 1000-grain

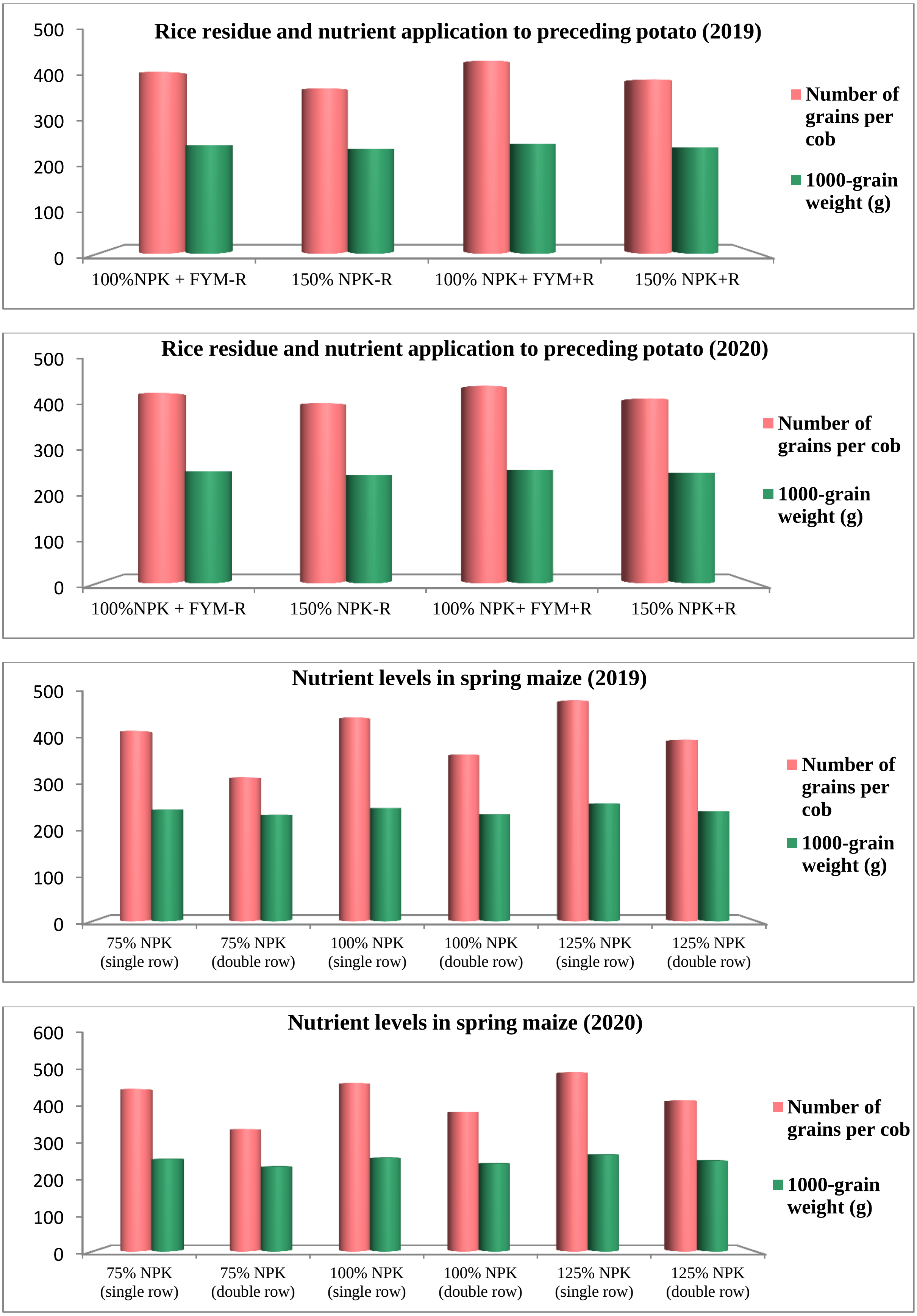


Fig. 4.13: Effect of rice residue and nutrient application to preceding potato and nutrient levels to spring maize on number of grains per cob and 1000-grain weight in spring maize

weight was found under application of 125% NPK which was at par with 100% NPK during 2019 and it was significantly better than 75% NPK during both year and 100% NPK during 2020. The per cent increase in 1000-grain weight was 3.1 and 7.2% under 125% NPK application over 75% NPK during the year 2019 and 2020, respectively. Onasanya *et al* (2009), Kumar (2009), Gul *et al* (2015) and Golla *et al* (2020) also reported higher 1000-grain weight under higher dose of nitrogen application as compared to lower dose due to higher translocation of photosynthates towards the grains.

4.1.3.4.8 Grain weight per cob

Grain weight per cob did not vary significantly with rice residue and nutrient applied to preceding potato during both the years (Table 4.19). The grain weight per cob increased significantly with increase in N levels. In case of single row bed planted spring maize, maximum grain weight per cob (108.4 and 117.5 g) was found in treatment which involves 125% NPK application and it was at par with 100% NPK application and significantly better than 75% NPK application. While in case of double row bed planted spring maize 125% NPK application recorded significantly higher grain weight (94.6 and 95.0 g) than 75% NPK and was statistically at par with 100% NPK application during both the years. The grain weight was higher by a margin of 11.4 and 25.1% under 125% NPK over 75% NPK application in single row planted maize and up to a margin of 9.0 and 18.6% in double row planted spring maize during 2019 and 2020, respectively. Higher levels of fertilizer dose harvest more solar radiation and accumulate more photosynthates at sink which increase the cob length and girth which ultimately leads to higher grain weight per cob. Gokmen *et al* (2001), Edalat *et al* (2009) and Delibaltova *et al* (2010) also recorded significantly higher grain weight per cob with increase in nitrogen levels.

4.1.3.4.9 Grain yield

Grain yield in spring maize is an important character from economic point of view as it directly correlated with net returns and benefit cost ratio. Data presented in table 4.20 and fig. 4.14 revealed that rice residue and nutrient application in previous crop of potato had significant effect of grain yield of spring maize. The results depict that grain yield of spring maize was significantly higher where residue was incorporated with 100% RDF + FYM @ 50 t ha^{-1} applied to preceding crop (80.1 and 83.6 q ha^{-1}) as compared to sole application of synthetic fertilizer without residue incorporation i.e. residue removal + 150% NPK and it was statistically at par with treatment involving residue removal and application of 100% NPK + FYM @ 50 t ha^{-1} during 2019 and 2020, respectively. The increase in grain yield was 10.6 and 14.6 % in residue incorporated plot with 100% NPK + FYM @ 50 t ha^{-1} as compared to residue removed + 150% NPK application during 2019 and 2020. Lowest grain yield of 72.4 and 72.9 q ha^{-1} was recorded in treatment which involves residue removal + 150% NPK applied to preceding crop. The increase in yield with combined application of fertilizer +

FYM to the preceding crop may be due to increase in organic biomass and carbon content in soil, which enhance the nutrient availability to the plant. The higher grain yield under residue incorporation and FYM applied plots may be due to combined effect of better growth and development which resulted in more cob length and more numbers of grains per cob and ultimately leads to more grain yield. Chahal *et al* (2019), Ejigu *et al* (2021) and Sigaye *et al* (2021) also reported higher maize grain yield in combined application of organic manures and synthetic fertilizers than sole application of synthetic fertilizers. Residue incorporation also had a positive effect on grain yield of maize which enhances the porosity and decreases the bulk density of soil. This led to better root penetration for nutrient and water uptake for growth and development which ultimately leads to higher grain yield. Zhu *et al* (2010), Chaudhary *et al* (2013) and Memon *et al* (2018) also reported higher grain yield under residue incorporation as compared to residue removal treatments.

The different levels of nutrient application treatments in spring maize also showed significant effect on grain yield. Treatment involving application of 125 % NPK to double row planted spring maize resulted with significantly higher grain yield (85.4 and 87.5 q ha^{-1}) as compared to all other treatment combinations and followed by application of 125 % NPK to single row bed planted spring maize (81.3 and 82.9 q ha^{-1}) during both the years. The average yield obtained from supply of 100% NPK to double row on bed was (78.8 and 81.4 q ha^{-1}) which was statistically at par with treatment involving 125% NPK to single row on bed. Lowest yield of 68.3 and 69.6 q ha^{-1} was recorded when 75% NPK was applied to single row on bed during both the years. The per cent increase in grain yield 125% NPK applied to double row planted spring maize was 25.0 %, 25.7 % and 14.6%, 12.9% as compared to 75 % NPK and 100% NPK application to single row planted spring maize (68.3, 69.6 q ha^{-1} and 74.5, 77.5 q ha^{-1}) during 2019 and 2020, respectively. Increasing nitrogen level up to 125 % NPK leads to higher grain yield due to better vegetative and reproductive growth of the plant. The increase might be due to increased availability of NPK, causing accelerated photosynthetic rate and thus leading to production of more carbohydrates and ultimately more yield. Similar findings was recorded by Srivastava *et al* (2018), Raj *et al* (2021) and Adhikari *et al* (2021). Moreover, higher grain yield with increasing population density came mainly from more numbers of plant and cobs per unit area which resulted in enhancement of grain and biological yield. A similar trend in yield has been reported by Tyagi *et al* (1998) and Alam *et al* (2003). Gul *et al* (2009), Amanullha *et al* (2009) and Arif *et al* (2010) also reported that increasing crop density with increased nitrogen dose, enhanced the grain yield. The interaction was non-significant.

4.1.3.4.10 Stover yield

Data pertaining to stover yield was presented in table 4.20 and fig. 4.14. From the analysis of data it was observed that stover yield of spring maize was significantly influenced by different treatments. Rice residue incorporated with application of 100% NPK + FYM @ 50 t ha^{-1} to preceding potato resulted in significantly higher stover yield (154.0 and 164.3 q ha^{-1}) as compared to all other treatment combinations during 2019 and 2020, but was at par with treatment consisting of residue removal + 100% NPK + FYM @ 50 t ha^{-1} during 2019. The lowest stover yield (142.8 and 150.9 q ha^{-1}) was recorded where rice residue was removed and preceding crop was applied with 150% NPK this treatment was at par with treatment involving 150% NPK along with residue incorporation.

Table 4.20: Effect of rice residue and nutrient application to preceding potato and nutrient levels to spring maize on grain and stover yield in spring maize

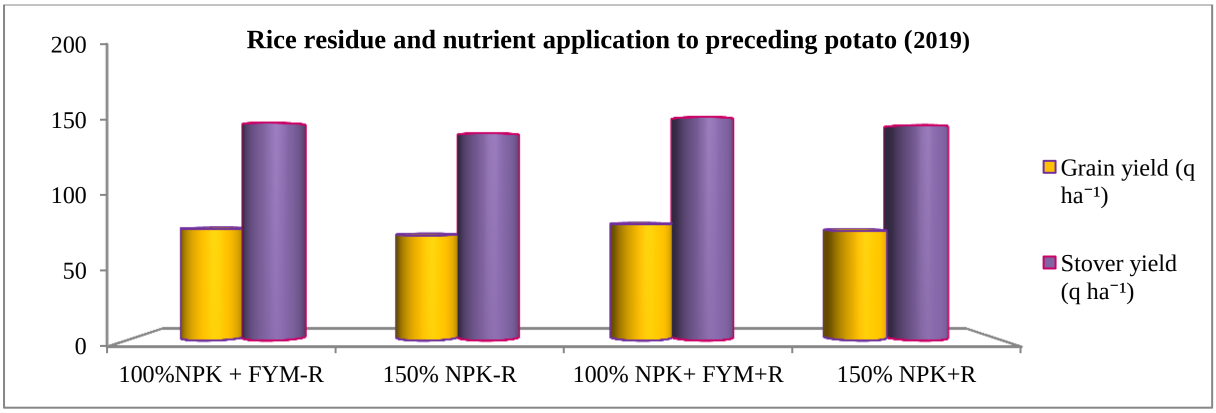
Treatment	**Seed yield (q ha^{-1})**		**Stover yield (q ha^{-1})**		**Harvest index**	
	2019	**2020**	**2019**	**2020**	**2019**	**2020**
Rice residue and nutrient application to preceding potato						
Straw removal + 100 % NPK+ FYM @ 50 t ha^{-1}	76.7	79.5	150.0	158.1	0.33	0.33
Straw removal + 150 % NPK	72.4	72.9	142.8	150.9	0.33	0.32
Straw incorporation + 100 % NPK+ FYM @ 50 t ha^{-1}	80.1	83.6	154.0	164.3	0.34	0.34
Straw incorporation + 150 % NPK	75.5	76.6	148.4	155.5	0.33	0.33
CD (p=0.05)	4.7	4.9	7.3	6.0	NS	NS
Nutrient levels in spring maize						
75 % NPK with single row on bed	68.3	69.6	133.5	140.4	0.33	0.33
75 % NPK with double row on bed	69.2	69.9	152.1	163.6	0.31	0.29
100% NPK with single row on bed	74.5	77.5	139.0	144.0	0.34	0.35
100 % NPK with double row on bed	78.5	81.4	160.3	169.4	0.32	0.32
125 % NPK with single row on bed	81.3	82.9	142.9	150.5	0.36	0.35
125 % NPK with double row on bed	85.4	87.5	165.1	175.4	0.34	0.33
CD (p=0.05)	3.1	3.8	7.7	9.5	0.02	0.02
Interaction	NS	NS	NS	NS	NS	NS

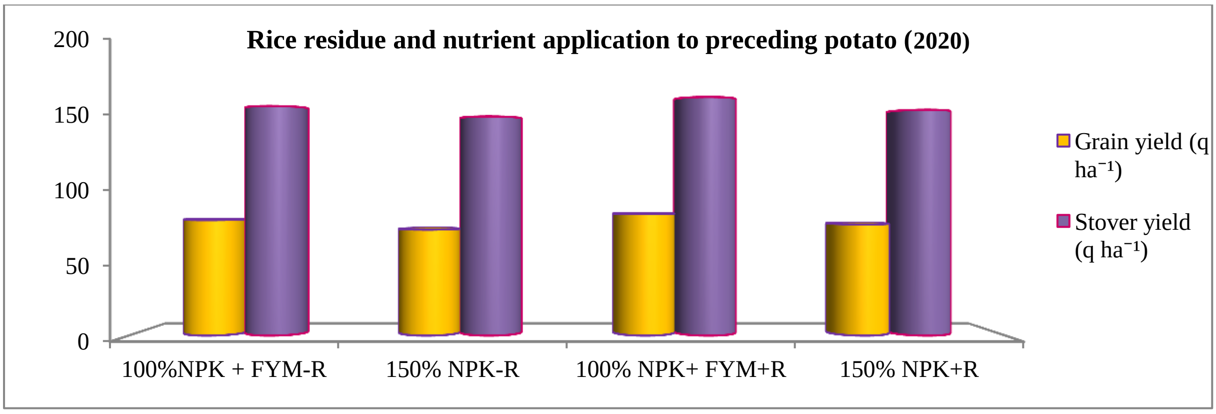
The increase in stover yield with application of 100% NPK + FYM @ 50 t ha^{-1} along with rice residue incorporation was 7.84% and 8.89% during both the years over residue removal + 150% NPK. The increase in stover yield with combined application of organic and inorganic fertilizer could be due to improved physical, chemical and biological properties of the soil (Singh and sekhon 2002). Better physical condition of soil led to better growth which enhances the photosynthate assimilation. Similar finding was given by Bua *et al* (2017). The higher stover yield under integrated application of organic and inorganic fertilizer was also due to better plant height, DMA and LAI which resulted into higher stover yield. These results were corroborated with the findings Pandurang (2006), Jamir *et al* (2013) and Ejigu *et al* (2021). Crop residue might have improved the physical properties of soil, moderated the microclimate around the plant and increased the grain and stover yield. Higher grain and stover yield resulted from application crop residue as mulch has been also reported by Sepat *et al* (2015), Saad *et al* (2015) and Ramesh *et al* (2016).

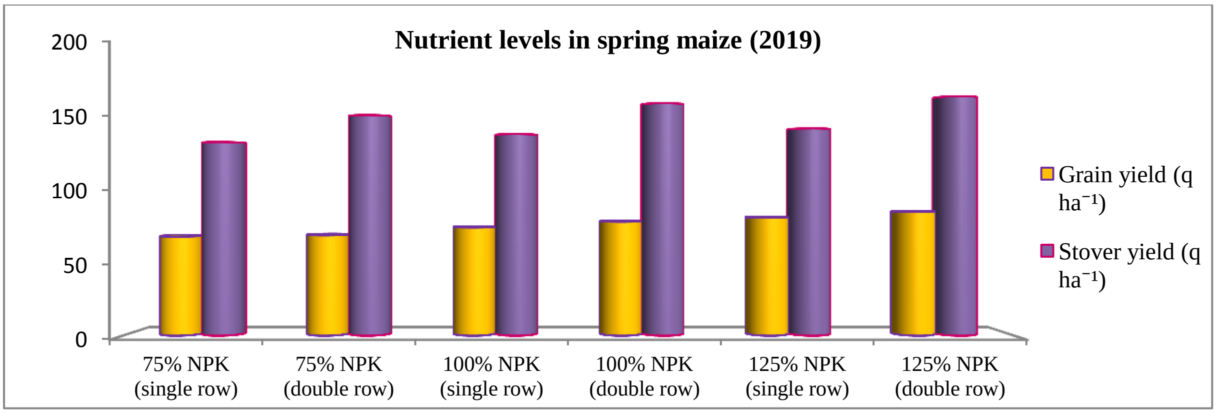
The stover yield also differed significantly with different nutrition applied to spring maize at different plant stand. The stover yield was significantly increased with each successive dose of N and with increase in plant stand. Spring maize planted in double row with application of 125% NPK recorded significantly higher stover yield (165.1 and 175.4 q ha^{-1}) as compared to all other treatments, but it was at par with 100% NPK application to double row planted spring maize during both the years**.** In case of single row on bed, application of 125% NPK results in significantly higher stover yield than 75% NPK, but was statistically at par with 100% NPK application during both the years. The lowest stover yield (133.5 and 140.6 q ha^{-1}) was recorded from single row on bed with 75% NPK application during 2019 and 2020. The increase in stover yield was 18.8 and 21.8% under 125% NPK to double row on bed and 15.3 and 17.6% under 100% NPK to double row on bed over that of 100% NPK applied to single row on bed. Whereas, 125% NPK application on bed planted double row spring maize and 100% NPK application on bed planted double row spring maize were statistically better by 23.6 and 24.8% and 20.0 and 20.7%, respectively over 75% NPK applied to single row bed planted spring maize during 2019 and 2020. Higher stover yield with increased levels of nitrogen was due to higher value of plant height, DMA and LAI resulted from better growth and development. Khanday and Thakur (1991), Brar *et al* (2001) and Singh (2010) also reported higher stover yield under various N levels. Abbasi *et al* (2010) and Srivastava *et al* (2018) reported that dry biomass at physiological maturity was significantly increased by N fertilization. Stover yield was also higher with increasing plant density and it was significantly greater at higher plant density as compared to lower density. Kiniry *et al* (2005), Dubeux *et al* (2006) and Raymond *et al* (2009) observed that with increase in plant population per unit area, stover yield was also increased.

4.1.3.4.11 Harvest index

Harvest index (HI) is an indicator of efficiency of crop plants to translocate manufactured food material from source level to the sink or grains. The data regarding harvest index are presented in table 4.20. Rice residue and nutrient applied to preceding potato had no significant effect on harvest index of spring maize. Whereas nutrient applied to spring maize had a significant effect on harvest index during both the years.







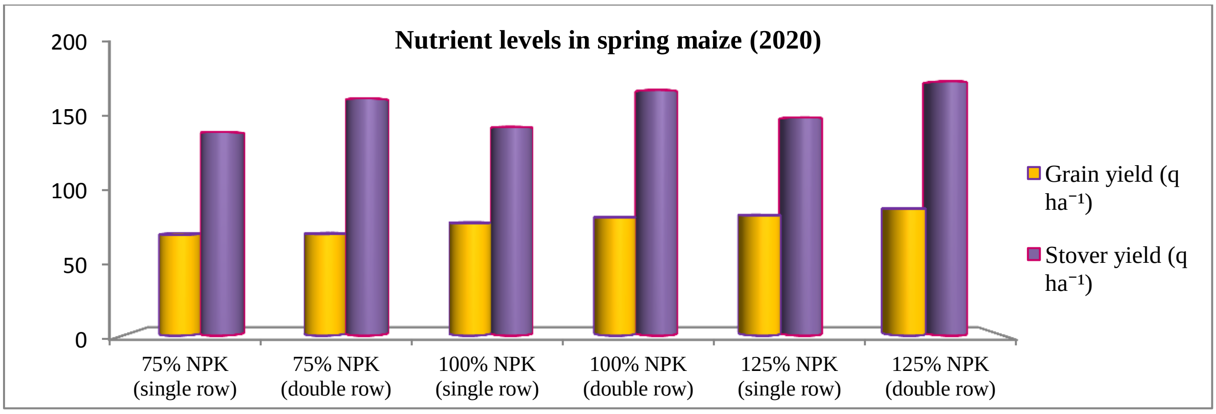


Fig. 4.14: Effect of rice residue and nutrient application to preceding potato and nutrient levels to spring maize on grain and stover yield of spring maize

Maximum HI was recorded under 125% NPK applied to single row planted spring maize which was at par with 100% NPK applied to single row planted maize and 125% NPK applied to double row planted spring maize during both the years. In single row on bed, the increase in HI under 125% NPK application was 9.1 and 6.1% higher over 75% NPK during 2019 and 2020, respectively. In double row planted maize, the increase in HI under 125% NPK application was 8.8 and 13.8% over 75% NPK during 2019 and 2020, respectively. Higher HI under higher fertilizer dose might be due to adequate availability of nutrients that improved nutrient uptake and better photosynthetic rate which ultimately leads to higher harvest index. Similar results were recorded by Adhikari *et al* (2021) and Raj *et al* (2021). Increase in plant density leads to decrease in harvest index, which was due to higher stover yield as compared to lower plant density. Similar results were also found by Kiniry *et al* (2005), Dubeux *et al* (2006) and Raymond *et al* (2009).

4.1.3.5 Quality parameters of spring maize

4.1.3.5.1 Protein content of grain

Grain protein content is an important parameter in maize from quality point of view. Data given in table 4.21 revealed that rice residue and nutrient application to preceding potato did not show any significant effect on protein content during both the years. While the protein content significantly varied with different nutrients level applied to spring maize. Maximum protein content was recorded (9.34 and 9.39%) under 125% NPK application to single row bed planted spring maize which was followed by 100% NPK application (9.22 and 9.36%) to single row bed planted spring maize. Minimum protein content was recorded (8.95 and 9.02%) under 75% NPK applied to double row bed planted spring maize. The per cent increase in protein content in 125% NPK applied to single row was 4.4 and 4.1% higher over application of 75% NPK to double row planted maize during 2019 and 2020, respectively. Nitrogen being the main component of protein might have considerably increased the protein content of grain due to increased uptake of nitrogen under higher N levels (Almaz *et al* 2017). A higher protein content with higher nutrients level might be due to efficient translocation of nitrogen from vegetative part to grains and increase the activity of nitrate reductase in protein synthesis. The above mentioned results were accordance with findings of Randhawa *et al* (2002) and Zafar *et al* (2011) who reported that protein content of grain increased with application of higher dose of nitrogen than its lower dose.

4.1.3.5.2 Starch content of grain

Data pertaining to starch content presented in table 4.21. Starch content in spring maize did not differ significantly with rice residue and nutrient application to preceding potato. But it significantly differed with different nutrient application to spring maize. There was a decreasing trend with respect to starch content with increase in nitrogen level. Higher starch content was observed under 75% NPK application to double row bed planted spring

Weighing of fertilizers

Allocation of fertilizers

Broadcasting of fertilizers

Preparation of beds

Plate 4: Field operation in spring maize

Seed treatment with Gaucho

Sowing of spring maize

Plate 5: Sowing of spring maize

Plate 6: Agronomic operations in spring maize

Plate 7: Agronomic operations in spring maize

Plate 8: Harvesting of spring maize

Plate 9: Cob sample collected for data collection

Plate 10: Estimation of total sugar

maize (66.0 and 65.9%) and minimum starch content was recorded (65.7 and 65.5%) under 125% NPK applied to single row bed planted spring maize during both the years. Decreasing trend of starch content with increasing levels of nitrogen was also reported by Ning *et al* (2018) and Mariem *et al* (2020).

Table 4.21: Effect of rice residue and nutrient application to preceding potato and nutrient levels to spring maize on protein and starch content in grain of spring maize

Treatment	Protein content (%)		Starch content (%)	
	2019	**2020**	**2019**	**2020**
Rice residue and nutrient application to preceding potato				
Straw removal + 100 % NPK+ FYM @ 50 t ha^{-1}	9.13	9.19	65.8	65.7
Straw removal + 150 % NPK	9.13	9.23	65.9	65.8
Straw incorporation + 100 % NPK+ FYM @ 50 t ha^{-1}	9.15	9.30	65.7	65.7
Straw incorporation + 150 % NPK	9.14	9.22	65.7	65.7
CD (p=0.05)	NS	NS	NS	NS
Nutrient levels in spring maize				
75 % NPK with single row on bed	9.10	9.29	65.8	65.8
75 % NPK with double row on bed	8.95	9.02	66.0	65.9
100% NPK with single row on bed	9.22	9.36	65.7	65.7
100 % NPK with double row on bed	9.10	9.15	65.9	65.8
125 % NPK with single row on bed	9.34	9.39	65.7	65.5
125 % NPK with double row on bed	9.11	9.21	65.7	65.7
CD (p=0.05)	0.17	0.25	0.2	0.2
Interaction	NS	NS	NS	NS

4.1.3.5.3 Total sugar content of grain

Data presented in table 4.22 revealed that total sugar content of maize grains was not significantly affected by either rice residue and nutrient application to preceding potato or nutrients applied to spring maize during both the years of study. But numerically higher total sugar content was observed with increase in nitrogen levels. Similar findings were reported by Ning *et al* (2018).

4.1.3.5.4 Oil content of grain

A perusal data on oil content in maize grain (Table 4.22) revealed that the oil content in grain was not significantly influenced by either rice residue and nutrient application to preceding crop or nutrient levels applied to spring maize during both the years of study. Holou and Kindomihou (2011) reported similar findings with respect to effect of N levels on oil content of maize grain.

Table 4.22: Effect of rice residue and nutrient application to preceding potato and nutrient levels to spring maize on total sugar and oil content in grain of spring maize

Treatment	Total sugar (%)		Oil content (%)	
	2019	**2020**	**2019**	**2020**
Rice residue and nutrient application to preceding potato				
Straw removal + 100 % NPK+ FYM @ 50 t ha^{-1}	2.97	2.92	4.07	4.58
Straw removal + 150 % NPK	2.96	2.96	4.19	4.55
Straw incorporation + 100 % NPK+ FYM @ 50 t ha^{-1}	3.03	2.88	4.13	4.61
Straw incorporation + 150 % NPK	2.99	2.83	4.10	4.58
CD (p=0.05)	NS	NS	NS	NS
Nutrient levels in spring maize				
75 % NPK with single row on bed	3.09	2.98	4.21	4.58
75 % NPK with double row on bed	2.86	2.82	4.05	4.57
100% NPK with single row on bed	3.04	3.03	4.14	4.57
100 % NPK with double row on bed	3.00	2.90	4.16	4.58
125 % NPK with single row on bed	3.00	2.85	4.10	4.56
125 % NPK with double row on bed	2.96	2.82	4.09	4.62
CD (p=0.05)	NS	NS	NS	NS
Interaction	NS	NS	NS	NS

4.1.3.6 Plant analysis

4.1.3.6.1 N, P and K content in grain

The data with respect to N, P and K content in the grain are presented in table 4.23. A perusal of data reveals that rice residue and nutrient application to potato had no significant effect on N, P and K content of grain during both the years. Nutrients applied to spring maize had a significant effect on N content in grain but P and K content did not vary significantly with application of different treatments. Higher N content (1.49 and 1.50%) was recorded under application of 125% NPK to single row on bed as compared to other treatments during both the years. Minimum N content was recorded under 75% NPK application to double row on bed during both the years. Higher N content in grain under higher level nutrient might be due to better uptake of nutrients from soil because of adequate N availability. Kumar *et al* (2008) and Singh (2010) observed significantly higher N content with increase in N levels in maize.

Table 4.23: Effect of rice residue and nutrient application to preceding potato and nutrient levels to spring maize on nitrogen, phosphorus and potassium content in grain of spring maize

Treatment	N (%)		P (%)		K (%)	
	2019	**2020**	**2019**	**2020**	**2019**	**2020**
Rice residue and nutrient application to preceding potato						
Straw removal + 100 % NPK+ FYM @ 50 t ha^{-1}	1.46	1.46	0.31	0.29	0.40	0.38
Straw removal + 150 % NPK	1.46	1.47	0.28	0.28	0.39	0.36
Straw incorporation + 100 % NPK+ FYM @ 50 t ha^{-1}	1.46	1.48	0.31	0.30	0.41	0.39
Straw incorporation + 150 % NPK	1.46	1.47	0.29	0.29	0.38	0.36
CD (p=0.05)	NS	NS	NS	NS	NS	NS
Nutrient levels in spring maize						
75 % NPK with single row on bed	1.45	1.48	0.30	0.29	0.39	0.37
75 % NPK with double row on bed	1.43	1.44	0.28	0.28	0.38	0.36
100% NPK with single row on bed	1.47	1.49	0.31	0.30	0.40	0.38
100 % NPK with double row on bed	1.45	1.45	0.29	0.29	0.39	0.36
125 % NPK with single row on bed	1.49	1.50	0.31	0.30	0.41	0.40
125 % NPK with double row on bed	1.45	1.47	0.30	0.29	0.40	0.38
CD (p=0.05)	0.02	0.04	NS	NS	NS	NS
Interaction	NS	NS	NS	NS	NS	NS

4.1.3.6.2 N, P and K content in stover

Rice residue and nutrient application to preceding potato and different nutrient levels applied to spring maize showed non-significant effect on N, P and K content in stover of maize grains during both the years of study. But numerically higher N, P and K content in stover was recorded with increase in fertilizer levels during both the years (Table 4.24).

4.1.3.6.3 N, P and K uptake in grain

The data on uptake of N, P and K grain are presented in table 4.25. The analysis of data revealed that higher N uptake was observed under residue incorporated plots along with application of 100% NPK + FYM @ 50 t ha^{-1} to the preceding crop which was statistically at par with residue removal + 100% NPK + FYM @ 50 t ha^{-1} during both the years. P and K uptake recorded to be non-significant under various treatments in main plots. Among various nutrient levels applied to spring maize in sub plots, 125% NPK applied to double row bed planted spring maize resulted with higher N, P and K uptake as compared to other treatments and it was statistically at par with 125% NPK applied to single row bed planted spring maize during both the years. This was due to higher NPK content and higher grain yield under these treatments. Lowest values of N, P and K uptake were recorded under 75% NPK applied to double row on bed. Brar *et al* (2001), Kumar *et al* (2008) and Singh (2010) observed significantly higher N and P uptake with increase in fertilizer levels in maize.

Table 4.24: Effect of rice residue and nutrient application to preceding potato and nutrient levels to spring maize on nitrogen, phosphorus and potassium content in stover of spring maize

Treatment	N (%)		P (%)		K (%)	
	2019	**2020**	**2019**	**2020**	**2019**	**2020**
Rice residue and nutrient application to preceding potato						
Straw removal + 100 % NPK+ FYM @ 50 t ha^{-1}	0.70	0.71	0.20	0.21	1.26	1.23
Straw removal + 150 % NPK	0.68	0.70	0.20	0.20	1.25	1.22
Straw incorporation + 100 % NPK+ FYM @ 50 t ha^{-1}	0.73	0.73	0.21	0.23	1.29	1.24
Straw incorporation + 150 % NPK	0.71	0.71	0.20	0.21	1.27	1.22
CD (p=0.05)	NS	NS	NS	NS	NS	NS
Nutrient levels in spring maize						
75 % NPK with single row on bed	0.71	0.70	0.20	0.21	1.27	1.23
75 % NPK with double row on bed	0.68	0.70	0.19	0.20	1.25	1.21
100% NPK with single row on bed	0.72	0.73	0.20	0.22	1.27	1.23
100 % NPK with double row on bed	0.71	0.72	0.20	0.20	1.26	1.22
125 % NPK with single row on bed	0.73	0.73	0.22	0.23	1.29	1.24
125 % NPK with double row on bed	0.69	0.71	0.20	0.21	1.27	1.22
CD (p=0.05)	NS	NS	NS	NS	NS	NS
Interaction	NS	NS	NS	NS	NS	NS

Table 4.25: Effect of rice residue and nutrient application to preceding potato and nutrient levels to spring maize on nitrogen, phosphorus and potassium uptake in grain of spring maize

Treatment	N uptake (kg ha^{-1})		P uptake (kg ha^{-1})		K uptake (kg ha^{-1})	
	2019	**2020**	**2019**	**2020**	**2019**	**2020**
Rice residue and nutrient application to preceding potato						
Straw removal + 100 % NPK+ FYM @ 50 t ha^{-1}	112.2	116.0	24.6	23.5	30.9	30.4
Straw removal + 150 % NPK	105.8	108.0	20.6	20.6	28.2	26.9
Straw incorporation + 100 % NPK+ FYM @ 50 t ha^{-1}	117.3	124.4	24.9	25.4	32.9	32.3
Straw incorporation + 150 % NPK	110.5	113.1	22.3	22.7	29.1	28.0
CD (p=0.05)	6.2	8.2	NS	NS	NS	NS
Nutrient levels in spring maize						
75 % NPK with single row on bed	99.5	103.2	21.0	20.2	26.9	25.9
75 % NPK with double row on bed	99.1	101.1	20.6	19.9	26.4	25.3
100% NPK with single row on bed	109.9	116.1	23.3	23.0	29.9	29.4
100 % NPK with double row on bed	114.3	118.3	23.1	24.1	30.8	30.2
125 % NPK with single row on bed	121.6	124.8	25.6	25.1	32.8	32.7
125 % NPK with double row on bed	124.5	128.8	25.0	26.0	34.6	33.0
CD (p=0.05)	5.0	6.8	2.5	2.6	3.0	3.2
Interaction	NS	NS	NS	NS	NS	NS

4.1.3.6.4 N, P and K uptake in stover

The data with respect to N, P and K uptake in stover by spring maize are presented in table 4.26. The scrutiny of data revealed that significantly higher values of N uptake in stover were observed under residue incorporated plots with application of 100% NPK + FYM @ 50 t ha^{-1} to the preceding crop as compared to all other treatments except straw removal + 100% NPK + FYM @ 50 t ha^{-1} during both the years and N uptake was also higher in this treatment during 2020. P and K uptake in stover was found to be non-significant with application of different treatments.

Different nutrient levels applied to spring maize showed significant influence on N, P and K uptake during both the years. Maximum N, P and K uptake was recorded under application of 125% NPK with double row on bed, which was at par with 100% NPK applied to double row on bed during both the years. This was due to higher stover yield under higher population density. Lower N, P and K uptake was recorded under 75% NPK application to single row on bed. Brar *et al* (2001) and Singh (2010) also observed significantly higher N, P and K uptake with increase in N levels in maize.

Table 4.26: Effect of rice residue and nutrient application to preceding potato and nutrient levels to spring maize on nitrogen, phosphorus and potassium uptake in stover of spring maize

Treatment	N uptake (kg ha^{-1})		P uptake (kg ha^{-1})		K uptake (kg ha^{-1})	
	2019	2020	2019	2020	2019	2020
Rice residue and nutrient application to preceding potato						
Straw removal + 100 % NPK+ FYM @ 50 t ha^{-1}	105.8	129.1	30.9	38.1	190.2	221.5
Straw removal + 150 % NPK	97.4	121.4	28.7	35.5	178.9	209.6
Straw incorporation + 100 % NPK+ FYM @ 50 t ha^{-1}	112.2	135.9	32.6	42.9	199.2	231.8
Straw incorporation + 150 % NPK	105.7	126.0	29.6	37.1	188.9	216.5
CD (p=0.05)	NS	8.7	NS	NS	11.2	9.3
Nutrient levels in spring maize						
75 % NPK with single row on bed	95.5	112.3	26.9	34.3	170.7	197.2
75 % NPK with double row on bed	103.8	129.9	29.1	38.7	190.2	226.0
100% NPK with single row on bed	99.8	120.0	27.9	36.2	176.8	201.9
100 % NPK with double row on bed	114.1	139.6	33.0	40.0	202.9	235.4
125 % NPK with single row on bed	104.5	124.8	32.7	39.2	185.1	213.7
125 % NPK with double row on bed	114.0	141.9	33.1	42.0	210.1	244.9
CD (p=0.05)	9.5	11.3	4.2	4.2	12.2	17.4
Interaction	NS	NS	NS	NS	NS	NS

4.1.3.7 Soil chemical analysis

4.1.3.7.1 Available nitrogen

The data recorded for available nitrogen from 0-15 and 15-30 cm soil depth after harvesting spring maize during 2019 and 2020 are presented in table 4.27. The treatments applied in main plot i.e. rice residue and nutrient applied to preceding potato had no significant effect on available nitrogen in 0-15 and 15-30 cm depth during both the years. Nutrient levels applied to spring maize had significant effect on available N at 0-15 cm soil depth during both the years. Higher available N (196.0 and 204.6 kg ha^{-1}) was recorded from treatment consisting of 125% NPK applied to single row planted spring maize. It was significantly higher than 75% NPK applied to double row bed planted maize but was statistically at par with all other treatments. With increased level of nutrients, available soil nitrogen was also increased. Dhaka *et al* (2016) also reported that with increase in dose of nitrogen resulted in higher available nutrients at the harvest of the crop. It was observed that available soil N status was increased from its initial status during both the growing season.

4.1.3.7.2 Available phosphorus

Data pertaining to available P are presented in table 4.27. An appraisal of data revealed that available P was not significantly influenced by residue incorporation and nutrient applied to potato at 0-15 and 15-30 cm soil depth during both years. But it differed significantly with application of various nutrient levels applied to spring maize at only 0-15 cm soil depth. The treatment which involves 125% NPK applied to single row on bed recorded significantly higher available P (22.9 and 19.1 kg ha^{-1}) as compared to other treatments. Minimum available P was recorded from plots which received 75% NPK with double row on bed during both the years. The available P was decreased after the completion of the system as compared to initial status of soil.

4.1.3.7.3 Available potassium

The data recorded for available K from 0-15 and 15-30 cm soil depth for 2019 and 2020 are given in table 4.27. Available K in 0-15 and 15-30 cm depth did not varied significantly with rice residue and nutrient applied to preceding potato during both the years. Nutrient applied to spring maize had significant effect on available K during 2020 at only 0-15 cm soil depth. Maximum available K (180.7 kg ha^{-1}) was recorded under 125% NPK application to single row on bed during 2020 and it was statistically at par with 75% NPK and 100% NPK application. Application of 75% NPK to double row planted maize recorded significantly lower available K during 2020. Available K in soil was also decreased after harvesting of the spring maize than its initial soil status.

Table 4.27: Effect of rice residue and nutrient application to preceding potato and nutrient levels to spring maize on soil available nitrogen, phosphorus and potassium

Treatment	Available N (kg ha^{-1})				Available P (kg ha^{-1})				Available K (kg ha^{-1})			
	0-15 cm		15-30 cm		0-15 cm		15-30 cm		0-15 cm		15-30 cm	
	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020
Rice residue and nutrient application to preceding potato												
Straw removal + 100 % NPK+ FYM @ 50 t ha^{-1}	191.7	197.7	183.7	185.2	19.5	18.2	17.9	17.4	177.5	176.5	164.3	163.8
Straw removal + 150 % NPK	187.6	195.9	179.6	183.2	18.5	18.2	17.7	17.1	177.0	176.8	166.3	163.4
Straw incorporation + 100 % NPK+ FYM @ 50 t ha^{-1}	193.7	201.9	184.5	190.6	19.5	18.7	18.1	17.5	178.0	177.7	166.6	164.4
Straw incorporation + 150 % NPK	190.7	196.4	179.8	182.7	19.6	18.6	17.8	17.1	178.3	176.4	166.5	162.1
CD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Nutrient levels in spring maize												
75 % NPK with single row on bed	189.8	199.3	182.0	185.8	18.8	18.6	17.7	16.8	176.1	177.2	165.6	163.5
75 % NPK with double row on bed	183.4	191.7	178.9	182.4	17.3	17.3	17.6	16.2	175.4	174.4	164.7	161.2
100% NPK with single row on bed	194.4	200.8	183.6	186.6	20.2	18.7	17.5	17.8	179.1	178.8	166.1	163.0
100 % NPK with double row on bed	187.2	194.2	179.7	183.7	17.6	17.9	17.9	17.9	176.7	175.1	165.6	164.4
125 % NPK with single row on bed	196.0	204.6	186.0	187.7	22.9	19.1	18.7	17.3	181.9	180.7	166.7	165.4
125 % NPK with double row on bed	194.6	197.2	181.2	186.6	19.0	18.9	17.7	17.8	179.9	174.8	166.8	162.9
CD (p=0.05)	8.8	7.7	NS	NS	1.9	1.0	NS	NS	NS	3.6	NS	NS
Interaction	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Initial status	188.2				23.4				193.2			

4.1.3.7.4 Soil pH and EC

The data pertaining to pH and EC at 0-15 and 15-30 cm of soil depth are presented in table 4.28. An appraisal of data revealed that treatments applied to main and sub plots did not significantly influence the pH and EC of soil at 0-15 and 15-30 cm soil depth during both the years. Numerically higher value of pH and EC was recorded under residue removal + 150% NPK treatment in main plot and 125% NPK applied to single row on bed in sub plot. After completion of two years of study, the soil pH and EC was decreased than its initial soil status.

