EFFECT OF NITROGEN, PHOSPHORUS AND GYPSUM ON GROWTH, YIELD AND QUALITY OF SPRING GROUNDNUT (*Arachis hypogaea* L.)

Thesis

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

MASTER OF SCIENCE
in
AGRONOMY
(Minor Subject: Soil Science)

By

Akashdeep Singh Brar
(L-2017-A-01-M)

Department of Agronomy
College of Agriculture

LUDHIANA – 141 004

2020

CERTIFICATE – I

This is to certify that the thesis entitled, **"Effect of nitrogen, phosphorus and gypsum on growth, yield and quality of spring groundnut (*Arachis hypogaea* L.)"** submitted for the degree of **M.Sc.** in the subject of **Agronomy** (Minor Subject: **Soil Science**) of the Punjab Agricultural University, Ludhiana, is a bonafide research work carried out by **Akashdeep Singh Brar (L-2017-A-01-M)** under my supervision and that no part of this thesis has been submitted for any other degree.

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

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CERTIFICATE II

This is to certify that the thesis entitled, **"Effect of nitrogen, phosphorus and gypsum on growth, yield and quality of spring groundnut (*Arachis hypogaea* L.)"** submitted by **Akashdeep Singh Brar (L-2017-A-01-M)** to the Punjab Agricultural University, Ludhiana, in partial fulfillment of the requirements for the degree of **M.Sc.** in the subject of **Agronomy** (Minor Subject: **Soil Science**) has been approved by the Student's Advisory Committee along with Head of Department after an oral examination on the same, in collaboration with an External Examiner.

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ACKNOWLEDGEMENT

First of all, I express my deep sense of gratitude to GOD, the almighty, with whose grace and blessings I have been able to complete my work.

Though the debt of learning cannot be repaid, it is my sovereign privilege to express my gratitude and moral obligation to my esteemed Major Advisor, ***Dr S S Manhas****, Assistant Extension Specialist (Agronomy), Department of Agronomy, Punjab Agricultural University, Ludhiana; for his inspiring guidance and constant encouragement in planning and execution of study and research work, which helped me to successfully complete the work in time.*

My cordial and sincere thanks to other members of my Advisory Committee, ***Dr Thakar Singh****, Senior Agronomist,* ***Dr S S Dhaliwal****, Senior Soil Chemist and* ***Dr Hari Ram****, Senior Agronomist (Nominee of Dean PGS) for their advice, valuable suggestions, keen interest and encouragement during the tenure of my research.*

I am grateful to ***Dr Pushpinder Pal Singh Pannu****, Head, Department of Agronomy, Punjab Agricultural University, Ludhiana for providing necessary facilities and moral support for successful completion of this work.*

In my opinion, God would not be everywhere; therefore, he made loving parents. A formal acknowledgement of my emotions is inadequate to convey the depth of my feelings of gratitude to my father Late ***Shri Dilbag Singh Brar****, mother* ***Smt. Sukhjinder Kaur Brar*** *and sister* ***Dilveer Kaur Brar****. I am forever indebted to my parents for their understanding, endless patience and encouragement when it was most required and for providing me the means to learn and understand.*

I cherish with appreciation the joyful and cheerful company and help of all my friends particularly ***Gurjinder, Rajdeep, Shamsher, Naveen, Gursewak, Nirmal, Gaurav Dhir, Aman, Sanjay, Raman, Pankaj, Arsh Dhillon, Lovepreet Bhullar, Saurav, Jaspreet, and Gurbhej*** *who cheered me in the moments of despair and made the things much smoother. I greatly value their friendship and I deeply appreciate their belief in me. I owe my heartiest gratitude to my senior friends* ***Manpreet Brar, Rukinder, Gourav Jain, Vishu, Harjinder Brar, Ketan, Dalbeer and Jaswinder*** *for their extensive support. I am thankful to the field, lab and office staff for their cooperation.*

I feel proud to be a part of PAU, Ludhiana where I learnt a lot and spent some unforgettable moments of my life.

I wish to record my gratitude for any person, my memory had failed to recall, and who rendered their support in various capacities throughout the period of the studies.

Date:

Place: Ludhiana ***(Akashdeep Singh Brar)***

Title of the Thesis	**:**	Effect of nitrogen, phosphorus and gypsum on growth, yield and quality of spring groundnut (*Arachis hypogaea* L.)
Name of the Student and Admission No.	:	Akashdeep Singh Brar L-2017-A-01-M
Major Subject	**:**	Agronomy
Minor Subject	**:**	Soil Science
Name and Designation of Major Advisor	**:**	Dr S.S. Manhas Assistant Extension Specialist (Agronomy)
Degree to be Awarded	**:**	M.Sc.
Year of award of degree	**:**	2020
Total pages in thesis	**:**	104 + Appendices (iii) + VITA
Name of the University	**:**	Punjab Agricultural University, Ludhiana – 141 004, Punjab, India

ABSTRACT

The present study entitled "Effect of nitrogen, phosphorus and gypsum on growth, yield and quality of spring groundnut (*Arachis hypogaea* L.)" was conducted at the Students' Research Farm, Department of Agronomy, Punjab Agricultural University, Ludhiana during 2018 and 2019 in the spring season. The soil of the experimental field was loamy sand in texture. The experiment was laid out in a split plot design replicated three times with four levels of gypsum (0, 125, 175 and 225 kg ha^{-1}) in combination with two gypsum application stages (Full at sowing and 50% at sowing + 50% at flower initiation stage) in the main plot and three levels of nitrogen and phosphorus (15 kg N ha^{-1} + 20 kg P_2O_5 ha^{-1}, 25 kg N ha^{-1} + 30 kg P_2O_5 ha^{-1} and 35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1}) in the sub-plot. Results revealed that the application of 225 kg ha^{-1} gypsum resulted in highest growth parameters *viz.* plant height, number of branches $plant^{-1}$ and dry matter accumulation, yield attributes (total number of pods $plant^{-1}$, 100-kernel weight and shelling percentage) as well as quality attributes (protein content and oil content) during both the years. Application of 225 kg ha^{-1} gypsum resulted in significantly higher pod yield, haulm yield, kernel yield and total N, P, K, Ca and S uptake over other gypsum levels during 2018 and 2019. Net returns and benefit cost ratio were highest with 225 kg ha^{-1} gypsum among different gypsum levels. Split application of gypsum (50% at sowing + 50% at flower initiation stage) resulted in significantly higher plant height, number of branches $plant^{-1}$ and dry matter accumulation over the application of full dose of gypsum at sowing, except at 30 DAS during both the years. Pod yield, haulm yield and kernel yield were significantly higher with the split application as compared to basal application of gypsum during both the years. Split application of gypsum also gave higher net returns and benefit cost ratio over basal application of gypsum. Growth parameters *viz.* plant height, number of branches $plant^{-1}$ and dry matter accumulation were increased significantly with increase in the levels of nitrogen and phosphorus up to 25 kg N ha^{-1} + 30 kg P_2O_5 ha^{-1} during both the years. However, 35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1} resulted in significantly higher protein and oil content of kernels over other levels of nitrogen and phosphorus, while pod yield, haulm yield, kernel yield and total N, P, K, Ca and S uptake were at par with 25 kg N ha^{-1} + 30 kg P_2O_5 ha^{-1} during both the years. The application of 25 kg N ha^{-1} + 30 kg P_2O_5 ha^{-1} and 35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1} resulted in almost similar net returns and benefit cost ratio during both the years.

Keywords: Groundnut, growth, gypsum, nitrogen, phosphorus, quality, yield.

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

ਖੋਜ ਦਾ ਸਿਰਲੇਖ	:	ਬਹਾਰ ਰੁੱਤ ਦੀ ਮੂੰਗਫਲੀ (*Arachis hypogaea* L.) ਦੇ ਵਿਕਾਸ, ਝਾੜ ਅਤੇ ਗੁਣਵਤਾ ਉਪਰ ਨਾਈਟ੍ਰੋਜਨ, ਫ਼ਾਸਫ਼ੋਰਸ ਅਤੇ ਜਿਪਸਮ ਦੇ ਪ੍ਰਭਾਵ ਦਾ ਮੁਲਾਂਕਣ
ਵਿਦਿਆਰਥੀ ਦਾ ਨਾਮ ਅਤੇ ਦਾਖਲਾ ਕ੍ਰਮਾਂਕ	:	ਅਕਾਸ਼ਦੀਪ ਸਿੰਘ ਬਰਾੜ ਐਲ-2017-ਏ-01-ਐਮ
ਪ੍ਰਮੁੱਖ ਵਿਸ਼ਾ	:	ਫ਼ਸਲ ਵਿਗਿਆਨ
ਸਹਿਯੋਗੀ ਵਿਸ਼ਾ	:	ਭੂਮੀ ਵਿਗਿਆਨ
ਮੁੱਖ ਸਲਾਹਕਾਰ ਦਾ ਨਾਮ ਅਤੇ ਅਹੁਦਾ	:	ਡਾ ਐਸ.ਐਸ. ਮਨਹਾਸ ਸਹਾਇਕ ਪਸਾਰ ਮਾਹਿਰ (ਖੇਤੀ ਵਿਗਿਆਨ)
ਡਿਗਰੀ	:	ਐੱਮ.ਐੱਸ.ਸੀ
ਡਿਗਰੀ ਮਿਲਣ ਦਾ ਸਾਲ	:	2020
ਖੋਜ ਪੱਤਰ ਵਿੱਚ ਕੁੱਲ ਪੰਨੇ	:	104 + ਅੰਤਿਕਾਵਾਂ (iii) + ਵੀਟਾ
ਯੂਨੀਵਰਸਿਟੀ ਦਾ ਨਾਮ	:	ਪੰਜਾਬ ਐਗਰੀਕਲਚਰਲ ਯੂਨੀਵਰਸਿਟੀ, ਲੁਧਿਆਣਾ-141 004, ਪੰਜਾਬ, ਭਾਰਤ।

ਸਾਰ-ਅੰਸ਼

ਮੌਜੂਦਾ ਅਧਿਐਨ "ਬਹਾਰ ਰੁੱਤ ਦੀ ਮੂੰਗਫਲੀ (*Arachis hypogaea* L.) ਦੇ ਵਿਕਾਸ, ਝਾੜ ਅਤੇ ਗੁਣਵਤਾ ਉਪਰ ਨਾਈਟ੍ਰੋਜਨ, ਫ਼ਾਸਫ਼ੋਰਸ ਅਤੇ ਜਿਪਸਮ ਦੇ ਪ੍ਰਭਾਵ ਦਾ ਮੁਲਾਂਕਣ" ਸਿਰਲੇਖ ਅਧੀਨ ਪੰਜਾਬ ਐਗਰੀਕਲਚਰਲ ਯੂਨੀਵਰਸਿਟੀ, ਲੁਧਿਆਣਾ ਦੇ ਫ਼ਸਲ ਵਿਗਿਆਨ ਵਿਭਾਗ ਦੇ ਵਿਦਿਆਰਥੀ ਖੋਜ ਫਾਰਮ ਵਿਖੇ ਸਾਲ 2018 ਅਤੇ 2019 ਦੀ ਬਹਾਰ ਰੁੱਤੇ ਕੀਤਾ ਗਿਆ। ਤਜ਼ਰਬੇ ਵਾਲੇ ਖੇਤ ਦੀ ਮਿੱਟੀ ਮੈਰਾ ਰੇਤਲੀ ਸੀ। ਮੁੱਖ ਪਲਾਟ ਵਿੱਚ ਜਿਪਸਮ ਦੇ ਚਾਰ ਪੱਧਰਾਂ (0, 125, 175 ਅਤੇ 225 ਕਿ.ਗ੍ਰਾ./ਹੈਕਟੇਅਰ) ਦੀ ਦੋ ਤਰ੍ਹਾਂ (ਬੀਜਾਈ ਸਮੇਂ ਪੂਰੀ ਮਤਾਰਾ ਅਤੇ ਬੀਜਾਈ ਸਮੇਂ 50% + ਫੁੱਲ ਪੈਣ ਸਮੇਂ 50% ਮਾਤਰਾ) ਵਰਤੋਂ ਕਰਕੇ ਅਤੇ ਉਪ ਪਲਾਟ ਵਿੱਚ ਨਾਈਟ੍ਰੋਜਨ ਅਤੇ ਫ਼ਾਸਫੋਰਸ ਦੇ ਤਿੰਨ ਪੱਧਰਾਂ (15 ਕਿ.ਗ੍ਰਾ. N ਪ੍ਰਤੀ ਹੈਕਟੇਅਰ + 20 ਕਿ.ਗ੍ਰਾ. P_2O_5 ਪ੍ਰਤੀ ਹੈਕਟੇਅਰ, 25 ਕਿ.ਗ੍ਰਾ. N ਪ੍ਰਤੀ ਹੈਕਟੇਅਰ + 30 ਕਿ.ਗ੍ਰਾ. P_2O_5 ਪ੍ਰਤੀ ਹੈਕਟੇਅਰ ਅਤੇ 35 ਕਿ.ਗ੍ਰਾ. N ਪ੍ਰਤੀ ਹੈਕਟੇਅਰ + 40 ਕਿ.ਗ੍ਰਾ. P_2O_5 ਪ੍ਰਤੀ ਹੈਕਟੇਅਰ) ਦੀ ਵਰਤੋਂ ਕਰਕੇ ਸਪਲਿੱਟ ਪਲਾਟ ਡਿਜ਼ਾਈਨ ਵਿਧੀ ਤਹਿਤ ਤਜ਼ਰਬਾ ਤਿੰਨ ਵਾਰ ਦੁਹਰਾਇਆ ਗਿਆ। ਅਧਿਐਨ ਦੇ ਨਤੀਜਿਆਂ ਤੋਂ ਪਤਾ ਚੱਲਿਆ ਕਿ ਜਿਪਸਮ ਦੀ 225 ਕਿ.ਗ੍ਰਾ. ਪ੍ਰਤੀ ਹੈਕਟੇਅਰ ਮਾਤਰਾ ਦੀ ਵਰਤੋਂ ਕਰਨ ਨਾਲ ਦੋਨਾਂ ਸਾਲਾਂ ਦੌਰਾਨ ਫ਼ਸਲ ਦੇ ਵਿਕਾਸ ਮਾਪਦੰਡ ਜਿਵੇਂ ਕਿ ਪੌਦੇ ਦੀ ਉਚਾਈ, ਪ੍ਰਤੀ ਪੌਦਾ ਸ਼ਾਖਾਵਾਂ ਦੀ ਗਿਣਤੀ ਅਤੇ ਸੁੱਕੇ ਮਾਦੇ ਦੀ ਜਜ਼ਬਤਾ, ਝਾੜ ਨਾਲ ਸਬੰਧਤ ਗੁਣ (ਪ੍ਰਤੀ ਪੌਦਾ ਫ਼ਲੀਆਂ ਦੀ ਗਿਣਤੀ, 100 ਗਿਰੀਆਂ ਦਾ ਭਾਰ ਅਤੇ ਛਿਲਕੇ ਦੀ ਪ੍ਰਤੀਸ਼ਤਤਾ) ਦੇ ਨਾਲ ਨਾਲ ਗੁਣਵਤਾ ਮਾਪਦੰਡਾਂ (ਪ੍ਰੋਟੀਨ ਅਤੇ ਤੇਲ ਦੀ ਮਾਤਰਾ) ਵਿੱਚ ਸਭ ਤੋਂ ਵਧੇਰੇ ਵਾਧਾ ਹੋਇਆ। ਸਾਲ 2018 ਅਤੇ 2019 ਦੌਰਾਨ, ਜਿਪਸਮ ਦੀਆਂ ਬਾਕੀ ਮਿਕਦਾਰਾਂ ਦੇ ਮੁਕਾਬਲੇ ਜਿਪਸਮ ਦੀ 225 ਕਿ.ਗ੍ਰਾ. ਪ੍ਰਤੀ ਹੈਕਟੇਅਰ ਮਾਤਰਾ ਦੀ ਵਰਤੋਂ ਕਰਨ ਨਾਲ ਫ਼ਲੀ ਦਾ ਝਾੜ, ਮੂੰਗਫਲੀ ਦੀ ਭੌਂ, ਗਿਰੀ ਦਾ ਝਾੜ ਅਤੇ ਕੁੱਲ ਨਾਈਟ੍ਰੋਜਨ, ਫ਼ਾਸਫ਼ੋਰਸ, ਪੋਟਾਸ਼ੀਅਮ, ਕੈਲਸ਼ੀਅਮ ਅਤੇ ਸਲਫਰ ਦੇ ਗ੍ਰਹਿਣ ਵਿੱਚ ਆਂਕੜਾ ਵਿਗਿਆਨ ਦੇ ਅਧਾਰ ਤੇ ਵਾਧਾ ਹੋਇਆ। ਜਿਪਸਮ ਦੇ ਬਾਕੀ ਪੱਧਰਾਂ ਦੇ ਮੁਕਾਬਲੇ ਜਿਪਸਮ ਦੀ 225 ਕਿ.ਗ੍ਰਾ. ਪ੍ਰਤੀ ਹੈਕਟੇਅਰ ਮਾਤਰਾ ਦੀ ਵਰਤੋਂ ਕਰਨ ਨਾਲ ਕੁੱਲ ਮੁਨਾਫਾ ਅਤੇ ਲਾਭ: ਲਾਗਤ ਅਨੁਪਾਤ ਵਧੇਰੇ ਪ੍ਰਾਪਤ ਹੋਇਆ। ਦੋਨਾਂ ਸਾਲਾਂ ਦੌਰਾਨ, ਜਿਪਸਮ ਦੀ ਇੱਕੋ ਸਮੇਂ ਵਰਤੋਂ ਕਰਨ ਦੇ ਮੁਕਾਬਲੇ ਜਿਪਸਮ ਦੀ ਦੋ ਵਾਰ ਵਰਤੋਂ ਕਰਨ (ਬੀਜਾਈ ਸਮੇਂ 50% + ਫੁੱਲ ਪੈਣ ਸਮੇਂ 50% ਮਾਤਰਾ) ਵਾਲੀ ਫ਼ਸਲ ਵਿੱਚ ਪੌਦੇ ਦੀ ਉਚਾਈ, ਪ੍ਰਤੀ ਪੌਦਾ ਸ਼ਾਖਾਵਾਂ ਦੀ ਗਿਣਤੀ ਅਤੇ ਸੁੱਕੇ ਮਾਦੇ ਦੀ ਜਜ਼ਬਤਾ ਆਂਕੜਾ ਵਿਗਿਆਨ ਦੇ ਅਧਾਰ ਤੇ ਵਧੇਰੇ ਸੀ। ਦੋਨਾਂ ਸਾਲਾਂ ਦੌਰਾਨ ਜਿਸਪਮ ਦੀ ਇਕੋ ਸਮੇਂ ਵਰਤੋਂ ਦੇ ਮੁਕਾਬਲੇ ਜਿਪਸਮ ਦੀ ਦੋ ਵਾਰ ਵਰਤੋਂ ਕਰਨ ਨਾਲ ਫ਼ਲੀ ਦਾ ਝਾੜ, ਮੂੰਗਫਲੀ ਦੀ ਭੌਂ ਅਤੇ ਗਿਰੀ ਦਾ ਝਾੜ ਆਂਕੜਾ ਵਿਗਿਆਨ ਦੇ ਅਧਾਰ ਤੇ ਜ਼ਿਆਦਾ ਸੀ। ਇਸ ਨਾਲ ਕੁੱਲ ਮੁਨਾਫਾ ਅਤੇ ਲਾਭ: ਲਾਗਤ ਅਨੁਪਾਤ ਵੀ ਜ਼ਿਆਦਾ ਹੋਇਆ। ਦੋਨਾਂ ਸਾਲਾਂ ਦੌਰਾਨ ਨਾਈਟ੍ਰੋਜਨ ਅਤੇ ਫ਼ਾਸਫ਼ੋਰਸ ਦੀ ਮਿਕਦਾਰ ਵਿੱਚ 25 ਕਿ.ਗ੍ਰਾ. N ਪ੍ਰਤੀ ਹੈਕਟੇਅਰ ਤੋਂ + 30 ਕਿ.ਗ੍ਰਾ. P_2O_5 ਪ੍ਰਤੀ ਹੈਕਟੇਅਰ ਤੱਕ ਵਾਧਾ ਹੋਣ ਨਾਲ ਵਿਕਾਸ ਦੇ ਮਾਪਦੰਡ ਜਿਵੇਂ ਕਿ ਪੌਦੇ ਦੀ ਉਚਾਈ, ਪ੍ਰਤੀ ਪੌਦਾ ਸ਼ਾਖਾਵਾਂ ਦੀ ਗਿਣਤੀ ਅਤੇ ਸੁੱਕੇ ਮਾਦੇ ਦੀ ਜਜ਼ਬਤਾ ਵਿੱਚ ਆਂਕੜਾ ਵਿਗਿਆਨ ਦੇ ਅਧਾਰ ਤੇ ਵਾਧਾ ਹੋਇਆ। ਹਾਲਾਂਕਿ ਨਾਈਟ੍ਰੋਜਨ ਅਤੇ ਫ਼ਾਸਫੋਰਸ ਦੇ ਬਾਕੀ ਪੱਧਰਾਂ ਦੇ ਮੁਕਾਬਲੇ, 35 ਕਿ.ਗ੍ਰਾ. N ਪ੍ਰਤੀ ਹੈਕਟੇਅਰ + 40 ਕਿ.ਗ੍ਰਾ. P_2O_5 ਪ੍ਰਤੀ ਹੈਕਟੇਅਰ ਦੀ ਵਰਤੋਂ ਨਾਲ ਗਿਰੀਆਂ ਵਿੱਚ ਪ੍ਰੋਟੀਨ ਅਤੇ ਤੇਲ ਦੀ ਮਾਤਰਾ ਵਿੱਚ ਆਂਕੜਾ ਵਿਗਿਆਨ ਦੇ ਅਧਾਰ ਤੇ ਵਾਧਾ ਹੋਇਆ ਜਦੋਂਕਿ ਫ਼ਲੀ ਦੇ ਝਾੜ, ਮੂੰਗਫਲੀ ਦੀ ਭੌਂ, ਗਿਰੀਆਂ ਦੇ ਝਾੜ ਅਤੇ ਕੁੱਲ ਨਾਈਟ੍ਰੋਜਨ, ਫ਼ਾਸਫ਼ੋਰਸ, ਪੋਟਾਸ਼ੀਅਮ, ਕੈਲਸ਼ੀਅਮ ਅਤੇ ਸਲਫਰ ਦੇ ਗ੍ਰਹਿਣ ਦੀ ਮਿਕਦਾਰ 25 ਕਿ.ਗ੍ਰਾ. N ਪ੍ਰਤੀ ਹੈਕਟੇਅਰ + 30 ਕਿ.ਗ੍ਰਾ. P_2O_5 ਪ੍ਰਤੀ ਹੈਕਟੇਅਰ ਦੀਆਂ ਮਿਕਦਾਰਾਂ ਦੇ ਸਮਰੂਪ ਸੀ। ਦੋਨਾਂ ਸਾਲਾਂ ਦੌਰਾਨ 25 ਕਿ.ਗ੍ਰਾ. N ਪ੍ਰਤੀ ਹੈਕਟੇਅਰ + 30 ਕਿ.ਗ੍ਰਾ. P_2O_5 ਪ੍ਰਤੀ ਹੈਕਟੇਅਰ ਅਤੇ 35 35 ਕਿ.ਗ੍ਰਾ. N ਪ੍ਰਤੀ ਹੈਕਟੇਅਰ + 40 ਕਿ.ਗ੍ਰਾ. P_2O_5 ਪ੍ਰਤੀ ਹੈਕਟੇਅਰ ਦੀ ਵਰਤੋਂ ਨਾਲ ਕੁੱਲ ਮੁਨਾਫਾ ਅਤੇ ਲਾਭ:ਲਾਗਤ ਅਨੁਪਾਤ ਲਗਭਗ ਇੱਕ ਸਮਾਨ ਸੀ।

ਮੁੱਖ ਸ਼ਬਦ: ਮੂੰਗਫਲੀ, ਵਿਕਾਸ, ਜਿਪਸਮ, ਨਾਈਟ੍ਰੋਜਨ, ਫ਼ਾਸਫ਼ੋਰਸ, ਗੁਣਵਤਾ, ਝਾੜ

ਮੁੱਖ ਸਲਾਹਕਾਰ ਦੇ ਹਸਤਾਖਰ **ਵਿਦਿਆਰਥੀ ਦੇ ਹਸਤਾਖਰ**

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CHAPTER I

INTRODUCTION

Groundnut (*Arachis hypogaea* L.) is known as the king of oilseeds and belongs to the family *Leguminosae* and sub-family *Papilionoideae*. South America is believed to be the place of origin of groundnut (Yayock *et al* 1998). It is a major oilseed crop of tropical and subtropical countries, which is also known as wonder nut, peanut, earthnut, monkey nut and poor men's cashew nut. The botanical name of groundnut is derived from the Greek word '*arachis*' which means 'legume' and '*hypogaea*' which means 'below the ground' which refers to the formation of pods in the soil. India is the second largest producer of groundnut and its oil after China. Groundnut is a major oilseed in India and it accounts for 25% of the total oilseed production in the country. It covered an area of 4.89 million ha with production of 9.25 million tonnes and productivity of 18.93 quintal ha^{-1} in India during 2017-18 (Anonymous 2018). In Punjab, groundnut crop was grown over an area of 1.2 thousand ha with an average annual production of 2.3 thousand tonnes and the productivity of 19.5 quintal ha^{-1} during 2017-18 (Anonymous 2019). Groundnut oil serves as an important vegetable oil. Groundnut kernels contain 48-50% edible oil, 25-34% protein, 10-20% carbohydrates and are rich source of vitamins (E, K and B complex). The protein content in the kernels on an average is 25.3% which is about 1.3 times more than meat and 2.5 times more than the eggs (Das 1997). Groundnut oil contains 40-50% oleic acid (MUFA) and 25-35% linoleic acid (PUFA) which makes the oil good from nutritive and culinary points of view. Groundnut kernels are a valuable source of minerals including phosphorus, calcium, magnesium and potassium. Groundnut kernel being highly digestible can be consumed as shelled nut or in other forms obtained after processing like peanut sauce, flour and butter. Shells of kernels also find an important application as fuel in industries and for the generation of electricity, besides being used as a filter for insulators and wallboard (Onwueme and Sinha 1991). After the extraction of oil, the residual oil cake obtained, being rich in nutrients (7-8% N, 1.5% P_2O_5 and 1.2% K_2O), acts as a valuable animal feed and organic manure. Groundnut crop improved the fertility level of soil by fixing atmospheric nitrogen in its root nodules (Bairagi *et al* 2017).