Table 4.28: Effect of rice residue and nutrient application to preceding potato and nutrient levels to spring maize on soil pH and EC

Treatment	pH				EC (dsm^{-1})			
	0-15 cm		15-30 cm		0-15 cm		15-30 cm	
	2019	2020	2019	2020	2019	2020	2019	2020
Rice residue and nutrient application to preceding potato								
Straw removal + 100 % NPK+ FYM @ 50 t ha^{-1}	6.89	6.94	6.90	6.94	0.223	0.222	0.225	0.222
Straw removal + 150 % NPK	6.90	6.94	6.90	6.95	0.225	0.223	0.225	0.224
Straw incorporation + 100 % NPK+ FYM @ 50 t ha^{-1}	6.85	6.91	6.88	6.93	0.221	0.219	0.222	0.221
Straw incorporation + 150 % NPK	6.88	6.93	6.89	6.94	0.221	0.221	0.224	0.222
CD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Nutrient levels in spring maize								
75 % NPK with single row on bed	6.87	6.92	6.88	6.94	0.221	0.220	0.222	0.221
75 % NPK with double row on bed	6.85	6.92	6.88	6.93	0.219	0.218	0.221	0.220
100% NPK with single row on bed	6.90	6.94	6.90	6.96	0.224	0.222	0.225	0.224
100 % NPK with double row on bed	6.88	6.92	6.89	6.93	0.222	0.221	0.223	0.220
125 % NPK with single row on bed	6.91	6.93	6.91	6.96	0.224	0.224	0.226	0.225
125 % NPK with double row on bed	6.90	6.95	6.90	6.93	0.223	0.222	0.226	0.225
CD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Interaction	NS	NS	NS	NS	NS	NS	NS	NS
Initial status	7.2				0.244			

4.1.3.7.5 Organic carbon

Organic carbon of surface soil is considered as primary indicator of soil quality because this horizon receives the seed, fertilizers and other chemicals applied to it. It is the epicenter of soil physical, chemical and biological health. OC releases nutrients for plant growth, promotes the structure, biological and physical health of soil and act is a buffer against harmful substances. The data pertaining to organic carbon content in soil are presented in table 4.29. The results revealed that rice residue and nutrient application to potato had a significant effect on OC at 0-15 cm soil depth during both the years but it did not differed significantly with various nutrient levels applied to spring maize in sub plots at 0-15 and 15-30 cm soil depth during both the years. There was improvement in OC status of soil after harvesting of the crop where residue was incorporated along with application of 100% NPK + FYM @ 50 t ha^{-1} to the preceding crop. Mean OC content in 2019 at 0-15 cm depth was 0.40%, which was increased to 0.41% during 2020. The percent increase in OC under residue incorporation + 100% NPK + FYM @ 50 t ha^{-1} was 8.1 and 10.8% over residue removal + 150% NPK application during 2019 and 2020, respectively. The residue retained on the soil surface undergoes decomposition over a period of time and add organic matter to soil. The higher OC under residue + FYM incorporated plots might be due to higher accumulation of crop residue which also increases the availability of mineral nutrition. Jat *et al* (2013), Meena *et al* (2015) and Chaudhary *et al* (2017) also reported improvement in soil organic carbon content under residue retained plots as compared to residue removed plots. Organic carbon content of the soil was incrased in residue retained plot after harvesting of crop as compared to its initial status.

4.1.3.8 Soil physical properties

4.1.3.8.1 Bulk density

Soil bulk density affects the root penetration as well as soil aeration has important role in crop growth and development. Bulk density has significant effect on plant growth due to its effect on soil strength and porosity. With increase in bulk density, soil strength tends to increase and porosity tends to decrease, that limit root growth. Soil bulk density is a significant indicator of change of soil physical health and water retention capacity. The data pertaining to bulk density of soil (0-15 and 15-30 cm depth) during 2019 and 2020 are given in table 4.29. The data revealed that bulk density was significantly affected by rice residue and nutrient application to preceding potato during both the years but was not-significantly influenced by different nutrient levels applied to spring maize. The data revealed that the bulk density of soil was significantly higher (1.31 and 1.30 g cm^{-3}) under treatment where residue was removed and 150% NPK was applied during 2019 and 2020. Lower bulk density (1.28 and 1.26 g cm^{-3}) was recorded under residue incorporated plot along with 100% NPK + FYM @ 50 t ha^{-1} applied to the preceding crop. Incorporation of residue in to soil decreased the soil compactness and increased porosity. Meena *et al* (2015) also recorded reduction in bulk density under residue retained treatment. Bulk density of the soil was decreased after completion of two years of study as compared to its initial soil status.

Table 4.29: Effect of rice residue and nutrient application to preceding potato and nutrient levels to spring maize on soil OC and Bulk density

Treatment	OC (%)				Bulk density (g cm^{-3})			
	0-15 cm		15-30 cm		0-15 cm		15-30 cm	
	2019	2020	2019	2020	2019	2020	2019	2020
Rice residue and nutrient application to preceding potato								
Straw removal + 100 % NPK+ FYM @ 50 t ha^{-1}	0.38	0.39	0.35	0.35	1.29	1.27	1.30	1.31
Straw removal + 150 % NPK	0.37	0.37	0.33	0.34	1.31	1.30	1.31	1.32
Straw incorporation + 100 % NPK+ FYM @ 50 t ha^{-1}	0.40	0.41	0.36	0.37	1.28	1.26	1.30	1.30
Straw incorporation + 150 % NPK	0.39	0.40	0.34	0.35	1.30	1.28	1.31	1.31
CD (p=0.05)	0.01	0.01	NS	NS	0.02	0.02	NS	NS
Nutrient levels in spring maize								
75 % NPK with single row on bed	0.38	0.38	0.33	0.35	1.29	1.28	1.30	1.30
75 % NPK with double row on bed	0.39	0.39	0.35	0.35	1.29	1.28	1.30	1.31
100% NPK with single row on bed	0.38	0.39	0.34	0.35	1.30	1.28	1.31	1.31
100 % NPK with double row on bed	0.38	0.40	0.35	0.36	1.29	1.27	1.29	1.30
125 % NPK with single row on bed	0.38	0.40	0.35	0.35	1.30	1.28	1.31	1.31
125 % NPK with double row on bed	0.39	0.40	0.35	0.36	1.30	1.27	1.30	1.30
CD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Interaction	NS	NS	NS	NS	NS	NS	NS	NS
Initial status	0.33				1.34			

4.1.3.9 Economic analysis

4.1.3.9.1 Spring maize equivalent yield (SMEY)

The data regarding SMEY are given in table 4.30 and fig. 4.15. The results indicated that residue incorporation along with 100% NPK + FYM @ 50 t ha^{-1} applied to the preceding potato resulted in significantly higher SMEY (257.6 and 267.4 q ha^{-1}) as compared to 150% NPK applied with and without residue incorporation and this treatment was statistically at par with residue removal plot with application of 100% NPK + FYM @ 50 t ha^{-1} during 2019 and 2020, repectively. Lowest SMEY was recorded from application of 150% NPK without residue incorporation to preceding potato during both the years. Sepat *et al* (2015) observed that combined application of organic and inorganic fertilizers resulted in higher wheat equivalent yield as compared to only application of inorganic fertilizer.

Application of 125% NPK to double row on bed resulted in significantly higher SMEY (251.1 and 261.4 q ha^{-1}) as compared to lower nutrients levels i.e. 75% NPK, 100% NPK applied to both single and double rows on bed and 125% NPK applied to single row on bed during 2019 and 2020. SMEY was recorded to be minimum with application of 75% NPK to single row on bed during both the years. The increase in SMEY with application of 125% NPK to double row on bed was 4.6% and 4.0% higher as compared to application of 100% NPK to single row on bed during 2019 and 2020, respectively.

Table 4.30: Effect of rice residue and nutrient application to preceding potato and nutrient levels to spring maize on spring maize equivalent yield and system productivity of rice-potato-spring maize cropping system

Treatment	**Spring maize equivalent yield (q ha^{-1})**		**System productivity (kg $ha^{-1}day^{-1}$)**	
	2019	**2020**	**2019**	**2020**
Rice residue and nutrient application to preceding potato				
Straw removal + 100 % NPK+ FYM @ 50 t ha^{-1}	249.8	259.6	81.1	87.2
Straw removal + 150 % NPK	226.9	236.0	74.1	78.4
Straw incorporation + 100 % NPK+ FYM @ 50 t ha^{-1}	257.6	267.4	82.9	89.1
Straw incorporation + 150 % NPK	232.9	244.7	74.5	80.8
CD (p=0.05)	4.7	4.8	1.5	2.5
Nutrient levels in spring maize				
75 % NPK with single row on bed	233.9	243.3	75.4	81.1
75 % NPK with double row on bed	234.8	243.7	76.5	81.8
100% NPK with single row on bed	240.1	251.3	77.1	83.2
100 % NPK with double row on bed	244.1	255.3	79.2	85.2
125 % NPK with single row on bed	246.9	256.7	79.3	84.9
125 % NPK with double row on bed	251.1	261.4	81.3	87.1
CD (p=0.05)	3.0	3.8	1.1	1.3
Interaction	NS	NS	NS	NS

4.1.3.9.2 System productivity

The data pertaining to system productivity are presented in table 4.30 and fig. 4.15. The results revelaed that system productivity was significantly higher (82.9 and 89.1 kg ha^{-1} day^{-1}) from residue incorporated plots with application of 100% NPK + FYM @ 50 t ha^{-1} to the preceding potato crop during 2019 and 2020, respectively as compared to sole application of synthetic fertlizers i.e. 150% NPK applied with and without residue incorporation.

Whereas, this treatment was statistically at par with application of 100% NPK + FYM @ 50t ha^{-1} to preceding potato without residue incorporation during both years. Lowest values of system productivity were recorded with sole application of 150% NPK under residue removal treatment during both the years. According to Kumar and Mukhopadhyay (2017), system productivity in terms of wheat equivalent yield was significantly higher with combined use of FYM and fertilizers.

Among different nutrient levels applied to spring maize, treatment which involving 125% NPK applied to double row on bed resulted in significantly higher system productivity (81.3 and 87.1 kg ha^{-1} day^{-1}) as compared to all other treatments during 2019 and 2020, respectively. Application of 75% NPK to single row on bed resulted in lowest system productivity during both the years. System productivity was increased to a margin of 5.4% and 4.7% with application of 125% NPK to double row on bed as compared to 100% NPK applied to single row on bed during 2019 and 2020, respectively.

4.1.3.9.3 Cost of cultivation

The data for cost of cultivation of rice-potato-spring maize cropping system is presented in table 4.31. Application of 100% NPK + FYM @ 50 t ha^{-1} to the preceding potato crop along with straw incorporation resulted in higher cost of cultivation (193.4 and 199.3 $\times 10^3$ Rs ha^{-1}) during 2019 and 2020, respectively. The increase in cost cultivation under combined application of organic and inorganic fertilizer was only due to additional cost of FYM. Application of 150% NPK to preceding potato without residue incorporation recorded with minimum cost of cultivation during both the years.

Among different nutrient levels applied to spring maize, maximum cost of cultivation (191.6 and 197.4 $\times 10^3$ Rs ha^{-1}) was recorded from treatment consisting of 125% NPK applied to double row bed on, followed by 125% NPK applied to single row on bed. Application of 75% NPK to single row on bed recorded with lowest cost of cultivation during both the years.

4.1.3.9.4 Gross returns

Gross returns of rice-potato-spring maize cropping system are given in table 4.31 and fig. 4.16. Application of 100% NPK + FYM @ 50 t ha^{-1} to the preceding potato crop along with straw incorporation resulted in maximum gross returns (453.3 and 499.6 $\times 10^3$ Rs ha^{-1}) as compared to all other treatments during 2019 and 2020, respectively. Higher gross returns of the cropping system under combined use of organic and synthetic fertilizer source was due to higher grain yield of the crop under this treatment that fetches higher returns during both the years. Kumawat *et al* (2019) revealed that combined application of organic and inorganic fertilizer resulted in higher gross returns as compared to sole application of synthetic fertilizers.

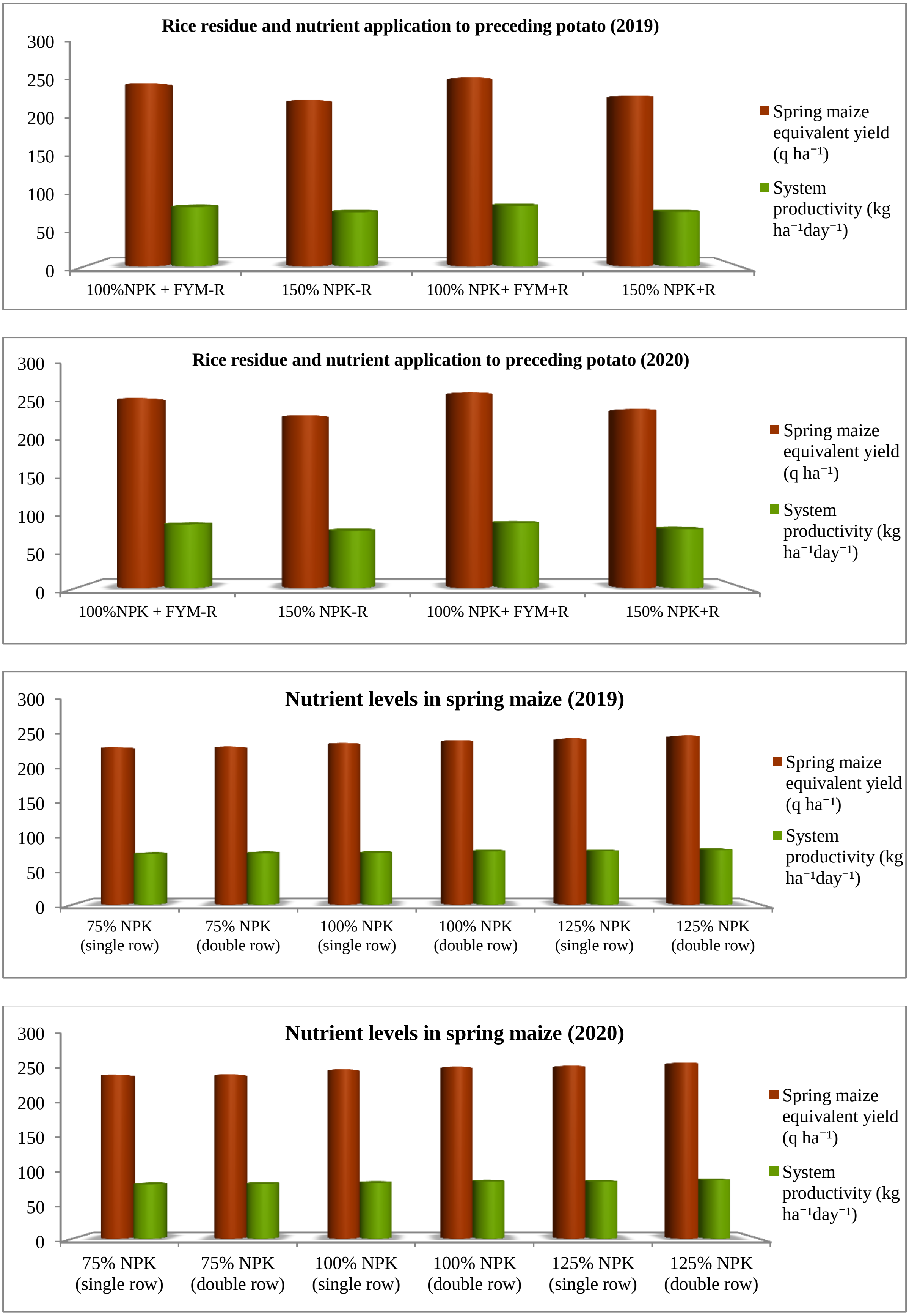


Fig. 4.15: Effect of rice residue and nutrient application to preceding potato and nutrient levels to spring maize on spring maize equivalent yield and system productivity of rice-potato-spring maize cropping system

Application of 125% NPK to double row on bed resulted in maximum gross returns (441.8 and 488.2 $\times 10^3$ Rs ha^{-1}) as compared to other treatments during 2019 and 2020, respectively. Minimum gross returns were obtained under the treatment consisting of 75% NPK applied to single row on bed. The per cent increase in gross returns with application of 125% NPK to double row on bed was 4.6% and 3.9% as compared to 100% NPK applied to single row on bed during both the years. Adhikari *et al* (2021) revealed that application of higher dose of nitrogen resulted in higher gross returns as compared to lower nitrogen levels.

4.1.3.9.5 Net returns

Data pertaining to net returns of rice-potato-spring maize cropping system are presented in table 4.31 and fig. 4.16. The data showed that net returns of the system was recorded to be maximum (259.9 and 300.2 $\times 10^3$ Rs ha^{-1}) from treatment involving application of 100% NPK + FYM @ 50 t ha^{-1} to the preceding potato crop along with residue incorporation followed by treatments involving 100% NPK + FYM @ 50 t ha^{-1} without residue incorporation, 150% NPK applied to preceding potato with residue incorporation and 150% NPK applied to preceding crop without residue incorporation during both the years. Highest net returns was attributed to higher gross returns obtained under this treatment. Minimum net returns of the system were recorded with application of 150% NPK to preceding potato without residue incorporation during both the years.

Application of 125% NPK to double row on bed recorded highest net returns (250.2 and 290.8 $\times 10^3$ Rs ha^{-1}) as compared to lower levels of fertilizer i.e. 75% NPK and 100% NPK applied to both single and double row on bed while, minimum net returns were obtained from single row on bed with 75% NPK application during 2019 and 2020. The per cent increase in net returns was 4.2% and 4.9% with application of 125% NPK to double row on bed as compared to 100% NPK applied to single row on bed during 2019 and 2020, respectively.

4.1.3.9.6 Benefit cost ratio

Benefit cost ratio (B:C) of rice-potato-spring maize cropping system are presented in table 4.31. Maximum B:C was obtained (1.34 and 1.51) from treatment involving the application of 100% NPK + FYM @ 50 t ha^{-1} to the preceding potato crop along with residue incorporation, followed by 100% NPK + FYM @ 50 t ha^{-1} without residue incorporation and 150% NPK applied with and without residue incorporation during both the years. Highest B:C was observed as a result of higher net returns obtained under this treatment during both the years. Chandel *et al* (2017) also recorded higher benefit cost ratio with conjoint application of organic and inorganic fertilizers.

Among various nutrient levels applied to spring maize, treatment involving application of 125% NPK to double row on bed recorded with higher B:C (1.30 and 1.47) as compared to all other treatments during 2019 and 2020. The increase in B:C under

Table 4.31: Effect of rice residue and nutrient application to preceding potato and nutrient levels to spring maize on economics of rice-potato-spring maize cropping system

Treatment	Cost of cultivation (×10^3 Rs ha^{-1})		Gross returns (×10^3 Rs ha^{-1})		Net returns (×10^3 Rs ha^{-1})		Benefit cost ratio		Profitability (Rs ha^{-1} day^{-1})	
	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020
Rice residue and nutrient application to preceding potato										
Straw removal + 100 % NPK+ FYM @ 50 t ha^{-1}	192.4	198.3	439.7	485.0	247.2	286.7	1.28	1.45	677.4	785.4
Straw removal + 150 % NPK	184.0	189.6	399.3	441.3	215.4	251.7	1.17	1.33	590.0	689.5
Straw incorporation + 100 % NPK+ FYM @ 50 t ha^{-1}	193.4	199.3	453.3	499.6	259.9	300.2	1.34	1.51	712.2	822.5
Straw incorporation + 150 % NPK	185.0	190.6	409.8	457.5	224.8	266.9	1.22	1.40	616.0	731.2
Nutrient levels in spring maize										
75 % NPK with single row on bed	186.2	192.0	411.6	454.9	225.4	262.9	1.21	1.37	617.6	720.3
75 % NPK with double row on bed	188.5	194.3	413.2	455.6	224.7	261.3	1.19	1.34	615.5	715.9
100% NPK with single row on bed	187.1	192.9	422.5	469.7	235.4	276.8	1.26	1.43	644.9	758.5
100 % NPK with double row on bed	189.4	195.2	429.6	477.0	240.2	281.7	1.27	1.44	658.1	771.9
125 % NPK with single row on bed	189.6	195.1	434.5	479.6	245.2	284.5	1.29	1.46	671.9	779.5
125 % NPK with double row on bed	191.6	197.4	441.8	488.2	250.2	290.8	1.30	1.47	685.4	796.9

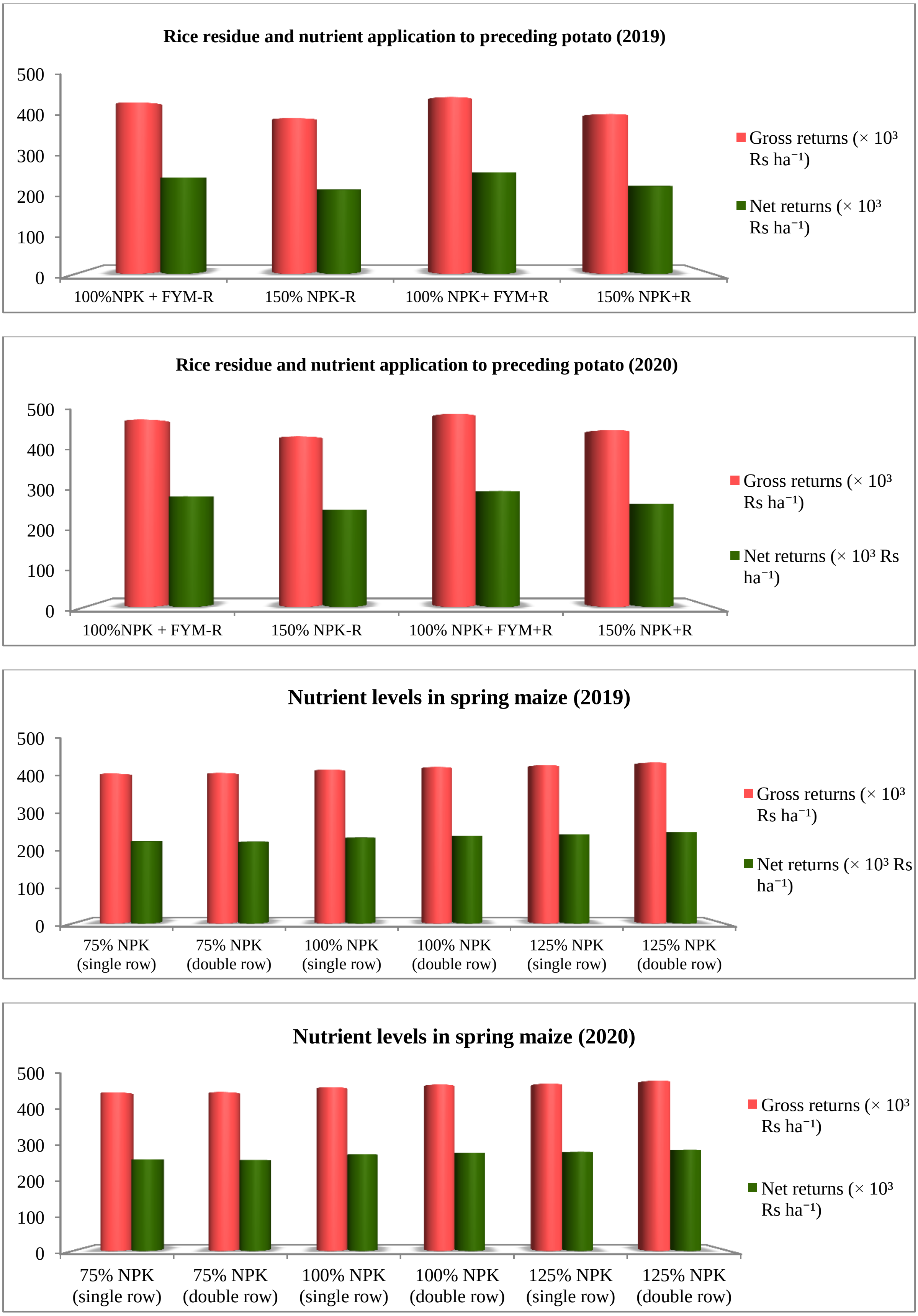


Fig. 4.16: Effect of rice residue and nutrient application to preceding potato and nutrient levels to spring maize on gross returns and net returns of rice-potato-spring maize cropping system

125% NPK application to double row on bed was up to a margin of 3.2 and 2.9% as compared to 100% NPK applied to single row on bed during 2019 and 2020, respectively. Raj *et al* (2021) revealed that application of higher dose of nitrogen resulted in higher B:C as compared to its lower dose.

4.1.3.9.7 Profitability

Data given in table 4.31 revealed that integrated nutrient management practices i:e application of 100% NPK + FYM @ 50 t ha^{-1} to the preceding potato crop along with straw incorporation resulted in significantly higher profitability (712.2 and 822.5 Rs ha^{-1} day^{-1}) as compared to 150% NPK applied with residue incorporation and residue removal + 150% NPK, but it was statistically at par with 100% NPK + FYM @ 50 t ha^{-1} without residue incorporation during both the years. The profitability was recorded to be lowest with application of 150% NPK without residue incorporation during both the years. Kumawat *et al* (2019) recorded higher profitability under mixed application of organic and inorganic fertilizers as compared to sole application of synthetic fertilizers.

Among different nutrient levels applied to spring maize, maximum profitability (685.4 and 796.9 Rs ha^{-1} day^{-1}) was recorded with application of 125% NPK to double row on bed which was statistically at par with 125% NPK application to single row on bed and significantly better than all other treatments during 2019 and 2020. Lowest profitability of the system was obtained from 75% NPK applied to single row on bed. Application of 125% NPK to double rows on bed increased the profitability up to margin of 6.3% and 5.0% as compared to 100% NPK applied to single row on bed during both the years.

4.2 EXPERIMENT II

The experiment entitled "Integrated nutrient management for enhancing productivity of *kharif* maize-pea-spring maize cropping system" was conducted in a split plot design and replicated three times in 2018-19 and 2019-20. The experiment comprised of 24 different treatment combinations, including *kharif* maize and pea in the main plots and spring maize in the sub plots. The impact of fertilizer application to preceding *kharif* maize and pea, as well as varying nutrient levels in spring maize, on growth and yield parameters was significant. For all of the parameters, the interaction effects were found to be non-significant.

4.2.1 *KHARIF* MAIZE

Kharif maize was grown as a general crop by following package and practices recommended by Punjab Agricultural University, Ludhiana. After harvesting *kharif* maize, pea was sown by randomizing four treatments in to main plots. Data pertaining to yield and yield attributes of *kharif* maize were recorded at maturity during 2018 and 2019 and are presented in table 4.32. The data recorded for plant height, cob length, cob girth, number of grains per cob and 1000-grain weight were 171.6 and 162.1 cm, 16.9 and 15.9 cm, 13.9 and 13.8 cm, 416 and 414 and 250 and 238.7 g during 2018 and 2019, respectively. The biological yield and grain yield of *kharif* maize was recorded to be 215.1 and 198.1 q ha^{-1} and 85.7 and 78.1 q ha^{-1} respectively during 2018 and 2019.

Table 4.32: Yield and yield attributes of *kharif* maize at maturity during 2018 and 2019

Sr. No.	Character	2018	2019
1	Plant height (cm)	171.6	162.1
2	Cob length (cm)	16.9	15.9
3	Cob girth (cm)	13.9	13.8
4	Number of grains per cob	416.0	414.0
5	1000-grain weight (g)	250.0	238.7
6	Biological yield (q ha^{-1})	215.1	198.1
7	Grain yield (q ha^{-1})	85.7	78.1

4.2.2 PEA

4.2.2.1 Pre harvest studies

4.2.2.1.1 Plant height

Plant height is a genetic character of a cultivar; it is also affected by the field conditions and agronomic manipulations in action during crop growth period. Plant height thus represents the gain in growth of the plant in relation to the field environment. Higher yield could be resulted from a better photosynthetic efficiency due to higher plant height and maximum number of leaves. Data pertaining to plant height of pea at different stages are presented in table 4.33 and fig. 4.17.

Table 4.33: Effect of nutrient application in preceding *kharif* maize and pea on plant height (cm) of pea

Nutrient application to preceding maize and pea	30 DAS		60 DAS		At maturity	
	2018-19	2019-20	2018-19	2019-20	2018-19	2019-20
Maize (100 % NPK) + Pea (100 % NPK)	13.9	17.6	30.7	46.8	40.1	56.8
Maize (100 % NPK) + Pea (100 % NPK + FYM @ 20 t ha^{-1})	13.7	20.3	32.8	50.3	41.5	61.0
Maize (100 % NPK+ FYM @ 15 t ha^{-1}) + Pea (100 % NPK)	14.0	18.7	32.2	48.5	41.4	57.6
Maize (100 % NPK + FYM @ 15 t ha^{-1}) + Pea (100 % NPK + FYM @ 20 t ha^{-1})	13.9	19.4	34.4	51.5	42.8	62.0
CD (p=0.05)	NS	NS	2.2	2.2	1.4	3.2

Plant height of pea did not vary significantly at 30 DAS with nutrient application to preceding maize and pea during both years. Plant height at 60 DAS and maturity was significantly higher (34.4, 51.5 cm and 42.8, 62.0 cm) in treatment consisting application of 100 % NPK + FYM @ 15 t ha^{-1} to *kharif* maize and 100 % NPK + FYM @ 20 t ha^{-1} to pea, and this treatment was statistically at par with treatment involving 100 % NPK application to maize and 100 % NPK + FYM @ 20 t ha^{-1} to pea during 2018-19 and 2019-20, respectively. It was significantly better than treatment which involves 100% NPK application to both maize and pea during both years. Application of 100% NPK to both maize and pea resulted in lowest plant height (30.7, 46.8 cm 40.1, 56.8 cm) at 60 DAS and maturity during 2018-19 and 2019-20, respectively. The increase in plant height under application of 100 % NPK + FYM @ 15 t ha^{-1} to *kharif* maize and 100 % NPK + FYM @ 20 t ha^{-1} to pea was up to a margin of 12.0, 10.4% and 6.7, 9.2% at 60 DAS and at maturity in comparison to 100% NPK to both the crops during 2018-19 and 2019-20, respectively. The higher plant height under integrated application of organic and inorganic nutrient sources might be due slow release of nutrients from organic manures when supplemented with inorganic fertilizers it helped microorganism in the faster decomposition of organic manures, thereby increases the availability of nutrient. This ultimately leads to higher growth and development of the plant. These findings are agreement with the findings of Sharma and Chauhan (2011) and Dubey *et al* (2012) who reported that application of FYM @ 3 t ha^{-1} + remaining PK (48:10 kg ha^{-1}) from chemical fertilizers resulted in maximum plant height of garden pea as compared to sole use of synthetic fertilizer.

4.2.2.1.2 Dry matter accumulation

Dry matter accumulation is a major indicator of plant development and metabolic efficiency, which has a significant impact on crop yield. It indicates the photosynthetic efficiency of the cultivar. The dry matter production and assimilation is expected to modify under various agronomic manipulations and also under various environmental factors. The dry matter portioning among various source and sink sites decides the final yield from the crop. Data with respect to DMA of pea are presented in table 4.34 and fig. 4.18. An analysis of data revealed that the DMA was significantly higher at 60 DAS and maturity (16.0, 17.2 g and 27.1, 31.4 g) under 100 % NPK + FYM @ 15 t ha^{-1} application to *kharif* maize and 100 % NPK + FYM @ 20 t ha^{-1} application to pea as compared to 100% NPK application to both maize and pea but it was at par with 100 % NPK to maize and 100 % NPK + FYM @ 20 t ha^{-1} to pea during both the years. However, the differences were not significant at 30 DAS during both the years. Minimum value for DMA was recorded when application of 100% NPK was done to both maize and pea during both the years. Application of 100 % NPK + FYM @ 15 t ha^{-1} to *kharif* maize and 100 % NPK + FYM @ 20 t ha^{-1} to pea increase the DMA up to a margin of 21.2, 26.4 and 14.8, 15.8% as compared to 100% NPK application to both maize and pea during 2018-19 and 2019-20, respectively.

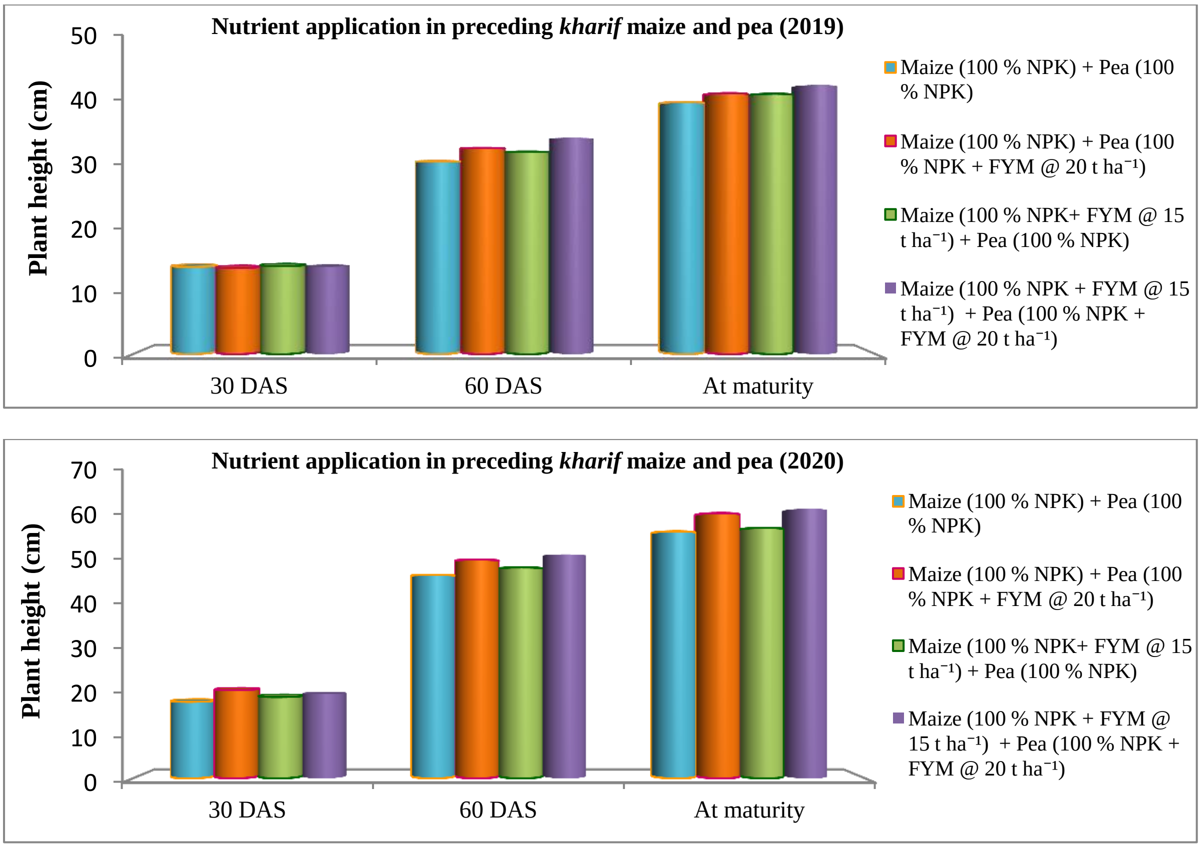


Fig. 4.17: Effect of nutrient application in preceding *kharif* maize and pea on plant height of pea

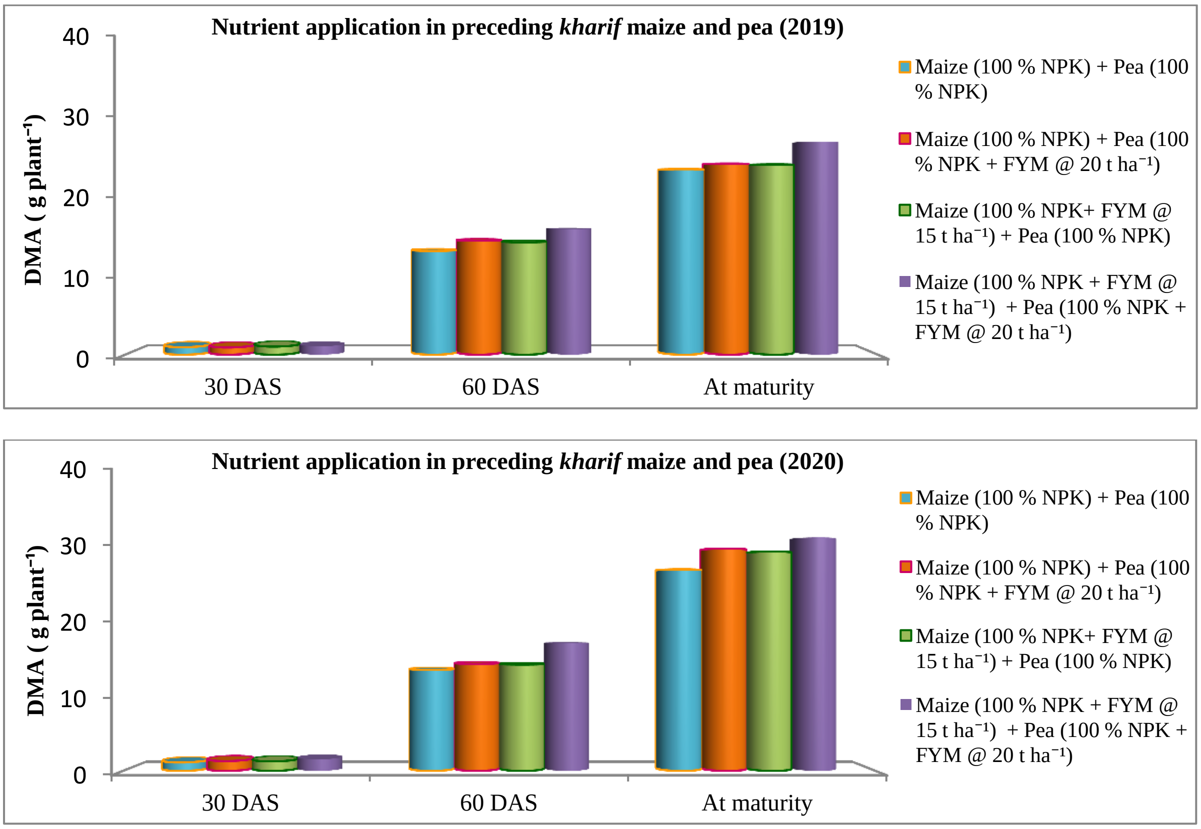


Fig. 4.18: Effect of nutrient application in preceding *kharif* maize and pea on DMA of pea

Maximum DMA under integrated use of organic and inorganic nutrient sources might be due to increased nutrient availability and improved soil physical condition that probably improved the plant height and number of leaves per plant. Higher plant height and photosynthetic area harvested more sunlight and accumulated more dry matter as compared to sole application of synthetic fertilizers. Jaipaul *et al* (2011), Kumari *et al* (2012) and Pawar *et al* (2017) also reported higher dry matter accumulation with combined application of organic and inorganic fertilizers when compared to sole use of inorganic fertilizers in garden pea.

Table 4.34: Effect of nutrient application in preceding *kharif* maize and pea on dry matter accumulation (g plant^{-1}) of pea

Nutrient application to preceding maize and pea	30 DAS		60 DAS		At maturity	
	2018-19	2019-20	2018-19	2019-20	2018-19	2019-20
Maize (100 % NPK) + Pea (100 % NPK)	0.96	1.14	13.2	13.6	23.6	27.1
Maize (100 % NPK) + Pea (100 % NPK + FYM @ 20 t ha^{-1})	0.92	1.33	14.5	14.4	24.3	29.9
Maize (100 % NPK+ FYM @ 15 t ha^{-1}) + Pea (100 % NPK)	1.03	1.28	14.3	14.3	24.2	29.5
Maize (100 % NPK + FYM @ 15 t ha^{-1}) + Pea (100 % NPK + FYM @ 20 t ha^{-1})	1.07	1.56	16.0	17.2	27.1	31.4
CD (p=0.05)	NS	NS	1.8	1.8	1.9	2.3

4.2.2.1.3 Leaf area index

Leaves are food production factories for the plant which carry over the process of photosynthesis to produce assimilates and thus adding dry matter to the plant. LAI decides the photosynthetic capacity and the source strength in the source-sink relationship. It directly indicates the total leaf area that is available for photosynthesis. The periodic LAI of pea was presented in table 4.35 and fig. 4.19. Leaf area was maximum at 60 DAS and it was decreases at maturity due to senescence of leaves. LAI at 30 DAS was recorded to be non-significant with nutrient application to preceding maize and pea during both the years. A significantly higher LAI at 60 DAS (3.0 and 3.08) and at maturity (0.87 and 0.90) was recorded with application of 100 % NPK + FYM @ 15 t ha^{-1} to maize and 100 % NPK + FYM @ 20 t ha^{-1} to pea as compared to all other treatments during 2018-19 and 2019-20, respectively.

Application of 100% NPK to both maize and pea recorded smallest values for LAI, which was statistically at par with 100 % NPK+ FYM @ 15 t ha^{-1} to maize and 100 % NPK to pea during both the years. In 2018-19 and 2019-20, the per cent increase in LAI under 100% NPK + FYM @ 15 t ha^{-1} to maize and 100% NPK + FYM @ 20 t ha^{-1} to pea was 48.5, 27.2 and 26.0, 42.9% higher at 60 DAS and maturity as compared to sole application of synthetic fertilizers, i.e. 100% NPK application to both maize and pea.

The higher LAI under integrated application of organic and inorganic nutrient sources might be due to higher plant height and number of leaves per plant. Integrated application of organic manure and synthetic fertilizers provided adequate nutrients for plant growth and improved the microclimatic environment of the plant that ultimately leads to higher crop canopy development. Wanniang *et al* (2017) also reported maximum leaf area index in maize with combined application of FYM @ 5 t ha^{-1} and 75% RDF as compared to sole use of 100% RDF in vegetable pea-maize cropping system.

Table 4.35: Effect of nutrient application in preceding *kharif* maize and pea on leaf area index of pea

Nutrient application to preceding maize and pea	30 DAS		60 DAS		At maturity	
	2018-19	**2019-20**	**2018-19**	**2019-20**	**2018-19**	**2019-20**
Maize (100 % NPK) + Pea (100 % NPK)	0.23	0.28	2.02	2.42	0.69	0.63
Maize (100 % NPK) + Pea (100 % NPK + FYM @ 20 t ha^{-1})	0.20	0.29	2.50	2.64	0.73	0.81
Maize (100 % NPK+ FYM @ 15 t ha^{-1}) + Pea (100 % NPK)	0.23	0.25	2.36	2.55	0.70	0.76
Maize (100 % NPK + FYM @ 15 tha^{-1}) + Pea (100 % NPK + FYM @ 20 t ha^{-1})	0.23	0.33	3.00	3.08	0.87	0.90
CD (p=0.05)	NS	NS	0.30	0.23	0.11	0.14

4.2.2.1.4 Chlorophyll index

The chlorophyll content of leaves is assessed by the chlorophyll index. A higher chlorophyll index shows darker foliage as compared to lower chlorophyll index. Greenery enhances photosynthetic rate, resulting in more photosynthates accumulation at the sink. A thorough analysis of data on chlorophyll index showed that it differed extensively with the utility of various treatments (Table 4.36 and fig. 4.20). Chlorophyll index recorded at 30 DAS was found to be non-significant during both the years. It was significantly higher at 60 DAS (37.3 and 39.8) and at maturity (23.1 and 24.1) under treatment which involving application of 100 % NPK + FYM @ 15 t ha^{-1} to maize and 100 % NPK + FYM @ 20 t ha^{-1} to pea as compared to other treatments during 2018-19 and 2019-20, respectively but was at par with 100 % NPK to maize + 100 % NPK + FYM @ 20 t ha^{-1} to pea and 100 % NPK+ FYM @ 15 t ha^{-1} to maize + 100 % NPK to pea at maturity during 2018-19. Minimum value of chlorophyll index was recorded under 100% NPK application to both maize and pea. Integrated use of organic and inorganic fertilizer improves the N availability in soil which was available to plant in adequate quantity. Higher N availability was due to N fixation by the

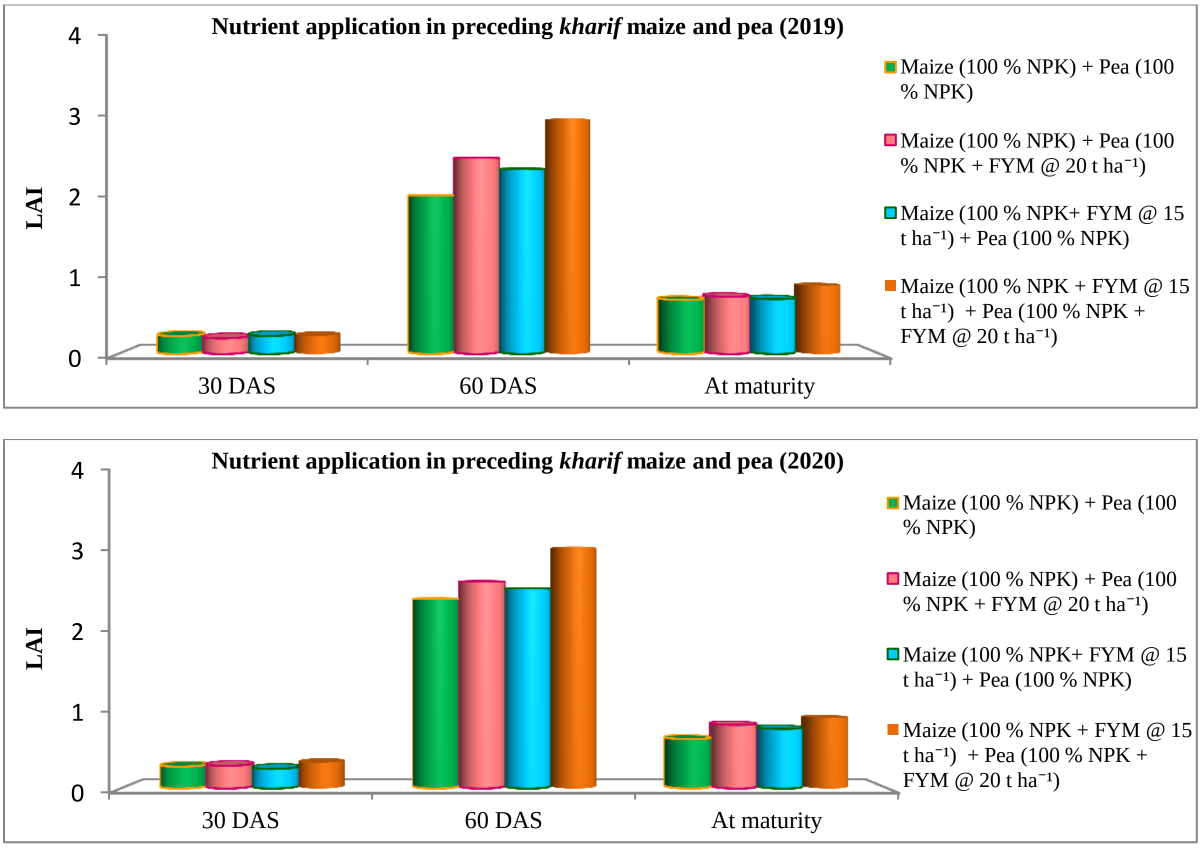


Fig. 4.19: Effect of nutrient application in preceding *kharif* maize and pea on LAI of pea

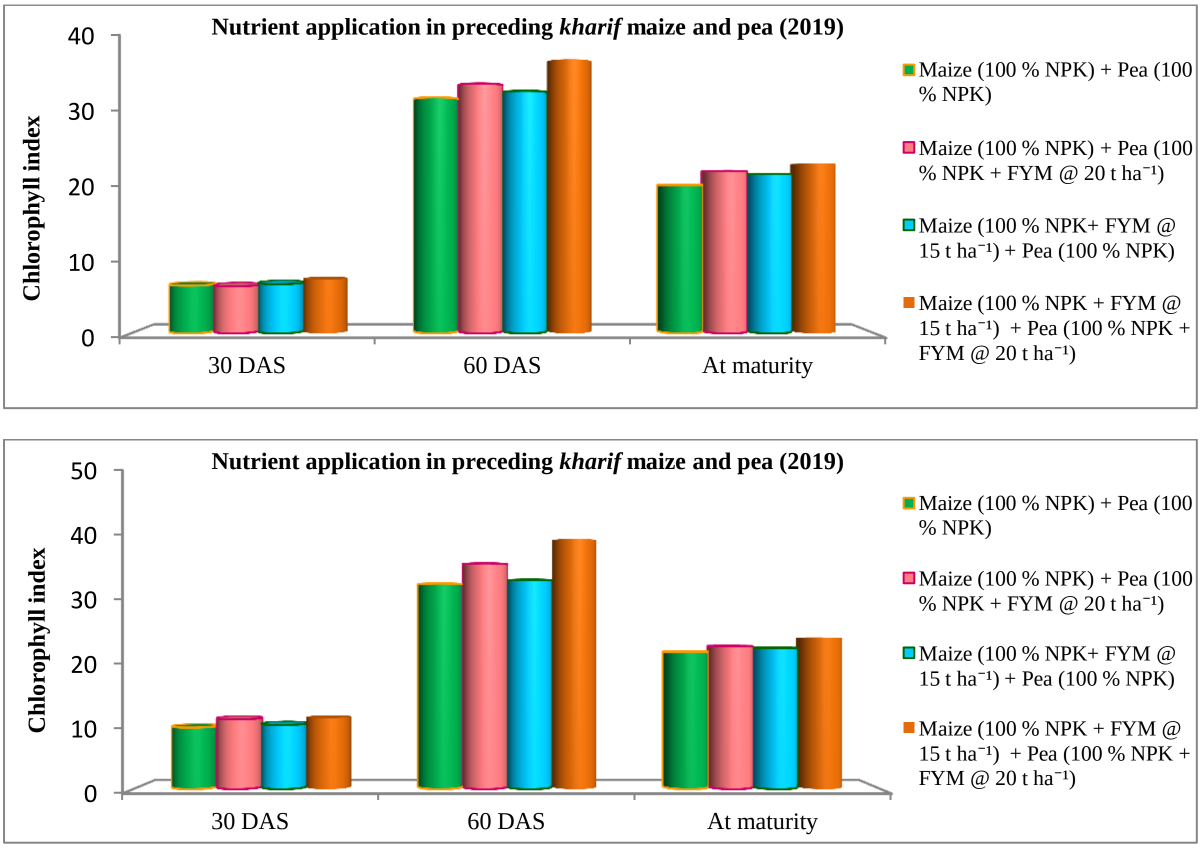


Fig. 4.20: Effect of nutrient application in preceding maize and pea on chlorophyll index of pea

legumes made the N availability more and also increased chlorophyll index in leaves. Snehaa *et al* (2019) recorded higher chlorophyll index with mixed application of organic manures and inorganic fertilizers.

Table 4.36: Effect of nutrient application in preceding *kharif* maize and pea on chlorophyll index of pea

Nutrient application to preceding maize and pea	30 DAS		60 DAS		At maturity	
	2018-19	2019-20	2018-19	2019-20	2018-19	2019-20
Maize (100 % NPK) + Pea (100 % NPK)	6.5	9.8	32.1	32.7	20.2	21.8
Maize (100 % NPK) + Pea (100 % NPK + FYM @ 20 t ha^{-1})	6.4	11.1	34.0	35.9	22.1	22.7
Maize (100 % NPK+ FYM @ 15 t ha^{-1}) + Pea (100 % NPK)	6.7	10.2	33.0	33.3	21.7	22.4
Maize (100 % NPK + FYM @ 15 tha^{-1}) + Pea (100 % NPK + FYM @ 20 t ha^{-1})	7.3	11.3	37.3	39.8	23.1	24.1
CD (p=0.05)	NS	NS	3.0	3.2	1.5	1.3

4.2.2.2 Post harvest studies

4.2.2.2.1 Number of pods per plant

Number of pods per plant is an indicator of plant reproductive growth. Number of pods per plant is an important parameter which directly related to pod yield. More number of pods per plant leads to higher pod yield. A scrutiny of the mean data presented in table 4.37 and fig. 4.21 indicated that application of inorganic fertilizers coupled with FYM had a profound effect on number of pods per plant.

Application of 100 % NPK + FYM @ 15 t ha^{-1} to maize and 100 % NPK + FYM @ 20 t ha^{-1} to pea resulted in maximum number of pods per plant (23.2 and 22.7), followed by 100 % NPK to maize and 100 % NPK + FYM @ 20 t ha^{-1} to pea, which was also statistically at par with 100 % NPK + FYM @ 15 t ha^{-1} to maize and 100 % NPK + FYM @ 20 t ha^{-1} to pea during both the year. Lowest number of pods per plant (18.5 and 19.4) was recorded under treatment which involves 100% NPK application to both maize and pea during 2018-19 and 2019-20. The per cent increase in number of pods per plant under 100 % NPK + FYM @ 15 t ha^{-1} to maize and 100 % NPK + FYM @ 20 t ha^{-1} to pea was 25.4 and 17.0% over 100% NPK applied to both maize and pea during 2018-19 and 2019-20, respectively. Treatments having combined application of organic and inorganic nutrient resulted with maximum number of pods per plant as compared to sole application of synthetic fertilizer. This may be attributed to greater root extension under integrated nutrient management that might have helped in greater uptake of different macro and micronutrients and enhanced photosynthesis and photosynthates production and ultimately increased number of pods per plant. These results are in conformity with findings of Singh and Singh (2002), Meena *et al* (2007) and

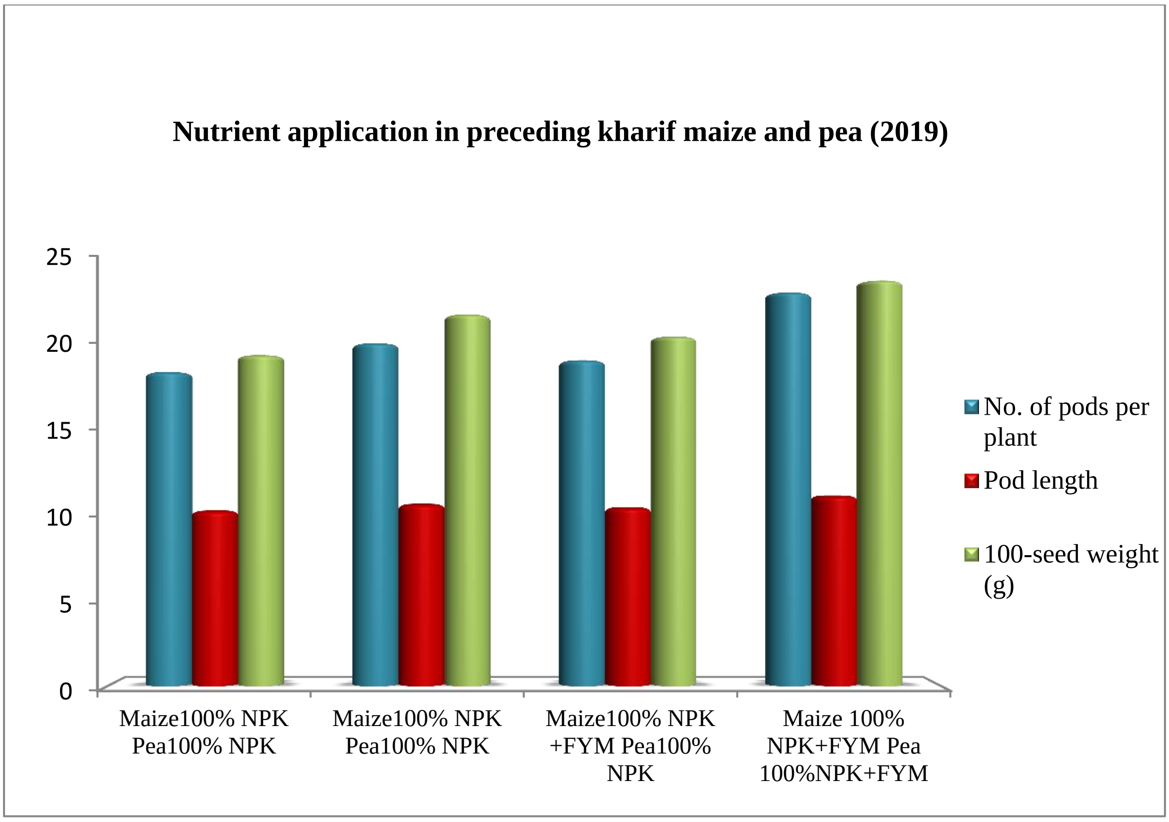
Chattoo *et al* (2009) who observed higher number of pods per plant under mixed application of poultry manure and synthetic fertlizers as compared to use of 100% RDF alone in garden pea.

Table 4.37: Effect of nutrient application in preceding *kharif* maize and pea on number of pods per plant and pod length of pea

Nutrient application to preceding maize and pea	Number of pods per plant		Pod length (cm)	
	2018-19	2019-20	2018-19	2019-20
Maize (100 % NPK) + Pea (100 % NPK)	18.5	19.4	10.3	10.2
Maize (100 % NPK) + Pea (100 % NPK + FYM @ 20 t ha^{-1})	20.2	22.0	10.7	10.7
Maize (100 % NPK+ FYM @ 15 t ha^{-1}) + Pea (100 % NPK)	19.2	21.1	10.5	10.4
Maize (100 % NPK + FYM @ 15 t ha^{-1}) + Pea (100 % NPK + FYM @ 20 t ha^{-1})	23.2	22.7	11.2	11.4
CD (p=0.05)	3.0	2.2	0.4	0.6

4.2.2.2.2 Pod length

Pod length is also an important character from yield point of view. More the length more will be the number of seeds and ultimately leads higher pod yield. Data for pod length are collected and presented in table 4.37 and fig. 4.21. Pod length of pea was recorded to be significantly higher (11.2 and 11.4 cm) under application of 100 % NPK + FYM @ 15 t ha^{-1} to maize and 100 % NPK + FYM @ 20 t ha^{-1} to pea during 2018-19 and 2019-20, respectively as compared to all other treatments. Application of 100 % NPK to maize and 100 % NPK + FYM @ 20 t ha^{-1} to pea also resulted in more pod length and it was statistically at par with 100 % NPK + FYM @ 15 t ha^{-1} to maize and 100 % NPK to pea during both the year. Minimum pod length (10.3 and 10.2 cm) was recorded under treatment consisting of 100% NPK application to both maize and pea during 2018-19 and 2019-20. The increase in pod length under 100 % NPK + FYM @ 15 t ha^{-1} to maize and 100 % NPK + FYM @ 20 t ha^{-1} to pea was 8.7 and 11.7% over treatment involving 100% NPK applied to both maize and pea during 2018-19 and 2019-20, respectively. The results showed that maximum pod length was found in treatment which involves integrated application of organic and inorganic fertilizers to both maize and pea as compared to sole application of inorganic fertilizer. This may be due to adequate and balanced supply of nutrient from integrated nutrient management and plant received large amount of nutrient throughout their growth period and nourished properly which enhanced yield attributing characters. Pandey *et al* (2006) and Gopinath and Mina (2011) also reported that integrated nutrient management i.e. application of RDF + FYM recorded maximum pod length than use of RDF alone in garden pea.



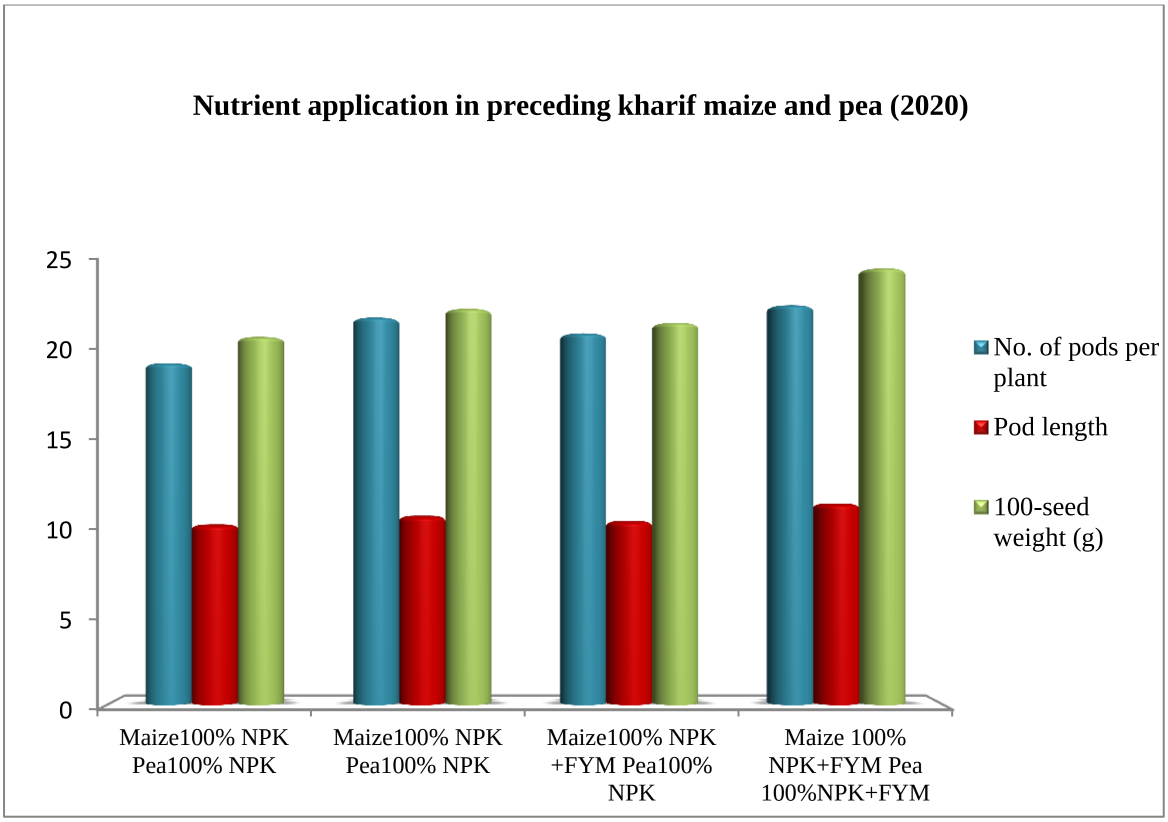


Fig. 4.21 Effect of nutrient application in preceding maize and pea on number of pods per plant, pod length and 100-seed weight of pea

4.2.2.2.3 Number of seeds per pod

The edible part of the pea is the seeds. So number of seeds per pod plays an important role in consumption point of view. Number of seeds per pod is another yield parameter which is likely to variant with climatic and management practices. Data with respect to number of seeds per pod are presented in table 4.38. Maximum number of seeds per pod was recorded with application of 100 % NPK + FYM @ 15 t ha^{-1} to maize and 100 % NPK + FYM @ 20 t ha^{-1} to pea (9.3 and 9.6), followed by application of 100 % NPK to maize and 100 % NPK + FYM @ 20 t ha^{-1} to pea which was statistically at par with 100 % NPK + FYM @ 15 t ha^{-1} to maize and 100 % NPK + FYM @ 20 t ha^{-1} to pea and significantly better than sole application of synthetic fertilizer during both the year. During 2018-19 and 2019-20, the treatment with 100% NPK application to both maize and pea produced the lowest number of seeds per pod (8.4 and 8.2). The number of seeds per pod was increase up to a margin of 10.7 and 17.0% under 100 % NPK + FYM @ 15 t ha^{-1} to maize and 100 % NPK + FYM @ 20 t ha^{-1} to pea over 100% NPK applied to both maize and pea during 2018-19 and 2019-20, respectively. This was due to the fact that seed development and filling was improved by better uptake of nutrients from combined application of organic and inorganic nutrients. Integrated nutrient management in the system provides 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 in number of seeds per pod. Nandi (2008) and Jaipaul *et al* (2011) reported higher number of seeds per pod under combined use of recommmeded dose of fertilizer and FYM in garden pea.

Table 4.38: Effect of nutrient application in preceding *kharif* maize and pea on number of seeds per pod and 100-seed weight of pea

Nutrient application to preceding maize and pea	Number of seeds per pod		100-seed weight (g)	
	2018-19	2019-20	2018-19	2019-20
Maize (100 % NPK) + Pea (100 % NPK)	8.4	8.2	19.5	20.9
Maize (100 % NPK) + Pea (100 % NPK + FYM @ 20 t ha^{-1})	8.7	8.9	21.9	22.5
Maize (100 % NPK+ FYM @ 15 t ha^{-1}) + Pea (100 % NPK)	8.5	8.7	20.6	21.7
Maize (100 % NPK + FYM @ 15 t ha^{-1}) + Pea (100 % NPK + FYM @ 20 t ha^{-1})	9.3	9.6	23.9	24.8
CD (p=0.05)	0.7	0.7	2.9	2.6

4.2.2.2.4 100-seed weight

Data with respect to 100-seed weight are presented in table 4.38 and fig. 4.21. Application of 100 % NPK + FYM @ 15 t ha^{-1} to maize and 100 % NPK + FYM @ 20 t ha^{-1} to pea recorded significantly higher 100-seed weight (23.9 and 24.8 g) during 2018-19 and 2019-20, respectively as compared to 100% NPK application to both maize and pea but this treatment was statistically at par to 100 % NPK to maize and 100 % NPK + FYM @ 20 t ha^{-1} application to pea. The 100-seed weight was recorded to be less (19.5 and 20.9 g) under 100% NPK application to both maize and pea during both the years. Supply of 100 % NPK + FYM @ 15 t ha^{-1} to maize and 100 % NPK + FYM @ 20 t ha^{-1} to pea increased the hundred seed weight up to 22.6 and 18.7% over 100% NPK applied to both maize and pea during 2018-19 and 2019-20, respectively. Integrated application of organic and inorganic fertilizer may enhance 100-seed weight by supplying nutrients in a balanced form which reflected on high photosynthetic efficiency and consequently translocation of assimilates towards reproductive part. Singh *et al* (2017), Biswas *et al* (2020) and Mahato *et al* (2020) reported higher 100-seed weight under conjoint application of organic and inorganic fertilizers as compared to sole application of synthetic fertilizers.

4.2.2.2.5 Pod yield

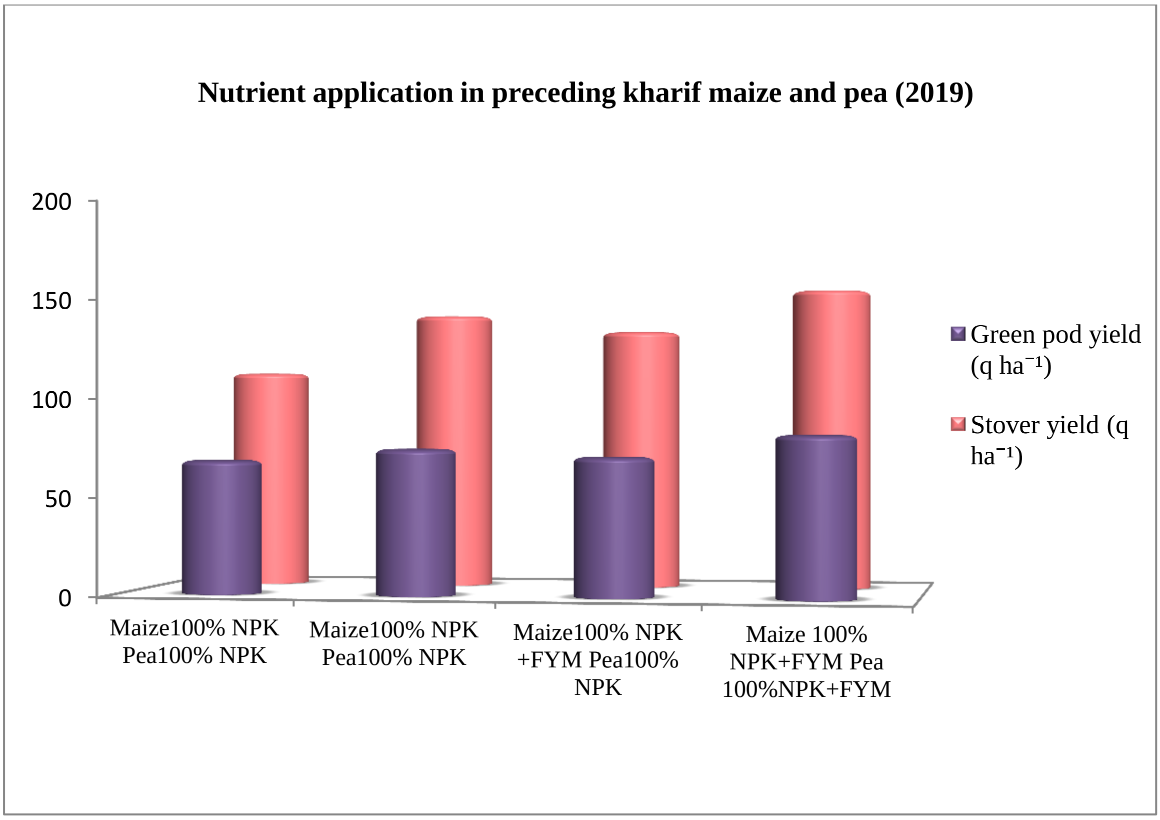
Yield is of paramount importance in the field of agriculture as it directly correlated with net returns and benefit cost ratio. A perusal of the data given in table 4.39 and fig. 4.22 showed that significantly higher pod yield was recorded (82.1 and 104.6 q ha^{-1}) under treatment which consists application of 100 % NPK + FYM @ 15 t ha^{-1} to maize and 100 % NPK + FYM @ 20 t ha^{-1} to pea during 2018-19 and 2019-20, respectively and it was on par with the treatment involving application of 100 % NPK to maize and 100 % NPK + FYM @ 20 t ha^{-1} to pea. During 2018-19 and 2019-20, sole use of synthetic fertilizers i.e 100% NPK application to both maize and pea resulted in minimum pod yield (68.6 and 82.9 q ha^{-1}). The increase in pod yield up to a margin of 19.7 and 26.1% was observed under application of 100 % NPK + FYM @ 15 t ha^{-1} to maize and 100 % NPK + FYM @ 20 t ha^{-1} to pea during 2018-19 and 2019-20, respectively, over 100% NPK applied to both maize and pea. This may be due to the fact that initially the chemical fertilizers provided rapidly better nutrition with all essential nutrients and their uptake by the plant which leads to better plant growth. In latter stages, the required plant nutrients are provided through decomposed organic manures for better development of the plants which in turn resulted into higher yield of the crop. These findings are in agreement with those of Kumari *et al* (2012), Sepehya *et al* (2012) and Pawar *et al* (2017) who reported higher pod yield under integrated application of organic manure and synthetic fertlizers in garden pea.

Table 4.39: Effect of nutrient application in preceding *kharif* maize and pea on pod yield and stover yield of pea

Nutrient application to preceding maize and pea	**Pod yield ($q\ ha^{-1}$)**		**Stover yield ($q\ ha^{-1}$)**	
	2018-19	**2019-20**	**2018-19**	**2019-20**
Maize (100 % NPK) + Pea (100 % NPK)	68.6	82.9	114.0	145.0
Maize (100 % NPK) + Pea (100 % NPK + FYM @ 20 t ha^{-1})	74.6	93.3	144.8	182.3
Maize (100 % NPK+ FYM @ 15 t ha^{-1}) + Pea (100 % NPK)	70.8	84.7	135.9	152.0
Maize (100 % NPK + FYM @ 15 t ha^{-1}) + Pea (100 % NPK + FYM @ 20 t ha^{-1})	82.1	104.6	157.5	193.3
CD (p=0.05)	8.1	11.8	25.8	24.6

4.2.2.2.6 Stover yield

The data given in table 4.39 and fig. 4.22 revealed that integrated application of organic and inorganic nutrients significantly influence the stover yield of pea. Conjoint application of organic and synthetic fertilizer i.e. 100 % NPK + FYM @ 15 t ha^{-1} to maize and 100 % NPK + FYM @ 20 t ha^{-1} to pea resulted in significantly higher stover yield (157.5 and193.3 q ha^{-1}) in comparison to 100% NPK application to both maize and pea, but it was statistically at par with 100 % NPK application to maize and 100 % NPK + FYM @ 20 t ha^{-1} to pea during both the years. With application of 100 % NPK + FYM @ 15 t ha^{-1} to maize and 100 % NPK + FYM @ 20 t ha^{-1} to pea, the increase in stover yield was 38.2 and 33.3 % as compared to 100% NPK applied to both maize and pea during 2018-19 and 2019-20, respectively. During both years, 100% NPK application to both maize and pea resulted in the lowest stover yield (114.0 and 145.0 q ha^{-1}). Higher stover yield in integrated nutrient management was due to better nutrient and water availability leads to better plant height, dry matter accumulation and leaf area of the plant which ultimately recorded higher stover yield. Pawar *et al* (2017) also reported higher growth of the plant and stover yield with combined application of organic fertilizers along with chemical fertilizers as compared to sole use chemical fertilizers.



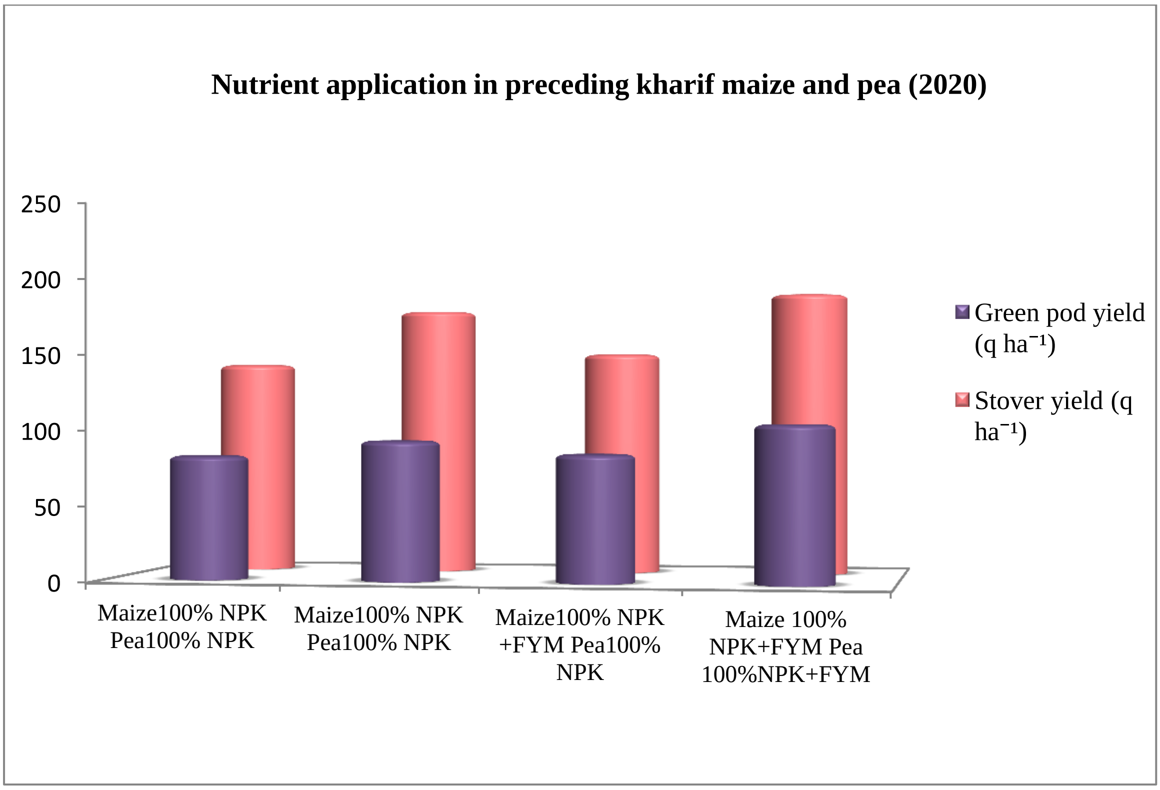


Fig. 4.22: Effect of nutrient application in preceding maize and pea on pod and stover yield of pea

FYM application

Field layout

Seed inoculation

Sowing

Plate 11: Agronomic operations in pea field

Plate 12: Agronomic operations in pea field

Plate 13: Treatments randomized in pea field

Plate 14: Harvesting of pea

4.2.3 SPRING MAIZE

4.2.3.1 Biometric observations

4.2.3.1.1 Plant height

Plant height is a measure of growth and development that represents infrastructure development over time. It depends upon genetic constitution of a particular cultivar and may also vary due to different agronomic intervention. The data for plant height of spring maize are given in table 4.40 and fig. 4.23. The height of spring maize plants increased progressively over time, peaking between 60 and 90 days after sowing. The data revealed that the nutrient applied to preceding *kharif* maize and pea, as well as the nutrient applied to spring maize had a significant impact on the periodic plant height of spring maize. During both the years, plant height did not differ significantly at 30 DAS with the nutrition applied to the preceding *kharif* maize and pea.

Table 4.40: Effect of nutrient application to preceding *kharif* maize and pea and nutrient levels to spring maize on plant height (cm) in spring maize

Treatment	30 DAS		60 DAS		90 DAS		At maturity	
	2019	**2020**	**2019**	**2020**	**2019**	**2020**	**2019**	**2020**
Nutrient application in preceding *kharif* maize and pea								
Maize (100 % NPK) + Pea (100 % NPK)	25.2	26.2	122.9	128.4	218.2	222.6	226.5	228.2
Maize (100 % NPK) + Pea (100 % NPK + FYM @ 20 t ha^{-1})	25.9	26.5	131.2	135.8	226.6	229.4	232.6	236.2
Maize (100 % NPK+ FYM @ 15 t ha^{-1}) + Pea (100 % NPK)	26.7	26.3	127.3	131.3	223.9	225.6	231.5	233.6
Maize (100 % NPK + FYM @ 15 t ha^{-1}) + Pea (100 % NPK + FYM @ 20 t ha^{-1})	27.1	27.0	133.3	137.7	231.2	234.7	238.1	241.5
CD (p=0.05)	NS	NS	7.0	6.7	7.5	8.0	7.3	7.9
Nutrient levels in spring maize								
75 % NPK with single row on bed	24.6	25.6	126.6	130.2	223.2	226.6	232.5	233.3
75 % NPK with double row on bed	24.1	25.1	112.7	121.4	212.9	214.9	216.0	220.1
100% NPK with single row on bed	25.9	27.1	135.2	138.4	230.8	233.2	237.9	239.7
100 % NPK with double row on bed	24.9	26.3	120.5	128.5	219.2	225.0	227.9	231.6
125 % NPK with single row on bed	29.6	28.1	146.9	144.8	234.0	237.9	245.0	247.4
125 % NPK with double row on bed	28.3	26.8	130.4	136.5	229.8	230.9	233.8	237.0
CD (p=0.05)	2.3	1.5	6.9	7.4	9.3	8.0	6.4	8.1
Interaction	NS	NS	NS	NS	NS	NS	NS	NS

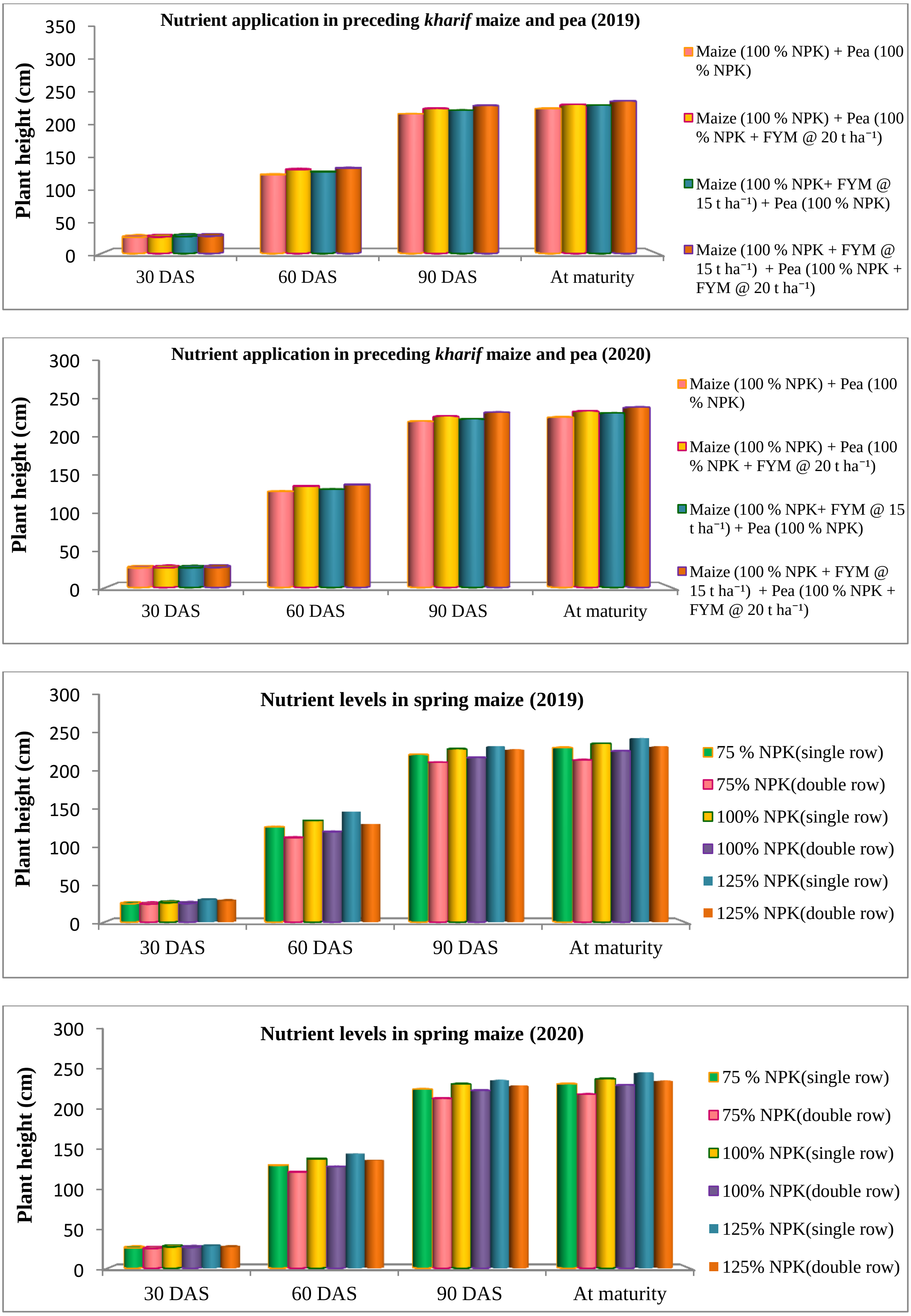


Fig. 4.23: Effect of nutrient application to preceding *kharif* maize and pea and nutrient levels to spring maize on plant height in spring maize

At 60, 90 DAS and at maturity, application of 100 % NPK + FYM @ 15 t ha^{-1} to maize and 100 % NPK + FYM @ 20 t ha^{-1} to pea recorded maximum plant height (133.3, 137.7 cm, 231.2, 234.7 cm and 238.1, 241.5 cm) and this treatment was statistically at par with 100 % NPK application to maize and 100 % NPK + FYM @ 20 t ha^{-1} to pea and 100 % NPK + FYM @ 15 t ha^{-1}application to maize and 100 % NPK to pea but was significantly better than sole use of inorganic fertilizers i.e. 100% NPK application to both *kharif* maize and pea during both the years. The minimum plant height was observed when 100% NPK was applied to both *kharif* maize and pea at all growth stages, but was statistically comparable when 100% NPK + FYM @ 15 t ha^{-1} was applied to maize and 100% NPK was applied to pea during both years. The tallest plant due to conjunctive application of FYM and chemical nitrogen fertilizer to the preceding crops might be due to the more availability of plant nutrients, enzymes, vitamins and congenial soil characters which helped the plant to uptake more soil nutrients along with water. This result was corroborated by Mahapatra *et al* (2018) in baby corn. Dhiman (2014) and Biswasi *et al* (2020) who also reported that application of fertilizers along with FYM and vermicompost resulted in tallest plants in comparision to application of chemical fertilizer only.