In Punjab, groundnut is mainly cultivated during the *kharif* season but the productivity in this season is quite low because of variations in monsoon rainfalls as well as due to various bio-stresses like diseases, insect-pests and weeds. Moreover, the cultivated area under groundnut during *kharif* season is less because of cultivation of economically more important crops like maize, rice and cotton during this season. Therefore, there is a great scope for cultivation of short duration spring groundnut in Punjab. Imbalanced and inadequate use of nutrients is the main reason for lower yield of groundnut. Since groundnut is a legume-oilseed crop, its requirement of phosphorus, calcium and sulphur is quite high. Moreover, as compared to the other legume crops, groundnut is a very exhaustive crop because it removes a large amount of nutrients from the soil (Varade and Urkude 1982). An average crop of groundnut removes about 112 kg nitrogen, 20 kg phosphorus and 84 kg potassium from one hectare (Chandra *et al* 2006). Optimization of mineral fertilization is important to improve the productivity of groundnut.

Gypsum is commonly used as a source of calcium and sulphur for groundnut all over the world. The dissolution of gypsum is quite rapid and therefore readily adds Ca and S to the podding zone. Gypsum contains about 18.6% S and 23% Ca and also it has impurities that provide magnesium. Calcium present in the pod zone of 5 cm depth of soil is taken up by the pegs and developing pods, therefore gypsum should be applied close to the base of plant. Application of gypsum improves soil structure which favours effective pegging in groundnut (Agasimani *et al* 1992). Apart from providing calcium and sulphur, gypsum also plays a significant role in the reclamation of alkaline soils. It causes micro-acidification therefore lowering down the soil pH and increasing the nutrient availability in the soil (Alcordo and Recheigl 1993, Singh and Chaudri 2007).

Sulphur is a component of protein and has an important role to play in oil synthesis. It also increases chlorophyll synthesis and decreases chlorosis. Most of the Indian soils are deficient in sulphur. Sulphur finds an important role in the synthesis of sulphur containing amino acids like methionine and cysteine and synthesis of proteins, chlorophyll and oil. It also plays important role in the synthesis of vitamins (biotine and thiamine), co-enzyme-A metabolism of carbohydrates, proteins and fats. It improved nodulation, pod yield and reduces the incidence of diseases (Singh and Chaudri 2007). Application of sulphur has been observed to have a positive influence on the yield attributes and yield of groundnut (Mishra *et al* 1990). Sulphur application increased the dry matter accumulation, plant height, pod yield and biological yield of groundnut (Poonia 2000).

Calcium maintains the membrane permeability and cell integrity, increases pollen germination, activates many enzymes involved in cell division and takes part in protein synthesis and carbohydrate transfer in groundnut. Calcium increases the growth and survival of the symbiotic bacteria in groundnut which therefore has a positive influence on biological nitrogen fixation. Gypsum at the rate of 200 to 1000 kg ha^{-1} needs to be applied when less than 0.25 cmol kg^{-1} Ca is present in the soil (Nyambok 2011). Zharare *et al* (2009) conducted a study using hydroponic nutrient solutions containing various concentrations of calcium and observed that the pod formation would not initiate in the solutions without calcium. They also reported that increasing the amount of calcium was required for proper pod set, proper seed set and morphological development for maturing pods and seed. In general, the calcium requirement is greater for pod filling than flowering and it is greater for flowering than vegetative growth in the groundnut crop. Calcium is more important and lack of Ca reduces the yield and quality of groundnut more than any other element (Singh and Chaudri 2007). Calcium deficiency in soil leads to the low Ca concentration in groundnut seeds which leads to reduced germination rates and seedling vigour (Adams *et al* 1993, Howe *et al* 2012). Deficiency of calcium leads to the production of immature pods, black embryo in seed, weak germination of seeds and increases production potential of aflatoxin and thus, decays peanut pod (Agasimani *et al* 1992, Evanylo 1989, Grichar 2002, Murata 2003). Calcium is absorbed by the roots and translocated to the aerial plant parts but not translocated from the aerial parts to the developing pods in soil, therefore calcium of the soil must be adequate around the growing pods (Norman *et al* 2005, Smart 1994, Ramachandrappa 1992, Slak 1972). Calcium uptake is highest during the early stages of fruit development mainly pod expansion and seed growth (Boote 1982). It was observed that withholding Ca from the pegging zone (0-8 cm soil depth) during the first 30 days after initial pegging severely reduces seed size and dry weight as compared to withholding Ca at the other stages of growth (Smal *et al* 1989).

Phosphorus plays a significant role in nodule formation and fixation of atmospheric nitrogen (Brady and Well 2002). Phosphorus application determines plant reproductive efficiency and promotes growth, development and yield of groundnut crop (Savani and Darji 1995, Bairagi *et al* 2017). Phosphorus is an important structural component of membrane system of the cell, chloroplast and mitochondria. It is an essential constituent of nucleic acid, amino acids, phytin, proteins, nucleoproteins and energy rich phosphate bonds (ADP and ATP). It is involved in the transfer of energy in major metabolic processes like photosynthesis, transformation of sugars and starch and nutrient movement in plants. The total amount of phosphorus taken up by the groundnut plant is very small. Though the amount of phosphorus required is small but a large quantity of fertilizer has to be applied, as the efficiency of uptake of phosphorus from the fertilizer is low. The supply of P below its critical level of 10 ppm P (FAO 1984, Mhango *et al* 2008) has been observed to reduce legume grain production by as much as 50% (Waddington 2003). Root nodules are the major sinks for P and their P content ranges between 0.72 to 1.2%, therefore nitrogen-fixing plants require phosphorus in higher amounts. (Hart 1989a, Hart 1989b).

Groundnut is a self-fertilizing crop, since its most of the nitrogen requirement is met by the nitrogen-fixing bacteria that are present in the root nodules. About 40-80 kg N ha^{-1}

year^{-1} is fixed by the groundnut crop (Islam and Noor 1992). About 86-92% of the nitrogen taken up by the groundnut crop comes from biological nitrogen fixation which comes out to be 125-178 kg N ha^{-1} (Dart *et al* 1983). Although groundnut plants can fix atmospheric nitrogen but they may need a starter dose of 10-20 kg N ha^{-1} at planting time mainly, if the total nitrogen in the soil is less than 0.1% (FAO 2006 and FAO 2013). The root nodules can fix nitrogen after 15-20 days of growth, therefore the top dressing of nitrogen is not needed (FAO 1984). Williams (1979) suggested that at very high yield levels, the nitrogen requirement of nodulated groundnut cannot be met from symbiotic nitrogen fixation alone. However, to meet the nitrogen requirement during early growth stages, nitrogen could be applied as starter dose (Iman and Ahmed 2014). The basal application of 30 to 60 kg N ha^{-1} at the sowing time gave highest number of pods plant^{-1}, plant height, shelling percentage, number of seeds pod^{-1}, seed oil content and protein content (Iman and Ahmed 2014, Bairagi *et al* 2017). The positive response of the groundnut crop to nitrogen fertilizer indicates that the N demand of the crop is not fully met by symbiotic N_2 fixing bacteria.

However, very less information on the balanced nutrition of spring groundnut is available. Therefore, there is a need to develop a nutrient management strategy to achieve the potential production of spring groundnut. Keeping all these points in view the present investigation was proposed to study the "Effect of nitrogen, phosphorus and gypsum on growth, yield and quality of spring groundnut (*Arachis hypogaea* L.)" with the following objectives:

- To optimize the mineral nutrition in terms of nitrogen, phosphorus and gypsum dose for optimum growth, yield and quality of spring groundnut.
- To find out the proper time for application of gypsum for optimum growth, yield and quality of spring groundnut.

CHAPTER II

REVIEW OF LITERATURE

The literature related to the study on "Effect of nitrogen, phosphorus and gypsum on growth, yield and quality of spring groundnut (*Arachis hypogaea* L.)." available in India or abroad has been reviewed under the following headings: -

2.1 Effect of gypsum levels and application time on growth, yield and quality of groundnut

2.2 Effect of nitrogen and phosphorus on growth, yield and quality of groundnut

2.3 Effect of nitrogen, phosphorus and gypsum combination on growth, yield and quality of groundnut

2.1 Effect of gypsum levels and application time on growth, yield and quality of groundnut

Gypsum provides calcium and sulphur in readily available form to the plants. Pod development is enhanced by application of gypsum at flowering stage since it increases the availability of calcium and sulphur in the fruiting zone. Deficiency of calcium may lead to immature pods, pops, pod decay, blackened embryo and weak germination (Henning *et al* 1982). Sulphur deficiency in groundnut results in chlorosis and decreased protein and oil synthesis in groundnut crop (Singh and Chaudri 2007).

It was revealed that the application of gypsum @ 200 kg ha^{-1} resulted in maximum output of all biological growth parameters (number of branches $plant^{-1}$, number of pegs $plant^{-1}$, number of nodules $plant^{-1}$ and plant height), yield attributes (100-seed weight and number of pods $plant^{-1}$) and pod yield of groundnut (Yadav *et al* 2015). Thilakarathna *et al* (2014) concluded that gypsum application @ 250 kg ha^{-1} improved plant height, number of branches $plant^{-1}$, number of pegs $plant^{-1}$, number of nodules $plant^{-1}$, 100-seed weight, number of pods $plant^{-1}$ and pod yield of groundnut as compared to no application of gypsum. It was also reported that protein and oil content in kernels of groundnut also improved with the increasing rate of gypsum application up to 250 kg ha^{-1}. Rao and Shaktawat (2001) and Rao and Shaktawat (2005) reported that application of gypsum @ 250 kg ha^{-1} significantly improved the plant height, number of branches $plant^{-1}$, root dry weight $plant^{-1}$, LAI, pod yield, oil content, protein content and harvest index as compared to control. Application of 100 kg ha^{-1} gypsum was concluded as the optimum dose for potential production in terms of plant height, number of branches $plant^{-1}$, pod yield, oil content, protein content and harvest index in groundnut (Mupangwa and Tagwira 2005). Shah *et al* (2012) reported that growth, yield attributing characters and pod yield of groundnut increased significantly with 500 kg ha^{-1} gypsum application over lower doses of gypsum. Sivanesarajah *et al* (1995) concluded that gypsum application at the rate of 500 kg ha^{-1} at the flower initiation stage significantly increased 100-kernel weight, dry weight of pods, number of pods per unit area and shelling percentage by 9.5, 34, 22 and 10% respectively over control. With the application of 250 kg ha^{-1} gypsum, the concentration of N, P, K, Ca, Mg and S in the kernels and above ground parts of groundnut crop increased significantly over control (Ismail *et al* 1998 and Rao and Shaktawat 2005). Manan and Sharma (2018) reported that the application of gypsum @ 125 kg ha^{-1} gave significantly higher pod yield (19.81 q ha^{-1}) as compared to control. Arnold *et al* (2017) found non-significant effect of gypsum application on pod yield whereas seed Ca concentration increased with the increasing dose of gypsum application. Kirthisinghe *et al* (2014) reported that the application of 250 kg ha^{-1} of gypsum gave significantly higher number of pegs $plant^{-1}$, mean pod dry weight $plant^{-1}$ and mean kernel weight as compared to the other three doses of gypsum. Taufiq *et al* (2016) concluded that the application of gypsum increased fresh pod yield by 12.6% and dry pod yield by 13.1% as compared to the control.

Adhikari *et al* (2003) reported that the application of 400 kg ha^{-1} gypsum resulted in highest number of pods $plant^{-1}$ (15.5), highest pod yield (2.38 t ha^{-1}), highest haulm yield (4.621 t ha^{-1}), highest 100-kernel weight (73.4 g), highest oil content (46.9%), highest net return (₹35,301 ha^{-1}) and benefit cost ratio over other treatments. Rao and Shaktwat (2002) carried out a study at Udaipur and observed that application of gypsum @ 250 kg ha^{-1} resulted in significantly higher number of pods $plant^{-1}$, pod weight $plant^{-1}$, filled pod percent, pod yield, 100-kernel weight and sound mature kernels $plant^{-1}$ as compared to the control treatment. Bagarama *et al* (2012) evaluated the impact of gypsum on groundnut performance and concluded that the application of gypsum at the rate of 400 kg ha^{-1} significantly increased the pod weight (2434 kg ha^{-1}) of groundnut as compared to no gypsum application. Pathak *et al* (2013) revealed that the application of gypsum resulted in a significant increase in Ca and S concentration but a decrease in P concentration in pod walls and seeds of groundnut. Mandal *et al* (2005) reported that the application of gypsum @ 400 kg ha^{-1} increased the plant height, number of pods $plant^{-1}$, pod yield, 100-kernel weight and shelling percentage of groundnut over control and also 400 kg ha^{-1} gypsum resulted in maximum gross returns and benefit cost ratio over lower levels of gypsum. Reddy and Rao (1993) concluded that the application of gypsum @ 1250 kg ha^{-1} resulted in a significant increase in oil content and dry matter production in groundnut over control.

Split application of gypsum provides calcium and sulphur in sufficient amounts at the stages of pegging and pod development. Hallock and Allison (1980a) revealed that higher production was obtained when calcium was applied at early flowering stage as compared to application at earlier stages. Jat and Singh (2006) reported that the application of gypsum @ 250 kg ha^{-1} at sowing + 125 kg ha^{-1} at flowering significantly increased the number of pods plant^{-1}, pod yield, seed index, shelling percentage, kernel yield and harvest index over gypsum application at sowing time. Split application of gypsum was found to give higher yield and yield attributes as compared to full application of gypsum at sowing or full application at flowering. Cheema *et al* (1991) reported that the application of gypsum @ 1000 kg ha^{-1} at time of flowering was more economical as compared to application of higher quantity (2000 kg ha^{-1}) of gypsum at the sowing time. Ghosh *et al* (2015) worked to study the effect of gypsum on groundnut by testing three doses of gypsum (50 kg ha^{-1}, 100 kg ha^{-1} and 150 kg ha^{-1} and three methods of application (100% basal, 50% basal + 50% top dressing and 75% basal + 25% top dressing). It was observed that the plant height, number of pods plant^{-1}, 100-pod weight, pod yield plant^{-1}, shelling percentage and 100-seed weight were significantly increased with the application of gypsum @ 100 kg ha^{-1} (50% basal + 50% top dressing). Also, it was concluded that split application of gypsum (50% basal + 50% top dressing) gave significantly higher yield attributes and yield as compared to the basal application of gypsum.

Jat and Singh (2006) under Rajasthan condition concluded that the application of 250 kg gypsum ha^{-1} at sowing + 125 kg gypsum ha^{-1} at flowering significantly enhanced the number of pods plant^{-1}, pod yield, kernel yield and shelling percentage of groundnut over full dose at sowing. Geethalakshmi and Lourduraj (1998) conducted a study to check the influence of gypsum on yield of groundnut in sandy loam soil of Coimbatore and found that 500 kg gypsum ha^{-1} applied at pegging stage gave highest pod yield (2463 kg ha^{-1}), highest haulm yield (3889 kg ha^{-1}), 12.3% increase in test weight (30.89 g) and highest shelling percentage (74.9%) while statistically at par with 400 kg gypsum ha^{-1} at pegging. Devakumar and Gajendra Giri (1998) at New Delhi concluded that the split application of gypsum @ 200 kg ha^{-1} resulted in a significant increase in pod yield (20.2% increase), haulm yield (29.7 q ha^{-1}), 100-kernel weight and shelling percentage over control while statistically at par with the split application of 400 kg gypsum ha^{-1}. Ravikumar *et al* (1994) observed that the split application of 500 kg gypsum ha^{-1} increased the dry matter production by 7.3% and pod yield by 13.5% as compared with the control (no gypsum application). Devi (1991) found that the split application of gypsum (250 kg ha^{-1} basal + 250 kg ha^{-1} at 30 DAS) increased the shelling percentage and number of pods plant^{-1} significantly.

2.2 Effect of nitrogen and phosphorus on growth, yield and quality of groundnut

2.2.1 Effect of nitrogen on growth, yield and quality of groundnut

Nitrogen is the main structural component of plant cell. It plays a significant role in plant metabolism and is involved in the synthesis of proteins, amino acids and nucleic acids. Nitrogen is required by groundnut plants in comparatively greater amounts than other elements, some of which comes from biological nitrogen fixation and the rest is added as fertilizers. Deficiency of nitrogen leads to small and yellow leaves along with stunted growth. Pareek and Poonia (2011) reported that the application of nitrogen @ 60 kg ha^{-1} increased overall vegetative growth, branching and also increased number of pods $plant^{-1}$ (79%), shelling percentage (15%), seed index (27.2%), pod index (12.2%), pod yield and benefit cost ratio in comparison with no nitrogen application. Venkateswarlu *et al* (1990) and Balasubramanian (1997) also reported similar results and revealed that higher nitrogen application (80 kg N ha^{-1}) greatly increased growth, pegging and pod yield. Iman and Ahmed (2014) concluded that the application of 60 kg N ha^{-1} resulted in highest plant height, number of pods $plant^{-1}$, shelling percentage, number of seeds pod^{-1}, seed oil content and protein content. El-Habbasha *et al* (2013) reported that the increase in N levels from 30 to 40 kg N $faddan^{-1}$ significantly increased number of pods $plant^{-1}$, weight of pods $plant^{-1}$, weight of seeds $plant^{-1}$, 100-seed weight, pod yield $faddan^{-1}$, seed yield $faddan^{-1}$ and straw yield $faddan^{-1}$ in groundnut crop. The application of 60 kg ha^{-1} nitrogen gave maximum plant height, number of mature pods $plant^{-1}$, mature pod weight, shelling percentage, seed length and width, pod yield and seed yield as compared to control and 30 kg ha^{-1} nitrogen (Gohari and Niyaki 2010).

Vijayakumar and Geethalakshmi (2018) found that the application of 67.93 kg N ha^{-1} resulted in significantly higher plant height (31.21 cm), dry matter production (7781.32 kg ha^{-1}), leaf area index (4.52 cm), number of matured pods $plant^{-1}$ (24.84), 100-seed weight (68.69 g), pod yield (2087.03 kg ha^{-1}) and haulm yield (5355.59 kg ha^{-1}) as compared to lower levels (54.25 and 40.76 kg ha^{-1}) of nitrogen. Similarly, Gad (2012a, 2012b) reported that 67 kg N $faddan^{-1}$ resulted in significantly higher plant height, dry weight of shoot and root, number of nodules $plant^{-1}$, number of pods $plant^{-1}$, weight of 100 seeds, seed yield $plant^{-1}$, pod yield and oil yield as compared to lower doses of nitrogen. The application of 40 kg N ha^{-1} significantly enhanced growth parameters like dry matter accumulation and number of nodules $plant^{-1}$ as well as yield parameters like number of pods $plant^{-1}$, test weight, number of kernels pod^{-1}, pod yield, haulm yield and biological yield as compared to control and 20 kg N ha^{-1} whereas it was statistically at par with 60 kg N ha^{-1} (Meena *et al* 2011). The application of 178.5 kg N ha^{-1} resulted in significantly higher plant height, number of branches $plant^{-1}$, seed index, shelling percentage, pod yield $plant^{-1}$ and pod yield ha^{-1} as compared to lower doses (107.1 and 142.8 kg ha^{-1}) of nitrogen (Abdel-Galil and Abd El-Ghany 2014). Chirwa *et al* (2017a) reported that the application of 20 kg N ha^{-1} resulted in an increase in pod yield, kernel yield and N uptake by plants of groundnut as compared to the control. Antony *et al* (2000) observed that leaf net assimilation rate, leaf area index and leaf area duration was enhanced by increased levels of nitrogen and the optimum yield was obtained by the application of 25 kg N ha^{-1}. Gogoi *et al* (2000) studied the effect of different rates of nitrogen fertilizer using five doses (0, 20, 40, 60 and 80 kg N ha^{-1}) and found that the number of pods $plant^{-1}$, shelling percentage, number of branches $plant^{-1}$ and number of pegs $plant^{-1}$ were increased by increasing the level of nitrogen upto 80 kg N ha^{-1} while 40 kg N ha^{-1} was concluded to be the optimum dose because yield and yield attributes increased significantly only upto 40 kg N ha^{-1}. Kandil *et al* (2007) found that the pod yield, haulm yield, number of pods $plant^{-1}$and 100-kernel weight were significantly enhanced by increasing the level of nitrogen upto 50 kg N ha^{-1}.