The data given in table 4.40 showed that different nutrient levels applied in spring maize showed a significant impact on plant height at 30, 60 and 90 DAS, as well as at maturity, during both the years. Plant height was significantly higher (29.6, 28.1 cm, 146.6, 144.8 cm, 234.0, 237.9 cm and 245.0, 247.4 cm) at 30, 60 and 90 DAS and at maturity during 2019 and 2020 with the application of 125% NPK to single row on bed. However, it was statistically at par with 100% NPK applied to single row on bed at 90 DAS during both the years and at 30, 60 DAS and at maturity during 2020. It was also at par with 125% NPK application to double row on bed at 30 and 90 DAS during both the years. At all growth stages the addition of 75% NPK to double row on bed resulted in the lowest plant height during both years. Higher plant height recorded under higher fertilizer levels could be attributed to a mere fact that higher rates of nitrogen may have caused rapid cell division and elongation. Sarwargaonkar *et al* (2008) and Gul *et al* (2015) reported significant increase in the plant height of maize with higher RDF as compared to lower dose. Plant height reduced as plant stand increased in spring maize, compared to lower plant stands, possibly because sparsely populated plants received more light and nutrients than densely populated plants. Tajul *et al* (2013) also reported a similar outcome as above. Pandey et al (2000) revealed that plant height increased greatly when maize seeds were sparingly sown and a sufficient amount of fertilizer was provided to them.

4.2.3.1.2 Dry matter accumulation

Dry matter accumulation (DMA) is a key indicator of plant development and metabolic efficiency, which has a direct impact on crop yield. The amount of photosynthates that can be translocated to the grain during filling is determined by dry matter accumulation, which is an essential driver of grain production in cereals. The data recorded for DMA on per plant basis at 30, 60, 90 DAS and at maturity is presented in table 4.41 and fig. 4.24. The amount of dry matter accumulated increased as the crop got older and the highest DMA values were found when the crop was fully mature. At 30 DAS the DMA in spring maize did not vary significantly with nutrient applied to preceding maize and pea during both the years. The data revealed that DMA was significantly higher (95.3, 97.6 g, 221.4, 223.9 g and 321.4, 334.2 g) in treatment involving application of 100 % NPK + FYM @ 15 t ha^{-1} to maize and 100 % NPK + FYM @ 20 t ha^{-1} to pea, which was statistically at par with treatment consisting of 100 % NPK to maize and 100 % NPK + FYM @ 20 t ha^{-1} to pea at 60, 90 DAS and at maturity during 2019 and 2020, respectively.

Table 4.41 Effect of nutrient application to preceding *kharif* maize and pea and nutrient levels to spring maize on dry matter accumulation (g plant^{-1}) in spring maize

Treatment	30 DAS		60 DAS		90 DAS		At maturity	
	2019	**2020**	**2019**	**2020**	**2019**	**2020**	**2019**	**2020**
Nutrient application in preceding *kharif* maize and pea								
Maize (100 % NPK) + Pea (100 % NPK)	1.18	1.21	87.0	88.7	209.4	211.0	308.9	315.4
Maize (100 % NPK) + Pea (100 % NPK + FYM @ 20 t ha^{-1})	1.08	1.23	92.1	93.5	216.2	219.6	315.8	324.1
Maize (100 % NPK + FYM @ 15 t ha^{-1}) + Pea (100 % NPK)	1.29	1.23	89.3	90.0	213.9	216.3	313.5	322.0
Maize (100 % NPK + FYM @ 15 t ha^{-1}) + Pea (100 % NPK + FYM @ 20 t ha^{-1})	1.23	1.22	95.3	97.6	221.4	223.9	321.4	334.2
CD (p=0.05)	NS	NS	5.3	6.0	7.6	8.6	7.2	11.7
Nutrient levels in spring maize								
75 % NPK with single row on bed	1.01	1.27	88.5	90.8	210.5	213.1	311.6	321.0
75 % NPK with double row on bed	1.11	1.13	81.9	84.2	196.3	200.3	284.5	294.5
100% NPK with single row on bed	1.34	1.18	94.6	96.0	223.9	225.8	324.6	335.5
100 % NPK with double row on bed	1.10	1.20	88.0	89.2	208.6	210.6	306.7	311.9
125 % NPK with single row on bed	1.33	1.29	99.2	99.8	233.2	235.1	340.2	352.7
125 % NPK with double row on bed	1.28	1.26	93.4	94.7	218.9	221.2	321.8	327.9
CD (p=0.05)	0.21	NS	3.4	5.1	5.7	5.9	11.3	8.5
Interaction	NS	NS	NS	NS	NS	NS	NS	NS

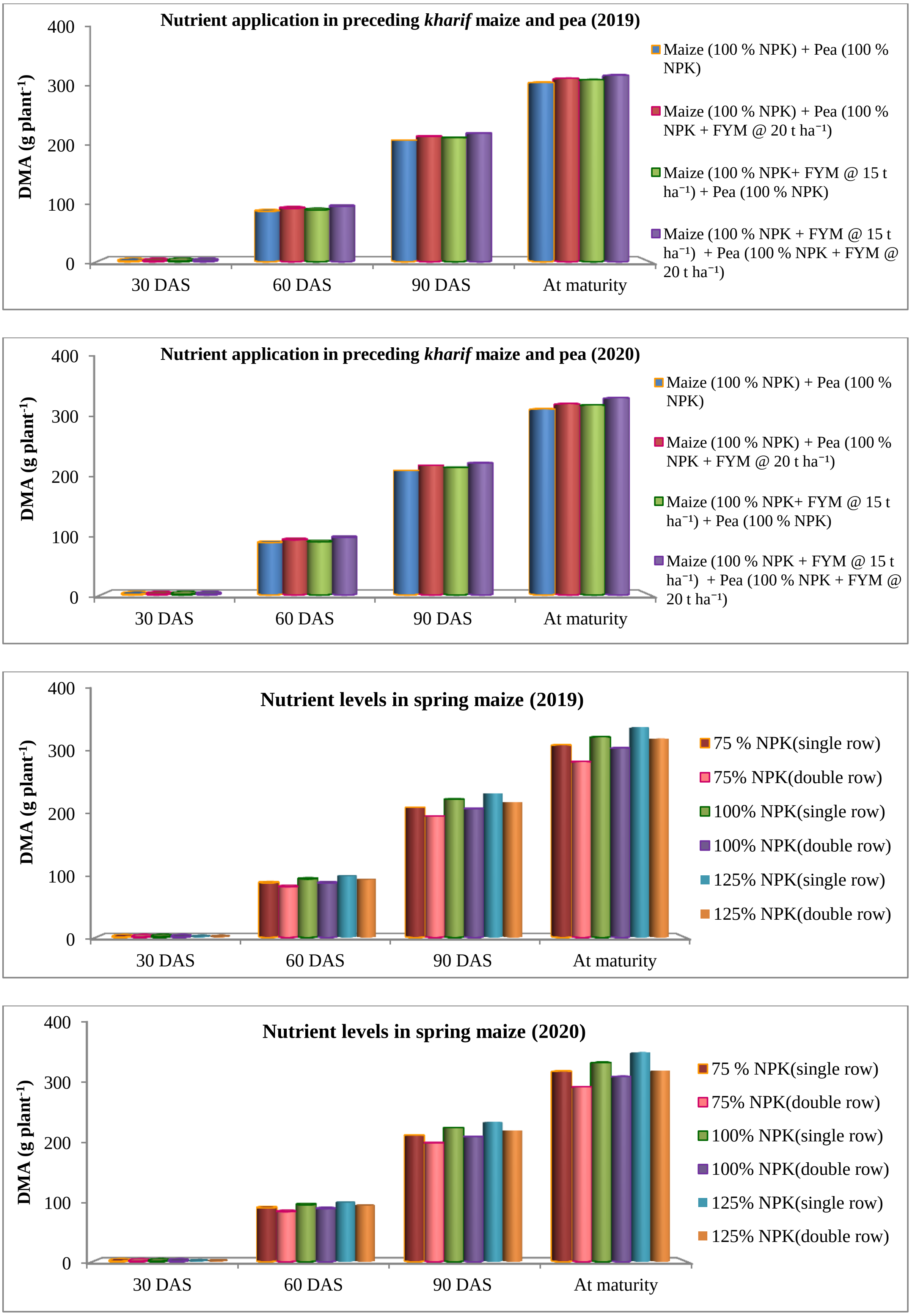


Fig. 4.24: Effect of nutrient application to preceding *kharif* maize and pea and nutrient levels to spring maize on dry matter accumulation in spring maize

Minimum DMA was recorded when 100% NPK was applied to both maize and pea. However, it was observed to be at par with 100 % NPK to maize and 100 % NPK + FYM @ 20 t ha^{-1} to pea and with 100 % NPK + FYM @ 15 t ha^{-1} to maize and 100 % NPK to pea at all the growth stages. The increase in dry matter under 100 % NPK + FYM @ 15 t ha^{-1} to maize and 100 % NPK + FYM @ 20 t ha^{-1} to pea was up to a margin of 9.5, 10.0%, 5.7, 6.1% and 4.0, 5.9% over 100% NPK application to both maize and pea at 60, 90 DAS and at maturity during 2019 and 2020, respectively. The higher DMA under combined application of organic and inorganic fertilizers treatments might be attributed to the greater availability of applied nutrients and higher uptake of primary nutrients by maize that leads to higher plant height and number of leaves per plant. Increase in photosynthetic area increased the dry matter accumulation. These results are in agreement with the findings of Tollenaar *et al* (2006), Kumawat (2010) and Biswasi *et al* (2020).

Application of different levels of nutrients in spring maize had significant effect on DMA at all the growth stages. At 30 DAS, the DMA was significantly varied only during 2019. At 30 DAS, maximum DMA was recorded (1.33 g) under single row on bed with 125% NPK application. At 60, 90 DAS and at maturity, application of 125% NPK to single row on bed resulted in significantly higher DMA (99.2, 99.8 g, 233.2, 235.1 g and 340.2, 352.7 g) than all other treatments during 2019 and 2020. It was followed by the treatment consisting 100% NPK application to single row on bed that was comparable to 125% NPK application to double row on bed at all growth stages during both years. Application of 75% NPK to double row on bed resulted with lowest DMA at all growth stages during both the years. The increase in DMA was up to a margin of 21.1, 18.5%, 18.9, 17.4% and 19.6, 19.8% under 125% NPK applied to single row over 75% NPK to double row on bed at 60, 90 DAS and at maturity during 2019 and 2020, respectively. The higher DMA per plant under higher dose of inorganic fertilizers treatments might be due to vigorous growth of crop in terms of gain in plant height and higher number of functional leaves per plant. Plants with more leaves and higher plant heights produced more photosynthetic dry matter. Similar results have also been reported by Sarwargaonkar *et al* (2008) and Gul *et al* (2015). Pandey *et al* (2000) and Tajul *et al* (2013) reported that lower population density with higher nutrient dose resulted in higher DMA, which could be owing to sufficient nutrient availability to the plant for better photosynthesis and dry matter production compared to higher population density.

4.2.3.1.3 Leaf area index

Leaf area index determines the effectiveness of the photosynthetic surface and is a measure of the source size. It represents the ratio of plant cover to ground area. A denser canopy and taller plant resulted in higher LAI. Data pertaining to LAI of spring maize are presented in table 4.42 and fig. 4.25. The LAI did not differed significantly at 30 DAS with application of different treatments to preceding maize and pea crops during both years. At 60, 90 DAS and maturity, application of 100% NPK + FYM @ 15 t ha^{-1} to maize and 100% NPK + FYM @ 20 t ha^{-1} to pea resulted in significantly higher LAI (3.00 and 3.16, 3.89 and 3.91 and 2.23, 2.46) as compared to application of 100% NPK + FYM @ 15 t ha^{-1} to maize and 100% NPK applied to pea and this treatment was statistically at par with 100% NPK applied to maize and 100% NPK + FYM @ 20 t ha^{-1} to pea during 2019 and 2020, respectively. Lowest values for LAI were recorded with application of 100% NPK to both preceding maize and pea crops. Increased LAI under combined application of organic and

Table 4.42: Effect of nutrient application to preceding *kharif* maize and pea and nutrient levels to spring maize on leaf area index in spring maize

Treatment	30 DAS		60 DAS		90 DAS		At maturity	
	2019	**2020**	**2019**	**2020**	**2019**	**2020**	**2019**	**2020**
Nutrient application in preceding *kharif* maize and pea								
Maize (100 % NPK) + Pea (100 % NPK)	0.18	0.20	2.67	2.77	3.43	3.50	1.95	2.20
Maize (100 % NPK) + Pea (100 % NPK + FYM @ 20 t ha^{-1})	0.22	0.20	2.92	3.00	3.78	3.76	2.11	2.37
Maize (100 % NPK+ FYM @ 15 t ha^{-1}) + Pea (100 % NPK)	0.18	0.19	2.74	2.85	3.53	3.62	2.02	2.26
Maize (100 % NPK + FYM @ 15 t ha^{-1}) + Pea (100 % NPK + FYM @ 20 t ha^{-1})	0.24	0.20	3.00	3.16	3.89	3.91	2.23	2.46
CD (p=0.05)	NS	NS	0.11	0.10	0.20	0.18	0.13	0.13
Nutrient levels in spring maize								
75 % NPK with single row on bed	0.18	0.17	2.10	2.33	3.07	3.00	1.53	1.79
75 % NPK with double row on bed	0.21	0.20	3.03	3.19	4.00	4.04	2.25	2.55
100% NPK with single row on bed	0.20	0.19	2.49	2.50	3.15	3.18	1.68	1.88
100 % NPK with double row on bed	0.19	0.21	3.28	3.33	4.12	4.12	2.49	2.68
125 % NPK with single row on bed	0.21	0.18	2.69	2.68	3.31	3.40	1.94	2.15
125 % NPK with double row on bed	0.23	0.22	3.42	3.63	4.32	4.44	2.59	2.90
CD (p=0.05)	NS	NS	0.14	0.10	0.19	0.21	0.10	0.11
Interaction	NS	NS	NS	NS	NS	NS	NS	NS

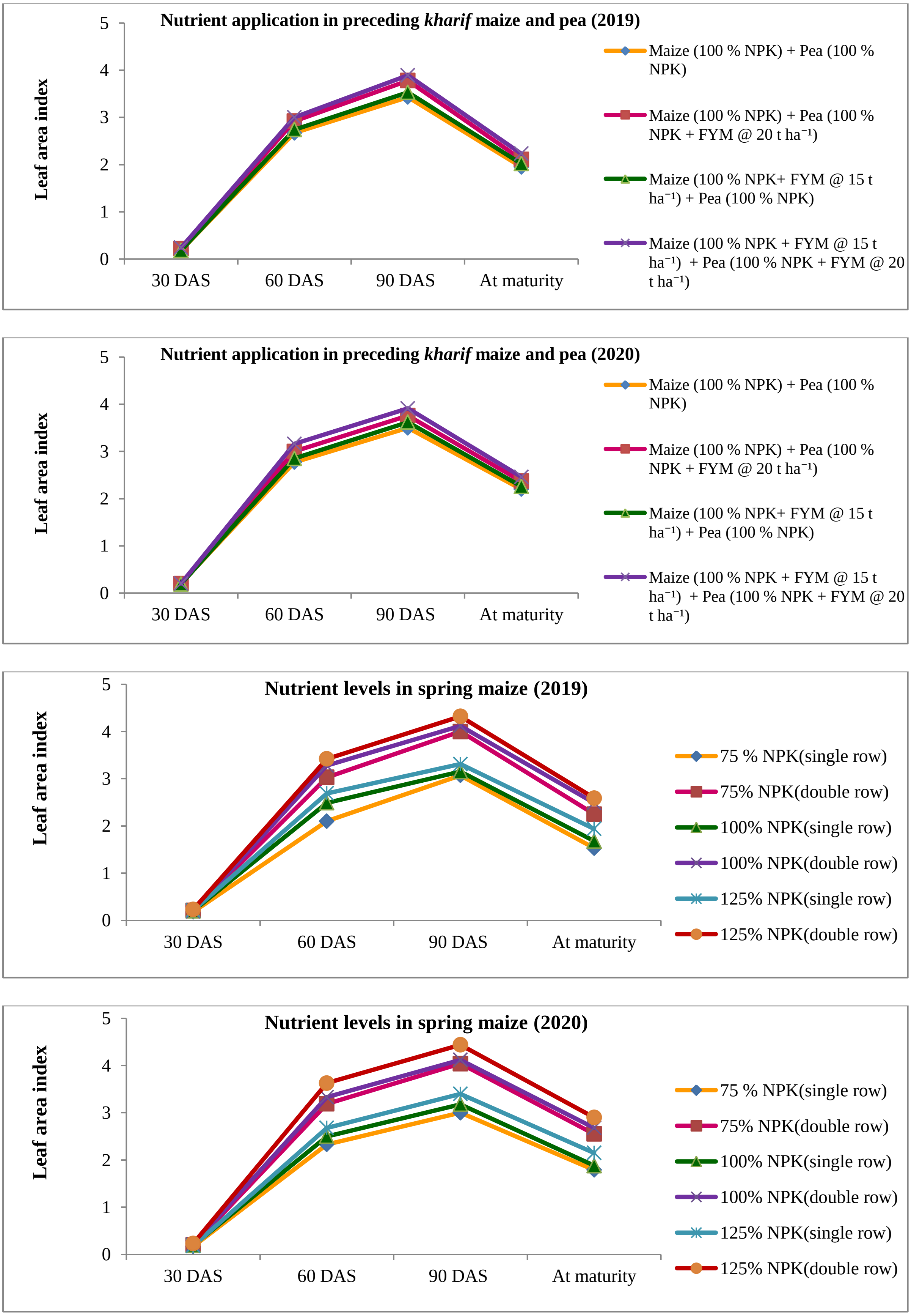


Fig. 4.25: Effect of nutrient application to preceding *kharif* maize and pea and nutrient levels to spring maize on leaf area index in spring maize

inorganic fertilizers may be attributed to improved soil physical condition and adequate nutrient availability for a longer duration resulting in taller plant height and higher DMA. Mahato *et al* (2020) also recorded higher LAI with combined application of organic and inorganic fertilizers as compared to sole use of inorganic fertilizers.

Among different fertilizer levels applied to spring maize, LAI differed significantly at 60, 90 DAS and maturity during both the years. Application of 125% NPK to double row on bed resulted in significantly higher LAI (3.43 and 3.63, 4.32 and 4.44, and 2.59 and 2.90) as compared to 75% NPK, 100% NPK and 125% NPK applied to single row on bed and 75% NPK applied to double rows on bed but this treatment was statistically at par with 100% NPK applied to double row on bed at 60, 90 DAS and maturity during 2019 and 2020, respectively. Lowest values for LAI were recorded with application of 75% NPK to single row on bed. Double rows on bed with 125% NPK application resulted in 37.3, 45%, 37.1, 39.6% and 54.1, 54.2% higher LAI as compared to 100% NPK applied to single row on bed at 60, 90 DAS and maturity during 2019 and 2020, respectively. Maximum leaf area under higher fertilizer dose might be due to adequate availability of nitrogen to plant for rapid cell division and cell elongation and thereby resulted in increased leaf area. Shivay and Singh (2000) and Gul *et al* (2015) also observed higher leaf area under higher nitrogen dose. Amanullah *et al* (2007) observed higher LAI at higher plant density as compared to lower plant density with increased nitrogen rates.

4.2.3.1.4 Chlorophyll index

The chlorophyll content of leaves is indicated by the chlorophyll index. A higher chlorophyll index indicates that the plant is greener. Greenery promotes better photosynthesis, which leads to a build-up of photosynthates at the sink. The data regarding chlorophyll index are given in table 4.43. Nutrient supplied to preceding maize and pea had a significant effect on the chlorophyll index of spring maize at 60, 90 DAS and maturity but the results were not significant at 30DAS during both years. Maximum chlorophyll index values (24.0 and 24.9, 33.8 and 34.6 and 18.2 and 18.1) were recorded with application of 100% NPK + FYM @ 15 t ha^{-1} to maize and 100% NPK + FYM @ 20 t ha^{-1} to pea, followed by 100% NPK applied to maize and 100% NPK + FYM @ 20 t ha^{-1} applied to pea, 100% NPK + FYM @ 15 t ha^{-1} to maize and 100% NPK to pea during both the years. The lowest values of chlorophyll index were observed under 100% NPK application to both preceding maize and pea crops at all growth stages during both the years. The availability of nitrogen in the soil increased as a result of mixed application of organic manure and inorganic fertilisers, resulted in higher leaf greenness and chlorophyll index of the crop. Abbasi *et al* (2010), Kumawat *et al* (2019) and Snehaa *et al* (2019) also recorded increase in SPAD values in maize crop with combined application of organic and inorganic fertilizers.

Table 4.43: Effect of nutrient application to preceding *kharif* maize and pea and nutrient levels to spring maize on chlorophyll index in spring maize

Treatment	30 DAS		60 DAS		90 DAS		At maturity	
	2019	**2020**	**2019**	**2020**	**2019**	**2020**	**2019**	**2020**
Nutrient application in preceding *kharif* maize and pea								
Maize (100 % NPK) + Pea (100 % NPK)	17.5	17.9	21.2	22.5	28.9	30.0	15.7	16.0
Maize (100 % NPK) + Pea (100 % NPK + FYM @ 20 t ha^{-1})	17.9	18.6	23.6	24.1	31.7	33.5	17.5	17.2
Maize (100 % NPK+ FYM @ 15 t ha^{-1}) + Pea (100 % NPK)	18.7	18.7	22.0	23.6	29.7	31.5	17.2	17.2
Maize (100 % NPK + FYM @ 15 tha^{-1}) + Pea (100 % NPK + FYM @ 20 t ha^{-1})	18.9	19.2	24.0	24.9	33.8	34.6	18.2	18.1
CD (p=0.05)	NS	NS	1.6	1.5	1.2	1.7	1.0	1.0
Nutrient levels in spring maize								
75 % NPK with single row on bed	18.1	18.8	23.3	23.5	31.2	32.4	17.3	18.3
75 % NPK with double row on bed	16.9	16.7	20.5	21.9	26.2	27.3	15.8	13.3
100% NPK with single row on bed	19.2	19.6	24.6	25.9	33.4	36.1	17.9	19.1
100 % NPK with double row on bed	17.4	17.7	20.6	22.5	28.4	28.9	16.6	14.7
125 % NPK with single row on bed	20.5	20.8	24.9	26.3	36.6	38.3	18.7	20.2
125 % NPK with double row on bed	17.5	17.9	22.1	22.6	30.3	31.4	16.7	17.1
CD (p=0.05)	1.4	1.4	1.1	1.2	1.9	2.0	1.2	1.0
Interaction	NS	NS	NS	NS	NS	NS	NS	NS

Different nutrient levels applied to spring maize had significant influence on chlorophyll index at all the growth stages during both the years. Application of 125% NPK to single row on bed resulted in significantly higher chlorophyll index values (20.5 and 20.8, 24.9 and 26.3, 36.6 and 38.3 and 18.7 and 20.2) whereas, this treatment was statistically at par with 100% NPK applied to single row on bed at 30, 60, 90 DAS and maturity during 2019 and 2020, respectively. Lowest values for chlorophyll index were recorded with application of 75% NPK to double rows on bed during both the years. Higher chlorophyll index values were recorded under single row on bed. This may be due to competition for available nutrients resulted in a decreased chlorophyll index at higher population density. The chlorophyll index values were increased with increase in nitrogen dose during both years. Singh *et al* (2010) reported that increased nitrogen dose from 100 to 150 kg ha^{-1} increased the chlorophyll content in maize crop.

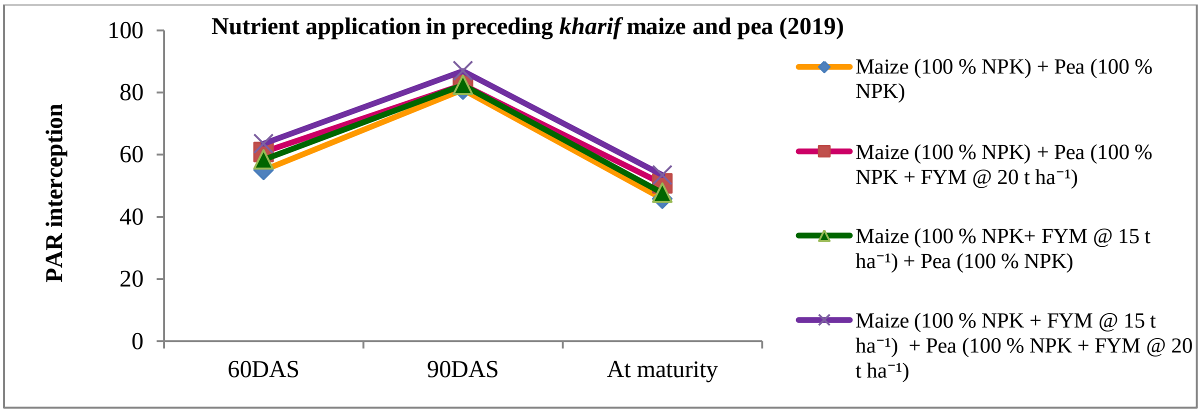
4.2.3.2 Microclimatic observations

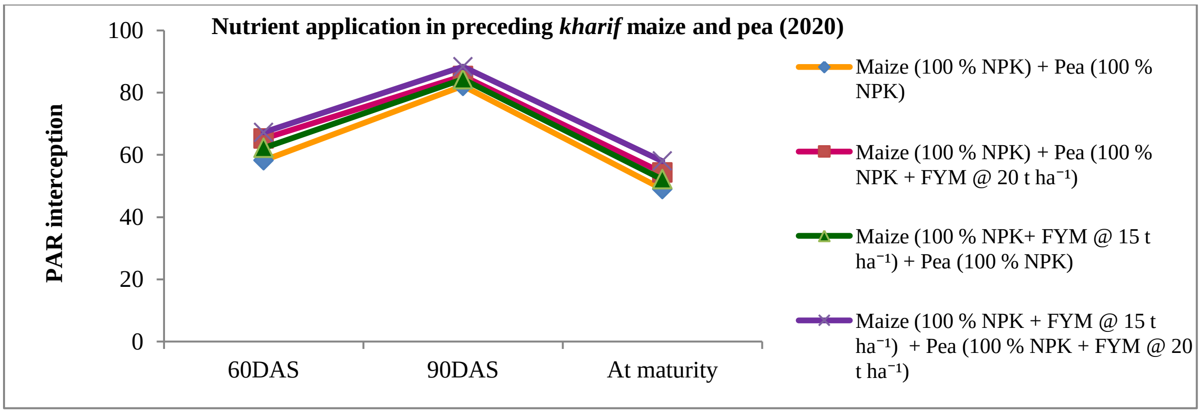
4.2.3.2.1 Photosynthetically active radiation (PAR) interception

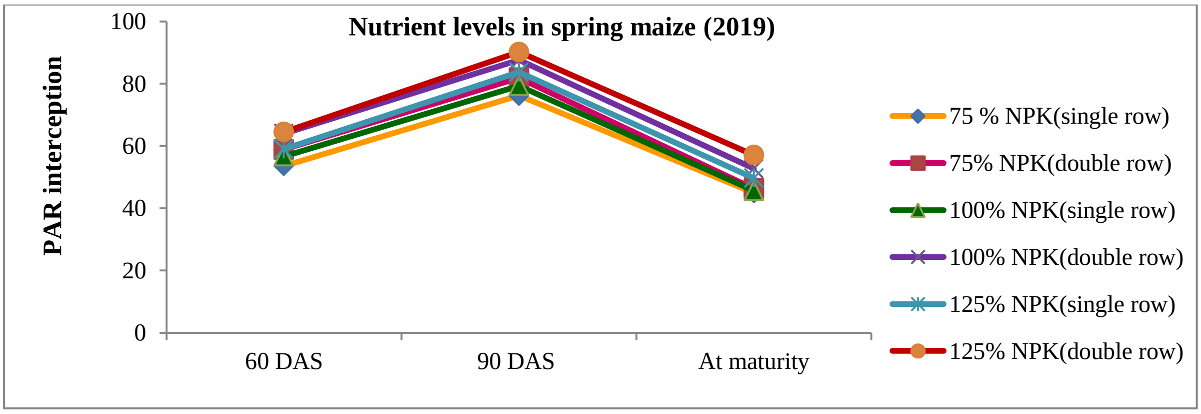
Interception of photosynthetic radiation inside crop cover is an important element that determines the photosynthetic capability of the crop. Photosynthetic efficiency influences the photosynthates manufacturing and its accumulation in the crop also impacts the yield of the crop. Data recorded on PAR interception are given in table 4.44 and fig. 4.26. The PAR interception differed significantly with nutrient application to preceding maize and pea at 60, 90 DAS and at maturity during both the years of study. Application of 100% NPK + FYM @ 15 t ha^{-1} to maize and 100% NPK + FYM @ 20 t ha^{-1} to pea resulted in significantly higher PAR values at all growth stages when compared to other treatments but at 60 DAS, it was at par with treatment consisting of 100% NPK to maize and 100% NPK + FYM @ 20 t ha^{-1} to pea. Application of 100% NPK to both maize and pea resulted in the lowest PAR values at all the growth stages.

Table 4.44: Effect of nutrient application to preceding *kharif* maize and pea and nutrient levels to spring maize on PAR interception (%) in spring maize

Treatment	60 DAS		90 DAS		At maturity	
	2019	**2020**	**2019**	**2020**	**2019**	**2020**
Nutrient application in preceding *kharif* maize and pea						
Maize (100 % NPK) + Pea (100 % NPK)	55.0	58.2	80.9	82.1	45.8	49.0
Maize (100 % NPK) + Pea (100 % NPK + FYM @ 20 t ha^{-1})	60.8	65.2	82.5	85.3	50.7	54.3
Maize (100 % NPK+ FYM @ 15 t ha^{-1}) + Pea (100 % NPK)	58.4	62.2	82.4	84.3	47.7	52.1
Maize (100 % NPK + FYM @ 15 t ha^{-1}) + Pea (100 % NPK + FYM @ 20 t ha^{-1})	63.5	67.2	86.9	88.3	53.4	58.0
CD (p=0.05)	3.6	3.5	4.0	3.8	3.1	3.6
Nutrient levels in spring maize						
75 % NPK with single row on bed	53.6	55.1	76.2	80.2	44.9	47.5
75 % NPK with double row on bed	58.9	62.9	81.9	83.7	46.3	52.7
100% NPK with single row on bed	56.7	59.0	79.3	82.8	45.6	49.4
100 % NPK with double row on bed	64.0	67.8	87.6	86.9	52.7	54.4
125 % NPK with single row on bed	59.0	64.3	83.7	85.3	49.7	56.4
125 % NPK with double row on bed	64.5	70.2	90.2	91.1	57.1	59.8
CD (p=0.05)	2.9	3.5	4.1	5.3	3.4	3.9
Interaction	NS	NS	NS	NS	NS	NS







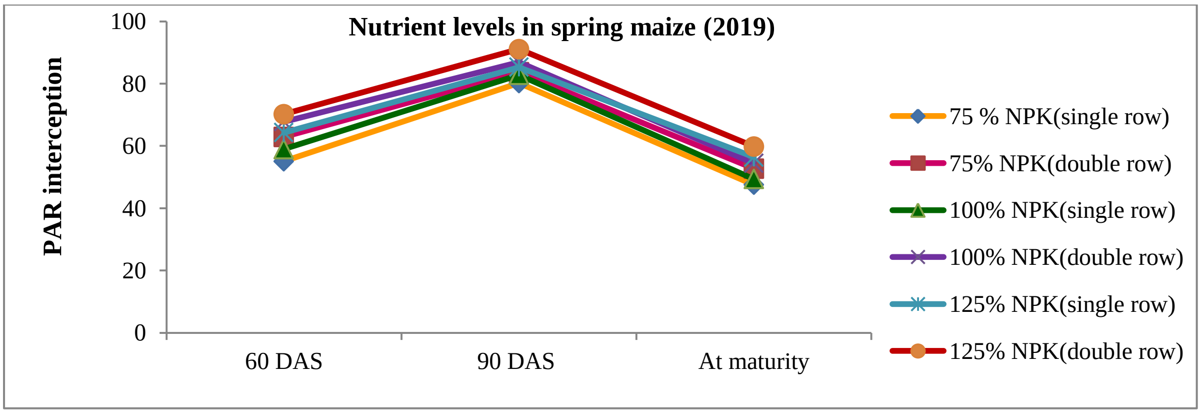


Fig. 4.26: Effect of nutrient application to preceding *kharif* maize and pea and nutrient levels to spring maize on PAR interception in spring maize

With increase in fertilizer levels and plant density, PAR interception value was also increased. Application of different fertilizer levels to spring maize, significantly higher PAR interception values was recorded (64.5 and 70.2%, 90.2 and 91.1% and 57.1 and 59.8%) under treatment which involves application of 125% NPK to double row on beds as compared to other treatments at all growth stages during 2019 and 2020, respectively and this treatment was statistically at par with 100% NPK application to double row on bed at 60 and 90 DAS during both years. Minimum values for PAR interception were recorded when crop was applied with 75% NPK to single row on bed during both the years. Application of 125% NPK to double rowon bed showed an increase in PAR interception up to 13.8 and 19.0%, 13.7 and 10.0%, and 25.2 and 21.0%, at 60, 90 DAS and at maturity, respectively, as compared to 100% NPK application to single row on bed during 2019 and 2020. In single row on bed, application of 125% NPK resulted in higher PAR interception as compared to 100% NPK and 75% NPK during both years at all the growth stages. With increase in fertilizer levels and plant population, PAR interception value increased due to better growth and development of crop resulted from better nutrient availability. Higher fertilizer dose recorded better plant height, leaf load and LAI of the crop which ultimately leads to higher PAR interception. Singh (2010) found that increasing the N dose from 100 to 150 kg ha^{-1} resulted in a considerable increase in PAR interception due to more leaves and a greater LAI.

4.2.3.3 Crop phenology

4.2.3.3.1 Days taken to 50% tasseling

The number of days taken to reach 50% tasseling was not influenced by nutrient application to preceding maize and pea crops, but it differed significantly with application of various nutrient levels in spring maize during both the years. Generally with increase in fertilizer levels days taken to reach tasseling stage were decreased (Table 4.45). The crop took more time (75 and 79 days) to reach 50% tasseling under 75% NPK applied to double rowon bed in comparision to all other treatments, but it was statistically at par with 100% (74 and 78 days) and 125% NPK (74 and 78 days) applied to double row planted spring maize in 2019 and 2020, respectively. Under application of 125 % NPK, tasseling occurred one day earlier than under 75 % NPK. In single row on bed with 75 % NPK applied to spring maize took longer time (74 and 78 days) to reach 50% tasseling than 100% NPK (72 and 76 days) and 125% NPK (70 and 74 days). Days taken to reach 50% tasseling was four days earlier under 125% NPK over 75% NPK applied to single row on bed during both the years. This may be due to the fact that the availability of nutrients in soil was increased with higher fertilizer dose. Reduced fertilizers rates promote competition among individual plants with different abilities to capture scarce resources results in extending their tasseling period, whereas higher nitrogen rates reduce competition among individual plants which may lead to uniform tasseling. These results are similar with the findings of Jassal *et al* (2017). The time taken for tasseling increased as the plant density increased. This could be because increased plant densities cause crop plants to compete more for diverse resources like light, nutrients, water and air. Due to competition for limited resources growth of the plant may have been slow down, leading tasseling to be delayed. Shrestha (2013) and Imran *et al* (2015) also reported similar results that days taken to tasseling under 55555 plants ha^{-1} was significantly lower (49 days) than that obtained under 83333 plants ha^{-1} (50 days).

4.2.3.3.2 Days taken to 50% silking

The days taken by the crop to attain 50% silking was not significantly affected by nutrient application to preceding maize and pea but it was significantly influenced with different nutrient levels applied to spring maize during both the year (Table 4.45). The number of days taken to silking of maize generally decreased as the fertilizer levels was increased. Days taken to reach 50% silking were more (78 and 83 days) with the application of 75% NPK to double row on bed during 2019 and 2020, respectively, as compared to 100% NPK (77 and 81 days) and 125% NPK (77 and 81 days). In comparison to single row on bed, double row on bed took longer period to reach 50% silking. Similarly in single row planted spring maize application of 75% NPK took more days (76 and 80 days) to reach 50% silking, which was at par with 100% NPK (75 and 79 days) and 125% NPK (75 and 79 days) during both the years. Silking was one day earlier under 125% NPK applied to single row on bed than under 75% NPK. This may be due to the fact that higher growth attributes like LAI and DMA resulted in greater energy levels in the plant, which boosted tasseling and also owing to fast growth, resulting in a reduction of number of days necessary for anthesis with increasing fertilizer levels. Shrestha *et al* (2018) concluded that application of 200 kg N ha^{-1} took 47 days to attain tasseling stage whereas, application of 0 kg N ha^{-1} took 52 days to attain tasselling stage. The crop took more days for silking stage at higher population density than it does for a lower population density plant. This could be due to competition for scarce resources, which slowed down phenological stages. Previous studies by Sharifi and Namvar (2016) and Golla *et al* (2020) also revealed that days taken to 50% silking were increased with increase in plant density.

4.2.3.3.3 Days taken to 50% dough stage

The data given in table 4.45 showed that nutrient application to preceding maize and pea had no significant influence on number of days taken to reach 50% dough stage, but it differed significantly with different nutrient levels applied to spring maize during both years. The data revealed that increasing the rate of fertilizer application significantly increased the number of days required to achieve 50% dough stage. Increased plant density, on the other hand, took less number of days to reach the 50% dough stage. Under application of 125% NPK to single row on bed, the crop took longer period to reach 50% dough stage (98 and 104 days) than all other treatments, but it was statistically at par to 100% NPK (97 and 102 days) and 75% NPK (97 and 102 days) during 2019 and 2020, respectively. In comparison to 125% NPK, 75% NPK took 1 and 2 days less to reach 50% dough stage in 2019 and 2020, respectively. Similarly application of 125% NPK took more period to reach 50% dough stage in double row on bed (96 and 101 days), followed by 100% NPK (96 and 101 days) and 75% NPK (95 and 100 days). The number of days taken to reach the 50% dough stage by the crop was greatly increased with higher fertilizer rate. This could be because increased fertilizer doses kept the foliage green for longer period. Dawadi and Sah (2012) and Sharifi and Namvar (2016) also reported that higher dose of nitrogen increased the days taken to dough and physiological maturity stage in maize. Increased plant density in spring maize shortened the time taken to reach the 50% dough stage, possibly because more competition for limited resources that fastens the phenological growth stages. These results were similar with findings of Imran *et al* (2015).