Singh and Singh (2001) reported that the use of 60 kg N ha^{-1} significantly improved the pod yield of groundnut crop. Ali and Seyyed (2010) revealed that the application of 60 kg N ha^{-1} gave significantly higher pod yield (2314 kg ha^{-1}) and kernel yield (1378 kg ha^{-1}) as compared to control. Ali and Ebrahim (2011) observed that the application of 60 kg N ha^{-1} resulted in the highest kernel yield of 1796 kg ha^{-1} as compared to lower doses of nitrogen. Moussa (2000) reported that increasing the rates of nitrogen fertilizer significantly increased the N, P, K and Ca content and uptake in the groundnut plants. Deka *et al* (2001a) concluded that enhancing nitrogen dose upto to 40 kg N ha^{-1} increased the N uptake (194 kg ha^{-1}), P_2O_5 uptake (24 kg ha^{-1}) and K_2O uptake (84 kg ha^{-1}) by the groundnut crop.

2.2.2 Effect of phosphorus on growth, yield and quality of groundnut

Phosphorus is the main nutrient for adequate growth, yield and quality of groundnut. The phosphorus requirement is more in legumes in comparison to non-legume crops (Brady and Well 2002). This is because of its major role in formation of root nodules and atmospheric N_2 fixation. Phosphorus plays a significant role in physiological processes of plant and therefore enhances yield of groundnut crop (Henry 2016). Application of 20 kg P_2O_5 ha^{-1} resulted in a significant increase in dry matter yield (16.63%), seed weight (3.96%), number of pods $plant^{-1}$ (33.9%), and shelled seed yield (33.97%) as compared to 10 kg P_2O_5 ha^{-1} (Sibhatu *et al* 2016). Shiyam (2010) concluded that application of 40 kg P_2O_5 ha^{-1} significantly increased plant height, number of branches $plant^{-1}$, number of nodules $plant^{-1}$, number of pegs $plant^{-1}$, number of filled pods $plant^{-1}$ and seed yield. Kabir *et al* (2013) reported that 50 kg P_2O_5 ha^{-1} gave higher plant height, number of branches $plant^{-1}$, dry weight of plant, leaf area index, total number of pods $plant^{-1}$, 100-pod weight, shelling percentage, biological yield, pod yield, straw yield and harvest index as compared to 25 kg P_2O_5 ha^{-1} and control. Kamara *et al* (2011) concluded that the application of phosphorus at the rate of 40 kg ha^{-1} considerably increased plant height, leaf number, total dry weight and pod yield of groundnut crop as compared to lower doses. Kumar *et al* (2008) studied the influence of phosphorus on growth, yield and quality of groundnut and concluded that application of 60 kg P_2O_5 ha^{-1} increased plant height, number of branches, yield contributing parameters and pod yield significantly as compared to 0, 20, and 40 kg P_2O_5 ha^{-1}. Balasubramanian and Singh (1990) revealed that the amount of nitrogen fixed in the root nodules increased with the higher dose (60 kg P_2O_5 ha^{-1}) of phosphorus. Musa *et al* (2017) revealed that with an increase in phosphorus application levels from 0 to 24 kg P_2O_5 ha^{-1}, there was a significant increase in the growth, yield and quality of groundnut as well as nutrient (N, P, K, Ca, Mg, S, Fe, Mn, Zn, and Cu) uptake by kernel, haulm and shell. Gobarah *et al* (2006) reported that increasing the dose of phosphorus fertilizer from 30 to 60 kg P_2O_5 $faddan^{-1}$ significantly increased dry weight of plant, number of pods $plant^{-1}$, number of seeds $plant^{-1}$, weight of pods $plant^{-1}$, weight of seeds $plant^{-1}$, 100-seed weight, seed yield, oil yield, protein yield, protein content as well as N, P and K concentration in the plant.

Manan and Sharma (2018) reported that the application of 20 kg P_2O_5 ha^{-1} gave significantly higher number of pods $plant^{-1}$ (29.0) and pod yield (19.81 q ha^{-1}) as compared to control. Soils fertilized with 75 kg P_2O_5 ha^{-1} produced the highest dry matter and yield of groundnut and this was significantly higher than control, 25 kg P_2O_5 ha^{-1} and 50 kg P_2O_5 ha^{-1} by 54%, 32% and 15% respectively for the two cropping seasons (Ikenganyia *et al* 2017). Naab *et al* (2009) observed that the application of 30 kg P_2O_5 ha^{-1} significantly increased pod yield and seed yield as compared to control but statistically at par with 60 and 90 kg P_2O_5 ha^{-1}. Yakubu *et al* (2010) reported that the application of 40 kg P_2O_5 ha^{-1} to groundnut increased the number of nodules $plant^{-1}$ by 160%, total N content in plant by 147% and amount of fixed nitrogen by 169% over the control. Nwokwu (2011) revealed that groundnut crop responded to 20 kg P_2O_5 ha^{-1} which resulted in an increase of grain yield by 39.04%. Kalita *et al* (2015) reported that the yield attributing characters including total number of pods $plant^{-1}$, total number of kernels pod^{-1}, pod weight $plant^{-1}$, kernel weight $plant^{-1}$ and pod yield increased significantly with increase in the levels of applied phosphorus up to 50 kg P_2O_5 ha^{-1}. Dutta *et al* (2004) observed a significant increase in the yield and yield attributes of groundnut upto 50 kg P_2O_5 ha^{-1}. Deka *et al* (2001b) found that increasing the dose of phosphorus upto 50 kg P_2O_5 ha^{-1} resulted in a significant increase in 100-kernel weight, dry matter accumulation and number of pods $plant^{-1}$ of the groundnut crop as compared to control. Similar results were also reported by Akbari *et al* (2002). Hadwani and Gundalia (2005) found that the application of 75 kg P_2O_5 ha^{-1} significantly increased the number of pods $plant^{-1}$, number of kernels pod^{-1}, shelling percentage, 100-kernel weight, pod yield, haulm yield, oil content and protein content over the control. Kausale *et al* (2009) reported that the plant height, dry matter accumulation, oil and protein content in kernels were increased significantly by the application of 50 kg P_2O_5 ha^{-1} over control. Rath *et al* (2000) found that 75 kg P_2O_5 ha^{-1} gave highest pod yield, haulm yield as well as harvest index whereas 50 kg P_2O_5 ha^{-1} increased the oil content and the shelling percentage of the groundnut crop. Singh and Singh (2000) revealed that phosphorus when applied at the rate of 50 kg P_2O_5 ha^{-1} resulted in significantly higher pod yield over the control. Kumar *et al* (2000) observed that by enhancing the phosphorus dose from 40 kg P_2O_5 ha^{-1} to 60 kg P_2O_5 ha^{-1}, an increase of 30.8% was seen in the pod yield. Majumdar *et al* (2001) reported that the application of 75 kg P_2O_5 ha^{-1} resulted in significantly higher pod yield (3.0 t ha^{-1}), haulm yield (4.67 t ha^{-1}) and P content (0.366%) of groundnut crop over control whereas an increase of 9.74% and 8.33% was seen in protein content and oil content respectively.

Rao and Shaktawat (2002) concluded that the application of phosphorus @ 40 kg P_2O_5 ha^{-1} gave significantly higher 100-kernel weight and pod weight $plant^{-1}$ of groundnut as compared to 20 kg P_2O_5 ha^{-1} but statistically at par with 60 kg P_2O_5 ha^{-1}. Panwar and Singh (2003) reported that 60 kg P_2O_5 ha^{-1} resulted in significantly higher pod yield (2.84 t ha^{-1}) and haulm yield (4.84 t ha^{-1}) as compared to no phosphorus application. Bharambe *et al* (2004) reported that 60 kg P_2O_5 ha^{-1} significantly boosted the pod yield over 30 kg P_2O_5 ha^{-1} and statistically at par with 90 kg P_2O_5 ha^{-1} while the effect of phosphorus levels on the protein and oil content of groundnut kernel was found to be non-significant. Dutta *et al* (2004) carried out a research trial in Assam and found that 50 kg P_2O_5 ha^{-1} significantly increased the pod yield, haulm yield, number of pods $plant^{-1}$ as well as shelling percentage of groundnut over control. Badole *et al* (2005) noted that the application of 50 kg P_2O_5 ha^{-1} resulted in maximum 100-kernel weight, pod yield and haulm yield of groundnut in comparison with 25 kg P_2O_5 ha^{-1}. Dutta and Mondal (2006) observed that enhancing the phosphorus dose upto 75 kg P_2O_5 ha^{-1} raised the 100-kernel weight, number of pods $plant^{-1}$, number of kernels pod^{-1} and shelling percentage of groundnut significantly. Gobarah *et al* (2006) revealed that 100-seed weight, number of pods $plant^{-1}$, kernels pod^{-1}, protein content and pod yield were increased by increasing the level of phosphorus from 30 to 60 kg P_2O_5 ha^{-1} and also resulted in a significant increase in the N, P and K concentrations in groundnut plant. Rajanikanth *et al* (2008) carried out a field study at Hyderabad and reported that the use of 40 kg P_2O_5 ha^{-1} gave significantly more shelling percentage and pod yield over control. Akbari *et al* (2011) observed that the application of 50 kg P_2O_5 ha^{-1} gave higher shelling percentage, harvest index, pod yield and haulm yield than the other treatments under Gujarat conditions. Kachot *et al* (2001) concluded that the use of 25 kg P_2O_5 ha^{-1} resulted in a significant increase in protein content, shelling percentage and oil yield of groundnut over control. Ranjit *et al* (2007a) found that the oil content of groundnut and the uptake of N, P, K and Ca was increased with the application of 112.5 kg P_2O_5 ha^{-1} as compared with the lower doses of phosphorus.

A significant increase in growth, yield and quality parameters was observed by the use of 60 kg P_2O_5 ha^{-1} in comparison with 20 kg P_2O_5 ha^{-1} (Rao and Shaktawat 2001).

Atayese (2007) reported that the use of 54 kg P_2O_5 ha^{-1} resulted in an increase in canopy spread, leaf area and root dry weight by 40, 14 and 17% respectively over no phosphorus application. Toungos *et al* (2009) found that the use of 60 kg P_2O_5 ha^{-1} resulted in an improvement in the number of flowers (18.7) and number of nodules $plant^{-1}$ (9.7) in groundnut as compared to control. Akbari *et al* (2010) reported that the plant height, number of branches $plant^{-1}$ and number of pods $plant^{-1}$ were significantly increased with the application of phosphorus over control. Gibril (2010) noticed the beneficial effect of 40 kg P_2O_5 ha^{-1} that gave increased vegetative growth and dry weight of groundnut. Application of 114 kg P_2O_5 ha^{-1} improved the yield and yield attributes of groundnut over control (El-Far and Ramadan 2000). Nguyen (2003) reported that the application of 90 kg P_2O_5 ha^{-1} increased the pod yield (0.96 t ha^{-1}) and kernel yield (0.78 t ha^{-1}) over the other levels of phosphorus. Ranjit *et al* (2007b) concluded that the application of 112.5 kg P_2O_5 ha^{-1} resulted in significantly more pod yield (35 q ha^{-1}), haulm yield (46 q ha^{-1}) and oil content (47.85%) of groundnut over control.

John (2010) found that the use of 40 kg P_2O_5 ha^{-1} increase the number of filled pods $plant^{-1}$ and kernel yield over no phosphorus application. Toungos *et al* (2010) found that the application of 60 kg P_2O_5 ha^{-1} gave higher 100-kernel weight (80 g) and haulm yield (454 kg ha^{-1}) as compared to other levels of phosphorus. Rath *et al* (2000) concluded that the application of 75 kg P_2O_5 ha^{-1} gave maximum pod yield of 21.51q ha^{-1}. Mirvat *et al* (2006) reported that by increasing the dose of phosphorus from 30 to 60 kg P_2O_5 $faddan^{-1}$, protein content and NPK content of groundnut were significantly increased over control. Deka *et al* (2001b) concluded that the uptake of N, P and K in groundnut was significantly increased with the application of 50 kg P_2O_5 ha^{-1} over control while at par with 75 and 100 kg P_2O_5 ha^{-1}.

2.2.3 Effect of nitrogen and phosphorus combination on growth, yield and quality of groundnut

Hasan and Sahid (2016) reported that the application of phosphorus and nitrogen @ 82 kg P_2O_5 ha^{-1} and 27 kg N ha^{-1} resulted in improved growth and yield parameters such as seed germination, number of branches, plant height, number of nodules, dry matter, number of pods $plant^{-1}$, pod yield, 100-seed weight, oil content, and protein content as compared to the lower levels of nitrogen and phosphorus. Hossain *et al* (2007) concluded that the application of 60 kg N ha^{-1} along with 60 kg P_2O_5 ha^{-1} resulted in a higher uptake of nitrogen and phosphorus as well as improved number of mature pods $plant^{-1}$ and 100-seed weight that subsequently led to increased pod yield as compared to the control. Sagvekar *et al* (2017) reported that the application of 30 kg N ha^{-1} + 75 kg P_2O_5 ha^{-1} resulted in a significantly higher pod yield (3.50 t ha^{-1}), higher kernel yield (2.63 t ha^{-1}), greater number of pods $plant^{-1}$

(30.7), higher dry pod weight (34.2 g plant^{-1}), higher net returns and higher B:C (1:1.78) over other nitrogen and phosphorus doses.

Meena *et al* (2013) reported that the application of 30 kg N+60 kg P_2O_5 ha^{-1} resulted in significantly higher pod yield (33.53 q ha^{-1}), kernel yield (21.70 q ha^{-1}), haulm yield (53.65 q ha^{-1}) and biological yield (87.18 q ha^{-1}) of groundnut as compared to control and 20 kg N+40 kg P_2O_5 ha^{-1} while statistically at par with the application of 40 kg N+80 kg P_2O_5 ha^{-1}. Kabadagi *et al* (2010) and Bala *et al* (2011a) evaluated the effect of different levels of NPK on growth, yield and quality of groundnut and found no significant difference. Bala *et al* (2011b) also found that days to 50% flowering were increased by the application of 30-39-39 NPK kg ha^{-1} as compared to 10-13-13 NPK kg ha^{-1}. Meena *et al* (2014) and Meena and Yadav (2015) conducted a field study to find out the optimum dose of nitrogen and phosphorus for the best performance of groundnut. Four fertility levels (0, 20 N+40 P_2O_5, 30 N+60 P_2O_5 and 40 N+80 P_2O_5 kg ha^{-1}) were applied. Application of 30 kg N+60 kg P_2O_5 ha^{-1} significantly increased the number of pods plant^{-1} (33.73), number of kernels pod^{-1} (1.74), shelling percentage (64.78 %), seed index (42.07 g), pod yield (33.53 q ha^{-1}), kernel yield (21.70 q ha^{-1}), haulm yield (53.65 q ha^{-1}) and biological yield (87.18 q ha^{-1}) over control and 20 kg N+40 kg P_2O_5 ha^{-1} while statistically at par with 40 kg N+80 kg P_2O_5 ha^{-1}. Hasan (2018) found that various physio-chemical properties of soil were non-significantly affected with different rates of nitrogen and phosphorus application however application of 27 kg N ha^{-1}+82 kg P_2O_5 ha^{-1} resulted in highest potassium content of soil (694.2 μg g^{-1}) as compared to the other treatments which was statistically at par with the application of 0 kg N ha^{-1}+82 kg P_2O_5 ha^{-1}. Munda *et al* (2004) reported that the application of 20 kg N ha^{-1} + 60 kg P_2O_5 ha^{-1} increased number of pods plant^{-1} (12.30) and number of branches plant^{-1} (10.10) in groundnut over control.

Thorave and Dhonde (2007) revealed that application of 25 kg N ha^{-1} + 50 kg P_2O_5 ha^{-1} resulted in maximum plant height and dry matter accumulation in groundnut crop. Khan *et al* (2009) noticed that the application of 27 kg N ha^{-1} + 69 kg P_2O_5 ha^{-1} significantly increased the plant height (60.44 cm), emergence of plants (11.71 plants m^{-2}), days to 50% flowering (33.33), days to maturity (183.28) and pod yield (1340.33 kg ha^{-1}) in comparison with the control treatment. Bala *et al* (2011b) noticed that application of 20 kg N ha^{-1} + 26 kg P_2O_5 ha^{-1} increased canopy spread significantly as compared to control. Subrahmaniyan *et al* (2000) reported that the use of 26 kg N ha^{-1} + 51 kg P_2O_5 ha^{-1} gave higher 100-kernel weight, number of matured pods plant^{-1}, shelling percentage, sound matured kernel percentage and pod yield of groundnut over control. Shinde *et al* (2000) revealed that the application of 25 kg N ha^{-1} + 50 kg P_2O_5 ha^{-1} recorded significantly higher dry pod yield (43.41 q ha^{-1}), haulm yield (88.18 q ha^{-1}), 100-pod weight (84.09 g), oil content (51.70%), oil yield (15.82 q ha^{-1}) and protein content (21.58%) of groundnut over control. Kumar *et al* (2000) observed that the application of 30 kg N ha^{-1} + 60 kg P_2O_5 ha^{-1} (0.50 N/P ratio) resulted in a significant increase of pod yield (2849 kg ha^{-1}) in comparison with lower levels of nitrogen and phosphorus. It was also concluded that the application of 30 kg N ha^{-1} + 60 kg P_2O_5 ha^{-1} (0.50 N/P ratio) resulted in the highest uptake of N (121.12 kg ha^{-1}), P (10.14 kg ha^{-1}) and K (34.89 kg ha^{-1}) in groundnut as compared to the other levels of nitrogen and phosphorus. Zhang *et al* (2000) found that the application of 100 kg N ha^{-1} + 80 kg P_2O_5 ha^{-1} increased the pod yield of groundnut significantly over control. Altab Hossain *et al* (2007) reported that the use of 60 kg N ha^{-1} and 39 kg P_2O_5 ha^{-1} gave significantly more pod yield (2870 kg ha^{-1}), 100-kernel weight (56.22 g) and number of mature pods $plant^{-1}$ (23) over the control treatment.

Hossian and Hamid (2007) reported that the application of 60 kg N ha^{-1} + 60 kg P_2O_5 ha^{-1} (N/P ratio of 1.00) gave significantly more number of mature pods $plant^{-1}$, 100-kernel weight and pod yield over control. Elayaraja and Singaravel (2009) found that the application of 150% NPK level per ha^{-1} resulted in significantly higher pod yield (2196 kg ha^{-1}) and haulm yield (2930 kg ha^{-1}) in comparison with 0, 100% and 125% NPK levels. Borse (2003) revealed that the application of 100% RDF (25 kg N ha^{-1} + 50 kg P_2O_5 ha^{-1}) significantly increased the plant height and number of branches $plant^{-1}$ over control but statistically at par with 75% RDF (18.75 kg N ha^{-1} + 37.5 kg P_2O_5 ha^{-1}). Subrahmaniyan *et al* (2000) observed that by raising the dose of NPK up to 150% RDF (26:51:81 kg N, P_2O_5 and K_2O ha^{-1}), there was a significant increase in the number of matured pods $plant^{-1}$, 100-kernel weight, shelling percentage, sound matured kernel per cent and pod yield of groundnut. More *et al* (2002) concluded that the use of 100% RDF (25 kg N ha^{-1} + 50 kg P_2O_5 ha^{-1}) recorded a significant increase in 100-kernel weight and dry pod yield of groundnut over other doses. Devi *et al* (2003) observed that the use of 40 kg N ha^{-1} + 50 kg P_2O_5 ha^{-1} + 50 kg K_2O ha^{-1} gave highest number of pods $plant^{-1}$ and pod yield of groundnut as compared to the lower levels of fertilizers. Dhawale and Charjan (2005) concluded that application of 36 kg N ha^{-1} + 75 kg P_2O_5 ha^{-1} recorded maximum number of pods $plant^{-1}$, pod yield, dry haulm yield and oil content of the groundnut crop.

2.3 Effect of nitrogen, phosphorus and gypsum combination on growth, yield and quality of groundnut

Jamal *et al* (2006) conducted a field experiment with two levels of gypsum (0 and 108 kg ha^{-1}) and two levels of nitrogen (23.5 and 43.5 kg ha^{-1}) in different combinations. It was reported that with the application of 108 kg gypsum ha^{-1} + 43.5 kg N ha^{-1}, seed yield was 90.04%, biological yield 67.04%, harvest index 20.39%, oil content 7.21%, oil yield

103.87%, number of pods plant^{-1} 41.52%, number of seeds pod^{-1} 24.84% and 100-seed weight 9.15% higher than the use of 0 kg gypsum ha^{-1} + 23.5 kg N ha^{-1}. Chirwa *et al* (2017a) reported that the application of 20 kg N +30 kg P_2O_5 +429 kg gypsum ha^{-1} resulted in a significant increase of 71.3% in kernel yield and 40.8% in pod yield of groundnut over control. Chirwa *et al* (2017b) reported that the application of the fertilizer combination at the rate of 858 kg gypsum ha^{-1} + 20 kg N ha^{-1} + 60 kg P ha^{-1} resulted in the highest kernel yield of 4.18 t ha^{-1}, pod yield of 6.72 t ha^{-1}, haulm yield of 5.87 t ha^{-1} and the highest 100 seed weight of 102.7 g. Kabir *et al* (2013) studied the interactive effect of phosphorus and calcium on groundnut and found that application of 50 kg P_2O_5 ha^{-1} + 472 kg gypsum ha^{-1} resulted in highest shelling percentage, pod yield, biological yield, straw yield and harvest index. Bairagi *et al* (2017) reported that the application of 100% N P K (20:60:40 kg ha^{-1}) + 100% gypsum (500 kg ha^{-1}) recorded a significant increase in the plant height, number of branches plant^{-1}, number of grains pod^{-1}, seed index, grain yield and pod yield of groundnut over other doses of the fertilizers. Rao and Shaktawat (2005) found that the application of phosphorus at 40 kg P_2O_5 ha^{-1} + 250 kg gypsum ha^{-1} increased the total uptake of all the nutrients and also the pod yield and haulm yield of groundnut.

CHAPTER III

MATERIALS AND METHODS

The field trials of the present investigation entitled **"Effect of nitrogen, phosphorus and gypsum on growth, yield and quality of spring groundnut (*Arachis hypogaea* L.)"**, were conducted at the Students' Research Farm, Department of Agronomy, Punjab Agricultural University, Ludhiana during spring season of 2018 and 2019.

3.1 Location and climate

Ludhiana is situated at 30° 56' N latitude, 75° 52' E longitude and at an altitude of 247 m above the mean sea level and representing the Indo-Gangetic Alluvial plain. Ludhiana features a sub-tropical and semi-arid climate. The summers are hot and dry from April to June and hot and humid during July to September, while very cold winters from November to January are observed. The temperature shows considerable fluctuations during both the summer and the winter seasons. During summer, the maximum temperature may go upto 47˚C and the minimum temperature may go below 4˚C during winter. Winters are generally accompanied by frosty spells during December to January. The average annual rainfall is about 500-750 mm. Approximately, 80 per cent of the rainfall is received during the months of July to September (monsoon period). However, a few showers are received during winter season also.

3.2 Weather during crop season

The climatic data recorded at the Agro-meteorological observatory situated at the Department of Climate Change and Agricultural Meteorology, Punjab Agricultural University, Ludhiana during *spring* season of 2018 and 2019 are given in Fig. 3.1 and 3.2 and Appendices I and II. The weekly mean temperature recorded during the crop season from the second week of March *i.e.* 11^{th} SMW (12-18 March) 2018 to first week of July *i.e.* 27^{th} SMW (02-08 July) 2018 ranged between 22˚C in 11^{th} SMW (12-18 March) to 29.9˚C in 27^{th} SMW (02-08 July) and the corresponding values for the year 2019 were 17.7˚C and 33.1˚C respectively. Weekly maximum and minimum temperatures during the *spring* season of 2018 ranged from 29.2 to 42.1˚C and 14.1 to 27.9˚C respectively, whereas during *spring* season of 2019, it ranged from 24.6 to 43˚C and 10.7-28.5˚C respectively. The weekly mean relative humidity ranged from 21-73% and 29-68% during the cropping seasons of 2018 and 2019, respectively. Total rainfall of 223.6 mm was recorded during the crop season of 2018, whereas the corresponding value for the *spring* season of 2019 was 105.9 mm. Evaporation during the corresponding period was 868.3 mm in the year 2018 and 832.1 mm in the year 2019. Total sunshine hours recorded during *spring* season of 2018 and 2019 were 134.9 and 156.1 hours, respectively during the cropping season.

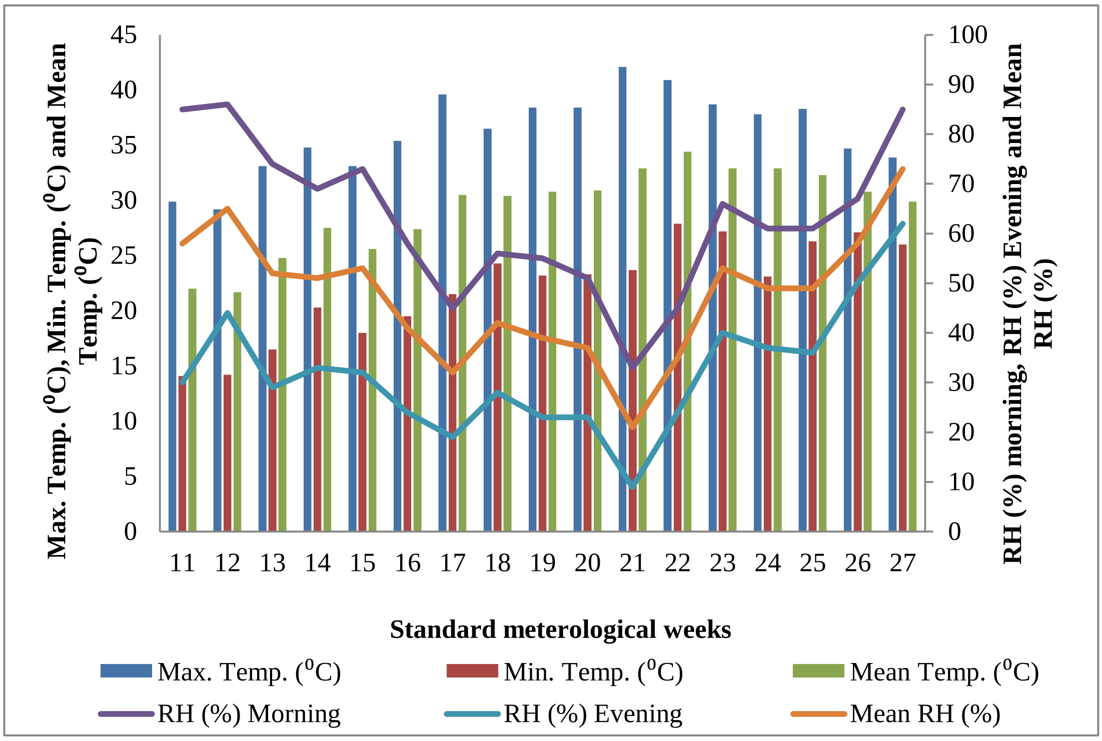

Fig. 3.1: Weekly weather (Temperature and relative humidity) during crop growing season 2018

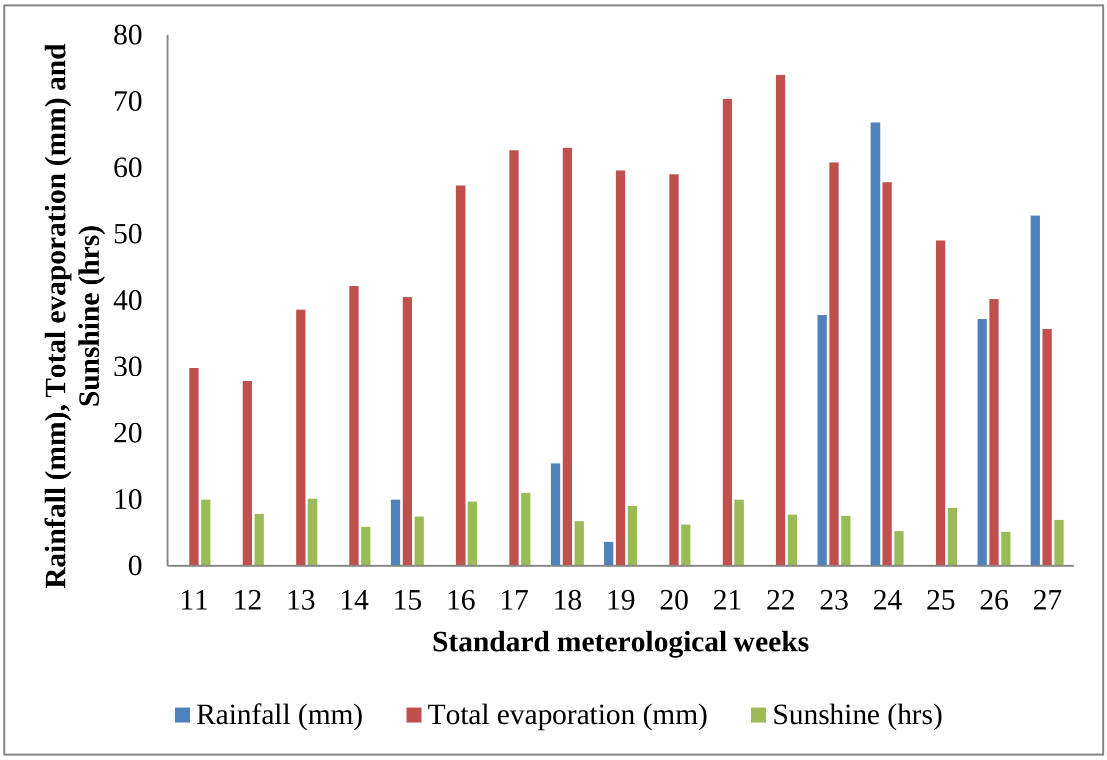

Fig. 3.2: Weekly weather (Rainfall, evaporation and sunshine hours) during crop growing season 2018

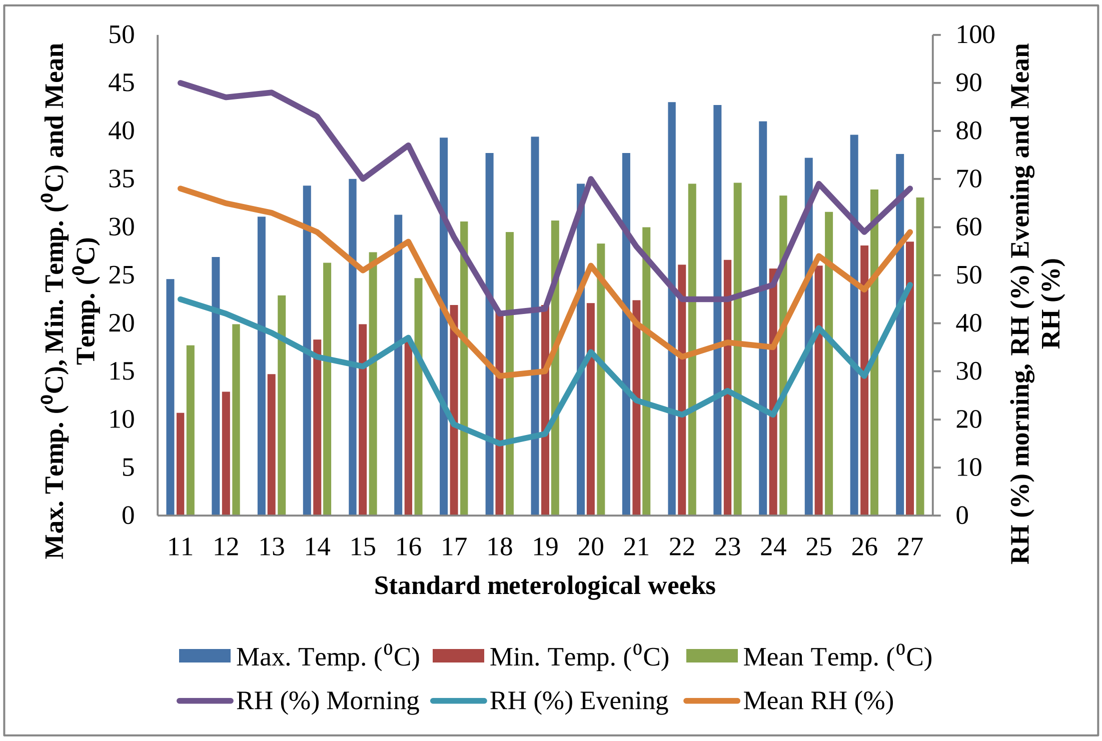

Fig. 3.3: Weekly weather (Temperature and relative humidity) during crop growing season 2019

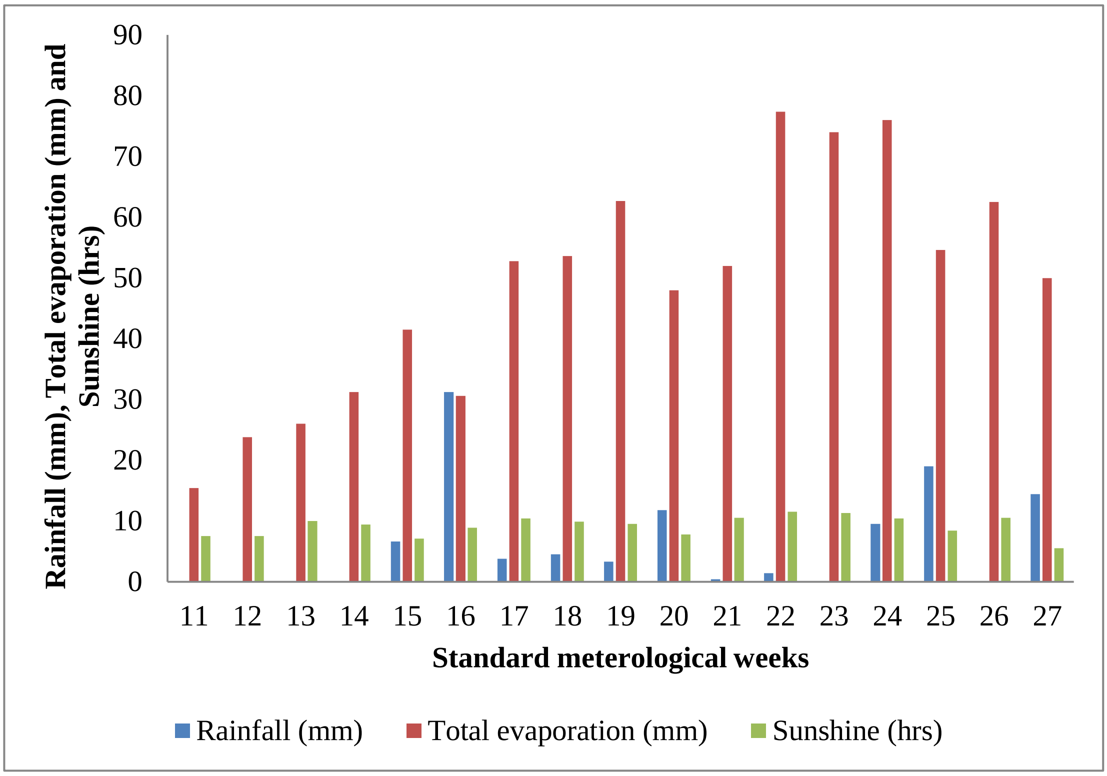

Fig. 3.4: Weekly weather (Rainfall, evaporation and sunshine hours) during crop growing season 2019

3.3 Soil characteristics

Soil samples from four randomly selected spots were collected from 0-15 cm depth and then two composite samples were prepared before initiating the experiment. The samples were air dried, ground and sieved through 2 mm sieve. The sieved samples were subjected to physical and chemical analysis to determine the soil properties. The physico-chemical characteristics of the soil are given in the table 3.1 below:

Table 3.1: Physico-chemical characteristics of the soil

Parameter	Year		Rating	Analytical method employed
	2018	2019		
pH	8.16	8.18	Normal	Blackman's glass electrode pH meter in 1:2 soil-water suspension (Jackson 1967)
EC (dS m^{-1})	0.57	0.58	Normal	In 1:2 soil-water suspension with solubridge conductivity meter (Jackson 1967)
OC (%)	0.32	0.34	Low	Rapid titration method (Walkley and Black 1934)
Available N (kg ha^{-1})	151.6	160.5	Low	Modified alkaline potassium permanganate method (Subbiah and Asija 1956)
Available P (kg ha^{-1})	15.75	16.82	Medium	0.5N sodium bicarbonate extractable P (Olsen et al 1954)
Available K (kg ha^{-1})	321.4	325.5	Medium	1N ammonium acetate extractable K (Piper 1966)
Available Ca (ppm)	112.22	115.84	Low	Versenate method (Cheng and Bray 1951)
Available S (kg ha^{-1})	24	25.5	Medium	Turbidimetric method (Chesnin and Yien 1951)

Chemical analysis of soil sample revealed that the soil of experimental field was normal in pH and electrical conductivity. The organic carbon, available nitrogen and available calcium were low while available phosphorus, available potassium and available sulphur were medium in the soil of experimental site.

Table 3.2: Textural composition of the soil

Soil depth (cm)	Sand (%)	Silt (%)	Clay (%)	Textural class
0-15	81.9	5.9	12.2	Loamy sand
15-30	80.8	7.2	12.0	Loamy sand

3.4 Cropping history of field

Cropping history of the experimental field in all the three cropping seasons is given below:

Table 3.3: Cropping history of field

Years	**Season of crop**		
	Kharif	***Rabi***	***Zaid***
2015-16	Arhar	Wheat	Fallow
2016-17	Arhar	Wheat	Fallow
2017-18	Fallow	Fallow	Groundnut
2018-19	Fallow	Fallow	Groundnut

3.5 Experimental detail

I. Name of the experiment: Effect of nitrogen, phosphorus and gypsum on growth, yield and quality of spring groundnut (*Arachis hypogaea* L.).

II. Location/place of work: Students' Research Farm, Department of Agronomy, Punjab Agricultural University, Ludhiana.

Treatments:

Main Plots –

(A) Gypsum levels: (04)

1. G_1: Control (0 kg ha^{-1})
2. G_2: 125 kg ha^{-1}
3. G_3: 175 kg ha^{-1}
4. G_4: 225 kg ha^{-1}

(B) Gypsum application stage: (02)

1. S_1: Full at sowing
2. S_2: 50% at sowing + 50% at flower initiation stage

Sub Plots- Nitrogen and phosphorus levels: (03)

1. N_1: 15 kg N ha^{-1} + 20 kg P_2O_5 ha^{-1}
2. N_2: 25 kg N ha^{-1} + 30 kg P_2O_5 ha^{-1}
3. N_3: 35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1}

Experimental design **:** Split-plot

Variety **:**TG37A

Number of replications **:** 3

Number of plots **: 72**

The experiment was laid out in a split plot design (Fig. 3.5) replicated three times with four gypsum levels, namely 0, 125, 175 and 225 kg ha^{-1} gypsum in combination with two stages of gypsum application (Full at sowing and 50% at sowing + 50% at flower initiation stage) in the main plot and three levels of nitrogen and phosphorus in the sub-plot. Sowing was done on 14 March in both the years and harvesting was done during last week of June.

A uniform dose of 25 kg K_2O ha^{-1} was applied in all the treatments and irrigations were applied as and when required by the crop. The gross plot size and net plot size used in the experiment were 6 m × 2.4 m and 6 m × 1.8 m, respectively.

3.6 Cultural operations

3.6.1 Field preparation

The experiment field was prepared by using cultivator one time followed by harrowing twice. This was followed by planking. Finally, the layout of the field was prepared by making the required plots and the irrigation channels.

3.6.2 Fertilizer application

Recommended dose of potassium (25 kg K_2O ha^{-1}) in the form of 42 kg muriate of potash was applied uniformly in all the plots just before the sowing of the crop. The application of nitrogen, phosphorus and gypsum was done as per the treatments of the experiment. DAP (Diammonium phosphate) was used as the source of phosphorus and nitrogen. The remaining amount of nitrogen was applied through urea.

3.6.3 Seed rate, sowing and spacing

The healthy and well-developed pods were hand-shelled. After this, the seeds (kernels) of groundnut variety TG37A were treated with Indofil M-45 at the rate of 3g per kg of kernels. The treated seeds were sown at 30 cm × 15 cm spacing. The recommended seed rate of 80 kg kernels ha^{-1} was used. The sowing was done on 14 March during 2018 and 2019 in the spring season.

3.6.4 Hoeing and weeding

Two manual hoeings were done at 3 and 6 weeks after sowing to control the weeds during both the years.

3.6.5 Thinning and gap filling

Thinning as well as gap filling was done after emergence and establishment of plants at 15 days after sowing to maintain the recommended plant population.

3.6.6 Irrigation

Four irrigations were applied to the crop during the crop season depending on the need of the crop. Last irrigation was given a few days before harvesting to facilitate the easy recovery of pods from the soil.

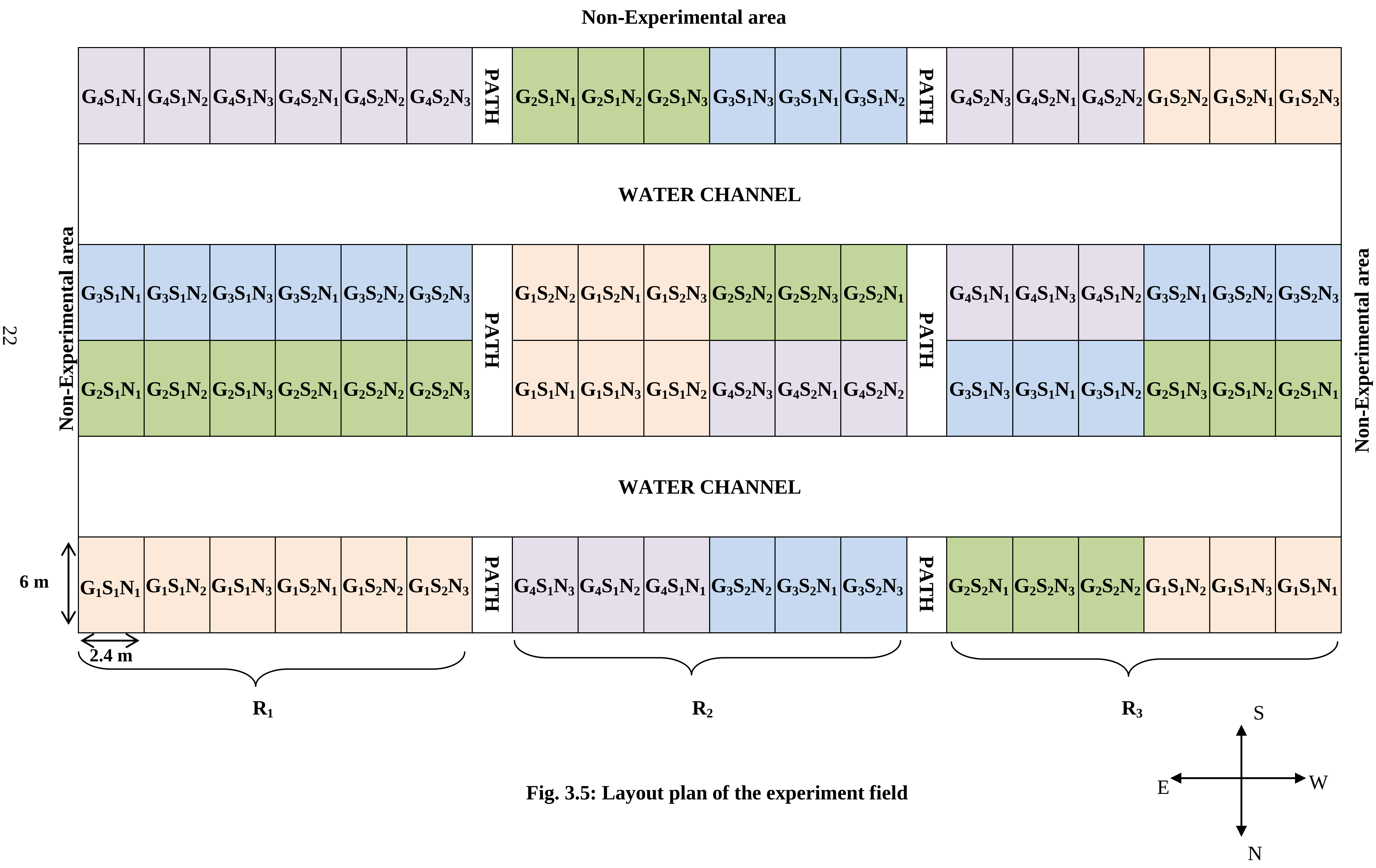

Fig. 3.5: Layout plan of the experiment field

3.6.7 Plant protection measures

The menace of collar-rot was controlled by spraying the crop with Bavistin 50 WP @ 125-150 g in 250 litres of water per hectare at 40 days after sowing.

3.6.8 Harvesting and threshing

The crop was harvested at maturity on 29th and 30th June during 2018 and 2019. Two border rows, one from each side of the plot were harvested as non-experimental area. After this, the net plot area was harvested and crop was left for curing in the field for 2 days. Then the pods were separated from the plants manually and the yield data was recorded.

3.7 Observations recorded

3.7.1 Growth parameters

3.7.1.1 Emergence count

The number of plants per metre row length were counted at 8, 10, 12 and 14 days after sowing (DAS) from two spots in the inner rows of the plot and this was represented as emergence count.

3.7.1.2 Plant height

Randomly, five plants were tagged in each plot. The plant height was measured from the base of the plant (soil level) to the last unopened leaf on the main stem of tagged plants at 30, 60 and 90 DAS and at harvest. Average value was computed for each plot by averaging the data of five plants.

3.7.1.3 Number of branches plant^{-1}

The branches emerging from the main shoot were counted from the five tagged plants in each plot at 30, 60 and 90 DAS and at harvest. The mean of the data of five plants gave average value for the plot.

3.7.1.4 Dry matter accumulation

One plant was cut at ground level randomly from each plot at 30, 60 and 90 DAS and at harvest. The above ground biomass was first air dried in the sun and then oven dried at 60-65˚C for 48 hours until a constant weight was achieved. Samples were then weighed on electronic balance and dry matter accumulation was expressed in g per plant.

3.7.2 Phenology

3.7.2.1 Days to 50% flowering

Number of days taken for 50% flowering in the net plot area were recorded and expressed as days taken to 50% flowering.

3.7.2.2 Days to 50% pegging

Number of days taken for 50% pegging in the net plot area were recorded and expressed as days taken to 50% pegging.

3.7.2.3 Total number of flowers plant^{-1}

Randomly, five plants were selected from each plot and the total numbers of flowers produced per plant were recorded every day at 8:30 A.M. from the 30th day onwards after sowing. The flower count was recorded up to 70th day from the date of sowing. Average of five plants was computed to get the total number of flowers plant^{-1}.