Table 4.45: Effect of nutrient application to preceding *kharif* maize and pea and nutrient levels to spring maize on phenological stages in spring maize

Treatment	Days taken to 50% tasselling		Days taken to 50% silking		Days taken to 50% dough		Days taken to physiological maturity	
	2019	2020	2019	2020	2019	2020	2019	2020
Nutrient application in preceding *kharif* maize and pea								
Maize (100 % NPK) + Pea (100 % NPK)	72	76	75	79	97	102	112	116
Maize (100 % NPK) + Pea (100 % NPK + FYM @ 20 t ha^{-1})	70	74	73	79	98	104	113	117
Maize (100 % NPK+ FYM @ 15 t ha^{-1}) + Pea (100 % NPK)	76	80	79	82	94	100	109	113
Maize (100 % NPK + FYM @ 15 t ha^{-1}) + Pea (100 % NPK + FYM @ 20 t ha^{-1})	75	79	78	82	96	101	111	114
CD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Nutrient levels in spring maize								
75 % NPK with single row on bed	74	78	76	80	97	102	112	115
75 % NPK with double row on bed	75	79	78	83	95	100	109	113
100% NPK with single row on bed	72	76	75	79	97	102	112	116
100 % NPK with double row on bed	74	78	77	81	96	101	110	114
125 % NPK with single row on bed	70	74	75	79	98	104	113	117
125 % NPK with double row on bed	74	78	77	81	96	101	111	115
CD (p=0.05)	2.3	2.7	1.9	1.9	2.0	2.0	2.0	2.1
Interaction	NS	NS	NS	NS	NS	NS	NS	NS

4.2.3.3.4 Days taken to physiological maturity

Days taken to physiological maturity was not significantly affected by nutrient application to previous maize and pea crops whereas, different levels of nutrient applied to spring maize had a significant impact during both years (Table 4.45). Increasing rate of fertilizer levels significantly increased the number of days required to attain physiological maturity. On the other side, increased plant density taken fewer days to reach physiological maturity. The crop took longer period to reach physiological maturity when 125 % NPK was applied to single row on bed (113 and 115 days) than the same level of nutrients applied to double row on bed (111 and 116 days), but it was statistically comparable to 100% NPK (112 and 116 days) and 75% NPK (112 and 115 days) applied to single row on bed in 2019 and 2020, respectively. The crop took one and two days less to reach physiological maturity with 75% NPK application in comparison to 125 % NPK application to during 2019 and 2020. Double row on bed took more days (111 and 115 days) to reach physiological maturity with 125% NPK, which was followed by 100% NPK (110 and 114 days) and 75% NPK (109 and 113 days) during both years. The days taken by maize crop to attain physiological maturity was increased with increased fertilizer dose. Higher fertilizer doses slowed down the leaf senescence, allowing the plants to remain green for longer period, which extending the time taken to reach physiological maturity. Similar results have been reported by Anwar *et al* (2017) and Shrestha *et al* (2018). The time taken by the crop to reach physiological maturity was reduced when it has a higher plant density. This could be due to increased competition among plants for various growth resources (light, moisture and nutrients). These findings are similar to those of Ketema *et al* (2017) and Golla *et al* (2020) who reported that increase in plant density decreased the days taken to physiological maturity in maize.

4.2.3.4 Yield and yield attributes

4.2.3.4.1 Number of cobs per plant

The number of cobs per plant is one of the most important yield attributing character that determines final yield. Most of the cultivars/hybrids generally bear only one cob per plant but sometime due to agronomic interventions the plant is expected to bear more than one cob. The data given in table 4.46 showed the number of cobs per plant. Nutrient application to preceding maize and pea had a significant effect on number of cobs per plant only during 2020. Maximum number of cobs per plant were resulted (1.11) with application of 100 % NPK + FYM @ 15 t ha^{-1} to maize and 100 % NPK + FYM @ 20 t ha^{-1} to pea which was significantly better than 100% NPK application to both maize and pea and statistically at par with the treatments involving 100 % NPK to maize and 100 % NPK + FYM @ 20 t ha^{-1} to pea as well as with 100 % NPK + FYM @ 15 t ha^{-1} to maize and 100 % NPK to pea during 2020. Maximum number of cobs per plant was recorded from combined application of organic and inorganic fertilizers might be due to better growth of plants in terms of plant height and dry matter. Yadav *et al* (2016) and Mahato *et al* (2020) also recorded higher number of cobs per plant from combined application of organic and inorganic nutrients.

Different nutrient levels applied to spring maize had significant influence on cobs bearing capacity of the plant. The number of cobs per plant were increased with increase in nitrogen levels, but it decreased with increase in plant population per unit area. Application of 125% NPK to single row on bed resulted in significantly higher number of cobs per plant (1.16 and 1.17) as compared to lower levels during 2019 and 2020, respectively. However, this treatment was at par with 100% NPK application to single row on bed during 2020. Lowest number of cobs per plant (0.97 and 0.99) was recorded with application of 75% NPK to double row on bed during 2019 and 2020, respectively. In single row bed planted spring maize application of 125% NPK produced 9.4, 9.3% and 6.4, 4.5% higher number of cobs per plant over 75% NPK and 100% NPK during 2019 and 2020, respectively. In double row planted spring maize, the percent increase under application of 125% NPK was 8.2, 8.0% and 5.0, 4.9% over 75% NPK and 100% NPK during 2019 and 2020, respectively. Increase in cobs per plant under higher fertilizer levels might be due to adequate supply of nutrient to the crop. Nitrogen being an essential constituent of plant tissue, involved in cell division and cell elongation which leads to better growth and development of the plants. Rasheed *et al* (2003), Gul *et al* (2015) and Raj *et al* (2020) have also reported similar findings. With increasing fertilizer levels, the number of cobs per plant increased but it decreased as the plant population increased. However, higher plant density out yielded in comparision to lower plant density when the nitrogen levels were increased. Arif *et al* (2010) concluded that increased nitrogen level with higher plant density resulted in higher number of cobs per plant. All the interaction effects were non-significant.

4.2.3.4.2 Cob length

Data pertaining to cob length are given in table 4.46. With mixed application of organic and inorganic fertilizers, the cob length of spring maize was increased as compared to application of synthetic fertilizer alone. Application of 100% NPK + FYM @ 15 t ha^{-1} to maize and 100% NPK + FYM @ 20 t ha^{-1} to pea resulted in significantly larger cob length (16.6 and 16.8 cm) as compared to 100% NPK application to both maize and pea and this treatment was statistically at par (16.2 and 16.5 cm) with application of 100 % NPK to maize and 100 % NPK + FYM @ 20 t ha^{-1} to pea during 2019 and 2020, respectively. The treatment involving 100% NPK application to both maize and pea resulted in smaller cob length (15.6 and 16.0 cm) during both the years. The increase in cob length up to a margin of 6.4 and 5.0% was recorded under 100% NPK + FYM @ 15 t ha^{-1} to maize and 100% NPK + FYM @ 20 t ha^{-1} to pea during 2019 and 2020, respectively over 100% NPK to both maize and pea. The combined use of organic and inorganic fertilizers improves root penetration for greater nutrient and water uptake, which leads to increased plant height and dry matter accumulation, that has beneficial effects on the yield and yield attributes. Snehaa *et al* (2019) and Biswasi *et al* (2020) also reported longer cob length with combined application of organic and inorganic fertilizer.

Table 4.46: Effect of nutrient application to preceding *kharif* maize and pea and nutrient levels to spring maize on yield attributing characters in spring maize

Treatment	Number of cob plant^{-1}		Cob length (cm)		Cob girth (cm)		Number of rows per cob	
	2019	2020	2019	2020	2019	2020	2019	2020
Nutrient application in preceding *kharif* maize and pea								
Maize (100 % NPK) + Pea (100 % NPK)	1.02	1.04	15.6	16.0	13.3	13.5	13.6	13.8
Maize (100 % NPK) + Pea (100 % NPK + FYM @ 20 t ha^{-1})	1.06	1.08	16.2	16.5	13.9	14.1	14.3	14.3
Maize (100 % NPK+ FYM @ 15 t ha^{-1}) + Pea (100 % NPK)	1.04	1.07	15.9	16.2	13.6	13.9	13.8	13.9
Maize (100 % NPK + FYM @ 15 t ha^{-1}) + Pea (100 % NPK + FYM @ 20 t ha^{-1})	1.10	1.11	16.6	16.8	14.2	14.4	14.4	14.5
CD (p=0.05)	NS	0.04	0.6	0.5	0.6	0.6	0.6	0.4
Nutrient levels in spring maize								
75 % NPK with single row on bed	1.06	1.07	16.3	16.6	13.7	14.1	14	14.3
75 % NPK with double row on bed	0.97	0.99	14.2	14.6	12.7	13.0	13.2	13.2
100% NPK with single row on bed	1.09	1.12	17.0	17.2	14.2	14.7	14.5	14.6
100 % NPK with double row on bed	1.0	1.02	15.1	15.6	13.1	13.2	13.3	13.6
125 % NPK with single row on bed	1.16	1.17	17.5	17.8	15.0	15.1	15.2	15.2
125 % NPK with double row on bed	1.05	1.07	16.3	16.4	13.7	13.9	13.8	13.9
CD (p=0.05)	0.06	0.05	0.7	0.5	0.5	0.5	0.5	0.6
Interaction	NS	NS	NS	NS	NS	NS	NS	NS

The cob length was significantly higher (17.5 and 17.8 cm) when 125% NPK was applied to single row bed planted maize as compared to 75% NPK application to both single and double row on bed but it was statistically similar (17.0 cm) with 100% NPK application to single row on bed during 2019. However, 125% NPK application to double row on bed and 75% NPK to single row on bed, the cob length was statistically comparable with each other but both the treatments were significantly superior to 75% NPK applied to double row on bed during both years. Application of 75% NPK to double row planted maize resulted with smallest cob length during both the years. Application of 125 % NPK to single row planted maize, the cobs were 7.4, 7.2% and 3.0, 3.4% longer than 75% NPK and 100% NPK application during 2019 and 2020, respectively. In case of double row on bed the percent increase in cob length under 125% NPK application was 14.8 and 12.3% over 75% NPK and 7.9 and 5.1% over application of 100% NPK during 2019 and 2020, respectively. Cob growth is enhanced with more nitrogen application in the maize crop. The highest cob length under higher fertilizer doses may be due to better utilization of solar light that resulted in more carbohydrate production, conversion into starches and ultimately produced longer ear length. Imran *et al* (2015) and Gul *et al* (2015) also found that higher nitrogen doses produced cobs with longer length than lower doses.

4.2.3.4.3 Cob girth

The data given in table 4.46 represents cob girth of spring maize. Nutrients applied to preceding maize and peas had significant effect on cob girth during both the years. A significantly higher cob girth (14.2 and 14.4 cm) was observed with application of 100% NPK + FYM @ 15 t ha^{-1} to maize and 100% NPK + FYM @ 20 t ha^{-1} to pea as compared to 100% NPK application to both maize and pea but it was statistically at par with application of 100% NPK to maize and 100% NPK + FYM @ 20 t ha^{-1} to pea and 100% NPK + FYM @ 15 t ha^{-1} to maize and 100% NPK to pea during both the years of study. The cob girth was recorded to be minimum (13.3 and 13.5 cm) during both years under the treatment consisting application of 100% NPK to both maize and pea. Application of 100% NPK + FYM @ 15 t ha^{-1} to maize and 100% NPK + FYM @ 20 t ha^{-1} to pea increases the cob girth of spring maize up to a margin of 6.8 and 6.3% in comparision to 100% NPK applied to both preceding maize and pea during 2019 and 2020, respectively. Increase in cob girth under conjoint application of organic and inorganic nutrient might be due to wider availability of nutrients throughout its growth period results in higher biomass production and better translocation of photosynthates, metabolites and nutrients to develop reproductive part. The present results are in line with findings of Edwin *et al* (2003), Thavaprakaash *et al* (2008) and Snehaa *et al* (2019) who reported that combined application of organic manures and chemical fertiizers resulted in higher cob girth as compared to sole use of inorganic fertilizers.

Cob girth of spring maize was significantly affected by different nutrient levels applied to spring maize during both the years. Application of 125% NPK to single row on bed resulted with maximum cob girth (15.0 and 15.1 cm) which was statistically comparable with 100% NPK applied to single row on bed during 2020 and significantly better that 75 % NPK applied to single row on bed during both the years. In response to varying nitrogen levels, a similar trend was observed in double row on bed. Smallest cob girth (12.7 and 13.0 cm) was recorded under 75% NPK application to double row on bed during both the years. The percentage increase in cob girth was 9.5 and 7.1% under 125% NPK application to single row on bed over 75% NPK application to single row on bed and the increase was 7.9 and 6.9% higher under 125% NPK applied to double row on bed as compared to 75% NPK to double row on bed during 2019 and 2020, respectively. Higher cob girth recorded under higher fertilizer dose may be due to better interception, absorption and utilization of radiant energy leading to higher photosynthetic rate and more accumulation of metabolites towards sink. Bakht *et al* (2007), Onasanya *et al* (2009) and Singh *et al* (2016) reported higher cob girth with application of nitrogen @ 120 kg ha^{-1} as compared to 60 kg ha$^{-1.}$

4.2.3.4.5 Number of grain rows per cob

The number of rows per cob is a hereditary trait of the cultivar, although it is expected that the agronomic modifications would improve the number of rows per cob. Data given in table 4.46 depict the effects of nutrient application to preceding maize and pea and application of different nutrient levels to spring maize on number of rows per cob. During both years, the nutrient applied to preceding maize and pea had a significant influence on the number of rows per cob.

Application of 100% NPK + FYM @ 15 t ha^{-1} to maize and 100% NPK + FYM @ 20 t ha^{-1} to pea resulted in significantly higher number of rows (14.1 and 14.5) as compared to 100% NPK applied to both maize and pea, but it was statistically at par with 100% NPK applied to maize and 100% NPK + FYM @ 20 t ha^{-1} to pea during 2019 and 2020, respectively. Minimum number of rows per cob was recorded with 100% NPK applied to both preceding maize and pea crops during both the years. Under application of 100% NPK + FYM @ 15 t ha^{-1} to maize and 100% NPK + FYM @ 20 t ha^{-1} to pea resulted in 5.9 and 5.1 % higher number of rows per cob over 100% NPK application to both maize and pea during 2019 and 2020, respectively. Combined application of organic and inorganic nutrient improves photosynthetic capacities which produces more metabolites and translocate it to the sink. Ghosh *et al* (2018) reported higher number of grain rows per cob under combined application of organic and inorganic fertilizers.

The number of rows per cob was improved as the fertilizer levels applied to spring maize was increased during both the years. The number of rows per cob was significantly higher under application of 125% NPK to single row on bed (15.2 and 15.2), which is statistically similar to 100% NPK application during 2020 and significantly better than 75% NPK application during both the years. Treatment which involves application of 125% NPK to double row on bed resulted in higher number of rows per cob (13.8 and 13.9) than 75% NPK and 100% NPK application to double row on bed but it was at par with 75% NPK application to single row on bed. The increase in number of rows per cob under 125% NPK applied to single row planted maize was 8.6 and 6.3% over 75% NPK application during 2019 and 2020, respectively. The per cent increase under 125% NPK application was up to a margin of 4.5 and 5.3% over 75% NPK application in double row bed planted spring maize during both the years. This may be due to the fact that higher fertilizer dose improves the nutrient availability that results in better growth attributes and provides more assimilates to improve number of grain rows per cob. The results get support from the findings by Shahid *et al* (2016), Majid *et al* (2017) and Adhikari *et al* (2021) who also reported higher number of rows per cob under increased nitrogen levels i.e. 220 kg ha^{-1} as compared to its lower doses.

4.2.3.4.5 Number of grains per row

The number of grains per row has a significant impact on the final grain yield of the crop. The data regarding the number of grains per row are given in table 4.47. It was observed that application of 100% NPK + FYM @ 15 t ha^{-1} to maize and 100% NPK + FYM @ 20 t ha^{-1} to pea produced significantly higher number of grains per row (30.7 and 31.3) as compared to 100% NPK applied to both preceding maize and pea, but it was statistically similar to the treatment involving 100% NPK to maize and 100% NPK + FYM @ 20 t ha^{-1} to pea during both the years and with 100% NPK + FYM @ 15 t ha^{-1} to maize and 100% NPK

Table 4.47: Effect of nutrient application to preceding *kharif* maize and pea and nutrient levels to spring maize on yield attributing characters in spring maize

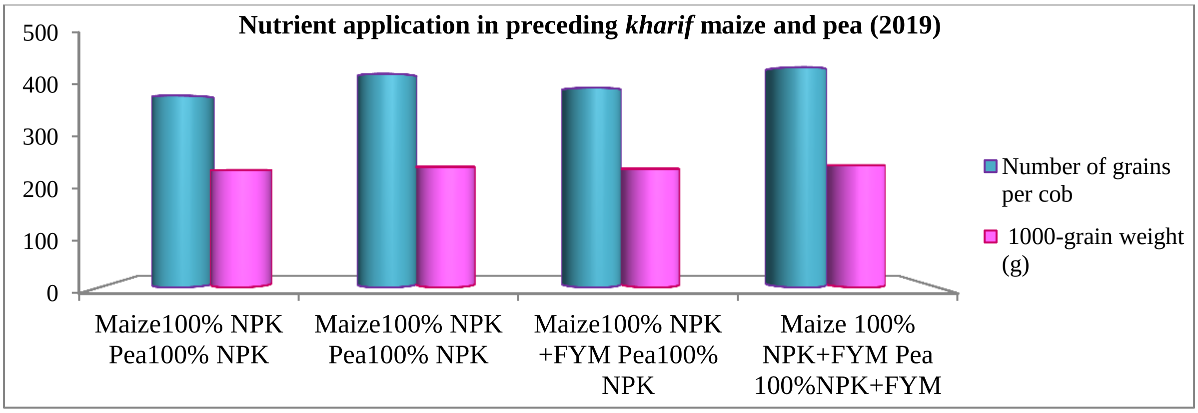
Treatment	**Grain weight cob^{-1} (g)**		**Number of grains row^{-1}**		**Total number of grains cob^{-1}**		**1000-grain weight (g)**	
	2019	**2020**	**2019**	**2020**	**2019**	**2020**	**2019**	**2020**
Nutrient application in preceding *kharif* maize and pea								
Maize (100 % NPK) + Pea (100 % NPK)	91.3	97.8	28.2	29.5	385.1	408.9	235.2	241.8
Maize (100 % NPK) + Pea (100 % NPK + FYM @ 20 t ha^{-1})	92.9	99.3	30.0	30.5	428.7	435.9	241.9	247.1
Maize (100 % NPK+ FYM @ 15 t ha^{-1}) + Pea (100 % NPK)	93.3	99.0	29.0	30.2	400.7	421.4	237.9	244.9
Maize (100 % NPK + FYM @ 15 t ha^{-1}) + Pea (100 % NPK + FYM @ 20 t ha^{-1})	93.5	100.3	30.7	31.3	442.0	454.0	245.4	250.3
CD (p=0.05)	NS	NS	1.2	1.1	34.9	17.1	7.1	5.4
Nutrient levels in spring maize								
75 % NPK with single row on bed	95.2	101.6	29.9	31.7	419.5	441.9	241.7	245.8
75 % NPK with double row on bed	75.5	85.0	25.9	27.2	342.9	358.9	228.9	235.6
100% NPK with single row on bed	103.9	106.6	31.3	31.9	454.3	462.2	244.5	252.8
100 % NPK with double row on bed	86.6	94.0	27.8	29.0	371.6	392.7	237.0	240.0
125 % NPK with single row on bed	106.6	111.3	33.0	33.1	500.2	503.9	248.1	257.6
125 % NPK with double row on bed	88.7	96.1	28.7	30.3	396.1	420.6	240.4	244.4
CD (p=0.05)	6.2	6.9	1.6	1.3	25.1	20.3	8.0	9.2
Interaction	NS	NS	NS	NS	NS	NS	NS	NS

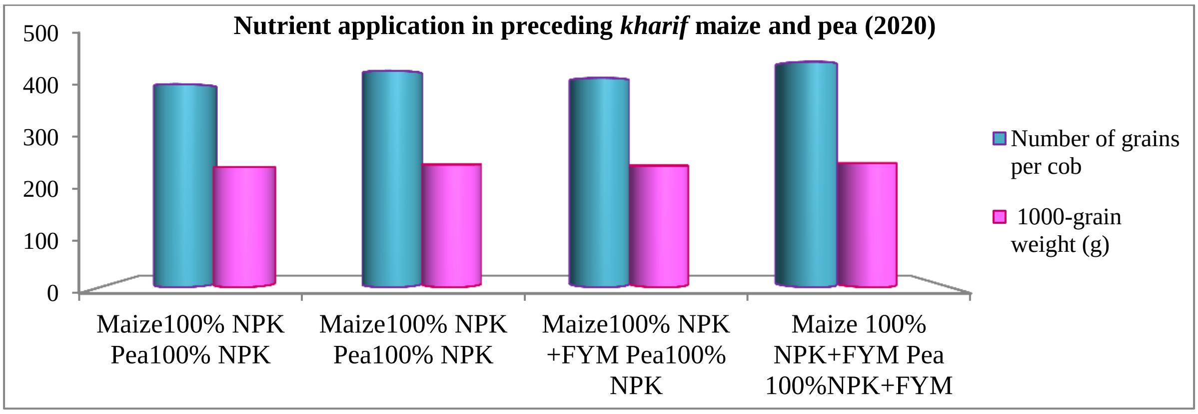
to pea during 2020. Lowest grains per row (28.2 and 29.5) were recorded under 100% NPK application to both maize and pea during 2019 and 2020, respectively. Combined use of both organic and inorganic fertilizer accumulates more biomass at the sink as a result of a higher photosynthetic rate that improves the cob grain filling ability. Singh *et al* (2017) and Rathod *et al* (2018) reported that integrated application of organic and inorganic fertilizers produced higher number of grains per row in comparison to sole use of inorganic fertilizers.

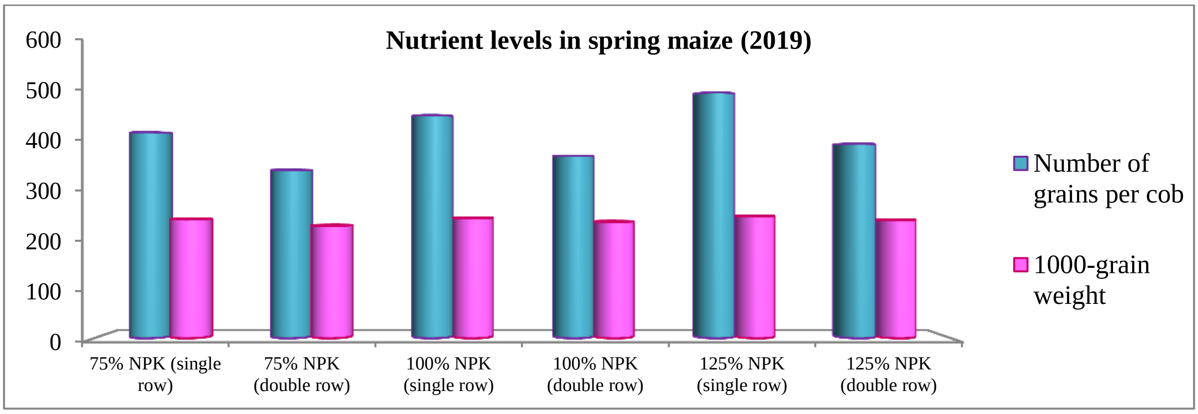
Maximum number of grains per row (33.0 and 33.1) was observed under application of 125% NPK to single row on bed, which was statistically at par with 100% NPK applied to single row on bed during 2020 but it was significantly better than 75% NPK applied to single row on bed during both years and 100% NPK application to single row on bed during 2019. In double row bed on bed, 125% NPK application resulted in higher number of grains per row (28.7 and 30.3) which were comparable to 100% NPK but significantly higher than 75% NPK application during both years of study. The increase in number of grains per row with 125% NPK application under single row bed planted maize was up to a margin of 10.4 and 4.4% as compared to 75% NPK to single row on bed during 2019 and 2020, respectively. However, under double row bed planted spring maize, the increase was 10.8 and 11.4% with 125% NPK application as compared to 75% NPK application during 2019 and 2020, respectively. Higher fertilizer levels increase the number of grains per row may be due to adequate availability of nutrients that increases vegetative and reproductive growth of the plant. Higher growth parameters harvest more solar energy for production of photosynthates leading to more grain number per row. Rasheed *et al* (2003) and Adhikari *et al* (2021) also reported higher number of grains per row with application of higher levels of nitrogen (220 kg ha^{-1}) as compared to its lower levels (160 kg ha^{-1}).

4.2.3.4.6 Number of grains per cob

The data given in table 4.47 and fig. 4.27 represents the total number of grains per cob, which revealed that nutrient applied to the preceding maize and pea had a significant impact on the total number of grains per cob. Total number of grains per cob was significantly higher (442.0 and 454.0) with application of 100% NPK + FYM @ 15 t ha^{-1} to maize and 100% NPK + FYM @ 20 t ha^{-1} to pea as compared to 100% NPK applied to maize and pea, but it was statistically at par with treatment involves application of 100% NPK to maize and 100% NPK + FYM @ 20 t ha^{-1} to pea during both the years. **A**pplication of 100% NPK to previous maize and pea recorded the lowest grains per cob in spring maize (385.1 and 408.9) during 2019 and 2020. Conjunctive application of organic and inorganic fertilizers has been reported to improve the plant greenery level causing the increase in production of photosynthates, duration of flowering and maturity that leads to increase in number of grains per cob. These results are confirmed by the findings of Chandrasekhar *et al* (2000), Manyuchi *et al* (2013) and Esmaeil *et al* (2015).







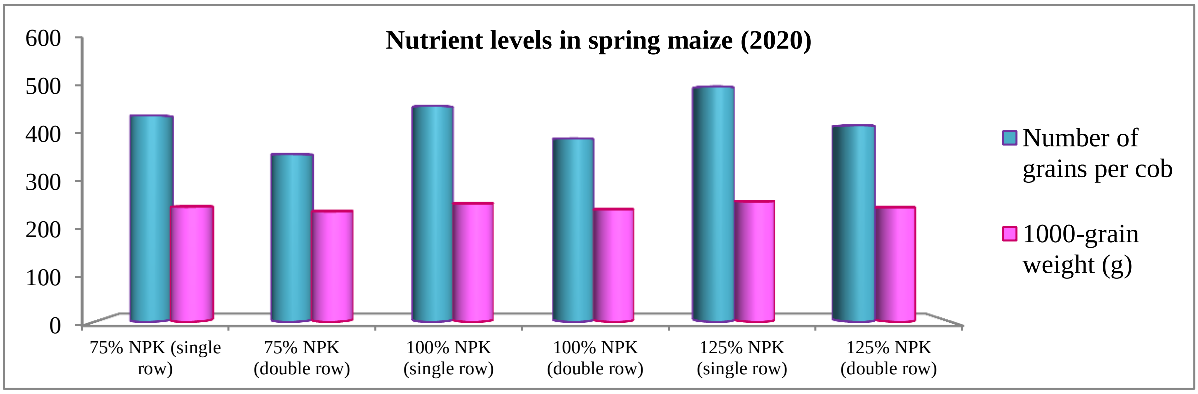


Fig.4.27: Effect of nutrient application to preceding *kharif* maize and pea and nutrient levels to spring maize on number of grains per cob and 1000-grain weight in spring maize

Application of different levels of nutrients in spring maize had significant influence on total number of grains per cob. The data showed the number of grains per cob was increased when the fertilizer level was increased. Total grains per cob increased under various nutrient levels in the order of 125% NPK > 100% NPK >75% NPK in both single and double row bed planted spring maize. During both the years of study, the highest number of grains per cob were observed when 125 % NPK was applied to single row on bed, while the lowest grains per cob were recorded with application of 75% NPK to double row planted spring maize. Application of 125% NPK to single row on bed increased number of grains per cob by 19.2, 14.0 % and 8.5, 9.0 % over 75% NPK and 100% NPK in 2019 and 2020, respectively. Likewise, in double row planted spring maize the increase of grains per cob was up to a margin of 15.5, 17.2% and 6.6, 7.1% under 125% NPK application as compared to 75% NPK and 100% NPK application during 2019 and 2020, respectively. More grains number under higher nutrient levels could be related to better availability of photosynthates, metabolites and nutrients during the growth cycle allowing for the better development of reproductive structure. Maqsood *et al* (2000), Bakht *et al* (2007) and Golla *et al* (2020) reported an increase in the number of grains with higher fertilizers levels.

4.2.3.4.7 1000-grain weight

Data with respect to 1000-grain weight of spring maize are presented in table 4.47 and fig. 4.27. Application of 100% NPK + FYM @ 15 t ha^{-1} to maize and 100% NPK + FYM @ 20 t ha^{-1} to pea resulted in significantly higher 1000-grain weight as compared to application of 100% NPK to preceding maize and pea but it was statistically at par with 100% NPK to maize and 100% NPK + FYM @ 20 t ha^{-1} to pea during both years. Minimum value for 1000-grain weight was recorded under 100% NPK applied to maize and pea during both the years. The percentage increase in 1000-grain weight with application of 100% NPK + FYM @ 15 t ha^{-1} to maize and 100% NPK + FYM @ 20 t ha^{-1} to pea was 4.3 and 3.1% over sole application of synthetic fertilizer i.e. 100% NPK applied to both maize and pea during 2019 and 2020, respectively. Integrated application of organic and inorganic fertilizers boosts photosynthetic efficiency and improves the transfer of assimilates to reproductive part. Singh *et al* (2017), Biswasi *et al* (2020) and Mahato *et al* (2020) observed higher 1000-grain weight when organic and inorganic fertilizers were applied together in comparison to sole application of synthetic fertilizers.

Among different nutrient levels, maximum 1000-grain weight (248.1 and 257.6 g) was recorded under 125 % NPK application treatment to single row on bed, which was significantly better than 75% and 100% NPK application to double row on bed and statistically at par with all other treatments during both the years. The increase in 1000-grain weight was 2.6, 4.8% and 1.5, 1.9% under 125% NPK application to single row on bed as compared to 75% NPK and 100% NPK application during 2019 and 2020, respectively. Application of 125% NPK to double row bed on bed, increased the 1000-grain weight by 5.0, 3.7% and 1.4, 1.8% over 75% NPK and 100% NPK applied to double row on bed during 2019 and 2020. Gul *et al* (2015) reported that higher 1000-grain weight was recorded under higher dose of nitrogen application as compared to its lower dose due to increased levels of photosynthates and their transfer to the grains.

4.2.3.4.8 Grain weight per cob

Grain weight per cob did not differ significantly with different nutrients levels applied to preceding maize and pea but it varied significantly with different nutrient levels applied to spring maize during both the years (Table 4.47). Increase in fertilizer levels resulted in significantly higher grain weight per cob. Maximum grain weight per cob (106.6 and 111.3 g) was observed in single row on bed with application of 125% NPK, which was at par with 100% NPK but statistically superior to 75% NPK application to single row on bed. In case of double row on bed, application of 125% NPK resulted in significantly higher grain weight (88.7 and 96.1 g) than 75% NPK and was statistically at par to 100% NPK application during both the years. The grain weight per cob was higher by a margin of 12.0 and 9.5% under 125% NPK application to single row on bed over 75% NPK application and by a margin of 17.5 and 13.1% over 75% NPK application to double row on bed during 2019 and 2020, respectively. Higher grain weight recorded under higher fertilizer levels may be due to better availability of nutrients resulting in higher plant height, DMA and LAI which provide more assimilate to sink for grain filling. Edalat *et al* (2009) and Delibaltova *et al* (2010) also observed that increasing nitrogen levels resulted in a considerable increase in grain weight per cob.

4.2.3.4.9 Grain yield

Grain yield in spring maize is an essential economic characteristic since it is directly related to net returns and benefit-cost ratio. The data given in the table 4.48 and fig. 4.28 showed that nutrient application to preceding *kharif* maize and pea had a significant impact on grain yield of spring maize during both the years. The results depict that application of 100% NPK + FYM @ 15 t ha^{-1} to preceding maize and 100% NPK + FYM @ 20 t ha^{-1} to pea produced significantly higher grain yield (81.1 and 84.3 q ha^{-1}) as compared to sole application of synthetic fertilizer i.e. 100% NPK application to both preceding maize and pea crops during 2019 and 2020, respectively. It was statistically at par with 100% NPK to maize and 100% NPK + FYM @ 20 t ha^{-1} to pea and 100% NPK + FYM @ 15 t ha^{-1} to maize and 100% NPK to pea only during 2020. Application of 100% RDF + FYM @ 15 t ha^{-1} to maize and 100% RDF + FYM @ 20 t ha^{-1} to pea increased grain yield of spring maize by 7.3 and 11.5% as compared to 100% NPK to both maize and pea during 2019 and 2020, respectively. Minimum yield (75.6 and 75.6 q ha^{-1}) was recorded with application of 100% NPK to both maize and pea during both the years. Increase in grain yield owing to integrated application of chemical fertilizer and organic manures might be attributed to steady release of nutrients from soil for longer period of time after decomposition resulting in better plant growth and grain yield . A remarkable increase in yield components under integrated utilization of nutrients also leads to higher yield. The findings are alike with those reported by Biswas and Dutta (2020), Ejigu *et al* (2021) and Sigaye *et al* (2021).

Table 4.48: Effect of nutrient application to preceding *kharif* maize and pea and nutrient levels to spring maize on grain yield, stover yield and harvest index in spring maize

Treatment	Grain yield (q ha^{-1})		Stover yield (q ha^{-1})		Harvest index	
	2019	**2020**	**2019**	**2020**	**2019**	**2020**
Nutrient application in preceding *kharif* maize and pea						
Maize (100 % NPK) + Pea (100 % NPK)	75.6	75.6	150.9	154.2	0.33	0.32
Maize (100 % NPK) + Pea (100 % NPK + FYM @ 20 t ha^{-1})	78.9	81.5	158.2	163.7	0.33	0.33
Maize (100 % NPK+ FYM @ 15 t ha^{-1}) + Pea (100 % NPK)	78.5	80.4	157.0	160.3	0.33	0.33
Maize (100 % NPK + FYM @ 15 t ha^{-1}) + Pea (100 % NPK + FYM @ 20 t ha^{-1})	81.1	84.3	162.2	168.7	0.33	0.33
CD (p=0.05)	3.4	4.3	6.9	7.1	NS	NS
Nutrient levels in spring maize						
75 % NPK with single row on bed	73.4	73.8	142.9	144.7	0.33	0.33
75 % NPK with double row on bed	75.0	75.5	157.4	167.8	0.32	0.30
100% NPK with single row on bed	75.9	77.5	147.4	151.6	0.33	0.33
100 % NPK with double row on bed	80.2	82.2	164.4	171.8	0.32	0.32
125 % NPK with single row on bed	81.2	84.9	155.8	157.8	0.34	0.34
125 % NPK with double row on bed	85.4	88.9	174.5	176.8	0.32	0.33
CD (p=0.05)	4.2	3.2	7.1	8.4	NS	0.01
Interaction	NS	NS	NS	NS	NS	NS

Various nutrient levels applied in spring maize had a significant effect on grain yield of spring maize. Application of 125% NPK to double row on bed planted spring maize recorded significantly higher grain yield (85.4 and 88.9 q ha^{-1}) than all other treatments, and it was followed by application 125 % NPK to single row on bed (81.2 and 84.9 q ha^{-1}) during 2019 and 2020, respectively. The average grain yield obtained from the application of 100%

NPK to double row on bed (80.2 and 82.2 q ha^{-1}) was statistically at par to the application of 125% NPK to single row planted spring maize. Application of 75% to single row on bed resulted in lowest grain yield (73.4 and 73.8 q ha^{-1}) during both the years. The grain yield increased up to a margin of 16.3, 20.4 % and 12.5, 14.7% under application of 125% NPK to double row on bed as compared to 75 % NPK and 100 % NPK to single row on bed (73.4, 73.8q ha^{-1} and 75.9, 77.5 q ha^{-1}) during 2019 and 2020, respectively. This may be attributed to greater vegetative and reproductive growth of plants due to increased nitrogen levels up to 125% NPK that resulted in higher grain yield. Increased nutrient availability increases the photosynthetic rate which leads to the formation of more carbohydrates and in turn more yield. Srivastava *et al* (2018), Raj *et al* (2021) and Adhikari *et al* (2021) also recorded higher grain yield in maize with increased nitrogen level from 160 kg ha^{-1} to 220 kg ha^{-1}. Higher grain yield was recorded from higher plant density which may due to higher number of cobs per unit area. Arif *et al* (2010) also recorded higher grain yield with increased plant density from 4 to 8 m^{-2} and nitrogen levels from 0 to 160 kg ha^{-1}.

4.2.3.4.10 Stover yield

Data with respect to stover yield is given in table 4.48 and fig. 4.28. Which revealed that the stover yield of spring maize varied greatly depending on the treatments applied there in. Application of 100% NPK + FYM @ 15 t ha^{-1} to maize and 100% NPK + FYM @ 20 t ha^{-1} to pea recorded in significantly higher stover yield (162.2 and 168.7 q ha^{-1}) in comparision to all other treatment combinations, but was at par with treatment consisting of 100% NPK to maize and 100% NPK + FYM @ 20 t ha^{-1} to pea during 2019 and 2020, respectively. Minimum stover yield (150.9 and 154.2 q ha^{-1}) was recorded with application of 100% NPK to both maize and pea during 2019 and 2020, respectively. The per cent increase in stover yield was 7.5% and 9.4% with application of 100% NPK + FYM @ 15 t ha^{-1} to maize and 100% NPK + FYM @ 20 t ha^{-1} to pea over 100% NPK to both maize and pea during 2019 and 2020, respectively. Integrated use of organic and inorganic fertilizer improves plant height, DMA and LAI of the crop which leads to higher stover yield. Mahato *et al* (2020) reported higher stover yield with mixed application of 75% RDF and vermicompost as compared to use of 100% RDF alone in maize.

Different nutrient levels applied to spring maize at different plant stands resulted with significant differences in stover yield. Spring maize planted in double row with 125% NPK recorded significantly higher stover yield (174.5 and 176.8 q ha^{-1}) as compared to 75% NPK and 100% NPK applied to single row bed planted maize but it was at par with 100% NPK application to double row planted spring maize. Application of 125% NPK with single rowon bed resulted in significantly higher stover yield (155.8 and 157.8 q ha^{-1}) as compared to 75% NPK during both the years. Minimum stover yield (142.9 and 144.7 q ha^{-1}) was recorded from single row on bed with 75% NPK application during 2019 and 2020, respectively.