3.7.2.4 Total number of pegs plant^{-1}

At harvest, five tagged plants were uprooted from each plot and the pegs were counted. Their average was worked out to get the number of pegs plant^{-1}.

3.7.3 Yield attributes and yield

3.7.3.1 Total number of pods plant^{-1}

After harvesting of the crop, five tagged plants from each plot were selected and the numbers of pods per plant were counted and their average was computed to get number of pods plant^{-1}.

3.7.3.2 100-kernel weight

The kernels obtained after the shelling of pods were mixed thoroughly and 100 kernels were counted and selected from the yield of each net plot and their weight was recorded to give 100-kernel weight.

3.7.3.3 Shelling percentage

A representative 200 g sample of dry pods from the produce of each net plot was taken and shelled out manually. After that kernel weight was recorded. The following formula was used to calculate the shelling percentage:

$$\text{Shelling percentage (\%)} = \frac{\text{Weight of Kernels (g)}}{\text{Dry weight of pods (g)}} \times 100$$

3.7.3.4 Sound Mature Kernels (%)

After the shelling of the pods, a representative sample of 100g kernels was taken from each plot. The well-developed and the shrivelled kernels from this sample were separated and the sound mature kernels (SMK) percentage was computed using the formula given as follows:

$$\text{SMK (\%)} = \frac{\text{Number of well-developed kernels}}{\text{Total number of kernels}} \times 100$$

3.7.3.5 Pod yield

Pods obtained from each net plot were weighed separately after threshing, winnowing and cleaning and recorded as pod yield (q ha^{-1}).

3.7.3.6 Haulm yield

After sun drying for a period of about one week, the weight of the above ground part of the plant from each net plot was recorded and given as haulm yield in q ha^{-1}.

3.7.3.7 Kernel yield

The kernel yield of each plot was obtained by multiplying the pod yield of each plot with their respective shelling percentage and dividing it by 100. The formula is as follows:

$$\text{Kernel yield} = \frac{\text{Pod yield} \times \text{shelling percentage}}{100}$$

3.7.3.8 Harvest index

The harvest index (HI) was calculated by dividing the economic yield (pod yield) by the biological yield (pod yield + haulm yield) and multiplying by 100 by using the following formula (Singh and Stoskopf 1971):

$$\text{HI} = \frac{\text{Economic yield (q ha}^{-1})}{\text{Biological yield (q ha}^{-1})} \times 100$$

3.7.4 Economics

3.7.4.1 Cost of cultivation (₹ ha^{-1})

The cost of cultivation for different treatments was calculated on the basis of enterprise budget of groundnut crop for the year 2018 and 2019 as given in Appendix III.

3.7.4.2 Gross returns (₹ ha^{-1})

The gross returns in terms of rupees per hectare was computed by multiplying the groundnut pod and haulm yield of each treatment with the prevailing market price of the pods and the haulm.

3.7.4.3 Net returns (₹ ha^{-1})

The total cost of cultivation of each treatment was subtracted from gross returns to give the net returns for each treatment.

3.7.4.4 Benefit cost ratio (BCR)

The benefit cost ratio was calculated by using the following formula:

$$\text{BCR} = \frac{\text{Gross returns (₹ ha}^{-1})}{\text{Total cost of cultivation (₹ ha}^{-1})}$$

3.7.5 Quality characteristics

3.7.5.1 Protein content in kernels

Nitrogen content in kernel was determined by Kjeldahl's method (Jackson 1967) and protein content was calculated by multiplying N content with the factor 6.25.

3.7.5.2 Oil content in kernels

Oil content was determined by using standardised Nuclear Magnetic Resonance (NMR) instrument and oil percentage was recorded on weight basis.

3.7.6 Plant Analysis

3.7.6.1 Sampling and preparation of plant samples

The samples of the groundnut plant (haulm and kernel) were collected at harvest, dried in sun and then oven-dried at 60º C for 24 hours. The samples were grounded and then the samples were analysed for total nitrogen, phosphorous, potassium, calcium and sulphur.

3.7.6.2 Nitrogen estimation

For the determination of total nitrogen in haulm and kernel samples, 0.5 gram grounded plant samples (haulm and kernel) were digested in 10 ml of concentrated sulphuric acid (H_2SO_4) to which, a pinch of digestion mixture (Mixture of potassium sulphate, copper sulphate, selenium powder and mercuric oxide) was added. All these contents were put in a digestion tube, which was kept for overnight, then heating was started on next day in Kjeldahl's digestion unit from low (75°C) to high temperature up to 400°C to get colourless extract. After that, digested material was used to make volume 50 ml in volumetric flask using distilled water. Nitrogen per cent in haulm and kernel sample was estimated by using Kjeldahl's distillation method (Jackson 1967).

3.7.6.3 Estimation of phosphorus

The phosphorus content in haulm and kernel samples was estimated by Vanadomolybdo- phosphoric yellow colour method in HNO_3 as suggested by Jackson (1967). 0.5 gram of sample (haulm and kernel) was digested in triple acid mixture of HNO_3: $HClO_4$: H_2SO_4 in the ratio of 9:3:1. Ammonium molybdate and ammonium vandate solution was used to develop colour and resultant intensity of yellow colour was taken at 470 nm in Elico spectrophotometer model CL24 (1973).

3.7.6.4 Estimation of potassium

Potassium concentration in plant acid extract was determined by using the Flame Photometer method. Reading was taken in Elico Flame photometer, model C-140 after digesting the samples with diacid mixture as suggested by Jackson (1967).

3.7.6.5 Estimation of calcium

Calcium concentration in haulm and kernel samples was estimated by versenate titration with 0.01 N EDTA solution using purpurate indicator after digesting the samples with diacid mixture (Cheng and Bray 1951).

3.7.6.6 Estimation of sulphur

Sulphur concentration in haulm and kernel samples was estimated by turbidometric method by using a known aliquot of the plant extract obtained by digesting the samples with diacid mixture. Barium chloride and gum acacia were added to the extract which leads to development of turbidity. The intensity of turbidity was determined using colorimeter 34 at 420 nm, as given by Chesnin and Yien (1951).

3.7.6.7 Total nutrient uptake (at harvest)

The total uptake of nitrogen, phosphorus, potassium, calcium and sulphur was computed from N, P, K, Ca and S concentration in kernel and haulm at harvest using following relationship:

$$\text{Total N uptake (kg ha}^{-1}) = \frac{\left(\begin{matrix}\text{N conc. in}\\ \text{kernel (\%)}\end{matrix} \times \begin{matrix}\text{Kernel yield}\\ \text{(kg ha}^{-1})\end{matrix}\right) + \left(\begin{matrix}\text{N conc. in}\\ \text{haulm (\%)}\end{matrix} \times \begin{matrix}\text{Haulm yield}\\ \text{(kg ha}^{-1})\end{matrix}\right)}{100}$$

$$\text{Total P uptake (kg ha}^{-1}) = \frac{\left(\begin{matrix}\text{P conc. in}\\ \text{kernel (\%)}\end{matrix} \times \begin{matrix}\text{Kernel yield}\\ \text{(kg ha}^{-1})\end{matrix}\right) + \left(\begin{matrix}\text{P conc. in}\\ \text{haulm (\%)}\end{matrix} \times \begin{matrix}\text{Haulm yield}\\ \text{(kg ha}^{-1})\end{matrix}\right)}{100}$$

$$\text{Total K uptake (kg ha}^{-1}) = \frac{\left(\begin{matrix}\text{K conc. in}\\ \text{kernel (\%)}\end{matrix} \times \begin{matrix}\text{Kernel yield}\\ \text{(kg ha}^{-1})\end{matrix}\right) + \left(\begin{matrix}\text{K conc. in}\\ \text{haulm (\%)}\end{matrix} \times \begin{matrix}\text{Haulm yield}\\ \text{(kg ha}^{-1})\end{matrix}\right)}{100}$$

$$\text{Total Ca uptake (kg ha}^{-1}) = \frac{\left(\begin{matrix}\text{Ca conc. in}\\ \text{kernel (\%)}\end{matrix} \times \begin{matrix}\text{Kernel yield}\\ \text{(kg ha}^{-1})\end{matrix}\right) + \left(\begin{matrix}\text{Ca conc. in}\\ \text{haulm (\%)}\end{matrix} \times \begin{matrix}\text{Haulm yield}\\ \text{(kg ha}^{-1})\end{matrix}\right)}{100}$$

$$\text{Total S uptake (kg ha}^{-1}) = \frac{\left(\begin{matrix}\text{S conc. in}\\ \text{kernel (\%)}\end{matrix} \times \begin{matrix}\text{Kernel yield}\\ \text{(kg ha}^{-1})\end{matrix}\right) + \left(\begin{matrix}\text{S conc. in}\\ \text{haulm (\%)}\end{matrix} \times \begin{matrix}\text{Haulm yield}\\ \text{(kg ha}^{-1})\end{matrix}\right)}{100}$$

3.7.7 Soil analysis

3.7.7.1 Soil pH

The soil pH was determined in 1:2 soil-water suspension using an Elico-glass electrode pH meter (Jackson 1967).

3.7.7.2 Electrical conductivity

Electrical conductivity of the soil samples was determined in 1:2 soil-water suspension equilibrated for 24 hour using a conductivity bridge (Jackson 1967).

3.7.7.3 Organic carbon

The organic carbon was determined by rapid titration method as detailed by Walkley and Black (1934).

3.7.7.4 Available nitrogen

The available nitrogen of soil was estimated by Alkaline Potassium Permanganate Method given by Subbiah and Asija method (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 a standard alkali by using methyl red indicator. From the volume of standard acid used for absorption of ammonia, the amount of nitrogen present in the soil sample was calculated.

3.7.7.5 Available phosphorus

Available phosphorus in the soil sample was estimated by 0.5 N $NaHCO_3$ method suggested by Olsen *et al* (1954). Soil was shaken with bicarbonate extractant for half an hour with the help of an 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 color. The intensity of the blue color was measured with a colorimeter at a wavelength of 760 mμ using red filter. From the standard curve, the amount of phosphorus present in the soil was calculated.

3.7.7.6 Available potassium

The available potassium of the soil was determined by the method given by Piper (1966). 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.

3.7.7.7 Available calcium

Available calcium in soil was estimated by versenate titration with 0.01 N EDTA solution using purpurate indicator. 50 gram of soil was taken in a 250 ml conical flask and was shaken on an electric shaker for one hour after adding 100 ml of distilled water. The solution was allowed to settle for overnight. When the soil has settled down, the supernatant solution was collected and centrifuged at 4500 RPM for 30 minutes. The filtered extract was titrated with 0.01 N EDTA solution using purpurate indicator after adding carbamate crystals (Cheng and Bray 1951).

3.7.7.8 Available sulphur

The available sulphur of the soil was determined by turbidimetric method given by Chesnin and Yien (1951). The soil was shaken with calcium chloride ($CaCl_2$) extractant for half an hour with the help of electric shaker at 2500 RPM. The clear filtrate was titrated with barium chloride in the presence of gum acacia solution. The turbidity that produced due to precipitation of sulphate as barium sulphate is measured with colorimeter, using a blue filter at a wavelength of 420 mμ. The available sulphur in the soil was calculated by plotting the concentration against transmittance on the graph paper.

3.8 Statistical analysis

The data collected on various growths, yield attributes, yield and quality parameters were statistically analyzed by using CPCS1, software developed by Department of Statistics, Punjab Agricultural University, Ludhiana based on the procedure of Cochran and Cox (1967) and adapted by Cheema and Singh (1991). All comparisons were made at 5 per cent level of significance. The degrees of freedom for split plot design are given below:

Table 3.4: Analysis of variance

Source of variation	Degree of freedom
Replications	2
Gypsum levels (a)	3
Gypsum application stage (b)	1
Gypsum levels (a) × Gypsum application stage (b)	3
Error (a)	14
Nitrogen and phosphorus levels (c)	2
Gypsum levels (a) × Nitrogen and phosphorus levels (c)	6
Gypsum application stage (b) × Nitrogen and phosphorus levels (c)	2
Gypsum levels (a) × Gypsum application stage (b) × Nitrogen and phosphorus levels (c)	6
Error (b)	32
Total	71

CHAPTER IV

RESULTS AND DISCUSSION

The field experiment entitled **"Effect of nitrogen, phosphorus and gypsum on growth, yield and quality of spring groundnut (*Arachis hypogaea* L.)"**, was carried out at the Students' Research Farm, Department of Agronomy, Punjab Agricultural University, Ludhiana during spring season of 2018 and 2019. The data recorded on various parameters of groundnut are presented and discussed under the following headings:

4.1 Growth parameters

4.2 Phenology

4.3 Yield attributes and yield at harvest

4.4 Economics

4.5 Quality characteristics

4.6 Plant analysis

4.7 Soil analysis

4.1 Growth parameters

4.1.1 Emergence count

Crop emergence is an essential pre-requisite for obtaining a good yield. In order to assess the effect of different treatments particularly gypsum levels, gypsum application stages and nitrogen and phosphorus levels, plant count was recorded periodically at 8, 10, 12 and 14 days after sowing (DAS). No emergence took place up to 8 days after sowing. A perusal of data on plant emergence per meter row length presented in table 4.1 indicated that different gypsum levels and gypsum application stages influenced the plant emergence non-significantly. The emergence count tended to increase with increase in the level of gypsum though the differences were non-significant.

Data presented in the same table also revealed that different levels of nitrogen and phosphorus resulted in non-significant effect on the emergence of groundnut. However, higher plant emergence was observed at 10, 12 and 14 DAS during both the years with the application of 35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1} over other levels of nitrogen and phosphorus though the differences were non-significant among the different levels of nitrogen and phosphorus. Similar results were reported by Tillman *et al* (2009) who observed that seed germination is not affected by basal fertilizer application.

Table 4.1: Emergence count of spring groundnut as influenced by gypsum levels, gypsum application stage and nitrogen and phosphorus levels

Treatments	Emergence count (plants m^{-1} row length)					
	2018			2019		
	10 DAS	12 DAS	14 DAS	10 DAS	12 DAS	14 DAS
Gypsum levels						
Control	1.50	3.25	4.97	1.86	3.75	5.86
125 kg ha^{-1}	1.53	3.28	5.03	1.92	3.89	5.92
175 kg ha^{-1}	1.53	3.31	5.14	2.00	3.97	5.94
225 kg ha^{-1}	1.69	3.31	5.19	2.03	4.14	6.28
CD (p=0.05)	NS	NS	NS	NS	NS	NS
Gypsum application stage						
Full at sowing	1.60	3.29	5.11	1.99	3.90	5.97
50% at sowing + 50% at flower initiation stage	1.53	3.28	5.06	1.92	3.97	6.03
CD (p=0.05)	NS	NS	NS	NS	NS	NS
Nitrogen and phosphorus levels						
15 kg N ha^{-1} + 20 kg P_2O_5 ha^{-1}	1.50	3.19	5.04	1.90	3.85	5.92
25 kg N ha^{-1} + 30 kg P_2O_5 ha^{-1}	1.56	3.33	5.06	1.96	3.90	5.94
35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1}	1.63	3.33	5.15	2.00	4.06	6.15
CD (p=0.05)	NS	NS	NS	NS	NS	NS
Interaction	NS	NS	NS	NS	NS	NS

4.1.2 Plant height

Plant height has been a reliable index of growth and metabolic activities of the crop plants. It is a measurement often used to monitor the effect of different treatments on crop growth. The data on periodic plant height recorded at 30, 60, 90 days after sowing (DAS) and at harvest stage are presented in table 4.2 and depicted in figure 4.1 and 4.2. It was observed that there was a progressive increase in the plant height from the sowing to the harvest of the crop.

Different levels of gypsum exerted significant influence on the plant height of spring groundnut in both the years. In the year 2018, maximum plant height of 4.54 cm (at 30 DAS), 27.17 cm (at 60 DAS), 44.37 cm (at 90 DAS) and 51.8 cm (at harvest) was obtained with the application of 225 kg ha^{-1} gypsum, which was statistically at par with 175 kg ha^{-1} gypsum while significantly higher than 125 kg ha^{-1} gypsum and control. Similarly, in the year 2019, application of 225 kg ha^{-1} gypsum resulted in highest plant height of 6.59 cm, 25.94 cm, 46.53 cm and 56.91 cm at 30 DAS, 60 DAS, 90 DAS and at harvest respectively, which was at par with 175 kg ha^{-1} gypsum while significantly higher than 125 kg ha^{-1} gypsum as well as control. Adhikari *et al* (2003) and Mandal *et al* (2005) also reported similar results. Yadav *et al* (2015) also supported the findings of the current study and reported that the application of 200 kg ha^{-1} of gypsum resulted in significantly higher plant height over control at 60 and 90 DAS. Similarly, Singh (2007) and Rao *et al* (2013) reported that the plant height was significantly increased with an increase in the level of gypsum up to 240 kg ha^{-1}. This increase in plant

Table 4.2: Plant height of spring groundnut as influenced by gypsum levels, gypsum application stage and nitrogen and phosphorus levels

Treatments	Plant height (cm)							
	2018				2019			
	30 DAS	60 DAS	90 DAS	At harvest	30 DAS	60 DAS	90 DAS	At harvest
Gypsum levels								
Control	3.48	23.50	38.64	45.59	5.01	22.95	40.07	50.86
125 kg ha^{-1}	4.07	25.40	41.76	48.88	5.87	24.52	43.30	54.01
175 kg ha^{-1}	4.31	26.37	43.37	50.43	6.27	25.06	45.00	55.70
225 kg ha^{-1}	4.54	27.17	44.37	51.80	6.59	25.94	46.53	56.91
CD (p=0.05)	0.44	1.74	2.48	2.83	0.62	1.22	3.02	2.72
Gypsum application stage								
Full at sowing	4.43	24.74	41.15	48.10	6.31	23.96	42.03	53.17
50% at sowing + 50% at flower initiation stage	3.78	26.47	42.92	50.25	5.56	25.27	45.42	55.57
CD (p=0.05)	0.31	1.23	1.75	2.00	0.44	0.87	2.14	1.92
Nitrogen and phosphorus levels								
15 kg N ha^{-1} + 20 kg P_2O_5 ha^{-1}	3.70	24.29	41.24	48.00	5.33	23.90	42.26	52.53
25 kg N ha^{-1} + 30 kg P_2O_5 ha^{-1}	4.22	26.17	42.38	49.36	6.06	24.82	44.29	54.85
35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1}	4.39	26.37	42.49	50.17	6.41	25.13	44.63	55.73
CD (p=0.05)	0.22	0.71	0.99	0.95	0.49	0.48	1.66	1.02
Interaction	NS	NS	NS	NS	NS	NS	NS	NS

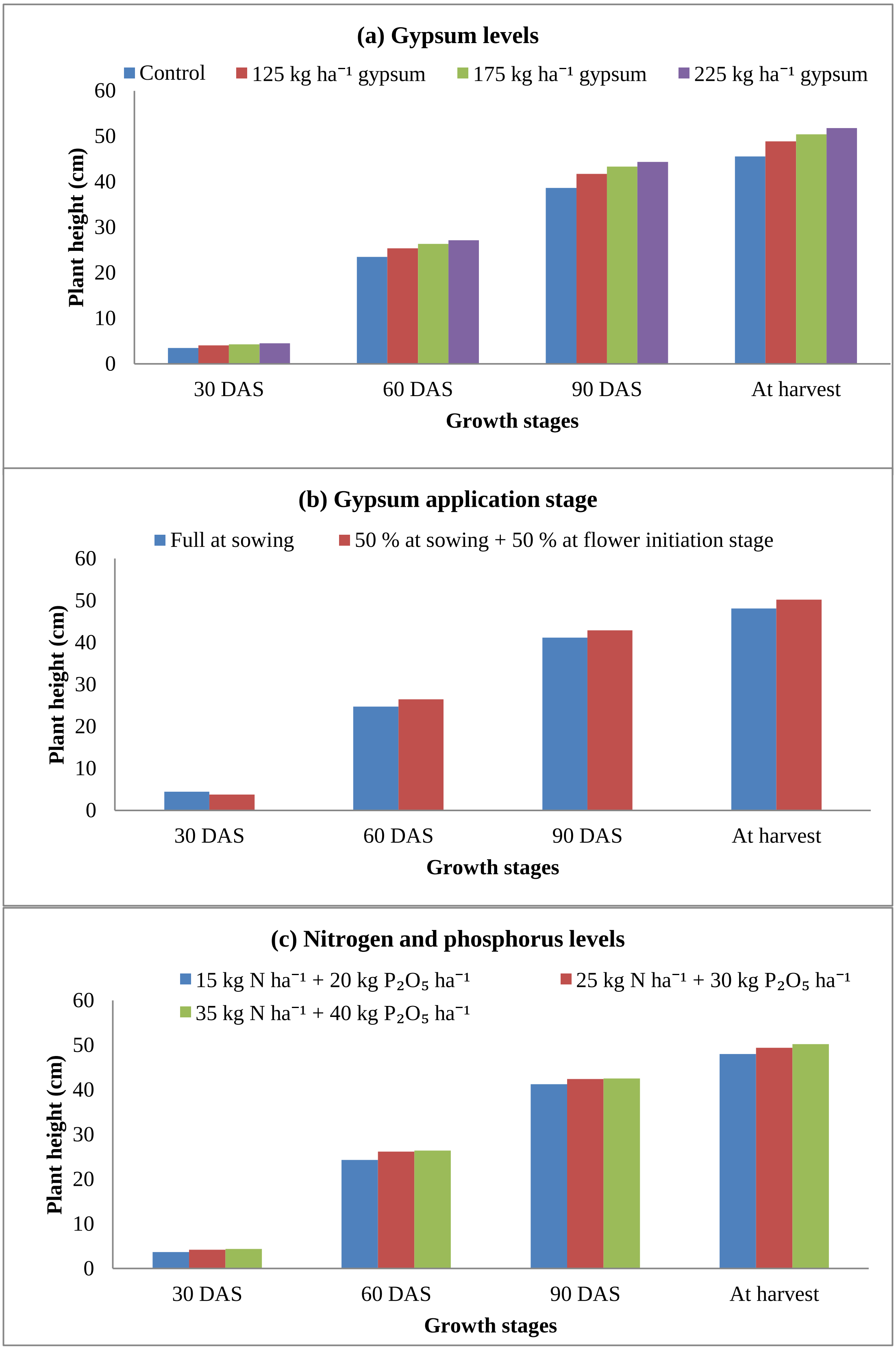

Fig. 4.1: Plant height of groundnut as influenced by (a) gypsum levels, (b) gypsum application stage and (c) nitrogen and phosphorus levels in 2018

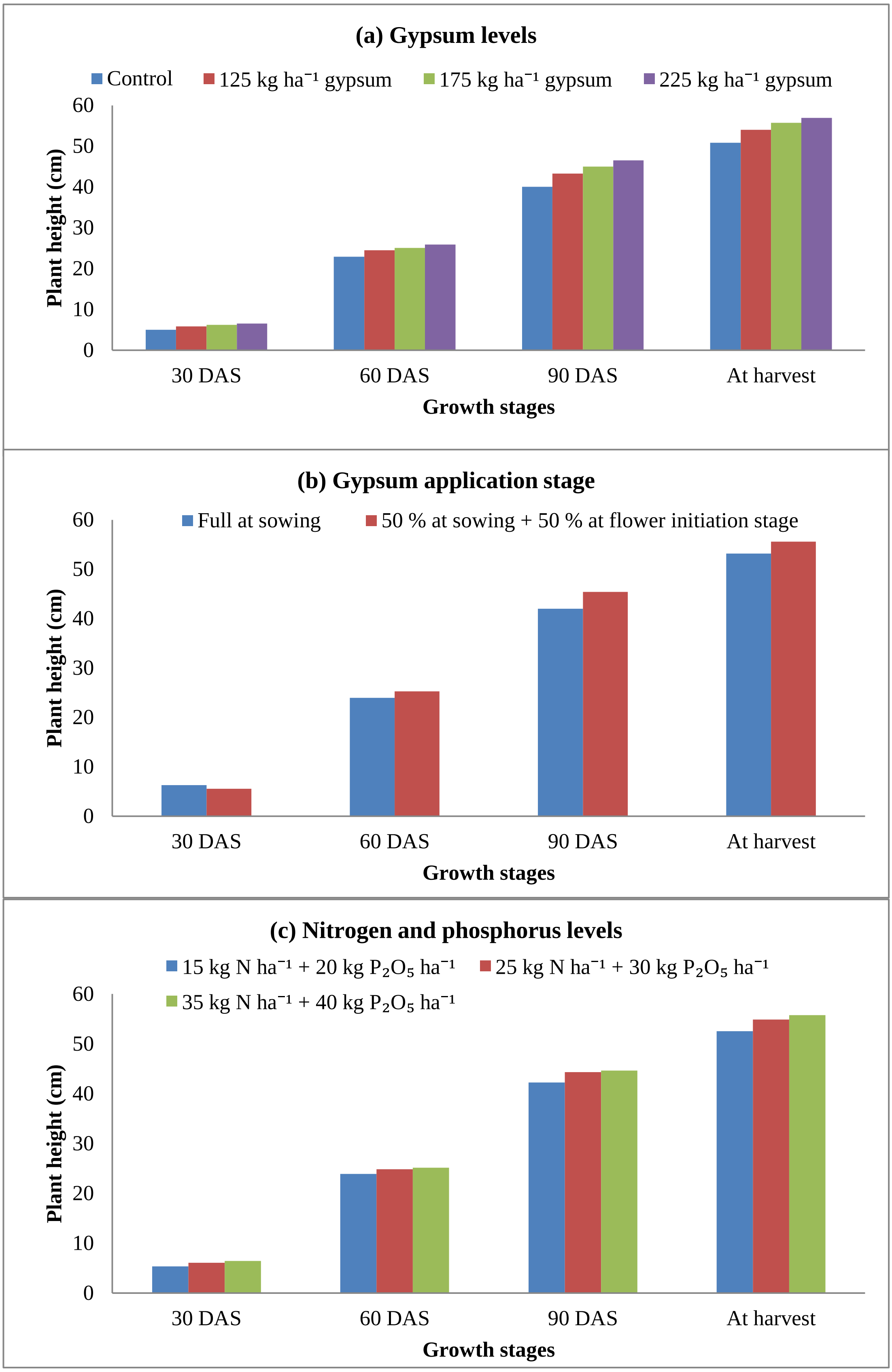

Fig. 4.2: Plant height of groundnut as influenced by (a) gypsum levels, (b) gypsum application stage and (c) nitrogen and phosphorus levels in 2019

height due to gypsum application might be due to better root formation, increased meristematic activities and apical growth due to sulphur (Kalaiyarasan *et al* 2003). Calcium through gypsum also improved plant height as it activates a number of enzymes for cell division and takes part in protein synthesis and carbohydrate transfer (Singh 2007).

Gypsum application stage also significantly influenced the plant height of groundnut at all the stages in both the years. Split application of gypsum (50% at sowing + 50% at flower initiation stage) resulted in significantly higher plant height of groundnut as compared to the application of full dose of gypsum at sowing at all the stages during both the years except at 30 DAS. It was due to the reason that the second split of gypsum was applied at flower initiation stage *i.e.* at 30 DAS, therefore, its effect could not show up in the data of plant height recorded at 30 DAS. The results are in accordance with the findings of Ghosh *et al* (2015) who observed that the plant height was significantly increased with the application of 100 kg gypsum ha^{-1} (50% basal + 50% top dressing) as compared to the basal application of gypsum. Split application of gypsum increases the availability of calcium and sulphur for longer period of crop growth, which results in more plant height at later stages due to better root formation, increased meristematic activities, apical growth as well as increased activity of enzymes for cell division.

Plant height was also significantly affected by different levels of nitrogen and phosphorus. Maximum plant height of 4.39 cm (30 DAS), 26.37 cm (60 DAS), 42.49 cm (90 DAS) and 50.17 cm (at harvest) in the year 2018 and 6.41 cm (30 DAS), 25.13 cm (60 DAS), 44.63 cm (90 DAS) and 55.73 cm (at harvest) in the year 2019 was observed with the application of 35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1} and it was statistically at par with 25 kg N ha^{-1} + 30 kg P_2O_5 ha^{-1}, while significantly higher than the use of 15 kg N ha^{-1} + 20 kg P_2O_5 ha^{-1}. Hasan and Sahid (2016) also confirmed the results of this study and reported that the application of phosphorus and nitrogen @ 82 kg P_2O_5 ha^{-1} and 27 kg N ha^{-1} resulted in improved plant height as compared to the lower levels of nitrogen and phosphorus. Gohari and Niyaki (2010) and Vijayakumar and Geethalakshmi (2018) also achieved parallel results and observed that 60-70 kg N ha^{-1} resulted in significantly higher plant height over lower nitrogen levels. Similarly, Kabir *et al* (2013) and Kamara *et al* (2011) observed that 40-50 kg P_2O_5 ha^{-1} resulted in significantly higher plant height over lower phosphorus levels. The increase in plant height due to higher doses of nitrogen might be due to the fact that, nitrogen increases transport of metabolites, photosynthates, cell division and expansion in plant, which enables the plant to have quick and better vegetative growth (Chandana and Dorajeerao 2014). Phosphorus also increased plant height due to the role of phosphorus in the development of more extensive root system.

4.1.2 Number of branches plant^{-1}

The number of branches is an important parameter which determines the haulm and kernel yield in the groundnut crop. Higher number of primary branches leads to higher number of pods which consequently increases the kernel yield. The data on number of branches plant^{-1} recorded at 30, 60, 90 DAS and at harvest stage are presented in table 4.3 and depicted in figure 4.3 and 4.4. It was observed that there was a regular increase in the number of branches from the sowing to the harvest stage of the crop in both the years.

Table 4.3: Number of branches plant^{-1} of spring groundnut as influenced by gypsum levels, gypsum application stage and nitrogen and phosphorus levels

Treatments	Number of branches plant^{-1}							
	2018				2019			
	30 DAS	60 DAS	90 DAS	At harvest	30 DAS	60 DAS	90 DAS	At harvest
Gypsum levels								
Control	4.89	8.92	10.06	11.98	3.64	6.64	7.70	9.13
125 kg ha^{-1}	5.70	9.95	11.32	13.05	4.34	7.47	8.63	10.11
175 kg ha^{-1}	5.86	10.16	11.63	13.17	4.64	7.82	9.10	10.32
225 kg ha^{-1}	5.98	10.58	11.79	13.58	4.89	7.99	9.80	10.78
CD (p=0.05)	0.59	0.91	0.88	0.93	0.20	0.78	0.86	0.79
Gypsum application stage								
Full at sowing	5.97	9.36	10.76	12.45	4.54	7.05	8.24	9.38
50% at sowing + 50% at flower initiation stage	5.24	10.45	11.64	13.44	4.22	7.91	9.38	10.80
CD (p=0.05)	0.42	0.64	0.62	0.66	0.14	0.55	0.61	0.56
Nitrogen and phosphorus levels								
15 kg N ha^{-1} + 20 kg P_2O_5 ha^{-1}	4.97	9.22	10.60	12.13	3.75	6.93	7.85	9.71
25 kg N ha^{-1} + 30 kg P_2O_5 ha^{-1}	5.83	10.20	11.41	13.26	4.55	7.62	9.03	10.16
35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1}	6.02	10.29	11.59	13.46	4.84	7.89	9.55	10.39
CD (p=0.05)	0.26	0.60	0.63	0.90	0.33	0.40	0.64	0.39
Interaction	NS	NS	NS	NS	NS	NS	NS	NS

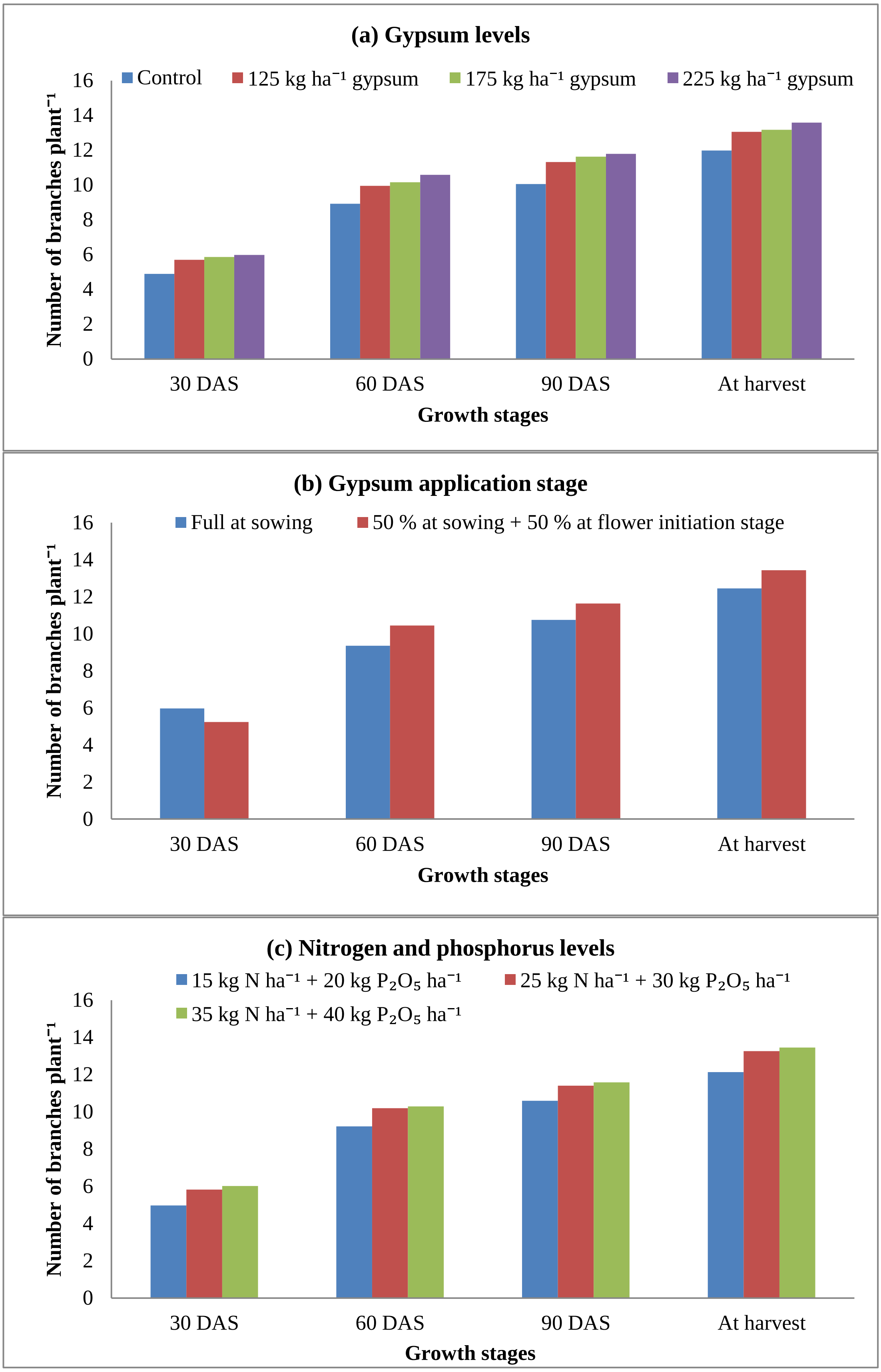

Fig. 4.3: Number of branches plant^{-1} of groundnut as influenced by (a) gypsum levels, (b) gypsum application stage and (c) nitrogen and phosphorus levels in 2018

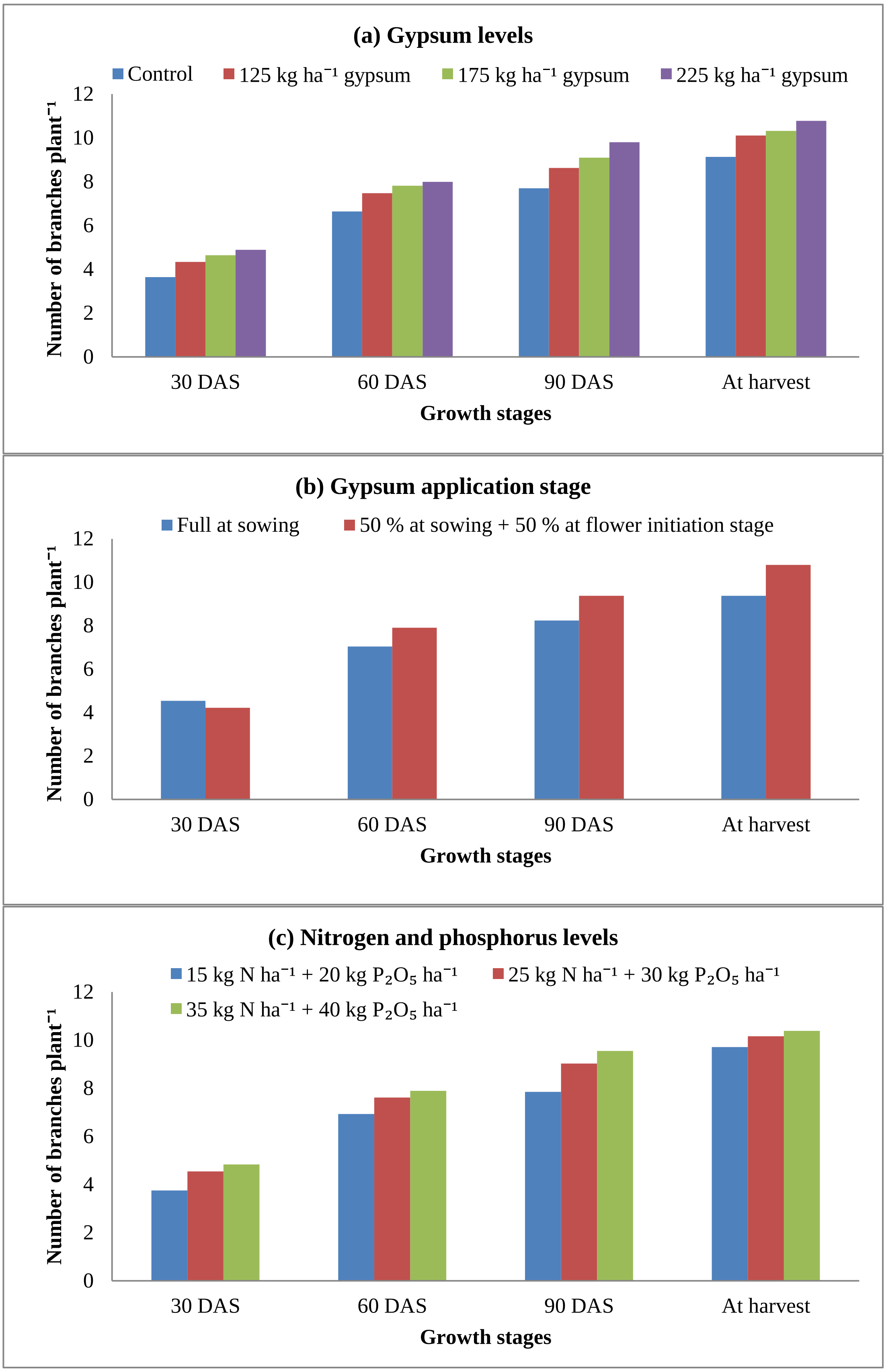

Fig. 4.4: Number of branches plant^{-1} of groundnut as influenced by (a) gypsum levels, (b) gypsum application stage and (c) nitrogen and phosphorus levels in 2019

Gypsum levels resulted in a significant difference in the number of branches at all the stages in both the years. In 2018, use of 225 kg ha^{-1} gypsum gave maximum number of branches (5.98, 10.58, 11.79 and 13.58 at 30, 60, 90 DAS and at harvest, respectively) which was at par with 175 kg ha^{-1} and 125 kg ha^{-1} gypsum while significantly higher over control. In 2019, application of 225 kg ha^{-1} gypsum gave highest number of branches, which were significantly higher than all other doses at 30 DAS, whereas at par with 175 kg ha^{-1} and 125 kg ha^{-1} gypsum at 60 DAS and at harvest. Yadav *et al (*2015) also reported that the number of branches $plant^{-1}$ were increased with the increase in gypsum dose. Thilakarathna *et al* (2014) also advocated that gypsum application @ 250 kg ha^{-1} improved number of branches $plant^{-1}$ as compared to no application of gypsum. Likewise, Singh (2007) reported that the number of branches $plant^{-1}$ were significantly increased with an increase in the level of gypsum upto 240 kg ha^{-1}. This increase in the number of branches due to gypsum application might be due to better root formation, increased meristematic activities and vegetative growth due to sulphur (Kalaiyarasan *et al* 2003). Calcium through gypsum also improved the number of branches as it activates a number of enzymes for cell division and takes part in protein synthesis and carbohydrate transfer (Singh 2007).

Stage of gypsum application also exerted a significant influence on the number of branches at all the growth stages in both the years. Split application of gypsum (50% at sowing + 50% at flower initiation stage) gave significantly greater number of branches over the application of full dose of gypsum at sowing during both the years at all stages except at 30 DAS. It was because second split of gypsum applied at 30 DAS could not show its effect on the data recorded at 30 DAS. So, at 30 DAS, full dose of gypsum at sowing gave significantly higher number of branches as compared to split application in both the years. Split application of gypsum increases the availability of calcium and sulphur for longer period of crop growth, which results in more number of branches at later stages due to better root formation, increased meristematic activities as well as increased activity of enzymes for cell division due to Ca and S application through gypsum.

Nitrogen and phosphorus levels also seem to affect the number of branches significantly at all stages during both the years. Application of 35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1} resulted in maximum number of branches at all the stages in both years which was statistically at par with 25 kg N ha^{-1} + 30 kg P_2O_5 ha^{-1} while significantly higher than 15 kg N ha^{-1} + 20 kg P_2O_5 ha^{-1}. Hasan and Sahid (2016) also reported that the application of phosphorus and nitrogen @ 82 kg P_2O_5 ha^{-1} and 27 kg N ha^{-1} increased the number of branches as compared to the lower levels of nitrogen and phosphorus. The results were also confirmed by Kabir *et al* (2013) who reported that 50 kg P_2O_5 ha^{-1} gave significantly higher number of branches $plant^{-1}$ as compared to lower doses. The increase in number of branches due to higher doses of nitrogen might be due to the fact that, nitrogen increases transport of metabolites, photosynthates, cell division and expansion in plant, which enables the plant to have quick and better vegetative growth (Chandana and Dorajeerao 2014). Phosphorus also increased the number of branches of groundnut due to the role of phosphorus in the development of more extensive root system.

4.1.3 Dry matter accumulation

Dry matter accumulation (DMA) is an important parameter having a clear influence on the yield of a crop. It is an important index to express the photosynthetic efficiency of the plant. The adequate accumulation of dry matter followed by adequate partitioning of assimilates to developing sinks enables the crop to attain its yield potential. Data of dry matter accumulation recorded at 30, 60, 90 DAS and at harvest are presented in table 4.4 and depicted in figure 4.5 and 4.6. Dry matter accumulation increased progressively with the advancement in the growth stage of the crop.

Effect of different gypsum levels on dry matter accumulation was observed to be significant at all the stages during 2018 as well as 2019. The use of 225 kg ha^{-1} gypsum resulted in maximum dry matter accumulation (g $plant^{-1}$) of 3.83 g (30 DAS), 18.49 g (60 DAS), 34.97 g (90 DAS) and 46.69 g (at harvest) in 2018 and 7.64 g (30 DAS), 16.32 g (60 DAS), 25.72 g (90 DAS) and 35.63 g (at harvest) during 2019, which was statistically at par with the application of 175 kg ha^{-1} gypsum while significantly higher than the other levels of gypsum. The findings of Ravikumar *et al* (1994) corroborate with the present study who observed that the application of 500 kg gypsum ha^{-1} increased the dry matter production by 7.3% as compared with the control. Similarly, Yadav *et al* (2017) reported that the progressive increase in the level of gypsum upto 324 kg ha^{-1} produced significantly higher amount of crop dry matter over the lower levels of gypsum. The higher level of gypsum resulted in more dry matter accumulation due to improved plant height and number of branches $plant^{-1}$ (Table 4.2 and 4.3).

The stage at which the gypsum was applied to the groundnut crop also exerted significant influence on the dry matter accumulation of plant at 30, 60, 90 DAS and at harvest during both the years. At 30 DAS, application of full dose of gypsum at sowing resulted in significantly highest dry matter accumulation of 3.64 g in 2018 and 7.30 g in 2019, which was significantly higher as compared to the split application of gypsum (50% at sowing + 50% at

Table 4.4: Dry matter accumulation of spring groundnut as influenced by gypsum levels, gypsum application stage and nitrogen and phosphorus levels

Treatments	Dry matter accumulation (g plant^{-1})							
	2018				2019			
	30 DAS	60 DAS	90 DAS	At harvest	30 DAS	60 DAS	90 DAS	At harvest
Gypsum levels								
Control	3.09	14.96	28.78	39.18	6.04	13.16	20.28	28.62
125 kg ha^{-1}	3.46	16.91	31.92	43.06	6.97	14.66	23.25	32.20
175 kg ha^{-1}	3.62	17.68	33.61	44.97	7.38	15.48	24.94	33.10
225 kg ha^{-1}	3.83	18.49	34.97	46.69	7.64	16.32	25.72	35.63
CD (p=0.05)	0.30	1.54	2.79	3.55	0.66	1.37	2.23	2.94
Gypsum application stage								
Full at sowing	3.64	16.41	30.73	42.20	7.30	14.11	22.11	31.18
50% at sowing + 50% at flower initiation stage	3.36	17.61	33.91	44.75	6.71	15.69	24.99	33.60
CD (p=0.05)	0.21	1.09	1.97	2.51	0.46	0.97	1.57	2.08
Nitrogen and phosphorus levels								
15 kg N ha^{-1} + 20 kg P_2O_5 ha^{-1}	3.26	15.39	27.50	41.07	6.15	13.91	20.84	30.16
25 kg N ha^{-1} + 30 kg P_2O_5 ha^{-1}	3.60	17.35	33.56	44.45	7.25	15.21	24.07	32.91
35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1}	3.64	18.29	35.90	44.90	7.62	15.59	25.73	34.09
CD (p=0.05)	0.28	1.18	2.62	3.05	0.54	0.94	2.29	1.75
Interaction	NS	NS	NS	NS	NS	NS	NS	NS

flower initiation stage). It was because the second half dose of gypsum in split application was applied at 30 DAS (at the time of flower initiation). At 60 DAS, 90 DAS and at harvest, split application of gypsum resulted in significantly higher dry matter accumulation as compared to application of full dose of gypsum at the time of sowing in both the years. With split application of gypsum, plant height and number of branches plant^{-1} were significantly increased, which led to higher dry matter accumulation as compared to application of full dose of gypsum at sowing.