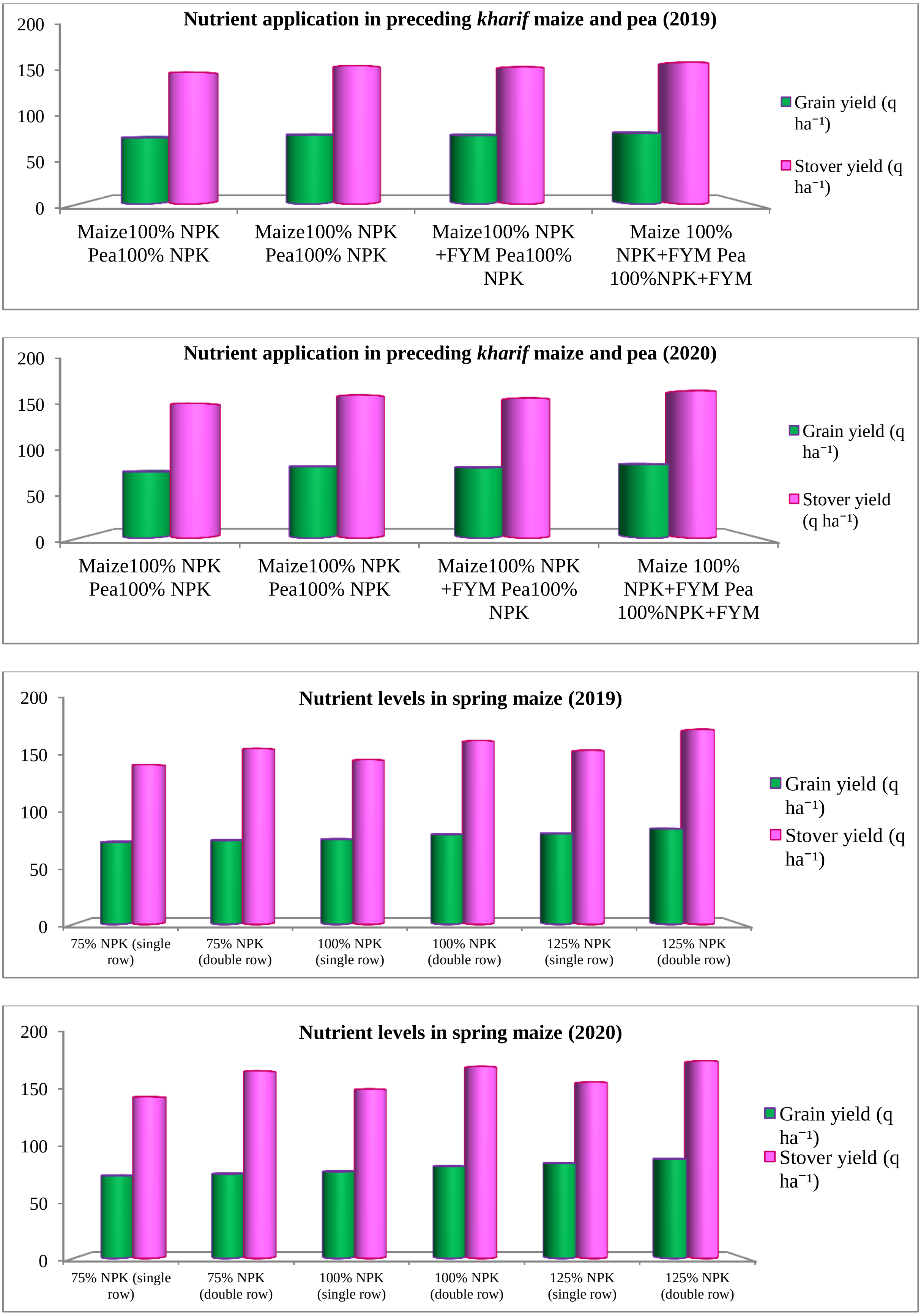


Fig. 4.28: Effect of nutrient application to preceding *kharif* maize and pea and nutrient levels to spring maize on grain and stover yield in spring maize

The percent increase in stover yield under 125% NPK to single row on bed was up to a margin of 9.0, 9.0% and 5.7, 4.1% over 75% NPK and 100% NPK during 2019 and 2020. In case of double row the increase in stover yield was up to a margin of 10.9, 5.3% and 6.4, 2.9% under 125% NPK as compared to 75% NPK and 100% NPK during 2019 and 2020, respectively. Higher stover yield with increased levels of nitrogen was due to higher plant height, DMA and LAI resulted from better growth and development. Khanday and Thakur (1991), Brar *et al* (2001) and Singh (2010) also reported higher stover yield under increased N levels. With increased plant density the stover yield was also increased as compared to lower plant density. This may be attributed to higher plant population per unit area. Similar results were observed by Dubeux *et al* (2006) and Raymond *et al* (2009) who reported that increasing plant density from 4 to 8 m^{-2} resulted in higher stover yield.

4.2.3.4.11 Harvest index

Harvest index (HI) is a measure of a plant's ability to transport created food material from the source to the sink or grains. Data pertaining to harvest index are presented in table 4.48 which showed that nutrients applied to both preceding maize and pea crops had no significant effect on the harvest index of spring maize. However application of different fertilizer levels to spring maize showed a significant effect on the harvest index only during 2020. Maximum HI was recorded with the application of 125% NPK to single row on bed which was at par with 100% NPK applied to single row on bed and 125% NPK applied to double row bed planted spring maize during 2020. The per cent increase in HI with application of 125% NPK to single row on bed was 3.0 % as compared to 75 % NPK applied to single row on bed during 2020. In double row on bed the percent increase in HI with 125% NPK application was 10.0% over 75% NPK during 2020. When the fertilizer levels increased, the harvest index was also increased, which may be due to higher yield under this treatment. Similar findings were observed by Adhikari *et al* (2021) and Raj *et al* (2021). Higher stover yield under increased plant density caused a decline in harvest index as compared to lower plant density. Kiniry *et al* (2005) reported in maize, who reported that increasing plant stand more than 10 m^{-2} resulted in lower harvest index.

4.2.3.5 Quality parameters of spring maize

4.2.3.5.1 Protein content in grain

Protein content is one of the most important quality parameter which improves the nutritional properties of maize grain. Nutrient application to preceding maize and pea did not show any significant effect on protein content during both years (Table 4.49). While the protein content of spring maize differed significantly with different nutrients level applied to spring maize. Application of 125 % NPK to single row on bed resulted in higher protein content (8.96 and 9.15 %), followed by 125 % NPK application to double row on bed (8.95 and 9.06 %) in 2019 and 2020, respectively. Minimum protein content was recorded (8.42

and 8.71 %) with application of 75% NPK to double row on bed during both the years. The increase in protein content with 125 % NPK application to single row on bed was 1.9 and 3.2 % as compared to 75 % NPK application to single row planted maize during 2019 and 2020. Increase in protein content with 125% NPK application to double row on bed was 6.3 and 4.1% over application of 75% NPK to double row on bed during both the years. The key element of protein is nitrogen which may have significantly boosted the protein content of the kernel due to greater nitrogen uptake at higher fertilizers levels (Almaz *et al* 2017). Higher nutrient application leads to higher protein recovery might be due to efficient nitrogen translocation from the vegetative to the reproductive parts of the plant, as well as increased nitrate reductase activity in protein synthesis. The findings of this study are in agreement with those of Siam *et al* (2008) and Zafar *et al* (2011).

Table 4.49: Effect of nutrient application to preceding *kharif* maize and pea and nutrient levels to spring maize on protein content and starch content in spring maize

Treatment	**Protein content (%)**		**Starch content (%)**	
	2019	**2020**	**2019**	**2020**
Nutrient application in preceding *kharif* maize and pea				
Maize (100 % NPK) + Pea (100 % NPK)	8.60	8.73	65.8	65.9
Maize (100 % NPK) + Pea (100 % NPK + FYM @ 20 t ha^{-1})	8.82	9.00	65.6	66.1
Maize (100 % NPK+ FYM @ 15 t ha^{-1}) + Pea (100 % NPK)	8.77	8.87	65.6	65.9
Maize (100 % NPK + FYM @ 15 t ha^{-1}) + Pea (100 % NPK + FYM @ 20 t ha^{-1})	8.85	9.19	65.5	65.7
CD (p=0.05)	NS	NS	NS	NS
Nutrient levels in spring maize				
75 % NPK with single row on bed	8.79	8.86	65.7	66.0
75 % NPK with double row on bed	8.42	8.71	65.9	66.1
100% NPK with single row on bed	8.82	9.03	65.4	65.8
100 % NPK with double row on bed	8.63	8.89	65.8	65.9
125 % NPK with single row on bed	8.96	9.15	65.4	65.6
125 % NPK with double row on bed	8.95	9.06	65.5	65.9
CD (p=0.05)	0.29	0.29	0.3	0.3
Interaction	NS	NS	NS	NS

4.2.3.5.2 Starch content in grain

The data regarding starch content in grain of spring maize are presented in table 4.49 which showed that it did not vary significantly with nutrients applied to maize and peas. However, application of different nutrient levels in spring maize significantly influenced the starch content during both the years. With increasing nitrogen levels, there was a declining tendency in starch content. Significantly higher starch content was recorded under 75% NPK application to double row on bed (65.9 and 66.1 %) as compared to 125% NPK applied to single row on bed. Lowest starch content was observed under 125 % NPK application to single row on bed maize (65.4 and 65.6 %) during 2019 and 2020. Hirano *et al* (2005), Ning *et al* (2018) and Mariem *et al* (2020) observed a decreasing trend in starch content with increase in nitrogen levels.

4.2.3.5.3 Total sugar content in grain

Total sugar content of grain was not significantly influenced either by nutrient applied to preceding maize and pea or with different nutrient levels applied to spring maize during both years of the study (Table 4.50). However, as nitrogen levels increased the over all sugar content was increased quantitatively. Ning *et al* (2018) reported that increased nitrogen level frm 0 to 300 kg ha^{-1} resulted in higher sugar biosynthesis in maize.

Table 4.50: Effect of nutrient application to preceding *kharif* maize and pea and nutrient levels to spring maize on total sugar content and oil content in spring maize grain

Treatment	Total sugar content (%)		Oil content (%)	
	2019	**2020**	**2019**	**2020**
Nutrient application in preceding *kharif* maize and pea				
Maize (100 % NPK) + Pea (100 % NPK)	3.00	2.77	3.99	4.41
Maize (100 % NPK) + Pea (100 % NPK + FYM @ 20 t ha^{-1})	2.85	2.78	4.10	4.44
Maize (100 % NPK+ FYM @ 15 t ha^{-1}) + Pea (100 % NPK)	3.05	2.75	4.08	4.42
Maize (100 % NPK + FYM @ 15 t ha^{-1}) + Pea (100 % NPK + FYM @ 20 t ha^{-1})	2.88	2.71	4.09	4.55
CD (p=0.05)	NS	NS	NS	NS
Nutrient levels in spring maize				
75 % NPK with single row on bed	2.86	2.70	4.18	4.45
75 % NPK with double row on bed	2.75	2.68	3.89	4.44
100% NPK with single row on bed	3.05	2.76	4.29	4.42
100 % NPK with double row on bed	3.03	2.78	3.94	4.43
125 % NPK with single row on bed	3.01	2.81	4.10	4.49
125 % NPK with double row on bed	2.97	2.80	4.00	4.50
CD (p=0.05)	NS	NS	NS	NS
Interaction	NS	NS	NS	NS

4.2.3.5.4 Oil content in grain

The data on oil content in grain (Table 4.50) demonstrates that nutrient application to preceding maize and pea or nutrient levels applied to spring maize had no significant effect on this quality parameter. There was numerically decrease in oil content with increase in fertilizer dose. Holou and Kindomihou (2011) reported similar findings with respect to effect of different nitrogen levels on oil content of maize grain.

4.2.3.6 Plant analysis

4.2.3.6.1 N, P and K content in grain

The data on nitrogen (N), phosphorus (P) and potassium content in maize grain and straw are presented in table 4.51 which showed that application of nutrients to previous maize and pea had no significant effect on the N, P and K content of grain during both years. The levels of nutrient applied to spring maize had a significant effect on the nitrogen content in the grain, while there was non-significant effect on P and K content in grain of spring maize.

Table 4.51: Effect of nutrient application to preceding *kharif* maize and pea and nutrient levels to spring maize on nitrogen, phosphorus and potassium content in spring maize grain

Treatment	N (%)		P (%)		K (%)	
	2019	**2020**	**2019**	**2020**	**2019**	**2020**
Nutrient application in preceding *kharif* maize and pea						
Maize (100 % NPK) + Pea (100 % NPK)	1.37	1.39	0.28	0.27	0.36	0.35
Maize (100 % NPK) + Pea (100 % NPK + FYM @ 20 t ha^{-1})	1.40	1.44	0.29	0.30	0.37	0.37
Maize (100 % NPK+ FYM @ 15 t ha^{-1}) + Pea (100 % NPK)	1.40	1.42	0.30	0.29	0.37	0.36
Maize (100 % NPK + FYM @ 15 t ha^{-1}) + Pea (100 % NPK + FYM @ 20 t ha^{-1})	1.41	1.47	0.29	0.31	0.38	0.37
CD (p=0.05)	NS	NS	NS	NS	NS	NS
Nutrient levels in spring maize						
75 % NPK with single row on bed	1.40	1.41	0.28	0.30	0.37	0.36
75 % NPK with double row on bed	1.34	1.39	0.27	0.28	0.36	0.35
100% NPK with single row on bed	1.41	1.44	0.30	0.30	0.38	0.36
100 % NPK with double row on bed	1.38	1.42	0.28	0.29	0.37	0.36
125 % NPK with single row on bed	1.43	1.46	0.30	0.31	0.38	0.38
125 % NPK with double row on bed	1.41	1.45	0.29	0.29	0.36	0.36
CD (p=0.05)	0.04	0.04	NS	NS	NS	NS
Interaction	NS	NS	NS	NS	NS	NS

Maximum N content in grain (1.43 and 1.46%) was recorded under application of 125% NPK to single row on bed which was significantly higher as compared to 75% NPK and 100% NPK applied to double row on bed but it was statistically at par with 75% NPK and 100% NPK applied to single row and 125% NPK applied to double row on bed during both the years. Application of 75% NPK to double row on bed recorded minimum N content (1.34 and 1.39 %) during both years. Application of 125% NPK to single and double row on bed recorded 6.7, 5.0% and 5.2, 4.3% higher N content over 75% NPK applied to double row on bed during 2019 and 2020, respectively. Higher N content in grain sample might be due to better uptake of this nutrient from soil because of adequate nutrient availability in the soil. Siam *et al* (2008) also recorded higher N, P and K content with increasing in N levels from 0 to 140 kg ha^{-1}.

4.1.3.6.2 N, P and K content in stover

The concentration of N, P and K in the stover of maize was not significantly affected either by nutrient application to preceding maize and pea or nutrients applied to spring maize during both the years (Table 4.52). However, N, P and K content in stover was numerically higher with increasing nutrients level during both the years.

Table 4.52: Effect of nutrient application to preceding *kharif* maize and pea and nutrient levels to spring maize on nitrogen, phosphorus and potassium content in maize stover

Treatment	N (%)		P (%)		K (%)	
	2019	2020	2019	2020	2019	2020
Nutrient application in preceding *kharif* maize and pea						
Maize (100 % NPK) + Pea (100 % NPK)	0.67	0.68	0.19	0.21	1.20	1.16
Maize (100 % NPK) + Pea (100 % NPK + FYM @ 20 t ha^{-1})	0.69	0.69	0.21	0.21	1.20	1.19
Maize (100 % NPK+ FYM @ 15 t ha^{-1}) + Pea (100 % NPK)	0.69	0.67	0.20	0.21	1.18	1.18
Maize (100 % NPK + FYM @ 15 t ha^{-1}) + Pea (100 % NPK + FYM @ 20 t ha^{-1})	0.70	0.71	0.23	0.23	1.23	1.19
CD (p=0.05)	NS	NS	NS	NS	NS	NS
Nutrient levels in spring maize						
75 % NPK with single row on bed	0.69	0.69	0.21	0.22	1.20	1.19
75 % NPK with double row on bed	0.67	0.67	0.19	0.20	1.19	1.16
100% NPK with single row on bed	0.69	0.69	0.22	0.22	1.20	1.19
100 % NPK with double row on bed	0.68	0.68	0.20	0.21	1.19	1.16
125 % NPK with single row on bed	0.70	0.70	0.23	0.23	1.22	1.20
125 % NPK with double row on bed	0.69	0.70	0.21	0.21	1.21	1.18
CD (p=0.05)	NS	NS	NS	NS	NS	NS
Interaction	NS	NS	NS	NS	NS	NS

4.2.3.6.3 N uptake in grain

The data pertaining to nitrogen uptake by spring maize grain are presented in table

4.53. During both the years, significantly higher N uptake (114.9 and 124.1 kg ha^{-1}) was recorded with application of 100% NPK + FYM @ 15 t ha^{-1} to maize and 100% NPK + FYM @ 20 t ha^{-1} to pea as compared to sole chemical fertilizer application. However, this treatment was statistically at par with treatment involving application of 100% NPK to maize and 100% NPK + FYM @ 20 t ha^{-1} to pea. Minimum N uptake was recorded under 100% NPK application to both preceding maize and pea crops during both the years. The increase in N uptake in 100% NPK + FYM @ 15 t ha^{-1} to maize and 100% NPK + FYM @ 20 t ha^{-1} to pea was 10.8 and 17.4% over sole application of inorganic fertilizer i.e. 100% NPK to maize and pea during 2019 and 2020, respectively.

Application of 125 % NPK to double row on bed resulted in significantly higher N uptake (121.3 and 128.9 kg ha^{-1}) as compared to all other treatments but it was statistically at par with 125 % NPK applied to single row on bed during both years. Higher N uptake under this treatment was due to higher N content in grain and grain yield. Lowest N uptake was recorded with application of 75 % NPK to double row on bed during both the years. The increase in N uptake under 125% NPK applied to double row on bed was up to a margin 20.0 and 22.4% over 75% NPK applied to double row planted maize, however increase was up to a margin of 13.2 and 15.0% over 100% NPK applied to single row bed on bed during 2019 and 2020, respectively. Brar *et al* (2001) and Siam *et al* (2008) recorded significantly higher N uptake with application of N @140 kg ha^{-1} as compared to control.

4.2.3.6.4 P uptake in grain

The data given in table 4.53 depict the P uptake in grains of spring maize. The analysis of the data revealed that the nutrient applied to the preceding maize and pea crops had no significant influence on P uptake in maize grain during both the years. Among the various nutrient levels in spring maize, 125% NPK applied to double row on bed resulted in higher P uptake (24.6 and 26.4 kg ha^{-1}) as compared to 75% NPK applied to both single and double row on bed but it was statistically at par with 100% NPK and 125% NPK applied to single and 100% NPK applied to double row on bed during both the years. This was mainly due to higher grain yield under this treatment. Lowest P uptake was recorded (20.7 and 21.2 kg ha^{-1}) under 75% NPK applied to single row on bed during 2019 and to double row during 2020. The P uptake in grain under 125% NPK applied to double row on bed was 17.7, 24.5% and 5.1, 10.0% higher as compared to 75% NPK applied to double row bed planted maize and 100% NPK applied to single row on bed during 2019 and 2020, respectively. Kumar *et al* (2008) and Singh (2010) reported that increasing fertilizer levels resulted in higher P uptake in maize.

4.2.3.6.5 K uptake in grain

The data with respect to K uptake by maize grain are presented in table 4.53, which revealed that K uptake by grain was not significantly influenced by nutrient application to preceding maize and pea but it differed significantly with different nutrients level in spring maize during both the years. Significantly higher K uptake by maize grain was recorded when 125% NPK was applied to double row on bed (30.9 and 32.8 kg ha^{-1}) as compared to 75% NPK applied to both single and double row on bed but this treatment was statistically at par with 125% NPK applied to single row on bed during both the years. Lowest K uptake was recorded under 75% NPK application to double row on bed (27.5 and 26.7 kg ha^{-1}) during 2019 and 2020. Increase in K uptake under 125% NPK applied to double row on bed was up to a margin of 12.4, 22.8% and 8.4, 15.9 over 75% NPK applied to double row on bed and 100% NPK applied to single row on bed during 2019 and 2020, respectively. Brar *et al* (2001) and Singh (2010) recorded higher K uptake under higher fertilizer doses.

Table 4.53: Effect of nutrient application to preceding *kharif* maize and pea and nutrient levels to spring maize on nitrogen, phosphorus and potassium uptake in spring maize grain

Treatment	N uptake (kg ha^{-1})		P uptake (kg ha^{-1})		K uptake (kg ha^{-1})	
	2019	2020	2019	2020	2019	2020
Nutrient application in preceding *kharif* maize and pea						
Maize (100 % NPK) + Pea (100 % NPK)	103.7	105.7	23.6	21.0	27.8	26.9
Maize (100 % NPK) + Pea (100 % NPK + FYM @ 20 t ha^{-1})	111.3	117.7	23.5	25.0	29.0	30.1
Maize (100 % NPK+ FYM @ 15 t ha^{-1}) + Pea (100 % NPK)	110.0	114.3	21.2	23.9	29.2	29.6
Maize (100 % NPK + FYM @ 15 t ha^{-1}) + Pea (100 % NPK + FYM @ 20 t ha^{-1})	114.9	124.1	22.9	26.3	31.0	31.9
CD (p=0.05)	5.5	8.8	NS	NS	NS	NS
Nutrient levels in spring maize						
75 % NPK with single row on bed	103.2	104.9	20.7	22.4	27.7	26.9
75 % NPK with double row on bed	101.1	105.3	20.9	21.2	27.5	26.7
100% NPK with single row on bed	107.2	112.1	23.4	24.0	28.5	28.3
100 % NPK with double row on bed	111.0	117.2	22.9	24.3	30.2	30.3
125 % NPK with single row on bed	116.4	124.2	24.4	26.0	30.9	32.6
125 % NPK with double row on bed	121.3	128.9	24.6	26.4	30.9	32.8
CD (p=0.05)	7.6	6.2	2.3	3.5	2.8	2.4
Interaction	NS	NS	NS	NS	NS	NS

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4.2.3.6.6 N uptake in stover

A perusal of the data presented in table 4.54 indicated that the nutrient application to preceding maize and pea had no significant influence on N uptake in maize stover during both years. Various nutritional treatments applied to spring maize in sub plots showed that application of 125% NPK to double row on bed recorded significantly higher N uptake (121.6 and 124.1 kg ha^{-1}) as compared to 75% NPK applied to single row on bed. However, it was statistically at par with 75% NPK applied to double rows on bed during 2020, with 100% NPK applied to double row on bed during both the years and with 125% NPK applied to single row on bed during 2019. Higher N uptake by stover was due to higher stover yield under double row on bed. Minimum N uptake by maize stover was recorded under 75% NPK applied to single row on bed during both years. Under the treatment which involves 125% NPK application to double row on bed, the per cent increase in N uptake was 23.2, 23.7% and 18.9, 16.6% over 75% NPK and 100% NPK applied to single row on bed during 2019 and 2020, respectively. Ramu and reddy (2007) and Bindhani *et al* (2008) observed significantly higher N uptake with increase in fertilizer levels in maize.

4.2.3.6.7 P uptake in stover

The data regarding P uptake by maize stover are given in table 4.54. The scrutiny of data revealed that P uptake by stover not significantly influenced by nutrient application in preceding maize and pea during both the year. Maximum uptake of P by maize stover was recorded with application of 125 % NPK to double row on bed (37.6 and 38.7 kg ha^{-1}) as compared to 75 % NPK, 100% NPK applied to single row and 75% NPK to double rows on bed, but it was statistically at par with 100 % NPK to double row and 125% NPK to single row on bed during both years. Higher P uptake was due to a higher stover yield obtained from maize crop planted in double row on bed. Lowest P uptake was observed with 75% NPK was application to double row on bed and single row on bed during both the years. Increase in P uptake under application of 125% NPK to double row bed planted spring maize was 13.6 and 13.8% higher over 100% NPK application to single row on bed during 2019 and 2020, respectively. Brar *et al* (2001) found that increase in fertilizer levels resulted in significantly higher nutrient uptake in maize.

4.2.3.6.8 K uptake in stover

The K uptake by maize stover was significantly influenced by different nutrient application to preceding maize and pea crops. The data revealed that higher K uptake (200.7 and 202.1 kg ha^{-1}) was recorded with application of 100% NPK + FYM @ 15 t ha^{-1} to maize and 100% NPK + FYM @ 20 t ha^{-1} to pea as compared to all other treatments during both the years. Minimum K uptake was recorded (181.3 and 179.4 kg ha^{-1}) under 100% NPK application to both maize and pea during both the years. Application of 100% NPK + FYM @ 15 t ha^{-1} to maize and 100% NPK + FYM @ 20 t ha^{-1} to pea recorded 10.7 and 12.7% higher K uptake by stover as compared to sole application of inorganic fertilizer i.e. 100% NPK to maize and pea during 2019 and 2020, respectively.

Table 4.54: Effect of nutrient application to preceding *kharif* maize and pea and nutrient levels to spring maize on nitrogen, phosphorus and potassium uptake by stover in spring maize

Treatment	N uptake ($kg\ ha^{-1}$)		P uptake ($kg\ ha^{-1}$)		K uptake ($kg\ ha^{-1}$)	
	2019	**2020**	**2019**	**2020**	**2019**	**2020**
Nutrient application in preceding *kharif* maize and pea						
Maize (100 % NPK) + Pea (100 % NPK)	101.0	106.0	30.1	32.6	181.3	179.4
Maize (100 % NPK) + Pea (100 % NPK + FYM @ 20 t ha^{-1})	109.5	113.6	34.1	35.6	189.7	194.4
Maize (100 % NPK+ FYM @ 15 t ha^{-1}) + Pea (100 % NPK)	109.0	108.8	32.1	33.6	185.7	189.4
Maize (100 % NPK + FYM @ 15 t ha^{-1}) + Pea (100 % NPK + FYM @ 20 t ha^{-1})	114.2	119.8	37.4	38.8	200.7	202.1
CD (p=0.05)	NS	NS	NS	NS	9.2	8.3
Nutrient levels in spring maize						
75 % NPK with single row on bed	98.7	100.3	30.1	32.0	172.2	171.9
75 % NPK with double row on bed	105.2	112.4	29.8	33.8	186.6	196.2
100% NPK with single row on bed	102.3	106.4	33.1	34.0	176.9	181.3
100 % NPK with double row on bed	111.7	118.1	34.5	35.9	196.2	200.2
125 % NPK with single row on bed	111.0	111.0	35.3	36.5	192.9	189.2
125 % NPK with double row on bed	121.6	124.1	37.6	38.7	211.5	209.2
CD (p=0.05)	12.8	12.1	4.4	4.2	9.1	14.0
Interaction	NS	NS	NS	NS	NS	NS

Different nutrient level applied to spring maize showed significant effect on K uptake by maize stover during both the years. Highest K uptake (211.5 and 209.2 kg ha^{-1}) was registered when 125% NPK was applied to double row on bed as compared to all other treatments during 2019 but it was statistically at par with 75% NPK and 100% NPK applied to double row on bed only during 2020. Application 75% NPK to single row on bed recorded lowest K uptake by stover (172.2 and 171.9 kg ha^{-1}) during both the years. Application of 125% NPK to double row on bed increased the K uptake up to a margin of 19.6 and 15.4% over 100% NPK applied to single row on bed during 2019 and 2020, respectively. Siam *et al* (2008) observed significantly higher K uptake with increase in N level from 0 to 140 kg ha^{-1}.

4.2.3.7 Soil chemical analysis

4.2.3.7.1 Available nitrogen

The soil samples were analyzed for available nitrogen at 0-15 and 15-30 cm soil depth and the data are presented in table 4.55. The treatments in the main plot i.e. nutrient applied to preceding maize and pea had no significant influence on available nitrogen at 0-15 and 15-30 cm soil depth during both years. Nutrient levels applied to spring maize had significant effect on available N at 0-15 cm soil depth during 2020. Application of 125 % NPK to single row on bed recorded significantly higher available N (210.0 kg ha^{-1}) in soil after harvest of the crops than 75% NPK and 100% NPK applied to double row on bed and 75% NPK applied to single row on bed but was statistically at par with 125% NPK applied to double row on bed and 100% NPK to single row on bed. Kumar *et al* (2008) and Dhaka *et al* (2016) also reported that with increase in nitrogen dose, available nitrogen in soil was also increased after the harvest of crop.

4.2.3.7.2 Available phosphorus

The data recorded for available phosphorus at 0-15 and 15-30 cm soil depth for 2019 and 2020 are presented in table 4.55. The available P in soil was not significantly influenced by the nutrients applied to preceding *kharif* maize and pea or by nutrients level applied in spring maize during both the years. However, the treatment consisting of 125% NPK application to single row on bed resulted in numerically higher values of available P (20.3 and 20 kg ha^{-1}) during 2019 and 2020.

4.2.3.7.3 Available potassium

Data with respect to available K are given in table 4.55 which showed that available K at 0-15 and 15-30 cm soil depth was not significantly affected by nutrient application to preceding *kharif* maize and pea or different nutrient levels applied to spring maize during both the years. However, numerically higher available K (180.4 and 173.3 kg ha^{-1}) was recorded under 125% NPK applied to single row on bed during 2019 and 2020, respectively.

Table 4.55: Effect of nutrient application to preceding *kharif* maize and pea and nutrient levels to spring maize on soil available nitrogen, phosphorus and potassium after harvest of crops

Treatment	N (kg ha^{-1})				P (kg ha^{-1})				K (kg ha^{-1})			
	0-15 cm		15-30 cm		0-15 cm		15-30 cm		0-15 cm		15-30 cm	
	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020
Nutrient application in preceding *kharif* maize and pea												
Maize (100 % NPK) + Pea (100 % NPK)	194.3	199.8	185.0	193.9	19.5	19.0	17.4	17.5	176.8	171.0	164.8	161.1
Maize (100 % NPK) + Pea (100 % NPK + FYM @ 20 t ha^{-1})	197.4	204.4	186.7	192.6	18.7	19.1	17.6	17.7	177.0	174.9	164.7	163.1
Maize (100 % NPK+ FYM @ 15 t ha^{-1}) + Pea (100 % NPK)	197.1	201.8	185.0	194.4	19.1	19.4	16.5	17.7	175.7	169.4	165.4	160.3
Maize (100 % NPK + FYM @ 15 t ha^{-1}) + Pea (100 % NPK + FYM @ 20 t ha^{-1})	201.4	206.5	189.8	194.5	19.8	19.3	17.3	18.0	176.4	172.3	165.2	161.4
CD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Nutrient levels in spring maize												
75 % NPK with single row on bed	197.1	201.8	186.9	193.9	19.6	19.0	16.9	17.7	177.5	171.1	165.7	160.6
75 % NPK with double row on bed	193.5	197.6	183.7	191.5	18.3	18.5	16.8	17.2	173.8	171.6	161.4	160.0
100% NPK with single row on bed	198.5	204.1	186.9	196.2	19.2	19.5	17.6	18.3	178.3	173.1	166.2	162.1
100 % NPK with double row on bed	195.8	201.7	185.3	191.5	19.2	19.0	17.0	17.1	174.0	170.9	163.9	161.7
125 % NPK with single row on bed	204.1	210.0	188.5	196.2	20.3	20.0	17.7	18.3	180.4	173.3	169.6	163.3
125 % NPK with double row on bed	196.4	203.5	188.4	193.9	19.1	19.1	17.2	17.6	174.8	171.4	163.3	161.1
CD(p=0.05)	NS	7.2	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Interaction	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Initial status	188.2				23.4				193.2			

4.2.3.7.4 Soil pH and EC

The data regarding pH and EC at 0-15 and 15-30 cm of soil depth are given in table 4.56. An appraisal of data revealed that pH and EC of soil was not significantly influenced either by nutrient applied to preceding *kharif* maize and pea or by application of various nutrients level in spring maize during both years.

Table 4.56: Effect of nutrient application to preceding *kharif* maize and pea and nutrient levels to spring maize on soil pH and EC after harvest of crops

Treatment	pH				EC (dSm^{-1})			
	0-15 cm		15-30 cm		0-15 cm		15-30 cm	
	2019	2020	2019	2020	2019	2020	2019	2020
Nutrient application in preceding *kharif* maize and pea								
Maize (100 % NPK) + Pea (100 % NPK)	6.93	6.91	6.91	6.90	0.226	0.225	0.224	0.222
Maize (100 % NPK) + Pea (100 % NPK + FYM @ 20 t ha^{-1})	6.91	6.90	6.90	6.90	0.224	0.225	0.224	0.220
Maize (100 % NPK+ FYM @ 15 t ha^{-1}) + Pea (100 % NPK)	6.90	6.90	6.89	6.89	0.224	0.223	0.223	0.220
Maize (100 % NPK + FYM @ 15 t ha^{-1}) + Pea (100 % NPK + FYM @ 20 t ha^{-1})	6.90	6.89	6.88	6.89	0.223	0.222	0.222	0.218
CD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Nutrient levels in spring maize								
75 % NPK with single row on bed	6.91	6.90	6.89	6.89	0.224	0.223	0.223	0.220
75 % NPK with double row on bed	6.90	6.88	6.89	6.89	0.222	0.223	0.222	0.219
100% NPK with single row on bed	6.92	6.91	6.91	6.90	0.227	0.224	0.223	0.222
100% NPK with double row on bed	6.90	6.89	6.89	6.90	0.225	0.223	0.223	0.219
125 % NPK with single row on bed	6.92	6.91	6.91	6.91	0.227	0.225	0.224	0.222
125 % NPK with double row on bed	6.90	6.90	6.90	6.90	0.226	0.224	0.223	0.222
CD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Interaction	NS	NS	NS	NS	NS	NS	NS	NS
Initial status	7.2				0.244			

4.1.3.7.5 Organic carbon

Organic carbon is the key indicator of soil health. It is the center of soil health in terms of physical, chemical and biological factors. Higher OC in soil improves soil structure, biological and physical health of soil and acting as a shield against hazardous elements. Data associated with organic carbon content are presented in table 4.57 which showed that nutrient levels supplied to spring maize in sub plots had no significant effect on OC at 0-15 and 15-30 cm soil depth, but nutrient levels applied to preceding maize and pea had a significant effect on OC at 0-15 cm soil depth during both years. After harvesting the crop, the OC content of the soil improved with application of 100% NPK + FYM @ 15 t ha^{-1} to maize and 100% NPK + FYM @ 20 t ha^{-1} to pea at soil depth of 0-15 cm. The maximum OC content of 0.40 % was observed during 2019 and 0.42 % during 2020. The per cent increase in OC under 100% NPK + FYM @ 15 t ha^{-1} to maize and 100% NPK + FYM @ 20 t ha^{-1} to pea was 11.1 and 7.7% during both the years over 100% NPK application to maize and pea.

Table 4.57: Effect of nutrient application to preceding *kharif* maize and pea and nutrient levels to spring maize on soil OC and bulk density of soil after harvest of the crops

Treatment	OC (%)				Bulk density(g cm^{-3})			
	0-15 cm		15-30 cm		0-15 cm		15-30 cm	
	2019	2020	2019	2020	2019	2020	2019	2020
Nutrient application in preceding *kharif* maize and pea								
Maize (100 % NPK) + Pea (100 % NPK)	0.36	0.39	0.35	0.37	1.32	1.31	1.31	1.31
Maize (100 % NPK) + Pea (100 % NPK + FYM @ 20 t ha^{-1})	0.38	0.39	0.35	0.36	1.31	1.30	1.31	1.30
Maize (100 % NPK+ FYM @ 15 t ha^{-1}) + Pea (100 % NPK)	0.38	0.40	0.35	0.38	1.30	1.29	1.31	1.30
Maize (100 % NPK + FYM @ 15 t ha^{-1}) + Pea (100 % NPK + FYM @ 20 t ha^{-1})	0.40	0.42	0.36	0.38	1.30	1.28	1.31	1.30
CD (p=0.05)	0.01	0.01	NS	NS	0.01	0.01	NS	NS
Nutrient levels in spring maize								
75 % NPK with single row on bed	0.38	0.40	0.36	0.36	1.31	1.29	1.31	1.30
75 % NPK with double row on bed	0.38	0.41	0.35	0.38	1.31	1.28	1.30	1.30
100% NPK with single row on bed	0.39	0.40	0.36	0.37	1.31	1.29	1.31	1.30
100% NPK with double row on bed	0.39	0.40	0.36	0.38	1.30	1.28	1.31	1.30
125 % NPK with single row on bed	0.38	0.40	0.35	0.37	1.31	1.30	1.32	1.31
125 % NPK with double row on bed	0.39	0.41	0.35	0.37	1.30	1.29	1.30	1.31
CD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Interaction	NS	NS	NS	NS	NS	NS	NS	NS
Initial status	0.33				1.34			

The OC after harvest of the crops was increased in comparision to its initial soil status. The organic manures that retained in the soil under goes decomposition over a period of time and adds organic matter to soil. Shambhavi *et al* (2017), Meena *et al* (2019) and Sigaye *et al* (2021) also reported improvement in soil organic carbon content under combined application of organic and inorganic fertilizer as compared to sole application of inorganic fertilizers.

4.2.3.8 Soil physical properties

4.2.3.8.1 Bulk density

Bulk density had a significant impact on plant development due to its effect on soil strength and porosity. A higher bulk density represents higher soil strength and compaction. Change in soil bulk density is a good measure of soil health and water retention capacity. The data presented in table 4.57 showed that nutrient application to previous maize and pea had a significant impact on bulk density during both years, but the results are non-significant under different nutrient levels applied in spring maize. The results showed that application of 100% NPK to both maize and pea, the bulk density was significantly increased (1.32 and 1.31 g cm^{-3}) during both the years as compared to combined application of organic and inorganic fertilizer treatments. Supply of 100% NPK + FYM @ 15 t ha^{-1} to maize and 100% NPK + FYM @ 20 t ha^{-1} to pea recorded lowest bulk density (1.30 and 1.28 g cm^{-3}) during both the years. This may be due to the fact that soil compaction is reduced and porosity is increased when organic and inorganic fertilizers are applied together. Meena *et al* (2019) and Ejigu *et al* (2021) also reported reduction in bulk density with combined use of organic manures and inorganic fertilizers as compared to sole use of inorganic fertilizers

4.2.3.9 Economic analysis

4.2.3.9.1 Spring maize equivalent yield (SMEY)

The data presented in table 4.58 and fig 4.29 manifested that combined application of organic and inorganic fertilizer i.e. 100% NPK + FYM @ 15 t ha^{-1} to maize and 100% NPK + FYM @ 20 t ha^{-1} to pea resulted in significantly higher SMEY (227.4 and 229.3 q ha^{-1}) as compared to all other treatments during 2019 and 2020. Application of 100% NPK to both preceding maize and pea crops resulted in lowest SMEY during both the years.

A significantly higher SMEY (225.5 and 224.9 q ha^{-1}) was recorded with 125% NPK application to double row on bed as compared to 75% NPK, 100% NPK applied to both single row and double rows on bed and 125% NPK applied to single row on bed during 2019 and 2020, respectively. Minimum SMEY was recorded under application of 75% NPK to single row on bed during both the years. Application of 125% NPK to double row on bed increased the SMEY up to 4.4% and 5.3% over 100% NPK applied to single row on bed during 2019 and 2020. Sepat *et al* (2015) and Ramesh *et al* (2016) concluded that conjoint application of both organic and inorganic fertilizer resulted in higher equivalent yield.

Table 4.58: Effect of nutrient application to preceding *kharif* maize and pea and nutrient levels to spring maize on equivalent yield and system productivity of *kharif* maize-pea-spring maize cropping system

Treatment	Spring maize Equivalent yield (q ha^{-1})		System productivity (kg $ha^{-1}day^{-1}$)	
	2019	**2020**	**2019**	**2020**
Nutrient application in preceding *kharif* maize and pea				
Maize (100 % NPK) + Pea (100 % NPK)	211.4	205.9	63.9	61.8
Maize (100 % NPK) + Pea (100 % NPK + FYM @ 20 t ha^{-1})	219.3	218.8	65.7	65.5
Maize (100 % NPK+ FYM @ 15 t ha^{-1}) + Pea (100 % NPK)	216.0	211.9	64.3	62.8
Maize (100 % NPK + FYM @ 15 t ha^{-1}) + Pea (100 % NPK + FYM @ 20 t ha^{-1})	227.4	229.3	67.5	67.5
CD (p=0.05)	3.5	4.4	1.1	1.1
Nutrient levels in spring maize				
75 % NPK with single row on bed	213.4	209.8	63.7	62.3
75 % NPK with double row on bed	215.0	211.5	64.6	63.2
100% NPK with single row on bed	215.9	213.6	64.4	63.4
100% NPK with double row on bed	220.3	218.3	66.1	65.1
125 % NPK with single row on bed	221.2	220.9	65.9	65.3
125 % NPK with double row on bed	225.5	224.9	67.5	67.0
CD (p=0.05)	4.2	3.2	1.3	1.0
Interaction	NS	NS	NS	NS

4.2.3.9.2 System productivity

Data with respect to system productivity are given in table 4.58 and fig 4.29. The total production in terms of system productivity was significantly higher (67.5 and 67.5 kg ha^{-1} day^{-1}) under application of 100 % NPK + FYM @ 15 t ha^{-1} to maize and 100% NPK + FYM @ 20 t ha^{-1} to pea as compared to treatments involving application of 100 % NPK to maize and 100 % NPK + FYM @ 20 t ha^{-1} to pea, 100% NPK + FYM @ 15 t ha^{-1} to maize and 100% NPK to pea as well as 100% NPK applied to both preceding maize and pea crops. The lowest values of system productivity were recorded when 100% NPK was applied to preceding maize and pea crops. According to Kumar and Mukhopadhyay (2017), system productivity in terms of wheat equivalent yield was significantly greater when FYM and fertilizers were used together.