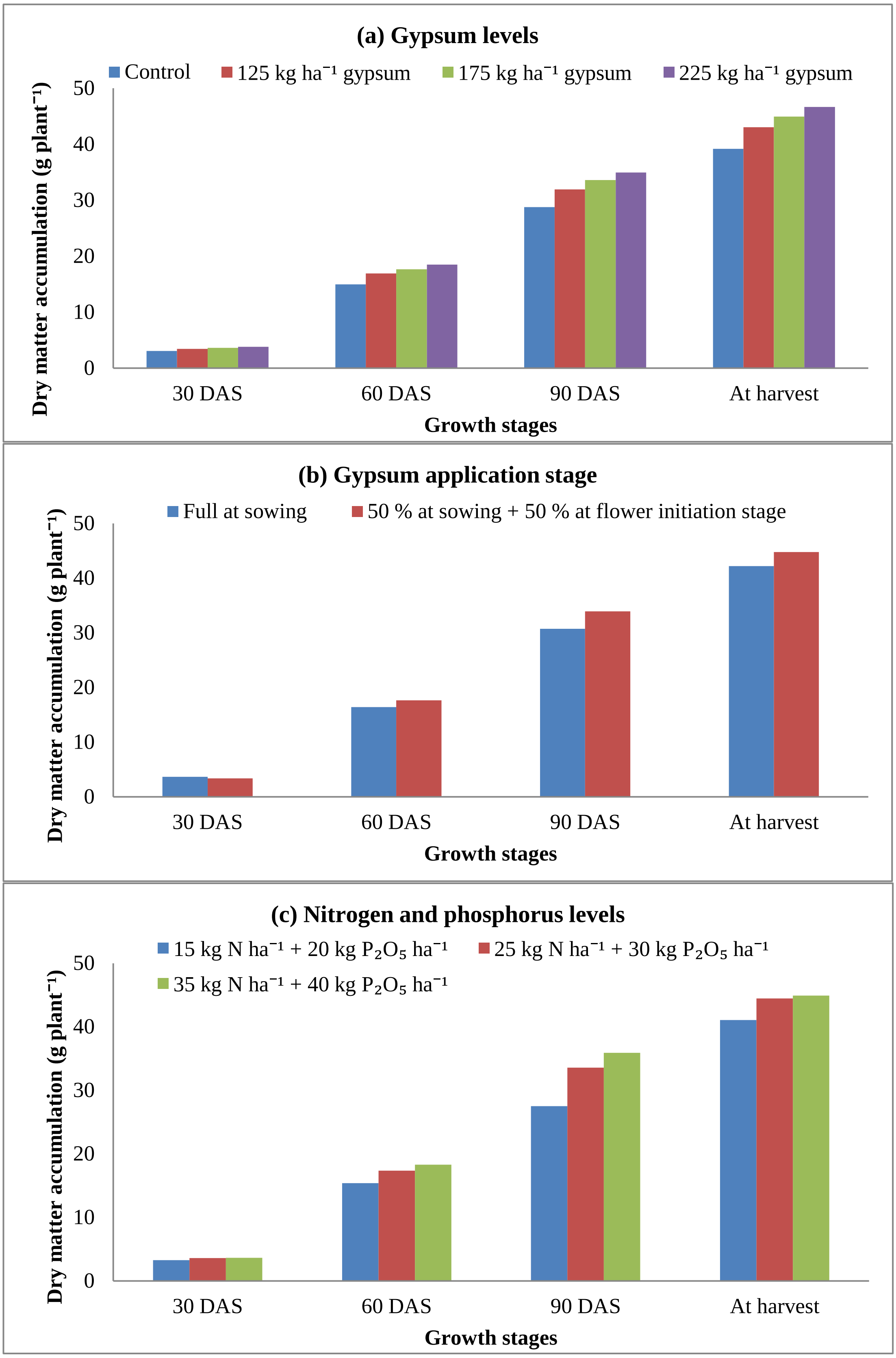

Fig. 4.5: Dry matter accumulation of groundnut as influenced by (a) gypsum levels, (b) gypsum application stage and (c) nitrogen and phosphorus levels in 2018

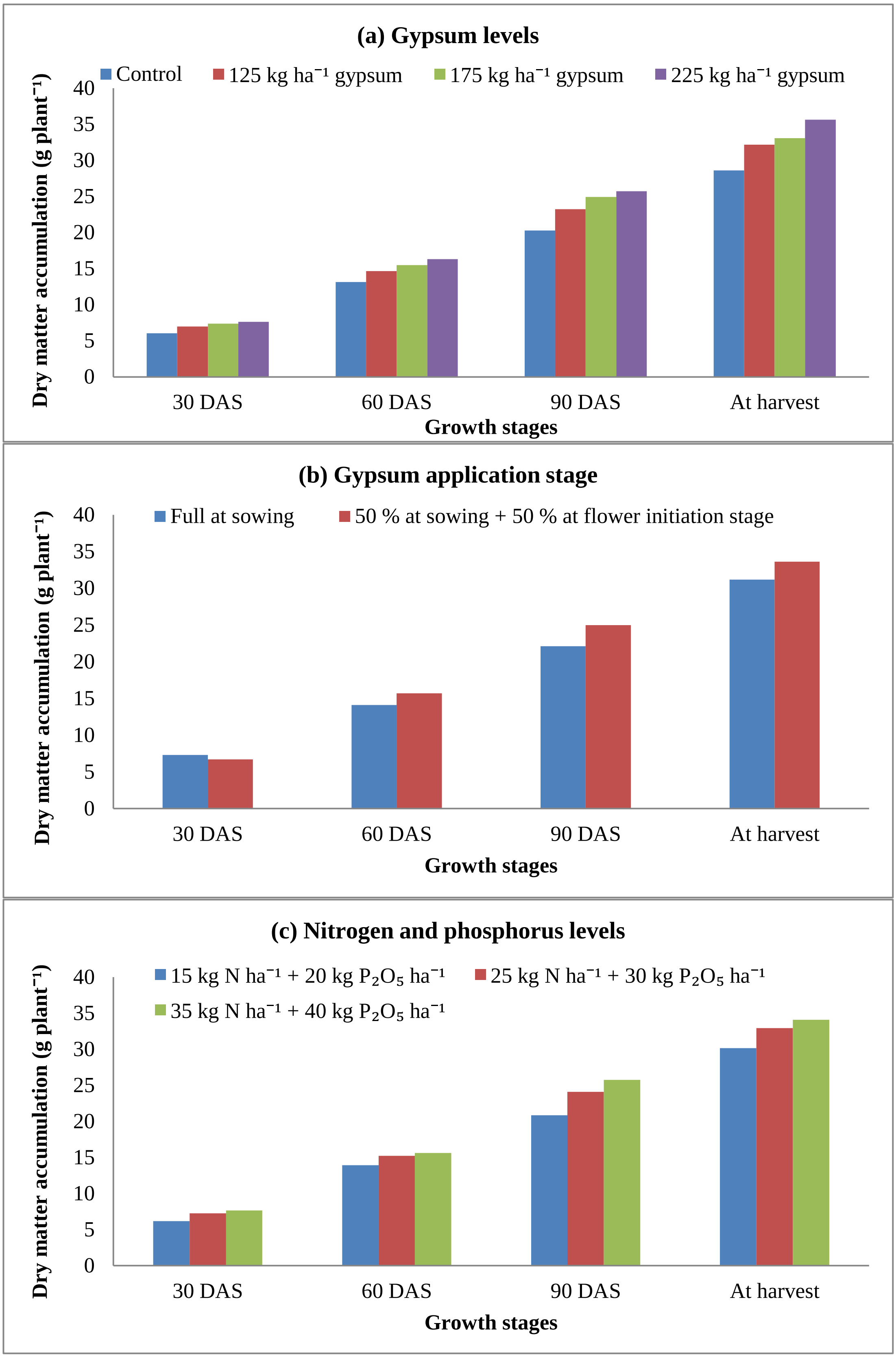

Fig. 4.6: Dry matter accumulation of groundnut as influenced by (a) gypsum levels, (b) gypsum application stage and (c) nitrogen and phosphorus levels in 2019

Different nitrogen and phosphorus levels also exerted a marked influence on the dry matter accumulation at 30, 60, 90 DAS and at harvest during both the years. Application of 35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1} gave maximum values of dry matter accumulation which were at par with those of 25 kg N ha^{-1} + 30 kg P_2O_5 ha^{-1} but significantly higher than the application of 15 kg N ha^{-1} + 20 kg P_2O_5 ha^{-1}. Data are supported by the findings of Hasan and Sahid (2016) who observed that dry matter accumulation is increased with an increase in the levels of nitrogen and phosphorus. Similar results were given by Meena *et al* (2011) who reported that the application of 40 kg N ha^{-1} significantly enhanced dry matter accumulation as compared to control. Kabir *et al* (2013) and Kamara *et al* (2011) advocated that 40-50 kg P_2O_5 ha^{-1} gave significantly higher dry weight of plant over lower doses of phosphorus. The application of higher dose of nitrogen and phosphorus resulted in more dry matter accumulation due to increase in photosynthesis, more transport of metabolites to the sink and the development of extensive root system (Sharma and Yadav 1997, Gobarah *et al* 2006).

4.2 Phenology

4.2.1 Days to 50% flowering

The data regarding the effect of various treatments on days to 50% flowering are presented in table 4.5.

The effect of different levels of gypsum on days to 50% flowering was non-significant in both the years. However, early flowering was noticed in control treatment (37.44 days in 2018 and 36.83 days in 2019) and was delayed with an increase in the levels of applied gypsum (37.67 to 38.22 days in 2018 and 36.94 to 38.89 days in 2019). Application of gypsum might have helped in better nitrogen content of crop, causing little delay in flowering (Ghosh *et al* 2015).

Gypsum application stage had non-significant effect on days to 50% flowering in both the years though the more days to 50% flowering were observed with the split application of gypsum.

Nitrogen and phosphorus levels also exerted non-significant influence on days to 50% flowering during both the years. Early flowering was observed in treatment receiving 15 kg N ha^{-1} + 20 kg P_2O_5 ha^{-1} (37.58 days in 2018 and 37.38 days in 2019) and was delayed by increasing the levels of nitrogen and phosphorus to 25 kg N ha^{-1} + 30 kg P_2O_5 ha^{-1} (37.71 days in 2018 and 37.63 days in 2019) and 35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1} (38.38 days in 2018 and 37.75 days in 2019) although the difference was non-significant. Similar findings were given by Bala *et al* (2011b) who reported that the days to 50% flowering were increased by the application of 30-39-39 NPK kg ha^{-1} as compared to 10-13-13 NPK kg ha^{-1} which indicates the fact that flowering in groundnut gets delayed due to higher doses of nitrogen and phosphorus.

4.2.2 Days to 50% pegging

The data regarding the effect of various treatments on days to 50% pegging are presented in table 4.5.

Table 4.5: Days to 50% flowering, days to 50% pegging, total number of flowers plant^{-1} and total number of pegs plant^{-1} of spring groundnut as influenced by gypsum levels, gypsum application stage and nitrogen and phosphorus levels

Treatments	Days to 50% flowering		Days to 50% pegging		Total number of flowers plant^{-1}		Total number of pegs plant^{-1}	
	2018	2019	2018	2019	2018	2019	2018	2019
Gypsum levels								
Control	37.44	36.83	53.94	52.94	58.42	61.56	43.52	45.56
125 kg ha^{-1}	37.67	36.94	54.22	53.28	64.27	67.34	47.59	50.18
175 kg ha^{-1}	38.22	37.67	54.39	54.39	69.87	71.76	51.43	54.41
225 kg ha^{-1}	38.22	38.89	54.56	55.28	75.57	76.21	55.37	58.62
CD (p=0.05)	NS	NS	NS	NS	5.48	4.21	3.70	4.16
Gypsum application stage								
Full at sowing	37.64	37.03	54.11	53.33	64.53	67.31	47.54	50.48
50% at sowing + 50% at flower initiation stage	38.14	38.14	54.44	54.61	69.54	71.12	51.42	53.91
CD (p=0.05)	NS	NS	NS	NS	3.87	2.98	2.62	2.94
Nitrogen and phosphorus levels								
15 kg N ha^{-1} + 20 kg P_2O_5 ha^{-1}	37.58	37.38	53.67	53.71	61.73	66.44	46.24	49.58
25 kg N ha^{-1} + 30 kg P_2O_5 ha^{-1}	37.71	37.63	54.25	54.00	68.10	69.67	50.31	52.60
35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1}	38.38	37.75	54.92	54.21	71.26	71.54	51.89	54.40
CD (p=0.05)	NS	NS	NS	NS	5.44	2.82	3.31	2.66
Interaction	NS	NS	NS	NS	NS	NS	NS	NS

Gypsum levels exerted non-significant influence on the days to 50% pegging in spring groundnut in both the years. Early pegging was observed in control treatment (53.94 days in 2018 and 52.94 days in 2019) and the pegging was delayed with an increase in the dose of applied gypsum (54.22 to 54.56 days in 2018 and 53.28 to 55.28 days in 2019) although the differences were non-significant.

Gypsum application stage did not influence the days to 50% pegging significantly in both the years. The delayed pegging was observed with split application although the differences were non-significant.

The effect of nitrogen and phosphorus levels on days to 50% pegging was also non-significant in both the years. Early pegging was seen in treatment receiving 15 kg N ha^{-1} + 20 kg P_2O_5 ha^{-1} (53.67 days in 2018 and 53.71 days in 2019) and was delayed with the increase in levels of nitrogen and phosphorus to 25 kg N ha^{-1} + 30 kg P_2O_5 ha^{-1} (54.25 days in 2018 and 54 days in 2019) and 35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1} (54.92 days in 2018 and 54.21 days in 2019) though the differences were non-significant with different levels of nitrogen and phosphorus.

4.2.3 Total number of flowers plant^{-1}

The data on the total number of flowers plant^{-1} are presented in table 4.5. Total number of flowers plant^{-1} is an important index which influences the final yield in the groundnut crop. Higher the number of flowers, more will be the number of pegs and consequently more will be the number of pods and therefore, higher the pod yield.

Gypsum levels exerted a significant influence on the total number of flowers plant^{-1} during 2018 as well as 2019. An increase in the number of flowers was observed in both years with increase in dose of gypsum from control to 225 kg ha^{-1} gypsum (58.42 to 75.57 in 2018 and 61.56 to 76.21 in 2019). Highest values were observed with 225 kg ha^{-1} gypsum which were significantly superior over all the other doses of gypsum.

Gypsum application stage also significantly influenced the total number of flowers plant^{-1} in both the years. Split application of gypsum (50% at sowing + 50% at flower initiation stage) gave significantly higher total number of flowers as compared to the application of full dose of gypsum at sowing during both the years.

Nitrogen and phosphorus levels also affected total number of flowers significantly in both the years. Application of 35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1} gave maximum values of total number of flowers (71.26 in 2018 and 71.54 in 2019), which were statistically at par with 25 kg N ha^{-1} + 30 kg P_2O_5 ha^{-1} (68.10 in 2018 and 69.67 in 2019) but significantly higher than the application of 15 kg N ha^{-1} + 20 kg P_2O_5 ha^{-1} (61.73 in 2018 and 66.44 in 2019). Application of phosphorus might have resulted in increased carbohydrate accumulation and their remobilization to reproductive parts of the plant and hence, resulted in increased flowering, pegging and pod formation (Majumdar *et al* 2001, Badole 2005 and Akbari 2011).

4.2.4 Total number of pegs plant^{-1}

The data on the total number of pegs plant^{-1} are presented in table 4.5. Total number of pegs plant^{-1} constitute a valuable index which contributes directly to the final yield realization. More the number of pegs, more will be the number of pods and therefore, higher the pod yield of groundnut.

Gypsum levels had a significant effect on the total number of pegs plant^{-1} during both the years. Application of 225 kg ha^{-1} gypsum resulted in maximum number of pegs (55.37 in 2018 and 58.62 in 2019), which were significantly higher than those obtained by the application of the other doses (Control, 125 and 175 kg ha^{-1}) of gypsum. The results are in coherence with the findings of Yadav *et al* (2015) who reported that 200 kg ha^{-1} gypsum resulted in higher number of pegs plant^{-1} of groundnut as compared to lower doses. Thilakarathna *et al* (2014) and Kirthisinghe *et al* (2014) also reported that the application of 250 kg ha^{-1} of gypsum gave significantly higher number of pegs plant^{-1} as compared to the lower doses of gypsum. Gypsum may have positive influence on the chemical properties of soil especially around the rhizosphere. Thus, all of these factors could directly or indirectly lead to an increase of pod growth rate, nutrient absorption from the soil and finally result in the increase of number of pegs (Adhikari *et al* 2003).

The stage at which the gypsum was applied to the crop also exerted a significant influence on the total number of pegs in groundnut in both the years. Split application of gypsum (50% at sowing + 50% at flower initiation stage) gave significantly higher total number of pegs as compared to the application of full dose of gypsum at sowing.

Nitrogen and phosphorus levels also had a significant influence on the total number of pegs in 2018 as well as 2019. The treatment receiving 35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1} resulted in highest number of pegs (51.89 in 2018 and 54.40 in 2019), which were statistically at par with the application of 25 kg N ha^{-1} + 30 kg P_2O_5 ha^{-1} (50.31 in 2018 and 52.60 in 2019) but significantly greater than 15 kg N ha^{-1} + 20 kg P_2O_5 ha^{-1} (46.24 in 2018 and 49.58 in 2019) during both the years. The findings are in line with the results of Shiyam (2010) and Mouri (2018) who concluded that application of 40-60 kg P_2O_5 ha^{-1} significantly increased the number of pegs plant^{-1} over lower levels of phosphorus.

4.3 Yield attributes and yield at harvest

4.3.1 Total number of pods plant^{-1}

The data regarding the effect of various treatments on total number of pods plant^{-1} are presented in table 4.6 and depicted in figure 4.7. The total number of pods plant^{-1} is considered to be an important yield contributing parameter. Pod yield of the groundnut crop is directly related to the total number of pods plant^{-1}.

Total number of pods were observed to have been significantly influenced by the use of different levels of gypsum during both the years. An increasing trend was observed in the total number of pods with the increasing levels of gypsum in both the years. 225 kg ha^{-1} gypsum resulted in significantly higher total number of pods (49.43 in 2018 and 52.17 in 2019) as compared to the other lower doses of gypsum. These results were supported by Thilakarathna *et al* (2014) who concluded that gypsum application @ 250 kg ha^{-1} improved number of pods plant^{-1} as compared to control. Similar results were obtained by Yadav *et al* (2015). Adhikari *et al* (2003) also reported that the application of 400 kg ha^{-1} gypsum resulted in significantly higher total number of pods plant^{-1} over lower levels. Pancholi *et al* (2017) reported that the supply of sulphur in adequate amount helps in the development of floral primordial *i.e.* reproductive parts, which results in the development of pods and kernels in plants. Also, calcium reduces ovule abortion and the importance of calcium in the fruiting zone for pod formation and pod development has been reported by Chahal and Viramani (1974) and Ramanathan and Ramanathan (1982). Greater partitioning of assimilates as well as adequate supply and translocation of metabolites and nutrients towards reproductive structures (*i.e.* sink) matching to their demand for growth and development could be the another possible reason of improvement in yield attributing characters of groundnut.

Table 4.6: Total number of pods plant^{-1}, 100-kernel weight, shelling percentage and sound mature kernels of spring groundnut as influenced by gypsum levels, gypsum application stage and nitrogen and phosphorus levels

Treatments	Total number of pods plant^{-1}		100-kernel weight (g)		Shelling percentage (%)		Sound mature kernels (%)	
	2018	2019	2018	2019	2018	2019	2018	2019
Gypsum levels								
Control	36.89	39.60	42.58	45.43	64.98	66.73	79.03	79.94
125 kg ha^{-1}	41.21	44.00	44.01	47.61	66.67	68.18	81.81	82.72
175 kg ha^{-1}	45.34	48.07	44.23	47.96	66.83	68.63	82.03	83.38
225 kg ha^{-1}	49.43	52.17	44.38	48.08	67.78	68.97	82.20	83.86
CD (p=0.05)	3.96	3.98	1.38	1.88	1.43	1.23	2.07	2.66
Gypsum application stage								
Full at sowing	41.66	44.01	43.59	46.74	66.11	67.72	80.50	81.51
50% at sowing + 50% at flower initiation stage	44.78	47.91	44.01	47.80	67.01	68.54	82.04	83.44
CD (p=0.05)	2.80	2.81	NS	NS	NS	NS	1.46	1.88
Nitrogen and phosphorus levels								
15 kg N ha^{-1} + 20 kg P_2O_5 ha^{-1}	39.98	43.22	43.43	46.78	66.21	67.54	79.05	80.57
25 kg N ha^{-1} + 30 kg P_2O_5 ha^{-1}	43.80	46.37	43.73	47.40	66.48	68.06	82.25	83.37
35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1}	45.88	48.29	44.24	47.63	67.00	68.79	82.52	83.48
CD (p=0.05)	3.22	2.70	NS	NS	NS	NS	3.05	2.54
Interaction	NS	NS	NS	NS	NS	NS	NS	NS

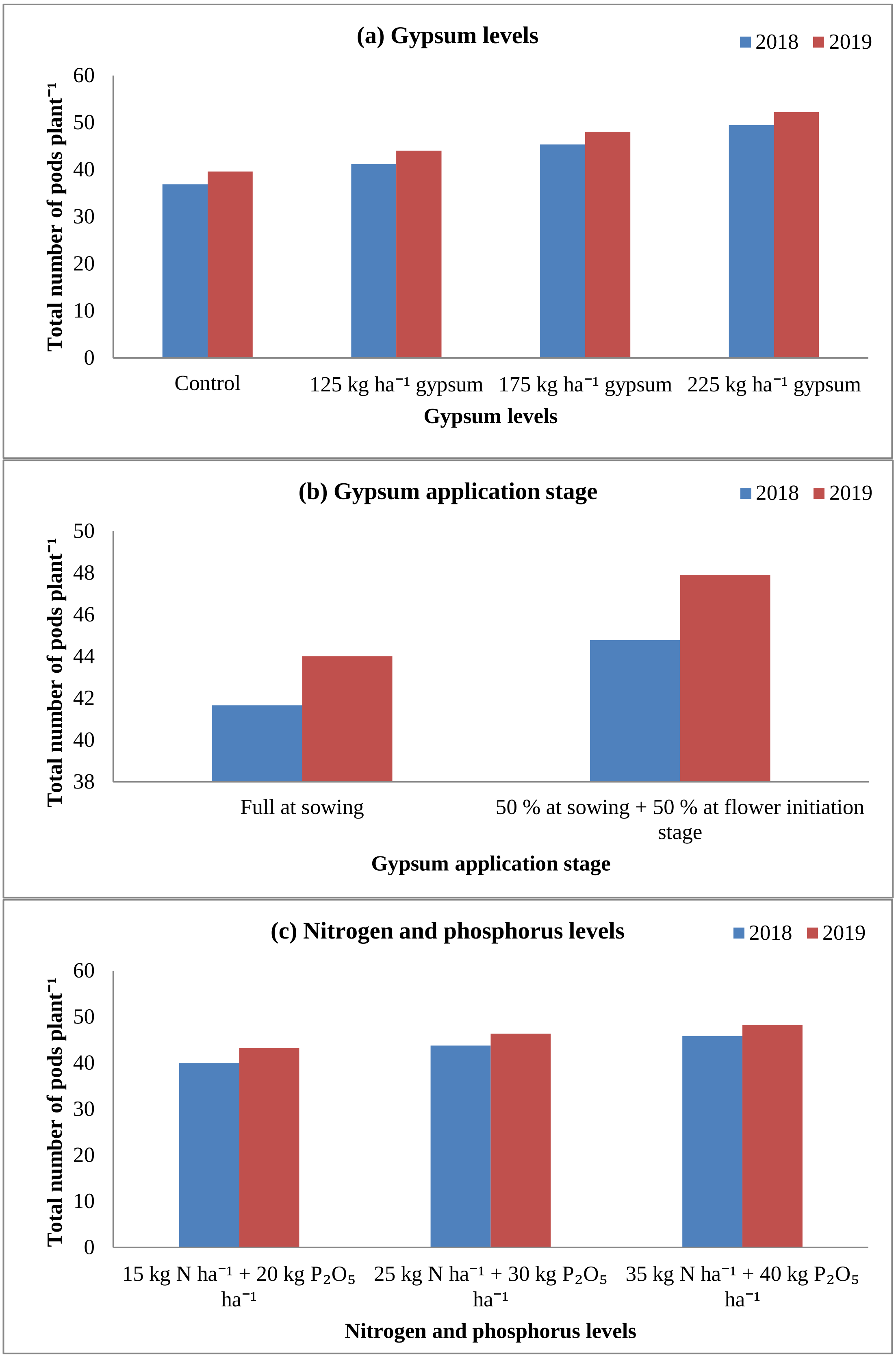

Fig. 4.7: Total number of pods plant^{-1} of groundnut as influenced by (a) gypsum levels, (b) gypsum application stage and (c) nitrogen and phosphorus levels

Similarly, gypsum application stage also had a significant influence on the total number of pods during both the years. Split application of gypsum (50% at sowing + 50% at flower initiation stage) gave significantly more total number of pods (44.78 in 2018 and 47.91 in 2019) as compared to the application of full dose of gypsum at sowing (41.66 in 2018 and 44.01 in 2019). The results were supported by Ghosh *et al* (2015) who reported that the number of pods plant^{-1} were significantly increased with the split application of gypsum as compared to application of full dose of gypsum at the time of sowing. Parallel findings were given by Jat and Singh (2006) who reported that the application of gypsum @ 250 kg ha^{-1} at sowing + 125 kg ha^{-1} at flowering significantly increased the number of pods plant^{-1} over gypsum application at sowing time. It is because the application of gypsum at the time of flowering will make available calcium and sulphur right in the site of fruiting zone at the appropriate time thus meeting the demand of the developing pods.