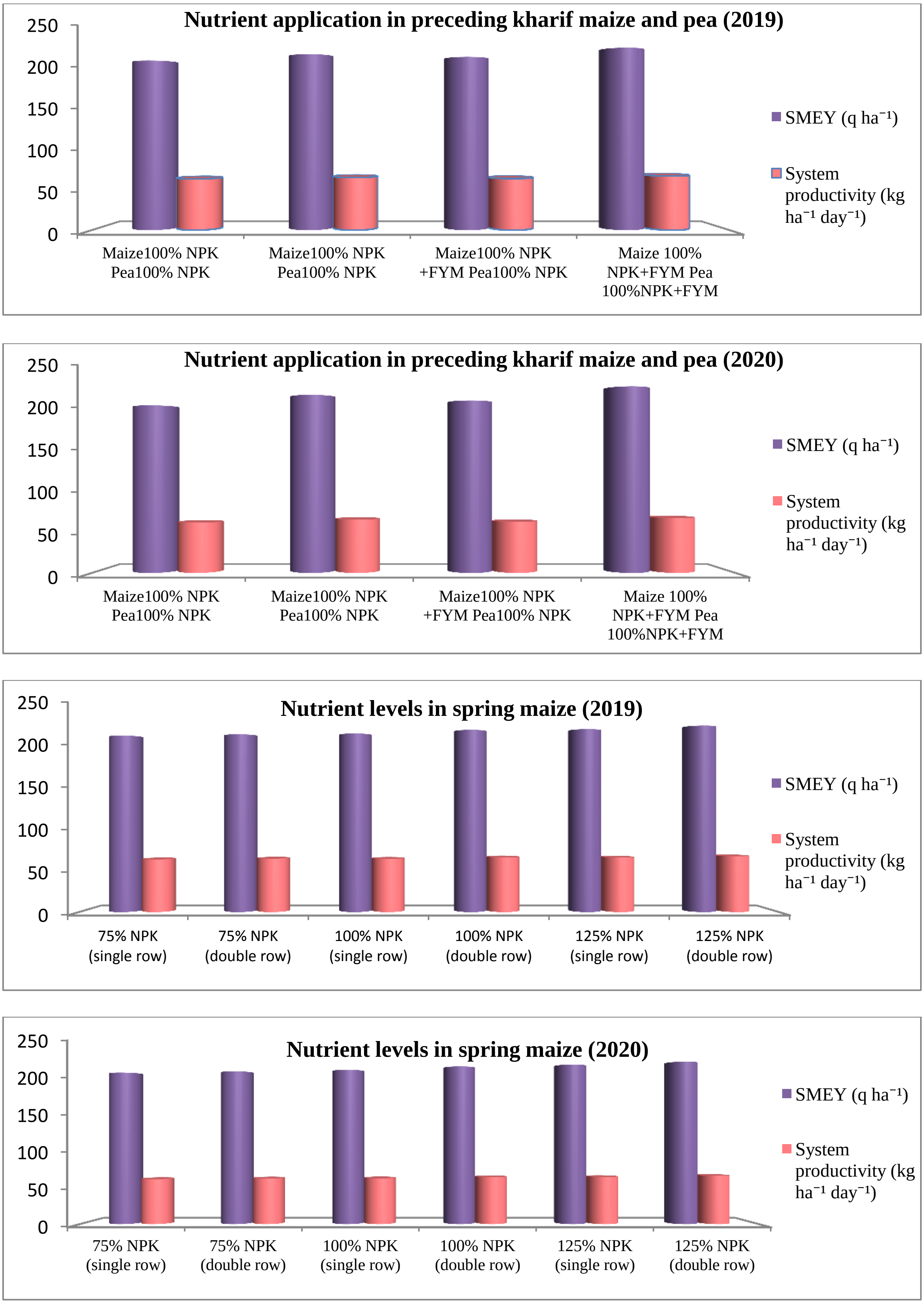


Fig. 4.29: Effect of nutrient application to preceding *kharif* maize and pea and nutrient levels to spring maize on SMEY and system productivity in maize-pea-spring maize cropping system

Among different nutrients level applied to spring maize, application of 125% NPK to double row on bed resulted in significantly higher system productivity (67.5 and 67.0 kg ha^{-1} day^{-1}) as compared to 75% NPK, 100% NPK applied to both single and double rows on bed and 125% NPK applied to single row on bed during 2019 and 2020, respectively. Application of 75% NPK to single row planted spring maize recorded lowest values for system productivity during both the years. Data indicated that with increased dose of nutrients from 75 to 125% NPK applied to spring maize, there was progressive increase in system productivity. The per cent increase in system productivity under 125% NPK application to double row was 6.0 and 7.5% as compared to 75% NPK application to single row on bed, however the increase was 4.8 and 5.8% over 100% NPK application to single row on bed during both the years.

4.2.3.9.3 Cost of cultivation

The data on economic analysis of the cropping system i.e *kharif* maize-pea-spring maize are presented in table 4.59. Application of 100% NPK + FYM @ 15 t ha^{-1} to maize and 100% NPK + FYM @ 20 t ha^{-1} to pea in the main plots recorded higher cost of cultivation (159.3 and 154.5 $\times 10^3$ Rs ha^{-1}) during 2019 and 2020, as compared to all other treatments. The minimum cost of cultivation was recorded under treatment which includes the application of 100% NPK to both maize and pea. The increase in cost cultivation under combined application of organic and inorganic fertilizer was only due to additional cost of FYM.

Among different nutrient levels applied to spring maize, higher cost of cultivation (157.8 and 152.5 $\times 10^3$ Rs ha^{-1}) was recorded under 125% NPK to double row on bed, followed by 125% NPK applied to single row on bed as compared to lower levels of fertilizer and single row planting. This was due to additional cost of seed and fertilizers under this treatment.

4.2.3.9.4 Gross returns

The gross returns of *kharif* maize-pea-spring maize cropping system are given in table 4.59 and fig. 4.30. The data showed that application of 100% NPK + FYM @ 15 t ha^{-1} to maize and 100% NPK + FYM @ 20 t ha^{-1} to pea in the main plots recorded maximum gross returns (400.2 and 424.2 $\times 10^3$ Rs ha^{-1}) during 2019 and 2020, respectively as compared to all other treatments. Application of 100% NPK to both maize and pea resulted in minimum gross returns during both the years. Higher gross returns under combined use of organic and synthetic fertilizers were due to higher yield of crops under this treatment. Kumawat *et al* (2019) also reported examined that higher gross returns under conjoint application of organic and inorganic fertilizer as compared to sole application of synthetic fertilizers.

Planting spring maize in double row on bed with 125% NPK application resulted in maximum gross returns (396.8 and 416.1 $\times 10^3$ Rs ha^{-1}) which was followed by 125% NPK applied to single row on bed during both the years. Minimum gross returns (375.6 and 388.1

$\times 10^3$ Rs ha^{-1}) were obtained from the treatment which consists of 75% NPK applied to single row on bed. The increase in gross returns under 125% NPK application to double row planted spring maize was up to a margin of 4.4 and 5.2% during 2019 and 2020, respectively over 100% NPK applied to single row on bed. Adhikari *et al* (2021) reported that application of higher dose of nitrogen gave higher gross returns as compared to lower nitrogen levels.

4.2.3.9.5 Net returns

Net returns for various treatments were worked out for the *kharif* maize-pea-spring maize cropping system and the data pertaining to the net returns are depicted in table 4.59 and fig. 4.30. It is apparent from the data that maximum net returns (240.9 and 269.7 $\times 10^3$ Rs ha^{-1}) were obtained from the treatment involving application of 100% NPK + FYM @ 15 t ha^{-1} to maize and 100% NPK + FYM @ 20 t ha^{-1} to pea. This treatment was followed by 100% NPK applied to maize and 100% NPK + FYM @ 20 t ha^{-1} to pea. Minimum net returns (221.6 and 232.5 $\times 10^3$ Rs ha^{-1}) were recorded with application of 100% NPK to both maize and pea. Higher net returns observed under this treatment was due to higher gross returns obtained during both the years. Sigaye *et al* (2021) also observed that combined application of organic and inorganic fertilizers resulted in higher net returns as compared to sole application of synthetic fertilizers.

Among various nutrient levels applied to spring maize, application of 125% NPK to double row on bed recorded maximum net returns (238.9 and 263.6 $\times 10^3$ Rs ha^{-1}) and it was followed by 125% NPK applied to single row on bed, while minimum net returns (223.2 and 241.0 $\times 10^3$ Rs ha^{-1}) were obtained from single row on bed with 75% NPK application during 2019 and 2020, respectively. The net returns with application of 125% NPK to double row on bed was 5.4% and 6.7% higher as compared to 100% NPK applied to single row on bed during both the years.

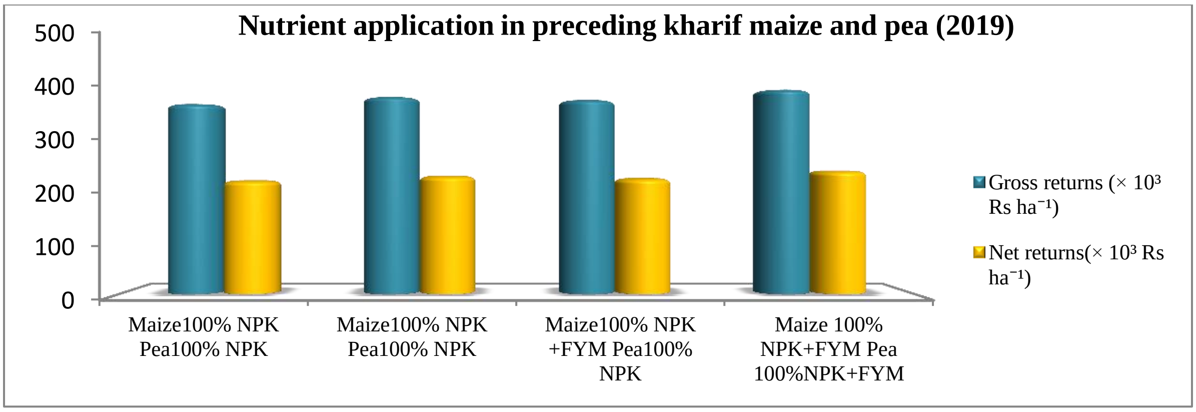
4.2.3.9.6 Benefit cost ratio

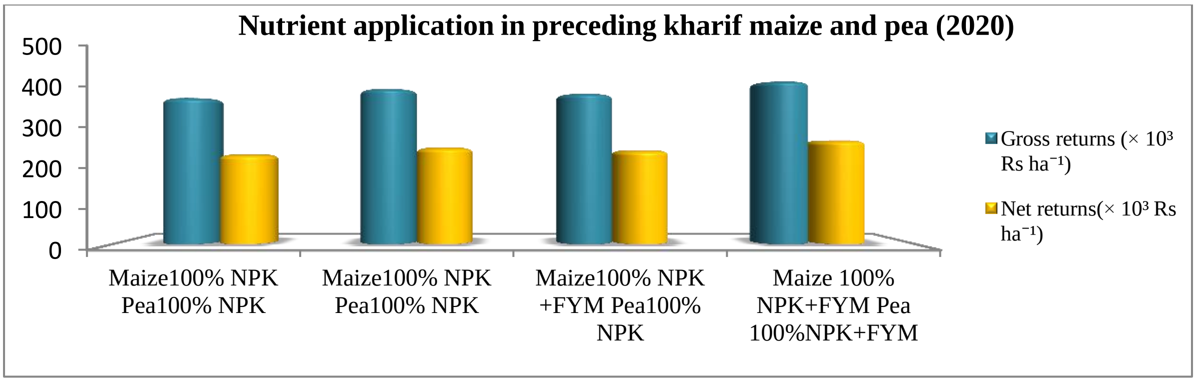
Benefit cost ratio (B:C) for different treatments in *kharif* maize-pea-spring maize cropping system was calculated and presented in table 4.59. Highest B:C (1.51 and 1.75) was recorded in the treatment involving application of 100% NPK + FYM @ 15 t ha^{-1} to maize and 100% NPK + FYM @ 20 t ha^{-1} to pea and the lowest ratio was recorded (1.47 and 1.63) under treatment involving the application of 100% NPK to both preceding maize and pea. Highest B:C observed under this treatment was attributed to higher net returns. Chandel *et al* (2017) also reported higher benefit cost ratio with combined application of organic and inorganic fertilizers.

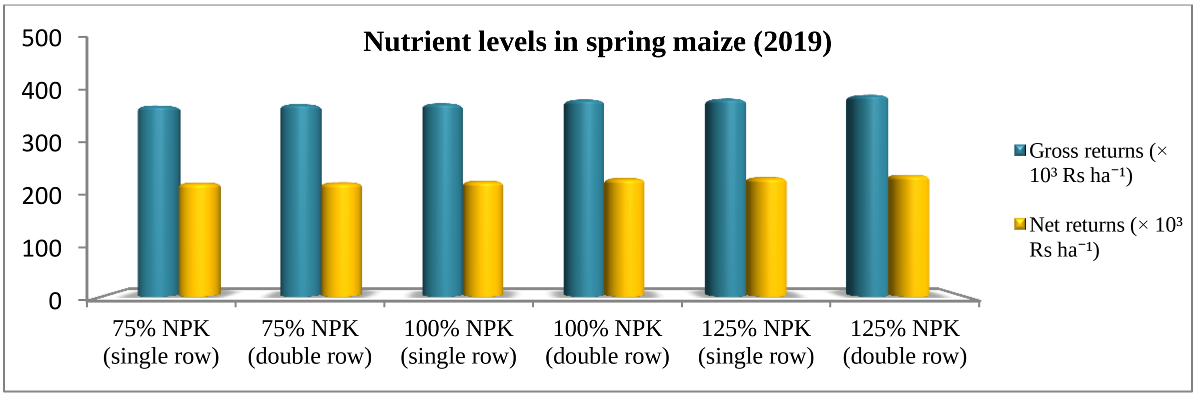
Under various treatments applied to spring maize, application of 125% NPK to double row on bed recorded higher B:C (1.51 and 1.73) as compared to all other treatments during 2019 and 2020. Application of 125% NPK to double row on bed increased the B:C up to a margin of 3.4%, 4.9% and 1.5%, 3.9% as compared to 75% NPK and 100% NPK applied

Table 4.59: Effect of nutrient application to preceding *kharif* maize and pea and nutrient levels to spring maize on economics of *kharif* maize-pea-spring maize cropping system

Treatment	Cost of cultivation ($\times 10^3$ Rs ha^{-1})		Gross returns ($\times 10^3$ Rs ha^{-1})		Net returns ($\times 10^3$ Rs ha^{-1})		Benefit cost ratio		Profitability (Rs ha^{-1} day^{-1})	
	2019	**2020**	**2019**	**2020**	**2019**	**2020**	**2019**	**2020**	**2019**	**2020**
Nutrient application in preceding *kharif* maize and pea										
Maize (100 % NPK) + Pea (100 % NPK)	150.5	144.7	372.1	380.9	221.6	232.5	1.47	1.63	607.0	647.2
Maize (100 % NPK) + Pea (100 % NPK + FYM @ 20 t ha^{-1})	155.5	150.7	386.0	404.8	230.4	250.4	1.48	1.69	631.3	696.2
Maize (100 % NPK+ FYM @ 15 t ha^{-1}) + Pea (100 % NPK)	154.3	148.5	380.2	392.0	225.9	243.6	1.46	1.64	619.0	667.3
Maize (100 % NPK + FYM @ 15 t ha^{-1}) + Pea (100 % NPK + FYM @ 20 t ha^{-1})	159.3	154.5	400.2	424.2	240.9	269.7	1.51	1.75	660.1	739.0
Nutrient levels in spring maize										
75 % NPK with single row on bed	152.4	147.1	375.6	388.1	223.2	241.0	1.46	1.64	611.4	660.2
75 % NPK with double row on bed	154.7	149.4	378.4	391.3	223.7	241.9	1.45	1.62	612.8	662.7
100% NPK with single row on bed	153.3	148.0	380.0	395.1	226.7	247.1	1.48	1.67	621.0	677.0
100% NPK with double row on bed	155.6	150.3	387.6	403.8	232.0	253.5	1.49	1.68	635.6	694.5
125 % NPK with single row on bed	155.5	150.2	389.3	408.6	233.8	258.4	1.50	1.72	640.6	708.0
125 % NPK with double row on bed	157.8	152.5	396.8	416.1	238.9	263.6	1.51	1.73	654.6	722.1







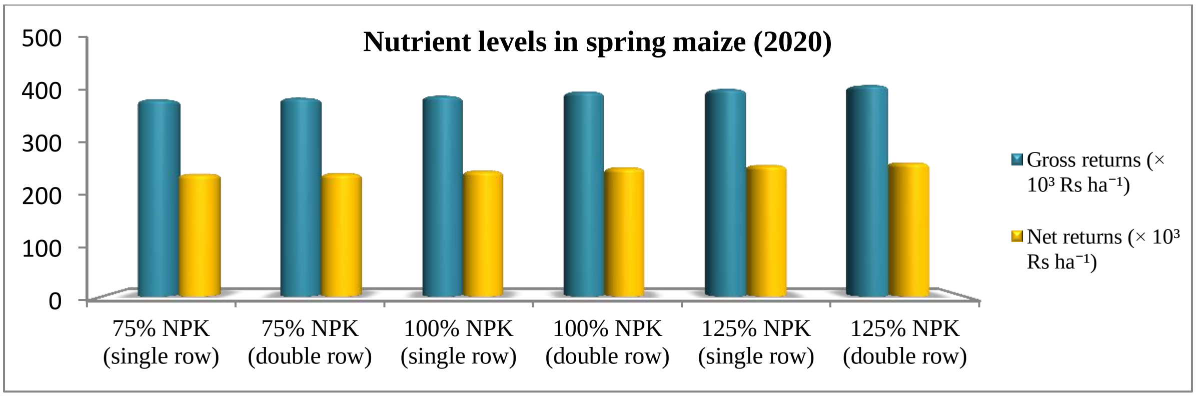


Fig 4.30: Effect of nutrient application to preceding *kharif* maize and pea and nutrient levels to spring maize on gross returns and net returns in maize-pea-spring maize cropping system

to single row on bed during 2019 and 2020, respectively. Raj *et al* (2021) also reported that application of higher dose of nitrogen resulted in higher B:C as compared to lower nitrogen levels.

4.2.3.9.7 Profitability

Data presented in table 4.59 indicated that integrated nutrient management practices i.e. application of 100% NPK + FYM @ 15 t ha^{-1} to maize and 100% NPK + FYM @ 20 t ha^{-1} to pea resulted in significantly higher profitability (660.1 and 739.0 Rs ha^{-1} day^{-1}) as compared to all other treatments during both the years. The per cent increase in profitability under treatment involving application of 100% NPK + FYM @ 15 t ha^{-1} to maize and 100% NPK + FYM @ 20 t ha^{-1} to pea was 8.7% and 14.1% over application of 100% NPK to both preceding maize and pea crops. Lowest profitability was recorded lowest with application 100% NPK to maize and pea during both years. Kumawat *et al* (2019) examined higher production efficiency and profitability under conjoint application of organic and inorganic fertilizer as compared to sole application of synthetic fertilizers.

Nutrient application to spring maize also showed significant influenced on profitability of the cropping system. Maximum profitability (654.6 and 722.1 Rs ha^{-1} day^{-1}) was recorded with application of 125% NPK to double row on bed which was statistically at par with single row planted maize with 125% NPK application and significantly better than all other treatments during 2019 and 2020. Lowest values for profitability of the cropping system (611.4 and 660.2 Rs ha^{-1} day^{-1}) were obtained from 75% NPK applied to single row on bed. The profitability of the system was increased up to a margin of 7.0, 9.4% and 5.4%, 6.7% under double row on bed with 125% NPK application in comparision to 75% NPK and 100% NPK applied to single row on bed during 2019 and 2020. All the interaction effects were found non-significant.

CHAPTER V

SUMMARY

Rice-wheat cropping system is a widely adopted cropping system in north India. This agricultural system covers approximately 12.3 million hectares of area in Indo Gangetic Plains of India (Bhatt *et al* 2021). The widespread adoption of this cropping system has improved agricultural production but over time this intensive system has resulted in diminishing yield and deterioration in soil productivity even with optimal fertilizer use. As a result, there is an urgent need to adopt alternative option, such as crop residue incorporation in the succeeding crop in order to restore soil fertility and increase productivity. Crop diversification is another management approach that is urgently needed to protect natural resources from over exploitation and to ensure the sustainability of the ecosystem.

Rice-potato-spring maize and maize-pea-spring maize are two important cropping systems that can be practiced in Punjab to diversify the existing rice-wheat cropping system. The nutrients applied to preceding crop has a huge impact on the returns obtained from succeeding crop in different cropping sequences. So, rather focusing on individual crop in a series, a greater emphasis should be given on the cropping system as a whole.

In terms of area and production, maize (*Zea mays* L.) is the third most important cereal crop in the world after rice and wheat. It is known as the "queen of cereals" because it has the highest genetic yield potential and a wide range of adaptability under diverse soil and climatic conditions. Spring maize cultivation is growing popular among farmers of Punjab due to its short duration and higher yield and it also used for diversifying some areas of cereal-based cropping system. The potato (*Solanum tuberosum* L.) is a popular vegetable crop that plays a significant role in our daily diet. It is known as the “poor man's friend” since it provides individuals with good nutrition and low-cost energy. Pea (*Pisum sativum* L.) is a popular temperate grain legume that is grown all over the world. Legumes are widely used in diversification plans because they fix atmospheric nitrogen which reduce the utilization of synthetic fertilizers and maintain the fertility status of the soil (Shah *et al* 2011).

Mineral fertilizers have become crucial in cultivation of crops. Chemical fertilizers cannot be totally avoided because they can provide a significant amount of primary and secondary nutrients in easily available form. The majority of agricultural crops respond quickly to chemical fertilizers, resulting in increased yield. Using only chemical fertilizers on the other hand is ineffective because it has been shown to degrade soil health. However, the incorporation of agricultural residues in soils and integrated use of organic and inorganic fertilizers can be used to substitute fertilizer doses. Incorporation of crop residue changes the soil ecosystem by improving the physical properties and increases the microbial community in the soil (Meena *et al* 2019). Integrated nutrient management (INM) is a strategy that aims at efficient utilization of inputs while minimizing environmental degradation. To ensure food and nutritional security in Indian agriculture, integrated plant nutrient supply and management strategies must be implemented to improve resource use efficiency, soil quality and system productivity. The use of inorganic fertilizers in conjunction with FYM increased the organic carbon content of the soil while decrease its bulk density (Sigaye *et al* 2021). The integrated use of inorganic fertilizers, organic manures and recyclable crop residues improves the system productivity and maintain soil fertility status.

Plant density is one of the important cultural practices which determine grain yield. Maize is more susceptible to changes in plant density and nitrogen levels than other members of grass family. Interplant competition for light, water and nutrients is increased when higher populations are maintained. Because it induces barrenness and reduces the number of cobs produced per plant and kernels set per cob, this may be deleterious to final yield. However, increasing plant density with additional dose of nitrogen and organic manure may result in higher grain yield.

Thus taking into consideration of above aspects the present study was conducted with following objectives:

- To study the effect of integrated nutrient management on growth, yield and quality of different crops under rice-potato-spring maize and maize-pea-spring maize cropping systems.
- To study soil properties, system productivity and economic viability of rice-potato-spring maize and maize-pea-spring maize cropping systems.

To accomplish these objectives present study entitled "**Integrated nutrient management for enhancing productivity of spring maize (*Zea mays* L.) in rice and maize based cropping systems"** was carried at the Student's Research Farm, Department of Agronomy, Punjab Agricultural University, Ludhiana, during the year 2018-19 and 2019-20 in split plot design. In experiment I four treatment combinations were applied to potato in main plots *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 and six nutrient levels to spring maize in sub plots *viz*., 75 % NPK applied to single row on bed, 75 % NPK applied to double row on bed, 100% NPK applied to single row on bed, 100% NPK applied to double row on bed, 125% NPK applied to single row on bed and 125% NPK applied to double row on bed. The experiment II consist of four treatment combinations in main plot *viz*., 100 % NPK to maize + 100 % NPK to pea, 100 % NPK to maize + 100 % NPK + FYM @ 20 t ha^{-1} to pea, 100 % NPK+ FYM @ 15 t ha^{-1} to maize + 100 % NPK to pea and 100 % NPK + FYM @ 15 t ha^{-1} to maize + 100 % NPK + FYM @ 20 t ha^{-1} to pea and 6 treatments were given to bed planted spring maize in sub plots *viz*., 75 % NPK applied to single row on bed, 75 % NPK applied to double row on bed, 100% NPK applied to single row on bed, 100%

NPK applied to double row on bed, 125 % NPK applied to single row on bed and 125 % NPK applied to double row on bed. Results obtained are summarized below:-

EXPERIMENT I

Residue incorporation and nutrient application in potato had significant effect on the growth and yield parameters of the potato crop. Application of 100% NPK + FYM 50 t ha^{-1} along with rice residue incorporation resulted in significantly higher plant height, dry matter accumulation and leaf area index in potato as compared to other treatments. The yield attributing characters like tillers count, number of tuber per plant and tuber weight per plant are significantly increased under this treatment. The tuber yield and fresh haulm yield were significantly higher with residue incorporation along with application of 100% NPK + FYM 50 t ha^{-1} as compared to residue removed plots with 150% NPK application. The per cent increase in tuber yield and haulm yield with application of 100% NPK + FYM @ 50 t ha^{-1} along with residue incorporation was 4.9, 3.6% and 4.8, 3.5% than treatment involving residue removal with 100% NPK + FYM 50 t ha^{-1} application.

The nutrient application to preceding potato had a significant effect on growth and yield attributing characters of spring maize. The growth attributes of spring maize like plant height, dry matter accumulation, leaf area index, chlorophyll index and PAR interception were higher with application of 100% NPK + FYM 50 t ha^{-1} along with residue incorporation in preceding potato at 60, 90 DAS and at maturity during both the years. Nutrient application in preceding crops did not showed any significant effect on all the growth attributes at 30 DAS and on all phonological stages. Nutrient applications in spring maize have significant effect over all the growth, yield and quality parameters of spring maize. The plant height, DMA and chlorophyll index were significantly higher in single row on bed with 125% NPK application during both the years. Application of 75% NPK to double row on bed resulted in smallest values for all the growth parameters except PAR interception. The lowest value of PAR interception was recorded under single row bed on bed with application of 75% NPK. The phenological stages were significantly varied with various nutrient levels in spring maize during both the years. Tasseling and silking was advanced by one to two days under 100% NPK applied to single row on bed than 125% NPK applied to double row on bed during 2019 and 2020, respectively. Application of 125% NPK applied to double row on bed took two days earlier to reach 50% dough stage and physiological maturity over 100% NPK applied to double row bed planted spring maize during 2019 and 2020, respectively.

The yield parameters of spring maize varied significantly with nutrient application to preceding crops and nutrient levels in spring maize. Yield attributes of spring maize *viz.*, number of cobs per plant, cob length, cob girth, number of rows per cob, number of grains per row, total number of grain per cob, 1000-grain weight and grain weight per cob were significantly increased with application of 100% NPK + FYM 50 t ha^{-1} along with residue incorporation in preceding potato during both years of study. The per cent increase in cob length, cob girth, number of rows per cob and total grains per cob with application of 100% NPK + FYM 50 t ha^{-1} along with residue incorporation was up to a margin of 5.8 and 4.5%, 7.7 and 4.3%, 5.9 and 4.2% and 16.8 and 9.6% as compared to treatment involving residue removal with 150% NPK application during 2019 and 2020, respectively. The grain yield, stover yield and harvest index were significantly higher under application of 100% NPK + FYM 50 t ha^{-1} along with residue incorporation. The increase in maize grain yield and stover yield under this treatment was 4.5, 5.1% and 2.9, 4.5% higher than with 100% NPK + FYM @ 50 t ha^{-1} application without residue incorporation during 2019 and 2020, respectively. Nutrient application in spring maize showed significant effect on yield attributes, grain yield and stover yield of spring maize. The grain and stover yield was significantly higher with application of 125% NPK to double row on bed as compared to all other treatments. The per cent increase in grain yield and stover yield under 125% NPK application to double row on bed was 14.6, 12.9% and 18.8, 21.8%, respectively over 100% NPK applied to single row on bed during 2019 and 2020.

The quality parameters of spring maize *viz*., protein content, starch content, oil content and total sugar were not significantly influenced by with rice residue and nutrient application to preceding potato but the protein and starch content were significantly varied with various nutrient levels applied to spring maize. Application of 125% NPK to single row on bed increased the protein content of spring maize up to 4.4% and 4.1% than 75% NPK applied to double row on bed during 2019 and 2020, respectively. The starch content was significantly higher with application of 75% NPK to double row on bed as compared to 125% NPK application to single row on bed.

Nutrient uptake in grain and stover of spring maize followed similar trend as that of grain and stover yield. Among nutrient application to spring maize, double row planted maize with 125% NPK application resulted with higher nutrient uptake in grain and stover during both the years. Soil OC was significantly increased under residue incorporation along with application of 100% NPK + FYM 50 t ha^{-1} as compared to sole application of synthetic fertilizer i.e 150% NPK application without residue incorporation. The bulk density was declined under residue incorporation along with application of 100% NPK + FYM 50 t ha^{-1} as compared to residue removal plots with 150% NPK application.

The total production in terms of spring maize equivalent yield, system productivity and profitability were significantly higher (257.6 and 267.4 q ha^{-1}, 82.9 and 89.1 kg ha^{-1} day^{-1} and 712.2 and 822.5 Rs ha^{-1} day^{-1}) in residue incorporated plot along with 100% NPK + FYM @ 50 t ha^{-1} application as compared to all other treatments during 2019 and 2020, respectively. Among different nutrient applied in main plots, treatment consisting residue incorporation along with 100% NPK + FYM @ 50 t ha^{-1} recorded highest gross returns (453.3

and 499.6 $\times10^3$ Rs ha^{-1}), net returns (259.9 and 300.2 $\times10^3$ Rs ha^{-1}) and B:C (1.34 and 1.51) during 2019 and 2020, respectively as compared to all other treatments. In spring maize, treatment involving application of 125% NPK to double row on bed recorded significantly higher spring maize equivalent yield (251.1 and 261.4 q ha^{-1}) and system productivity (81.3 and 87.1 kg ha^{-1} day^{-1}) as compared to all other treatments during 2019 and 2020, respectively. Application of 125% NPK to double row on bed resulted in significantly higher gross returns (441.8 and 488.2 $\times10^3$ Rs ha^{-1}), net returns (250.2 and 290.8 $\times10^3$ Rs ha^{-1}), B:C (1.30 and 1.47) and profitability (685.4 and 796.9 Rs ha^{-1} day^{-1}) as compared to lower doses of fertilizers during 2019 and 2020.

EXPERIMENT II

Nutrients applied to preceding maize and pea had a significant impact on growth and yield parameters of pea. Application of 100% NPK + FYM 15 t ha^{-1} to maize and 100% NPK + FYM 20 t ha^{-1} to pea resulted in significant increase in plant height, dry matter accumulation and leaf area index in pea as compared to 100% NPK applied to both maize and pea . Yield attributes of pea such as number of pods per plant, number of seeds per pod, pod length and 100-seed weight were significantly increased under combined application of organic and inorganic fertilizer as compared to sole application of inorganic fertilizer i.e. 100% NPK application to both maize and pea. Application of 100% NPK + FYM 15 t ha^{-1} to maize and 100% NPK + FYM 20 t ha^{-1} to pea recorded maximum green pod yield and stover yield. The increase in pod yield and stover yield was 19.7, 26.1% and 38.2, 33.3 % higher over 100% NPK applied to both maize and pea.

Nutrient application to preceding *kharif* maize and pea in main plots and different nutrients level applied to spring maize in sub plots had significant effect on growth attributes, yield attributes and quality parameters of spring maize during both the years. Application of 100% NPK + FYM 15 t ha^{-1} to maize and 100% NPK + FYM 20 t ha^{-1} to pea resulted in significantly higher plant height, DMA, LAI, chlorophyll index and PAR interception as compared to 100% NPK applied to both maize and pea at 60, 90 DAS and at maturity. However at 30 DAS, all growth parameters were found non-significant. Growth parameters of spring maize also varied significantly with different nutrient levels applied in spring maize. Application of 125% NPK to single row on bed recorded significantly higher plant height, DMA and chlorophyll index at 60, 90 DAS and at maturity as compared to 75% NPK applied to both single and double row on bed but it was statistically at par with 100% NPK applied to single row on bed during 2019 and 2020. The data recorded for LAI and PAR interception was significantly higher with application of 125% NPK to double row on bed as compared to all other treatments during both the years. Application of 125% NPK to single row on bed took four and two days earlier to reach 50% tasselling and silking, respectively than 75% NPK applied to double row on bed. Days taken to reach 50% dough and physiological maturity was advanced by one and two days under 75% NPK as compared to 125% NPK applied to double row on bed during both the years.

Yield and yield attributes of spring maize were significantly influenced by combined application of organic and inorganic nutrients to preceding maize and pea. Application of 100% NPK + FYM 15 t ha^{-1} to maize and 100% NPK + FYM 20 t ha^{-1} to pea recorded significantly higher yield attributing characters of spring maize as compared to 100% NPK application to both maize and pea. The increase in cob length, cob girth, number of rows per cob and 1000-grain weight was up to a margin of 6.4 and 5.0%, 6.8 and 6.3%, 5.9% and 5.1%, 4.3 and 3.1%, respectively with 100% NPK + FYM @ 15 t ha^{-1} applied to maize and 100% NPK + FYM @ 20 t ha^{-1} applied to pea in comparision to 100% NPK to both maize and pea. The increase in grain yield and stover yield was 7.3, 11.5% and 7.5, 9.4% higher with combined application of 100% NPK + FYM @ 15 t ha^{-1} to maize and 100% NPK + FYM @ 20 t ha^{-1} to pea as compared to sole 100% NPK application to both maize and pea. Nutrients applied to spring maize in sub plots also showed significant influence on all yield and yield attributing characters during both the years. Yield attributing characters like cob length, cob girth, number of rows per cob, nuber of grains per cob and 1000-grain weight increased up to 9.5 and 7.1%, 12.0 and 9.5%, 8.6 and 6.3%, 19.2 and 14.0 % , 2.6 and 4.8% higher with application of 125% NPK to single row on bed as compared to 75% NPK to single row on bed during 2019 and 2020, respectively. Application of 125% NPK to double row on bed resulted in significantly higher grain yield and stover yield as compared to all other nutrient levels during both the years. The increase in grain yield and stover yield under this treatment was due to increase in number of cobs per unit area. Grain yield and stover yield increased up to a margin of 12.5, 14.7 % and 18.4, 16.2% under 125% NPK application to double row on bed as compared to 100% NPK application to single row on bed during both years.

Nutrients applied to preceding *kharif* maize and pea did not show any significant effect on quality parameters of spring maize viz., protein content, starch content, oil content and total sugar content during both the years. But different nutrient levels applied to spring maize had significant influence on protein and starch content of maize grain. Application of 125% NPK to single row on bed recorded significantly higher protein content as compared to 75% NPK applied to double row on bed during both years, whereas, maximum starch content was recorded with 75% NPK applied to double row on bed.

The N, P and K content and uptake of spring maize grain and straw did not differ significantly with various nutrients applied to maize and pea. N content of maize grain was significantly higher with 125% NPK applied to single row on bed as compared to 75% NPK applied to double row on bed during both the years. Application of 125% NPK to double row on bed resulted in higher N, P and K uptake by maize grain and stover as compared to 75%

NPK applied to single rowon bed. The OC was increased under combined application of organic and inorganic fertilizer i.e. 100% NPK + FYM @ 15 t ha^{-1} to maize and 100% NPK + FYM @ 20 t ha^{-1} to pea as compared to 100% NPK applied to both maize and pea. Bulk density of soil was significantly increased with application of 100% NPK to maize and pea as compared to mixed application of organic manure and inorganic fertilizer during both the years.

Application of 100% NPK + FYM @ 15 t ha^{-1} to maize and 100% NPK + FYM @ 20 t ha^{-1} to pea recorded maximum values of SMEY (227.4 and 229.3 q ha^{-1}), system productivity (67.5 and 67.5 kg ha^{-1} day^{-1}), gross returns (400.2 and 424.2 $\times 10^3$ Rs ha^{-1}), net returns (240.9 and 269.7 $\times 10^3$ Rs ha^{-1}), B:C (1.51 and 1.75) and profitability (660.1 and 739.0 Rs ha^{-1} day^{-1}) as compared to all other treatments during 2019 and 2020, respectively. Different nutrient levels applied to spring maize in sub plots showed that treatment involving application of 125% NPK to double row on bed recorded highest SMEY (225.5 and 224.9 q ha^{-1}), system productivity (67.5 and 67.0 kg ha^{-1} day^{-1}), gross returns (396.8 and 416.8 $\times 10^3$ Rs ha^{-1}), net returns (238.9 and 263.6 $\times 10^3$ Rs ha^{-1}), B:C (1.51 and 1.73) and profitability (654.6 and 722.1 Rs ha^{-1} day^{-1}) as compared to all other treatments during 2019 and 2020, respectively.

CONCLUSION

- In rice-potato-spring maize cropping system, combined use of 100% NPK + FYM @ 50 t ha^{-1} along with rice residue incorporation to preceding potato and 125% NPK applied to single row on bed recorded significantly higher plant height, DMA, chlorophyll index and yield attributing characters of spring maize during both the years. However LAI, PAR interception and numbers of cobs per hectare were significantly higher with 125% NPK applied to double row bed planted spring maize.
- Significantly higher grain yield (80.1 and 83.6 q ha^{-1}), SMEY (257.6 and 267.4 q ha^{-1}), system productivity (82.9 and 89.1 kg ha^{-1} day^{-1}) and net returns (259.9 and 300.2 $\times 10^3$ Rs ha^{-1}) were obtained from rice-potato-spring maize cropping system with application of 100% NPK + FYM @ 50 t ha^{-1} to preceding potato along with rice residue incorporation as compared to all the treatments. Application of 125% NPK applied to double row bed planted spring maize recorded 14.6 and 12.9%, 4.5 and 4.0%, 5.4 and 4.7%, 6.2 and 5.0% higher grain yield, SMEY, system productivity and net returns during 2019 and 2020, respectively in comparision to 100% NPK applied to single row on bed.
- In *kharif* maize-pea-spring maize cropping system, application of 100% NPK + FYM @ 15 t ha^{-1} to maize + 100% NPK + FYM @ 20 t ha^{-1} to pea in main plots and 125% NPK applied to single row bed planted spring maize in sub plots resulted in significantly higher plant height, DMA, chlorophyll index and yield attributing characters of spring maize during both years. However LAI, PAR interception and numbers of cobs per hectare were

significantly higher with 125% NPK applied to double row bed planted spring maize.

- Significantly higher grain yield (81.1 and 84.3 q ha^{-1}), SMEY (227.4 and 229.3 q ha^{-1}), net returns (240.9 and 269.7 × 10^3 Rs ha^{-1}) and system productivity (67.5 and 67.5 kg $ha^{-1}day^{-1}$) were obtained from maize-pea-spring maize cropping system with application of 100% NPK + FYM @ 15 t ha^{-1} to preceding maize and 100% NPK + FYM @ 20 t ha^{-1} to preceding pea as compared to all other treatments. Double row bed planted spring maize with 125% NPK application resulted in 12.5 and 14.7% higher grain yield, 4.4 and 5.3% higher SMEY, 4.8 and 5.7% higher system productivity and 5.3 and 4.4% higher net returns as compared to 100% NPK applied to single row bed planted maize during 2019 and 2020, respectively.
- Protein content in spring maize was increased but starch content was decreased with increasing levels of nutrients.
- Organic carbon of soil was increased with combined application of organic and inorganic fertilizer in both the cropping systems.
- After two years of study,bulk density of soil was decreased with mixed application of inorganic fertilizers and FYM as compared to sole application of synthetic fertilizer in both the cropping systems.

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APPENDIX-I
WEEKLY WEATHER DATA RECORDED DURING THE GROWTH OF RICE (2018)

Standard meteorological week	T max (°C)	T min (°C)	Sun shine (hr)	Mean RH (%)	Rainfall (mm)	ET_0 (mm)
26th (25th June-1st July)	34.7	27.1	36.0	50.1	37.3	40.2
27th (2nd-8th July)	33.9	26.1	48.0	62.0	52.8	35.7
28th (9th-15th July)	35.5	28.1	44.4	58.3	64.0	42.6
29th (16th-22nd July)	33.4	26.0	28.1	76.6	167.8	25.2
30th (23rd-29th July)	33.9	26.6	29.0	64.7	91.0	26.8
31st (30th July-5th August)	35.2	27.6	55.4	58.3	0.98	38.0
32nd (6th-12th August)	32.7	26.5	33.5	72.3	53.8	25.8
33rd (13th-19th August)	33.9	26.8	30.1	69.6	13.0	25.0
34th (20th-26th August)	34.2	27.3	40.0	67.7	0.00	27.0
35th (27th August -2nd September)	34.8	27.5	34.2	63.1	7.21	27.4
36th (3rd-9th September)	33.4	26.6	37.2	64.0	35.2	27.2
37th(10th-16th September)	33.4	25.2	58.3	60.1	0.00	28.6
38th (17th-23rd September)	31.1	22.3	53.2	61.3	146.8	28.5
39th (24th-30th September)	29.8	21.3	57.5	64.9	68.2	25.8
40th (1st-7th October)	32.5	20.5	67.4	47.0	0.00	23.4
41st (8th- 14th October)	30.8	18.6	55.9	40.1	0.00	26.2
Total			708.1		738.1	473.5

APPENDIX-II

WEEKLY WEATHER DATA RECORDED DURING THE GROWTH OF RICE (2019)

Standard meteorological week	**T max (°C)**	**T min (°C)**	**Sun shine (hr)**	**Mean RH (%)**	**Rainfall (mm)**	**ET_0 (mm)**
28th (9th-15th July)	31.5	23.9	15.5	78.8	131.0	39.6
29th (16th-22nd July)	32.9	26.2	35.4	72.9	2.80	37.0
30th (23rd-29th July)	33.4	27.2	25.6	77.4	35.2	29.4
31st (30th July-5th August)	32.4	26.7	27.7	79.6	102.4	32.6
32nd (6th-12th August)	34.7	27.7	44.3	73.4	44.2	29.2
33rd (13th-19th August)	32.1	25.4	35.1	80.7	208.0	35.9
34th (20th-26th August)	34.5	26.7	61.9	72.6	0.00	28.0
35th (27th August -2nd September)	34.9	27.4	44.9	76.6	112.6	27.8
36th (3rd-9th September)	34.7	26.9	51.1	76.9	30.4	27.4
37th (10th-16th September)	34.5	26.9	42.3	73.3	6.02	22.0
38th (17th-23rd September)	32.8	24.7	57.1	72.0	3.78	22.0
39th (24th-30th September)	30.3	23.3	24.7	83.2	123.8	23.6
40th (1st-7th October)	30.2	20.5	50.4	72.9	0.00	23.2
41st (8th- 14th October)	31.2	19.2	63.1	69.8	0.00	16.5
42nd (15th-21st October)	30.5	18.5	38.8	66.0	0.00	15.4
Total			617.8		800.2	409.6

APPENDIX-III

WEEKLY WEATHER DATA RECORDED DURING *KHARIF* MAIZE (2018)

Standard meteorological week	**T max (°C)**	**T min (°C)**	**Sun shine (hr)**	**Mean RH (%)**	**Rainfall (mm)**	**ET_0 (mm)**
25th (18th-24th June)	38.3	26.3	60.8	48.5	0.07	49.0
26th (25th June-1st July)	34.7	27.1	36.0	58.4	37.3	40.2
27th (2nd -8th July)	33.9	26.1	48.0	73.3	52.8	35.7
28th (9th-15th July)	35.5	28.1	44.4	68.8	64.0	42.6
29th (16th-22nd July)	33.4	26.0	28.1	80.4	167.8	25.2
30th (23rd-29th July)	33.9	26.6	29.0	75.0	91.0	26.8
31st (30th July -5th August)	35.2	27.6	55.4	69.7	0.98	38.0
32nd (6th-12th August)	32.7	26.5	33.5	79.4	53.8	25.8
33rd (13th-19th August)	33.9	26.8	30.1	76.8	13.0	25.0
34th (20th-26th August)	34.2	27.3	40.0	75.5	0.00	27.0
35th (27th August -2nd September)	34.8	27.5	34.2	74.7	7.21	27.4
36th (3rd-9th September)	33.4	26.6	37.2	75.9	35.2	27.2
37th (10th-16th September)	33.4	25.2	58.3	72.9	0.00	28.6
38th (17th-23rd September)	31.1	22.3	53.2	73.8	146.8	28.5
39th (24th-30th September)	29.8	21.3	57.5	78.9	68.2	25.8
40th (1st-7thOctober)	32.5	20.5	67.4	69.9	0.00	23.4
Total			713.0		738.2	496.3

APPENDIX-IV

WEEKLY WEATHER DATA RECORDED DURING *KHARIF* MAIZE (2019)

Standard meteorological week	T max (°C)	T min (°C)	Sun shine (hr)	Mean RH (%)	Rainfall (mm)	ET_0 (mm)
26th (25th June-1st July)	39.6	28.1	73.8	46.4	0.00	62.5
27th (2nd -8th July)	37.6	28.9	38.3	58.4	14.4	50.6
28th (9th-15th July)	31.5	23.9	15.5	78.8	131.0	39.6
29th (16th-22nd July)	32.9	26.2	35.4	72.9	2.80	37.0
30th (23rd-29th July)	33.4	27.2	25.6	77.4	35.2	29.4
31st (30th July-5th August)	32.4	26.7	27.7	79.6	102.4	32.6
32nd (6th-12th August)	34.7	27.7	44.3	73.4	44.2	29.2
33rd (13th-19th August)	32.1	25.4	35.1	80.7	208.0	35.9
34th (20th-26th August)	34.5	26.7	61.9	72.6	0.00	28.0
35th (27th August -2nd September)	34.9	27.4	44.9	76.6	112.6	27.8
36th (3rd-9th September)	34.7	26.4	51.1	76.9	30.4	27.4
37th (10th -16th September)	34.7	26.9	42.3	73.3	6.02	22.0
38th (17th-23rd September)	32.8	24.7	57.1	72.0	3.78	22.0
39th (24th-30th September)	30.3	23.3	24.7	83.2	123.8	23.6
40th (1st-7th October)	30.2	20.5	50.4	72.9	0.00	23.2
Total			628.0		814.6	490.8

APPENDIX-V

WEEKLY WEATHER DATA RECORDED DURING THE GROWTH OF POTATO (2018-19)

Standard meteorological week	T max (°C)	T min (°C)	Sun shine (hr)	Mean RH (%)	Rainfall (mm)	ET_0 (mm)
43rd (22nd-28th October)	30.6	14.2	57.2	62.5	0.00	18.4
44th (29th October- 4th November)	29.6	16.2	14.9	66.4	0.37	15.0
45th (5th-11th November)	27.1	11.0	45.8	61.5	0.00	14.3
46th (12th-18th November)	26.4	11.5	44.1	63.9	0.00	13.9
47th (19th-25th November)	27.1	10.8	58.0	59.3	0.00	17.2
48th (26th November -2nd December)	25.8	10.1	39.6	63.8	0.00	14.5
49th (3rd-9th December)	22.7	7.66	33.8	68.9	0.00	8.68
50th (10th-16th December)	20.3	7.37	33.3	71.1	0.00	9.03
51st (17th-23rd December)	20.3	3.60	44.3	66.6	0.00	8.89
52nd (24th-31st December)	18.4	2.79	38.4	68.2	0.00	7.77
1st (1st-7th January)	18.2	6.70	15.7	72.8	0.29	8.19
2nd (8th-14th January)	19.8	6.03	35.2	67.6	0.29	9.03
3rd (15th-21st January)	19.3	6.19	28.2	69.5	0.00	10.9
4th (22nd-28th January)	17.2	5.91	53.5	73.2	8.86	10.4
5th (29th January- 4th February)	19.1	6.26	33.0	72.4	0.00	8.4
6th (5th-11th February)	19.4	8.40	32.9	75.3	9.77	11.6
Total			550.8		137.1	186.3

APPENDIX-VI
WEEKLY WEATHER DATA RECORDED DURING THE GROWTH OF POTATO (2019-20)

Standard meteorological week	**T max (°C)**	**T min (°C)**	**Sun shine (hr)**	**Mean RH (%)**	**Rainfall (mm)**	**ET_0 (mm)**
43rd (22nd-28th October)	30.5	15.8	44.4	64.1	0.00	16.0
44th (29th October-4th November)	29.0	16.2	8.68	70.0	0.00	12.6
45th (5th-11th November)	27.4	13.6	41.1	59.9	0.00	16.0
46th (12th-18th November)	25.1	13.6	29.0	70.2	0.00	12.6
47th (19th-25th November)	24.8	11.6	36.0	66.9	0.00	11.4
48th (26th November-2nd December)	22.4	12.0	35.1	74.7	35.2	12.6
49th (3rd-9th December)	22.4	7.17	43.1	68.3	0.00	8.61
50th (10th-16th December)	16.2	9.37	16.1	82.2	46.8	7.63
51st (17th-23rd December)	13.6	8.14	8.33	83.9	0.00	6.72
52nd (24th-31st December)	10.4	5.46	7.35	82.3	0.00	4.2
1st (1st-7th January)	16.3	5.77	20.2	78.3	13.4	3.78
2nd (8th-14th January)	15.2	7.09	29.3	81.0	20.0	5.67
3rd (15th-21st January)	16.1	7.40	27.1	80.3	0.00	4.97
4th (22nd-28th January)	18.3	6.20	44.5	73.9	6.37	8.40
5th (29th January - 4th February)	17.6	5.69	50.7	77.5	0.00	10.0
6th (5th-11th February)	18.9	4.91	55.4	71.5	0.00	11.0
Total			496.3		121.8	152.3

APPENDIX-VII

WEEKLY WEATHER DATA RECORDED DURING THE GROWTH OF PEA (2018-19)

Standard meteorological week	T max (°C)	T min (°C)	Sun shine (hr)	Mean RH (%)	Rainfall (mm)	ET_0 (mm)
42nd (15th-21st October)	31.7	16.0	62.0	60.2	0.00	22.2
43rd (22nd-28th October)	30.6	14.2	57.2	62.5	0.00	18.4
44th (29th October -4th November)	29.6	16.2	14.9	66.4	2.59	15.0
45th (5th-11th November)	27.1	11.0	45.8	61.5	0.00	14.3
46th (12th -18th November)	26.4	11.5	44.1	63.9	0.00	13.9
47th (19th-25th November)	27.1	10.8	58.0	59.3	0.00	17.2
48th (26th November -2nd December)	25.8	10.1	39.6	63.8	0.00	14.5
49th (3rd-9th December)	22.7	7.66	33.8	68.9	0.00	8.68
50th (10th-16th December)	20.3	7.37	33.3	71.1	0.00	9.03
51st (17th-23rd December)	20.3	3.60	44.3	66.6	0.00	8.89
52nd (24th-31st December)	18.4	2.79	38.4	68.2	0.00	7.77
1st (1st-7th January)	18.2	6.70	15.7	72.8	2.03	8.19
2nd (8th-14th January)	19.8	6.03	35.2	67.6	2.03	9.03
3rd (15th -21st January)	19.3	6.19	28.2	69.5	0.00	10.9
4th (22nd-28th January)	17.2	5.91	53.5	73.2	62.0	10.4
5th (29th January-4th February)	19.1	6.26	33.0	72.4	0.00	8.4
6th (5th-11th February)	19.4	8.40	32.9	75.3	68.4	11.6
7th (12th-18th February)	19.9	10.6	17.0	76.6	7.21	9.80
Total			687.0		144.3	218.3

APPENDIX-VIII
WEEKLY WEATHER DATA RECORDED DURING THE GROWTH OF PEA (2019-20)

Standard meteorological week	T max (°C)	T min (°C)	Sun shine (hr)	Mean RH (%)	Rainfall (mm)	ET_0 (mm)
43rd (22nd-28th October)	30.5	15.8	44.4	64.1	0.00	16.0
44th (29th October-4th November)	29.0	16.2	8.68	70.0	0.00	12.6
45th (5th-11th November)	27.4	13.6	41.1	59.9	0.00	16.0
46th (12th-18th November)	25.1	13.6	29.0	70.2	0.00	12.6
47th (19th-25th November)	24.8	11.6	36.0	66.9	0.00	11.4
48th (26th November-2nd December)	22.4	12.0	35.1	74.7	35.2	12.6
49th (3rd-9th December)	22.4	7.17	43.1	68.3	0.00	8.61
50th (10th-16th December)	16.2	9.37	16.1	82.2	46.8	7.63
51st (17th-23rd December)	13.6	8.14	8.33	83.9	0.00	6.72
52nd (24th-31st December)	10.4	5.46	7.35	82.3	0.00	4.20
1st (1st-7th January)	16.3	5.77	20.2	78.3	13.4	3.78
2nd (8th-14th January)	15.2	7.09	29.3	81.0	20.0	5.67
3rd (15th-21st January)	16.1	7.40	27.1	80.3	0.00	4.97
4th (22nd-28th January)	18.3	6.20	44.5	73.9	6.37	8.40
5th (29th January-4th February)	17.6	5.69	50.7	77.5	0.00	10.0
6th (5th-11th February)	18.9	4.91	55.4	71.5	0.00	11.0
7th (12th-18th February)	23.0	7.84	68.4	69.9	0.00	14.4
8th (19th-25th February)	23.5	12.0	48.7	68.0	6.02	18.0
Total			613.4		127.9	184.7

APPENDIX-IX
WEEKLY WEATHER DATA RECORDED DURING SPRING MAIZE (2019)

Standard meteorological week	T max (°C)	T min (°C)	Sun shine (hr)	Mean RH (%)	Rainfall (mm)	ET_0 (mm)
8th (19th-25th February)	21.1	10.3	47.5	74.6	14.6	14.4
9th (26th February-4th March)	20.0	9.57	46.6	71.9	11.4	14.4
10th (5th-11th March)	22.7	9.97	57.2	69.0	1.40	16.2
11th (12th-18th March)	24.6	10.7	52.2	67.9	0.00	15.4
12th (19th-25th March)	26.9	12.9	52.3	64.9	0.00	23.8
13th (26th March -1st April)	31.1	14.7	70.1	63.2	0.00	26.0
14th (2nd-8th April)	34.3	18.3	66.1	58.4	0.00	31.2
15th (9th-15th April)	35.0	19.9	49.8	50.5	6.58	41.5
16th (16th-22nd April)	31.3	18.1	62.5	57.1	31.2	30.6
17th (23rd-29th April)	39.3	21.9	72.8	38.6	3.78	52.8
18th (30th April-6th May)	37.7	21.3	69.0	28.6	4.48	53.6
19th (7th-13th May)	39.4	21.9	66.3	30.1	3.29	62.7
20th (14th-20th May)	34.5	22.1	54.7	52.0	11.8	42.0
21st (21st-27th May)	37.7	22.4	73.6	40.1	0.42	52.0
22nd (28th May-3rd June)	43.0	26.1	80.6	32.9	1.40	77.4
23rd (4th-10th June)	42.7	26.6	78.9	35.7	0.00	74.0
24th (11th-17th June)	41.0	25.7	73.1	35.5	9.52	75.4
Total			1073.2		100.0	703.4

APPENDIX-X

WEEKLY WEATHER DATA RECORDED DURING THE GROWTH OF SPRING MAIZE (2020)

Standard meteorological week	T max (°C)	T min (°C)	Sun shine (hr)	Mean RH (%)	Rainfall (mm)	ET_0 (mm)
6th (5th-11th February)	18.9	4.91	55.4	71.5	0.00	11.0
7th (12th-18th February)	23.0	7.84	68.4	69.9	0.00	14.4
8th (19th-25th February)	23.5	12.0	48.7	68.0	6.02	18.0
9th (26th February -4th March)	23.5	13.3	40.5	73.4	9.03	17.0
10th (5th March-11th March)	22.1	11.0	49.9	73.1	18.6	18.2
11th (12th-18th March)	22.4	11.5	50.0	71.9	28.6	14.4
12th (19th-25th March)	27.3	14.4	51.8	69.5	3.01	18.6
13th (26th March -1st April)	26.1	15.5	39.6	72.2	18.8	20.4
14th (2nd-8th April)	29.1	14.5	71.1	59.9	0.00	26.8
15th (9th-15th April)	34.0	16.7	68.5	51.3	0.00	32.5
16th (16th-22nd April)	33.8	19.3	61.4	51.1	9.80	33.8
17th (23rd-29th April)	33.2	19.3	66.3	52.1	3.43	34.0
18th (30th April-6th May)	35.6	21.8	68.3	51.5	16.2	41.0
19th (7th-13th May)	35.7	21.1	63.2	45.8	5.39	41.8
20th (14th-20th May)	35.7	21.7	66.0	44.9	19.6	42.2
21st (21st-27th May)	41.3	22.9	86.2	30.1	0.00	57.6
22nd (28th May-3rd June)	35.5	23.7	54.1	48.1	8.40	52.4
23rd (4th-10th June)	35.5	23.4	64.5	50.9	0.63	46.6
Total			1073.9		147.6	540.8

APPENDIX-XI

COST OF CULTIVATION

Crop	Returns (Rs q^{-1})	
	2018-19	**2019-20**
Rice	1770	1835
Potato	454	540
Kharif Maize	1700	1760
Pea	1361	1250
Spring Maize	1760	1850
Input	**Variable cost**	
Seed (Rs $acre^{-1}$)		
Rice	300	480
Potato	15000	18750
Kharif Maize	1440	1440
Pea	3750	2250
Spring Maize	1800	1800
Seed treatment (Rs $acre^{-1}$)		
Bavistein	19	19
Gaucho 70 WS	240	204
Indofil M-45	1314	1368
Rhizobium	40	40
Fertilizers (Rs q^{-1})		
Urea	591	591
Dia ammonium phosphate	2800	2440
Muriate of potash	1900	1700
Plant protection (Rs $acre^{-1}$)		
Tilt and Nativo	772	544
Fame 480 SC	340	340
Confidor	98	99
Butachlor 50 EC	390	390
Atrataf 50 WP	175	130
Metasystox 25 EC	840	1120
Decis 2.8 EC	600	540
Coragen 18.5 SC	390	380
Miscellaneous		
Irrigation cost	75 Rs $irrigation^{-1}$	80 Rs $irrigation^{-1}$
Human labour	45 Rs hr^{-1}	45 Rs hr^{-1}
Tractor hours	455 Rs hr^{-1}	465 Rs hr^{-1}

LIST OF PUBLISHED/ SUBMITTED RESEARCH PAPERS

Sr. No.	Title	Journal	Score	Remarks
1	Effect of residue incorporation and integrated nutrient management on productivity and soil properties of spring maize in rice-potato-spring maize cropping system	Journal of Plant Nutrition and Soil Science	NAAS 8.01	Submitted
2	Effect of residue incorporation and integrated nutrient management on tuber grading, yield and yield attributes of potato	Indian Journal of Agricultural Science	NAAS 6.12	Submitted

Journal of Plant Nutrition and Soil Science

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Effect of residue incorporation and integrated nutrient management on productivity and soil properties of spring maize in rice-potato-spring maize cropping system

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Key words: Bulk density, grain yield, integrated nutrient management, nutrient uptake, residue incorporation and soil organic carbon

ABSTRACT

Background- The rice-wheat cropping system (RWCS) is the backbone of food grain production in South-East Asia. However, this system is showing stagnation in yield, negative nitrogen balance and reduced responses to applied fertilizer. The return of rice residues has potential to recycle up to 20%–30% of absorbed N by the crops.

Aims- To overcome this, residue incorporation in a diversified cropping system i.e. rice-potato-spring maize was supplemented with different nutrient levels and their effects on productivity and soil properties of spring maize were investigated.

Methods-The treatment include rice and potato in main plots with four treatment combinations were applied to 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 and each main plot was divided into six sub plots to allocate different nutrient levels (75%, 100% and 125% NPK) to spring maize planted in single row and double rows on bed.

Results- The results showed that in rice-potato-spring maize cropping system, combined application of straw incorporation + 100 % NPK+ FYM @ 50 t ha^{-1} to potato resulted in significantly higher grain yield (80.1 and 83.6 q ha^{-1}), organic carbon content and lower bulk density in main plots and application of 125% NPK to double row on bed resulted in significantly 14.6% and 12.9% higher grain yield of spring maize as compared to 100% NPK applied to single row on bed.

Conclusion- Residue incorporation along with INM recorded to increase the grain yield, enhance soil organic carbon content and decrease bulk density of soil.

1 INTRODUCTION

In India, rice-wheat is the predominant cropping system occupying 12.3 million hectares of area and around 85 per cent of this area falls under Indo Gangetic Plains (Bhatt *et al.* 2021). During green revolution, there was a rapid increase in production of rice based cropping system due to increase in area and yield (Nawaz *et al.* 2019). This has brought a number of ecological and environmental issues including depletion of ground water and low nutrient use efficiency (Bhatt *et al.* 2020a). This increased concern about detrimental impact of uncontrolled use of synthetic fertilizers on soil fertility enforced a re-evaluation of agricultural nutrient management practices. These issues had given a major thrust to upgrade resource management system, choice of crops and cropping systems (Aulakh *et al.* 2012). In India, the estimated cereal crop residues production is 361 x 10^{6} kg yr^{-1}, of which wheat residue contribute about 33 % and rice residue contribute about 53 % (Rathod *et al.* 2019). 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. Residue burning is not advantegous act because it leads to air pollution and loss of nutrients from soil. Modern concepts in crop production have been developed to solve these issues and increase the production level, without hampering the natural resources. Singh *et al.* (2019) explained that crop diversification in agriculture can be regarded as the re-allocation of current crops/cropping systems/farm enterprises to some alternative crops. In context to diversify the existing rice-wheat cropping system, rice-potato-spring maize is an important cropping system that can be practiced in Punjab region to obtain higher yield and sustainable productivity. Efficient nutrient management in India had played an outstanding role in achieving huge increase in food grain production from 52 million tonnes in 1951-52 to 280 million tonnes during 2020-21 (Anonymous 2021). However, application of imbalance and/or excessive nutrients led to decline in nutrient-use efficiency, making fertilizer consumption uneconomical and causing adverse effects on atmosphere and groundwater quality (Lamessa 2016 and Adimalla 2018). Chemical fertilizer cannot be avoided completely since they are the potential sources of large amount of primary and secondary nutrients in easily available forms. Contrarily, organic manures outplay in maintaining soil fertility status but have lower potential to achieve higher productivity (Sharma *et al.* 2019). Integration of organic manure along with synthetic fertilizers and residue management 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 (Mengistu *et al.* 2017, Mahapatra *et al.* 2018 and Bhatt *et al.* 2020b). The objective was to study the effect of residue incorporation and nutrient management on grain yield, N uptake and soil properties of spring maize in rice-potato-spring maize cropping system.

2 MATERIALS AND METHODS

2.1 Experimental site

The field experiments were conducted at Student's Research Farm, Department of Agronomy, Punjab Agricultural University, Ludhiana, Punjab, India (30^{0}54' N latitude and 75^{0}48' E longitude) on a loamy sand soil of pH 7.2 during the cropping season 2018-19 and 2019-20. Ludhiana 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. It 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. Spring season is marked with mild temperature during the sowing of spring crops and bright sunshine hours during the flowering or maturity period. Data on physical and chemical properties of soil are given in table 1 and 2. The data presented in (Table 2) indicated that initially the soil 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.

Table 1: Physico-mechanical properties of the experimental field

Soil depth (cm)	Sand (%)	Silt (%)	Clay (%)	Textural classes
0-15	79.7	11.7	8.6	Loamy sand
15-30	80.5	11.6	7.9	Loamy sand
Method used	**International Pipette Method (Piper 1966)**			

Table 2: Chemical properties of the soil

Chemical property	2019	2020	Rating	Method used
pH	7.2	6.9	Normal	Beckman's glass electrode meter (Jackson 1967)
EC (dS m^{-1})	0.244	0.265	Normal	Solu bridge conductivity meter (Jackson 1967)
OC (%)	0.36	0.38	Low	Walkley and Black's rapid titration method (Jackson 1967)
Available N (kg ha^{-1})	188.2	175.6	Low	Alkaline potassium permanganate method (Subbiah and Asija 1956)
Available P (kg ha^{-1})	23.4	22.6	High	0.5 N Sodium bicarbonate extractant method (Olsen *et al.* 1954)
Available K (kg ha^{-1})	193.2	181.4	Medium	1N Ammonium acetate extractable method (Muhr *et al.* 1965)

2.2 Plant material

The rice (*Oryza sativa* L.) hybrid PR 126 is an early maturing rice variety. It's average plant height is 102 cm and matures in about 93 days after transplanting. It possesses long slender, clear translucent grains. It is resistant to seven of the ten presently prevalent pathotypes of bacterial blight pathogen in the Punjab state. It has a yield potential of 30.0 q acre^{-1}.

The potato (*Solanum tuberosum*) variety Kufri Pukhraj plants are tall, vigorous and erect. It is an early bulking variety which gives economic yield in 70 days. It is susceptible to late blight but escapes due to earliness. Its tubers are large uniform, oval, white with fleet eyes. It yields 130 q acre^{-1} in 70-90 days.

The spring maize (*Zea mays* L.) hybrid PMH 10 is a single cross hybrid are medium tall with medium ear placement. Leaves are broad, tassels are medium in size, semi-open with green anthers. Silks are pink in colour. Ears are medium long, conico-cylindrical with attractive orange flint grains. It matures in about 120 days. Its average yield is 31.5 q acre^{-1}.

2.3 Experimental design and data analysis

The field experiment was conducted in split plot design (SPD) consisting of two crops i.e. rice and potato in main plots with four treatment combinations applied to potato viz., M_1-straw removal + 100 % NPK + FYM @ 50 t ha^{-1}, M_2-straw removal + 150 % NPK, M_3-straw incorporation + 100 % NPK + FYM @ 50 t ha^{-1} and M_4-straw incorporation + 150 % NPK and each main plot was divided into six sub plots to allocate different treatments to bed planted spring maize viz., S_1-75 % NPK with single row on bed, S_2-75 % NPK with double row on bed, S_3-100% NPK with single row on bed, S_4-100 % NPK with double row on bed, S_5-125 % NPK with single row on bed and S_6-125 % NPK with double row on bed during 2018-19 and 2019-20. 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.

2.4 Method of analysis

Plant samples were collected at harvesting stage from spring maize as per treatment. The nitrogen content in grain samples was estimated by micro Kjeldahl's distillation method, as given by Piper (1966). The phosphorus content in grain samples were determined by vanado- phospho-molybdate yellow color method by digesting the samples with di-acid. The potassium content in grain samples was estimated by using flame photometer as described by Muhr (1965). After completing two cycle of rice-potato-spring maize cropping system, soil sample (0-15 cm soil depth) for each plot were collected and were analyzed for organic carbon content and bulk density of soil.

3 Results

3.1 Grain yield

Data presented in table 3 revealed that rice residue and nutrient application in previous potato crop had significant effect of grain yield of spring maize. The results depict that grain yield of spring maize was significantly higher where residue was incorporated with 100% RDF + FYM @ 50t ha^{-1} applied to preceding crop (80.1 and 83.6

q ha^{-1}) as compared to sole application of synthetic fertilizer without residue incorporation i.e. residue removal + 150% NPK and it was statistically at par with treatment involving residue removal and application of 100% NPK + FYM @ 50 t ha^{-1} during 2019 and 2020, respectively. The increase in grain yield was 10.6 and 14.6 % in residue incorporated plot with 100% NPK + FYM @ 50 t ha^{-1} as compared to residue removed + 150% NPK application during 2019 and 2020. Lowest grain yield of 72.4 and 72.9 q ha^{-1} was recorded in treatment which involves residue removal + 150% NPK applied to preceding crop.

The different levels of nutrient application treatments in spring maize also showed significant effect on grain yield. Treatment involving application of 125 % NPK to double row on bed resulted in significantly higher grain yield (85.4 and 87.5 q ha^{-1}) as compared to all other treatment combinations and followed by application of 125 % NPK to single row on bed (81.3 and 82.9 q ha^{-1}) during both the years. The average yield obtained from supply of 100% NPK to double row on bed was (78.8 and 81.4 q ha^{-1}), which was statistically at par with treatment involving 125% NPK to single row on bed. The per cent increase in grain yield in 125% NPK applied to double row on bed was 25.0 %, 25.7 % and 14.6%, 12.9% as compared to 75% NPK and 100% NPK application to single row on bed (68.3, 69.6 q ha^{-1} and 74.5, 77.5 q ha^{-1}) during 2019 and 2020, respectively.

3.2 N, P and K uptake in grain

The data on uptake of N, P and K grain are presented in table 4. The analysis of data revealed that higher N uptake was observed under residue incorporated plots along with application of 100% NPK + FYM @ 50 t ha^{-1} to the preceding crop which was significantly better than residue incorporation + 150% NPK and residue removal + 150% NPK and it was statistically at par with residue removal + 100% NPK + FYM @ 50 t ha^{-1} during both the years. P and K uptake in grain was recorded non-significant under various treatments in main plots. Among different nutrient levels applied to spring maize in sub plots, 125% NPK applied to double row bed planted spring maize resulted in higher N, P and K uptake in grain as compared to lower nutrient levels i.e. 75% NPK and 100% NPK applied to both single row and double rows on bed and it was statistically at par with 125% NPK applied to single row bed planted spring maize during both the years.

3.3 Soil organic carbon

Organic carbon of surface soil is considered as primary indicator of soil quality because this horizon receives the seed, fertilizers and other chemicals applied to it. It is the epicenter of soil physical, chemical and biological health. OC releases nutrients for plant growth, promotes the structure, biological and physical health of soil and act is a buffer against harmful substances. The data pertaining to organic carbon content in soil are presented in table 5. The results revealed that rice residue and nutrient application to potato had a significant effect on OC at 0-15 cm soil depth during both the years but it did not differed significantly with various nutrient levels applied to spring maize in sub plots at 0-15 and 15- 30 cm soil depth during both the years. There was improvement in OC status of soil after harvesting of the crop where residue was incorporated along with application of 100% NPK + FYM @ 50 t ha^{-1} to the preceding potato crop. Mean OC content in 2019 at 0-15 cm depth was 0.40%, which was increased to 0.41% during 2020. The per cent increase in OC under residue incorporation + 100% NPK + FYM @ 50 t ha^{-1} was 8.1% and 10.8% over residue removal + 150% NPK application during 2019 and 2020, respectively.

3.4 Bulk density

Soil bulk density is a significant indicator of change of soil physical health and water retention capacity. The data pertaining to bulk density of soil (0-15 and 15-30 cm depth) during 2019 and 2020 are given in table 5. The data revealed that bulk density was significantly affected by rice residue and nutrient application to preceding potato during both the years but was not-significantly influenced by different nutrient levels applied to spring maize. The data revealed that the bulk density of soil was significantly higher (1.31 and 1.30 g cm^{-3}) under treatment where residue was removed and 150% NPK was applied during 2019 and 2020. Lower bulk density (1.28 and 1.26 g cm^{-3}) was recorded under residue incorporated plot along with 100% NPK + FYM @ 50 t ha^{-1} applied to the preceding crop. The per cent decrease in bulk density was recorded to be 3.2% under residue incorporated plot along with application of 100% NPK + FYM @ 50 t ha^{-1} as compared to sole application of synthetic fertilizer i.e. 150% NPK without residue incorporation after completion of two year experiments.

4 Discussion

4.1 Effect of rice residue and nutrient application to preceding potato

The higher grain yield under residue incorporation and FYM applied plots may be due to combined effect of better growth and development which resulted in more cob length and more numbers of grains per cob and ultimately leads to more grain yield. Chahal *et al.* (2019), Ejigu *et al.* (2021) and Sigaye *et al.* (2021) also reported higher maize grain yield in combined application of organic manures and synthetic fertilizers than sole application of synthetic fertilizers. Residue incorporation also had a positive effect on grain yield of maize which enhances the porosity and decreases the bulk density of soil. This led to better root penetration for nutrient and water uptake for growth and development which ultimately leads to higher grain yield. Zhu *et al.* (2010), Chaudhary *et al.* (2013) and Memon *et al.* (2018) also reported higher grain yield under residue incorporation as compared to residue removal treatments.

The residue retained on the soil surface undergoes decomposition over a period of time and add organic matter to soil. The higher OC under residue + FYM incorporated plots might be due to higher accumulation of crop residue which also increases the availability of mineral nutrition. Jat *et al.* (2013), Meena *et al.* (2015) and Chaudhary *et al.* (2017) also reported improvement in soil organic carbon content under residue retained plots as compared to residue removed plots. Organic carbon content of the soil was increased in residue retained plot after harvesting of crop as compared to its initial status.

The data revealed that the bulk density of soil was significantly higher under treatment where residue was removed and 150% NPK was applied during 2019 and 2020. Lower bulk density was recorded under residue incorporated plot along with 100% NPK + FYM @ 50 t ha^{-1} applied to the preceding crop. Incorporation of residue in to soil decreased the soil compactness and increased porosity. Meena *et al.* (2015) also recorded reduction in bulk density under residue retained treatment.

4.2 Effect of nutrient levels in spring maize

Increasing nitrogen level up to 125 % NPK leads to higher grain yield due to better vegetative and reproductive growth of the plant. The increase might be due to increased availability of NPK, causing accelerated photosynthetic rate and thus leading to production of more carbohydrates and ultimately more yield. Similar findings were recorded by Srivastava *et al.* (2018), Raj *et al.* (2021) and Adhikari *et al.* (2021). Moreover, higher grain yield with increasing population density came mainly from more numbers of plant and cobs per unit area which resulted in enhancement of grain and biological yield. A similar trend in yield has been reported by Tyagi *et al.* (1998) and Alam *et al.* (2003). Gul *et al.* (2009), Amanullha *et al.* (2009) and Arif *et al.* (2010) also reported that increasing crop density with increased nitrogen dose, enhanced the grain yield.

Higher N, P and K uptake under 125% NPK applied to double row on bed was due to higher yield under this treatment. Brar *et al.* (2001), Kumar *et al.* (2008) and Singh (2010) observed significantly higher N and P uptake with increase in fertilizer levels in maize.

5 Conclusion

Significantly higher grain yield (80.1 and 83.6 q ha^{-1}) was obtained from rice-potato-spring maize cropping system with application of 100% NPK + FYM @ 50 t ha^{-1} to preceding potato along with rice residue incorporation as compared to all the treatments. Application of 125% NPK applied to double row bed planted spring maize recorded 14.6% and 12.9% higher grain yield during 2019 and 2020, respectively in comparison to 100% NPK applied to single row on bed. Organic carbon of soil was increased with combined application of organic and inorganicfertilizer i.e. 100% NPK + FYM @ 50 t ha^{-1} to preceding potato along with rice residue incorporation in this cropping system. After two years of study, bulk density of soil was decreased with mixed application of inorganic fertilizers and FYM as compared to sole application of synthetic fertilizer i.e. 150% NPK + residue removal during both the years.

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Table 1: Physico-mechanical properties of the experimental field

Soil depth (cm)	Sand (%)	Silt (%)	Clay (%)	Textural classes
0-15	79.7	11.7	8.6	Loamy sand
15-30	80.5	11.6	7.9	Loamy sand
Method used	**International Pipette Method (Piper 1966)**			

Table 2: Chemical properties of the soil

Chemical property	2019	2020	Rating	Method used
pH	7.2	6.9	Normal	Beckman's glass electrode meter (Jackson 1967)
EC (dS m^{-1})	0.244	0.265	Normal	Solu bridge conductivity meter (Jackson 1967)
OC (%)	0.36	0.38	Low	Walkley and Black's rapid titration method (Jackson 1967)
Available N (kg ha^{-1})	188.2	175.6	Low	Alkaline potassium permanganate method (Subbiah and Asija 1956)
Available P (kg ha^{-1})	23.4	22.6	High	0.5 N Sodium bicarbonate extractant method (Olsen *et al.* 1954)
Available K (kg ha^{-1})	193.2	181.4	Medium	1N Ammonium acetate extractable method (Muhr *et al.* 1965)

Table 3: Effect of rice residue and nutrient application to preceding potato and nutrient levels to spring maize on grain yield in spring maize

Treatment	Seed yield (q ha^{-1})	
	2019	**2020**
Rice residue and nutrient application to preceding potato		
Straw removal + 100 % NPK+ FYM @ 50 t ha^{-1}	76.7^{abc}	79.5^{ab}
Straw removal + 150 % NPK	72.4^{c}	72.9^{c}
Straw incorporation + 100 % NPK+ FYM @ 50 t ha^{-1}	80.1^{a}	83.6^{a}
Straw incorporation + 150 % NPK	75.5^{bc}	76.6^{bc}
Nutrient levels in spring maize		
75 % NPK with single row on bed	68.3^{f}	69.6^{f}
75 % NPK with double row on bed	69.2^{ef}	69.9^{ef}
100% NPK with single row on bed	74.5^{d}	77.5^{d}
100 % NPK with double row on bed	78.5^{c}	81.4^{c}
125 % NPK with single row on bed	81.3^{bc}	82.9^{bc}
125 % NPK with double row on bed	85.4^{a}	87.5^{a}
Interaction	NS	NS

Table 4: Effect of rice residue and nutrient application to preceding potato Effect of rice residue and nutrient application to preceding potato and nutrient levels to spring maize on nitrogen, phosphorus and potassium uptake in grain of spring maize

Treatment	N uptake (kg ha^{-1})		P uptake (kg ha^{-1})		K uptake (kg ha^{-1})	
	2019	**2020**	**2019**	**2020**	**2019**	**2020**
Rice residue and nutrient application to preceding potato						
Straw removal + 100 % NPK+FYM @ 50 t ha^{-1}	112.2^{ab}	116.0^{bcd}	24.6^{ns}	23.5^{ns}	30.9^{ns}	30.4^{ns}
Straw removal + 150 % NPK	105.8^{c}	108.0^{d}	20.6	20.6	28.2	26.9
Straw incorporation + 100 %NPK+ FYM @ 50 t ha^{-1}	117.3^{a}	124.4^{a}	24.9	25.4	32.9	32.3
Straw incorporation + 150 % NPK	110.5^{bc}	113.1^{cd}	22.3	22.7	29.1	28.0
Nutrient levels in spring maize						
75 % NPK with single row on bed	99.5^{de}	103.2^{de}	21.0^{de}	20.2^{cd}	26.9^{de}	25.9^{cd}
75 % NPK with double row on bed	99.1^{e}	101.1^{e}	20.6^{e}	19.9^{d}	26.4^{e}	25.3^{d}
100% NPK with single row on bed	109.9^{c}	116.1^{c}	23.3^{bc}	23.0^{b}	29.9^{cd}	29.4^{b}
100 % NPK with double row onbed	114.3^{bc}	118.3^{bc}	23.1^{cd}	24.1^{ab}	30.8^{bc}	30.2^{ab}
125 % NPK with single row on bed	121.6^{a}	124.8^{ab}	25.6^{ab}	25.1^{ab}	32.8^{ab}	32.7^{ab}
125 % NPK with double row onbed	124.5^{a}	128.8^{a}	25.0^{ab}	26.0^{a}	34.6^{a}	33.0^{a}
Interaction	NS	NS	NS	NS	NS	NS

Table 5: Effect of rice residue and nutrient application to preceding potato and nutrient levels to spring maize on soil OC and bulk density

Treatment	OC (%)				Bulk density (g cm^{-3})			
	0-15 cm		15-30 cm		0-15 cm		15-30 cm	
	2019	2020	2019	2020	2019	2020	2019	2020
Rice residue and nutrient application to preceding potato								
Straw removal + 100 % NPK+ FYM @ 50 t ha^{-1}	0.38^{bc}	0.39^{b}	0.35^{ns}	0.35^{ns}	1.29^{ab}	1.27^{bc}	1.30^{ns}	1.31^{ns}
Straw removal + 150 % NPK	0.37^{c}	0.37^{c}	0.33	0.34	1.31^{a}	1.30^{a}	1.31	1.32
Straw incorporation + 100 % NPK+ FYM @ 50 t ha^{-1}	0.40^{a}	0.41^{a}	0.36	0.37	1.28^{b}	1.26^{c}	1.30	1.30
Straw incorporation + 150 % NPK	0.39^{ab}	0.40^{ab}	0.34	0.35	1.30^{ab}	1.28^{abc}	1.31	1.31
Nutrient levels in spring maize								
75 % NPK with single row on bed	0.38^{ns}	0.38^{ns}	0.33^{ns}	0.35^{ns}	1.29^{ns}	1.28^{ns}	1.30^{ns}	1.30^{ns}
75 % NPK with double row on bed	0.39	0.39	0.35	0.35	1.29	1.28	1.30	1.31
100% NPK with single row on bed	0.38	0.39	0.34	0.35	1.30	1.28	1.31	1.31
100 % NPK with double row on bed	0.38	0.40	0.35	0.36	1.29	1.27	1.29	1.30
125 % NPK with single row on bed	0.38	0.40	0.35	0.35	1.30	1.28	1.31	1.31
125 % NPK with double row on bed	0.39	0.40	0.35	0.36	1.30	1.27	1.30	1.30
Interaction	NS	NS	NS	NS	NS	NS	NS	NS

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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

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).

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Integrated nutrient management (INM) is defined as the use of inorganic, organic and biological 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 x 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 advantegous act because it leads to air pollution, loss nutrients from soil, destruction in soil structure, serious health hazards in human being and global warming. 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. 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. 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.

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 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 an important parameters which directly relates to tuberyield. More number of tubers per plant leads to higher yield. Data recorded for tuber numberper plant are presented in table 1. Plots where rice residue was incorporated 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 increasedrate 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) as compared to rest of the treatments during both the years. Straw removal with application of 100% NPK + FYM @ 50 t ha^{-1} also resulted with higher tubers weight and was statistically at par with residue incorporation + 150% NPK application during both the years. A lowest tuber weight per plant (537.3 and 622.3 g) was recorded under treatment that involves residue removal + 150% NPK during 2018-19 and 2019-20. 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 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. Babu (2019) also reported similar findings.

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 provide space for 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).

Tuber yield

Data presented in table 4 the effect of rice residue and nutrientapplication 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.

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 itwas 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, drymatter accumulation and leaf area of the plant which ultimately resulted into higher haulm yield. 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.

Economics 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.

According to above investigation it was concluded that yield attributes *viz.*, number of tillers per plant, number of tubers per plant and tuber yield per plant, number and weight of medium sized tubers, tuber yield, gross returns, net returns and B:C were recorded significantly higher under treatment which involving integrated use of residue incorporation and 100% NPK + FYM @ 50 t ha^{-1} application as compared to sole application of synthetic fertilizers.

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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}

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

Table 3: Effect of rice residue incorporation and nutrient application on grade wiseweight 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

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}

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

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