Nitrogen and phosphorus levels also seem to have a significant effect on the total number of pods in both the years. Highest number of pods were obtained with the application of 35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1} (45.88 in 2018 and 48.29 in 2019) and these were at par with 25 kg N ha^{-1} + 30 kg P_2O_5 ha^{-1} (43.80 in 2018 and 46.37 in 2019), while significantly greater than those obtained by the application of 15 kg N ha^{-1} + 20 kg P_2O_5 ha^{-1} (39.98 in 2018 and 43.22 in 2019). The results are similar as documented by Hasan and Sahid (2016) who reported that the increase in the dose of phosphorus and nitrogen resulted in improved number of pods plant^{-1} as compared to the lower levels of nitrogen and phosphorus. Sagvekar *et al* (2017) also reported that the application of 30 kg N ha^{-1} + 75 kg P_2O_5 ha^{-1} resulted in a significantly greater number of pods plant^{-1} over lower doses. Similarly, Meena and Yadav (2015) found that the application of 30 kg N ha^{-1} +60 kg P_2O_5 ha^{-1} significantly increased the number of pods plant^{-1} over lower doses. Improved overall growth and profuse branching due to nitrogen and phosphorus fertilization led to increased net photosynthesis on one hand and greater mobilization of photosynthates towards reproductive structures on the other, which might have increased the number of pods plant^{-1} and other yield attributes significantly (Majumdar *et al* 2001, Badole 2005 and Akbari 2011).

4.3.2 100-kernel weight

The data regarding the effect of various treatments on 100-kernel weight are presented in table 4.6. Test weight or the 100-kernel weight is considered to be an important parameter which contributes directly to the final pod yield of the groundnut crop. It is a suitable estimate of kernel filling.

Gypsum levels were observed to have a significant influence on the test weight during both the years. Application of 225 kg ha^{-1} gypsum resulted in maximum 100-kernel weight of 44.38 g in 2018 and 48.08 g in 2019, which were statistically at par with 175 kg ha^{-1}

and 125 kg ha^{-1} gypsum, while significantly higher than that of control during both the years. Yadav *et al* (2015) supported these results by concluding that the application of 200 kg gypsum ha^{-1} resulted in maximum 100-seed weight of groundnut than the lower gypsum doses. Thilakarathna *et al* (2014) also gave parallel observations. The results were also supported by Singh (2007) and Adhikari *et al* (2003) who reported that 100-kernel weight of groundnut was significantly increased with an increase in the level of gypsum up to 400 kg ha^{-1}. The increase in weight of kernels might be due to increased transportation of photosynthetic materials towards growing kernels with the application of calcium and sulphur through gypsum (Gashti *et al* 2012).

The effect of gypsum application stage on the test weight was found to be non-significant in both the years. The maximum test weight was observed with the split application though the differences were non-significant during both the years. However, Jat and Singh (2006) reported that the split application of gypsum significantly increased the seed index over gypsum application at sowing time.

The effect of nitrogen and phosphorus levels on the 100-kernel weight of groundnut was non-significant in both the years. However, an increasing trend was observed in the 100-kernel weight (43.43 g to 44.24 g in 2018 and 46.78 g to 47.63 g in 2019) with an increase in the levels of nitrogen and phosphorus though the difference was non-significant during both the years. Similarly, Hasan and Sahid (2016) reported that the increase in nitrogen and phosphorus levels significantly increased the 100-kernel weight of groundnut. Hossain *et al* (2007) also gave parallel findings and found that the application of 60 kg N ha^{-1} along with 60 kg P_2O_5 ha^{-1} resulted in significantly higher 100-seed weight over control. Meena and Yadav (2015) also found that the application of 30 kg N ha^{-1} +60 kg P_2O_5 ha^{-1} significantly increased the seed index over the lower doses of nitrogen and phosphorus. Early and plentiful availability of nitrogen and phosphorus to plants favourably influenced the kernel development and kernel size, which ultimately resulted in increased pod and seed index.

4.3.3 Shelling percentage

The data regarding the effect of various treatments on shelling percentage are presented in table 4.6. Shelling percentage is considered to be an important parameter which has a direct influence on the kernel yield of the groundnut crop. Higher shelling percentage is an indicator of proper pod filling. Because the final yield depends on kernels, so shelling percentage is one of the most important factor related to the thickness of shell, kernel development and flowering pattern during the growth of plant.

Gypsum levels resulted in a significant effect on the shelling percentage of groundnut in both the years. An increasing trend in shelling percentage was observed with an increase in the levels of applied gypsum. Maximum shelling percentage of 67.78% and 68.97% in 2018 and 2019 respectively was obtained with the application of 225 kg ha^{-1} gypsum, which was statistically at par with that obtained with the use of 175 kg ha^{-1} and 125 kg ha^{-1} gypsum while significantly greater than control during both the years. Similarly, Mandal *et al* (2005) and Sivanesarajah *et al* (1995) observed that the application of gypsum @ 400 and 500 kg ha^{-1} respectively increased the shelling percentage as compared to lower doses. The increase in shelling percentage with gypsum application may be due to the sulphur and calcium which may have attributed to the transfer of food materials at a sufficient rate by the plant to the shell for its proper development (Gashti *et al* 2012).

Gypsum application stage seems to have a non-significant effect on the shelling percentage in both the years. The maximum shelling percentage was obtained with the split application although the difference was non-significant during both the years. Jat and Singh (2006) also reported that the split application of gypsum @ 250 kg ha^{-1} at sowing + 125 kg ha^{-1} at flowering increased the shelling percentage over gypsum application at sowing time.

The effect of nitrogen and phosphorus levels on the shelling percentage of groundnut was also non-significant during both the years. An increasing trend in shelling percentage was obtained with progressive increase in the levels of nitrogen and phosphorus and highest shelling percentage of 67% and 68.79% during 2018 and 2019 respectively was obtained with the application of 35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1}. The findings are in concordance with the results noticed by Gohari and Niyaki (2010) who observed that 60 kg N ha^{-1} resulted in higher shelling percentage as compared to control and 30 kg N ha^{-1}. Similarly, Mouri (2018) revealed that 60 kg P_2O_5 ha^{-1} gave significantly higher shelling percentage over 40 and 20 kg P_2O_5 ha^{-1}. Meena and Yadav (2015) also revealed that the application of 30 kg N + 60 kg P_2O_5 ha^{-1} increased the shelling percentage over the lower doses of nitrogen and phosphorus. This increase in shelling percentage could be attributed to enhanced synthesis of carbohydrates, fats and proteins constituting the kernels and could have been caused by the application of high fertilizer levels (Shiyam 2010). The higher values of yield attributes were the result of higher nutrient availability resulting in better growth and more translocation of photosynthates from source to sink (Kumawat *et al* 2014).

4.3.4 Sound mature kernels

The data on percentage of sound mature kernels are presented in table 4.6. Sound mature kernels percentage indicates the proportion of well-developed kernels and is an important parameter contributing to the final yield of the crop.

Gypsum levels had a significant influence on the percentage of sound mature kernels in both the years. Application of 225 kg ha^{-1} gypsum resulted in maximum sound mature kernels percentage of 82.2% in 2018 and 83.86% in 2019, which were statistically at par with 175 kg ha^{-1} (82.03% in 2018 and 83.38% in 2019) and 125 kg ha^{-1} gypsum (81.81% in 2018 and 82.72% in 2019), while significantly higher as compared to the control (79.03% in 2018 and 79.94% in 2019). The results were confirmed by Rao and Shaktwat (2002) who observed that application of 250 kg ha^{-1} gypsum resulted in significantly higher sound mature kernels $plant^{-1}$ as compared to the lower doses of gypsum. Sullivan *et al* (1974) also observed a significant increase in percentage of sound mature kernels of groundnut due to an increase of gypsum application rates. This increase in the percentage of sound mature kernels suggests that the higher rate of gypsum has favourable influence on the seed quality. It may be due to improved seed physiological conditions.

Percentage of sound mature kernels was also significantly influenced by the gypsum application stage during both the years. It was observed that the split application of gypsum (50% at sowing + 50% at flower initiation stage) gave significantly higher sound mature kernels percentage (82.04% in 2018 and 83.44% in 2019) over the application of full dose of gypsum at sowing during both the years. The findings are in line with the results of Cheema *et al* (1991) who reported that the application of gypsum @ 1000 kg ha^{-1} at the time of flowering resulted in significantly higher percentage of sound mature kernels over lower doses of gypsum applied at the sowing time. The application of gypsum at the time of flowering increases the availability of calcium to the developing pods thus improving the quality of kernels leading to increased percentage of sound mature kernels.

Nitrogen and phosphorus levels also exerted a significant influence on sound mature kernels percentage during both the years. Application of 35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1} resulted in maximum sound mature kernels percentage (82.52% in 2018 and 83.48% in 2019), which was statistically at par with the application of 25 kg N ha^{-1} + 30 kg P_2O_5 ha^{-1} while significantly more than the application of 15 kg N ha^{-1} + 20 kg P_2O_5 ha^{-1} during both the years. The results of present study corroborate with the findings of Subrahmaniyan *et al* (2000) who reported that the use of 26 kg N ha^{-1} + 51 kg P_2O_5 ha^{-1} gave higher sound matured kernel percentage of groundnut over lower doses.

4.3.5 Pod yield

The data regarding the effect of various treatments on pod yield of groundnut are presented in table 4.7 and depicted in figure 4.8. The final yield of the crop reflects the eventual effect of the experimental variables. So, it helps to identify the efficiencies of various treatments in a given situation.

Table 4.7: Pod yield, haulm yield, kernel yield and harvest index of spring groundnut as influenced by gypsum levels, gypsum application stage and nitrogen and phosphorus levels

Treatments	Pod yield (q ha^{-1})		Haulm yield (q ha^{-1})		Kernel yield (q ha^{-1})		Harvest Index (%)	
	2018	2019	2018	2019	2018	2019	2018	2019
Gypsum levels								
Control	33.69	36.73	100.80	106.15	21.92	24.47	25.06	25.85
125 kg ha^{-1}	36.79	40.14	107.47	115.43	24.54	27.34	25.55	25.89
175 kg ha^{-1}	39.73	43.58	113.59	124.37	26.56	29.93	25.97	25.96
225 kg ha^{-1}	43.04	46.84	119.62	133.30	29.17	32.34	26.49	26.02
CD (p=0.05)	2.66	3.10	5.89	8.83	1.53	2.15	NS	NS
Gypsum application stage								
Full at sowing	37.13	40.65	108.06	116.65	24.61	27.53	25.54	25.92
50% at sowing + 50% at flower initiation stage	39.49	42.99	112.67	122.97	26.48	29.52	25.99	25.94
CD (p=0.05)	1.88	2.19	4.17	6.24	1.08	1.52	NS	NS
Nitrogen and phosphorus levels								
15 kg N ha^{-1} + 20 kg P_2O_5 ha^{-1}	36.60	39.43	106.50	115.25	24.29	26.62	25.58	25.65
25 kg N ha^{-1} + 30 kg P_2O_5 ha^{-1}	38.68	42.36	111.25	120.75	25.76	28.85	25.79	26.02
35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1}	39.66	43.68	113.36	123.43	26.59	30.09	25.94	26.11
CD (p=0.05)	1.34	2.77	4.32	4.77	0.95	1.88	NS	NS
Interaction	NS	NS	NS	NS	NS	NS	NS	NS

Different gypsum levels exerted a significant influence on the pod yield of groundnut in both the years. With an increase in the levels of applied gypsum, an increasing trend in the pod yield was observed. Application of 225 kg ha^{-1} gypsum resulted in maximum pod yield of 43.04 q ha^{-1} in 2018 and 46.84 q ha^{-1} in 2019 and it was significantly higher as compared to the other doses (Control, 125 and 175 kg ha^{-1}) of gypsum. Yadav *et al (*2015) confirmed the above results and reported that 200 kg ha^{-1} gypsum resulted in maximum pod yield of groundnut. Thilakarathna *et al* (2014) also concluded that application of 250 kg ha^{-1} gypsum resulted in an increase of 39.9% in pod yield of groundnut as compared to control. Similar findings were observed by Mandal *et al* (2005) who reported that the application of 400 kg ha^{-1} gypsum increased pod yield over control. Singh (2007) also supported the results of this study

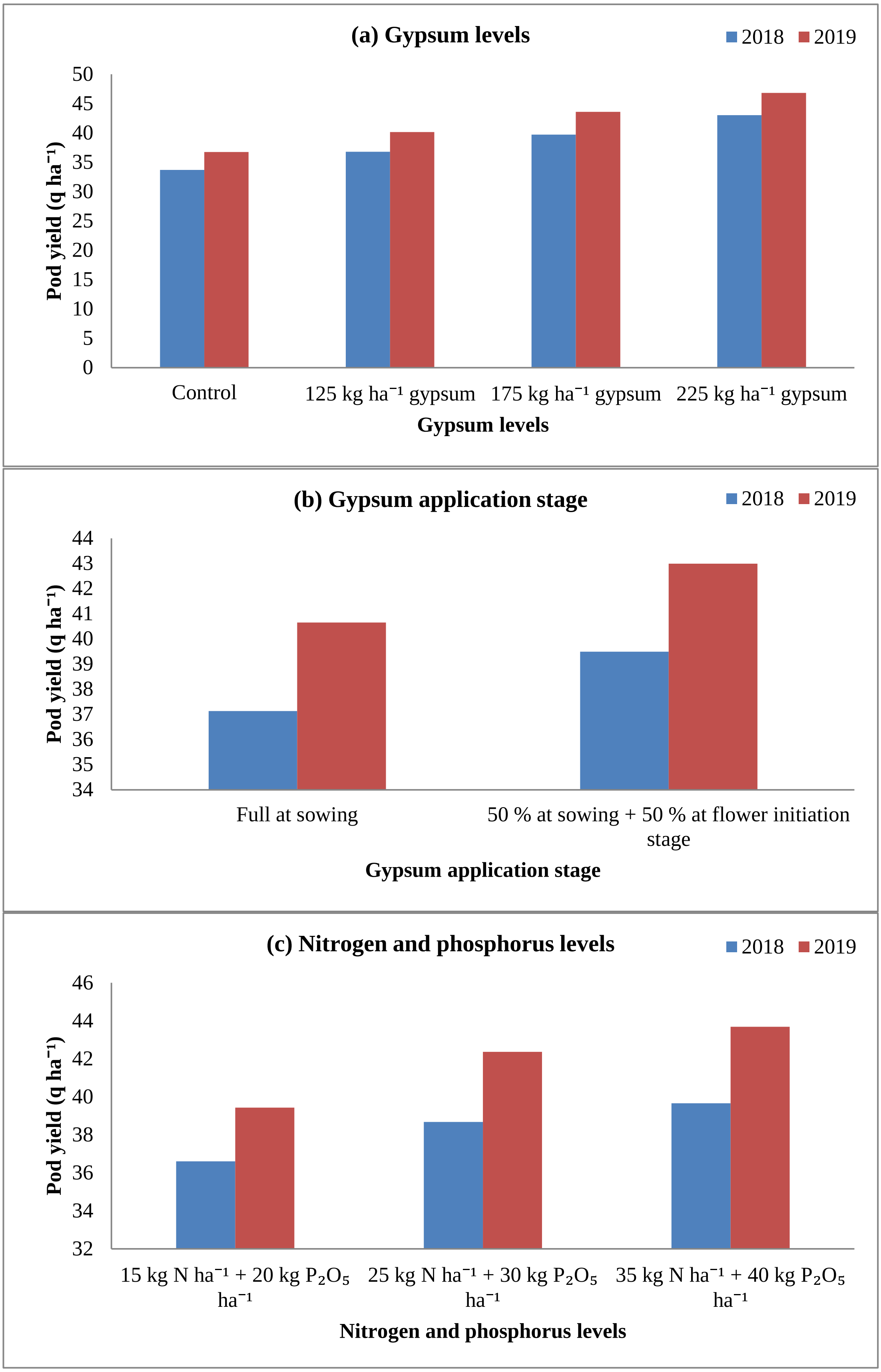

Fig. 4.8: Pod yield of groundnut as influenced by (a) gypsum levels, (b) gypsum application stage and (c) nitrogen and phosphorus levels

and reported that the pod yield of groundnut significantly increased with increase in the level of applied gypsum upto 240 kg ha^{-1}. The influence of gypsum on growth and yield attributes was found significant which resulted in a significant increase in the pod yield of groundnut. The improvement observed in the pod yield of groundnut could be attributed to that observed in the number of pods per plant, shelling percentage and 100-seed weight with gypsum application. Sulphur might have encouraged total biomass production and kernel development in groundnut, which was finally reflected in the improved pod yield. Calcium plays an important role in groundnut pod development and it was necessary for proper filling of pods in adequate quantities in the fruiting zone (Jat and Singh 2006).

Gypsum application stage also significantly influenced the pod yield of spring groundnut during both the years. Highest pod yield of 39.49 q ha^{-1} in 2018 and 42.99 q ha^{-1} in 2019 was observed with the split application of gypsum (50% at sowing + 50% at flower initiation stage) which was significantly higher over application of full dose of gypsum at the time of sowing. The findings are in line with the results of Jat and Singh (2006) who reported that the split application of gypsum @ 250 kg ha^{-1} at sowing + 125 kg ha^{-1} at flowering significantly increased the pod yield over gypsum application at sowing time. Hallock and Allison (1980a) also reported that significantly higher pod yield of groundnut was obtained when calcium was applied at early flowering stage as compared to application at earlier stages. Split application of gypsum would have ensured adequate calcium and sulphur availability in the fruiting zone at the time of pegging and pod development, where the pods can absorb the nutrients directly (Jat and Singh 2006).

Nitrogen and phosphorus levels also had a significant effect on the pod yield in 2018 as well as 2019. Application of 35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1} gave maximum pod yield of 39.66 q ha^{-1} in 2018 and 43.68 q ha^{-1} in 2019 which was statistically at par with the pod yield obtained by the application of 25 kg N ha^{-1} + 30 kg P_2O_5 ha^{-1} (38.68 q ha^{-1} in 2018 and 42.36 q ha^{-1} in 2019) while significantly higher than that of 15 kg N ha^{-1} + 20 kg P_2O_5 ha^{-1} (36.60 q ha^{-1} in 2018 and 39.43 q ha^{-1} in 2019) during both the years. The results are on corroboration with findings of Hasan and Sahid (2016) who reported that the application of higher dose of nitrogen and phosphorus resulted in improved pod yield as compared to the lower levels of nitrogen and phosphorus. Sagvekar *et al* (2017) also supported the results of current study and reported that the application of 30 N kg ha^{-1} + 75 P_2O_5 kg ha^{-1} resulted in a significantly higher pod yield over lower doses. Hossain *et al* (2007) also found that the application of 60 kg N ha^{-1} along with 60 kg P_2O_5 ha^{-1} resulted in significantly higher pod yield over control. Similarly, Meena and Yadav (2015) found that the application of 30 kg N ha^{-1} + 60 kg P_2O_5 ha^{-1} significantly increased the pod yield of groundnut over lower doses of nitrogen and phosphorus. The application of increased levels of nitrogen and phosphorus resulted in more nutrient availability to plant and resulted in greater utilization of assimilates into pods and ultimately increased the number of pods, 100-seed weight and the yield of groundnut. Nitrogen played an important role in plant metabolisms by virtue of being an essential constituent of metabolically active component like amino acid, protein, nucleic acid, enzyme, co-enzymes and alkaloids which are important for higher growth and yield (Patel *et al* 2014). The increase in yield due to phosphorus application might be attributed to the activation of metabolic processes, where its role in building phospholipids and nucleic acid is known (Kabir *et al* 2013).

4.3.6 Haulm yield

The data regarding the effect of various treatments on haulm yield of groundnut are presented in table 4.7 and depicted in figure 4.9.

Gypsum levels exerted a significant influence on the haulm yield of groundnut crop during both the years. An increasing trend in haulm yield was observed with an increase in the levels of applied gypsum. Application of 225 kg ha^{-1} gypsum resulted in maximum haulm yield (119.62 q ha^{-1} in 2018 and 133.30 q ha^{-1} in 2019) which was significantly higher over all the other doses of applied gypsum during both the years. The results are in coherence with the findings of Adhikari *et al* (2003) who reported that the application of 400 kg ha^{-1} gypsum resulted in highest haulm yield over lower doses of gypsum. Similar results were given by Yadav *et al* (2015) who reported that the application of 200 kg ha^{-1} gypsum resulted in significantly higher straw yield of groundnut as compared to the control. This increase in haulm yield may be due to favourable effect of gypsum on growth and yield attributes which was reflected in realizing higher haulm yield. The well-developed root system due to synergistic effect of S and Ca may have led to utilization of large quantities of nutrients which might have resulted in better plant development and higher straw yield at maturity (Mandal *et al* 2005).

Similarly, the stage of gypsum application had a significant effect on the haulm yield during both years. It was seen that with the split application of gypsum (50% at sowing + 50% at flower initiation stage), significantly higher haulm yield (112.67 q ha^{-1} in 2018 and 122.97 q ha^{-1} in 2019) was obtained as compared to the application of full dose of gypsum at sowing during both the years.

Haulm yield was also significantly affected by different levels of nitrogen and phosphorus in both the years. Maximum haulm yield of 113.36 q ha^{-1} in 2018 and 123.43 q ha^{-1} in 2019 was observed with the application of 35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1}, which was

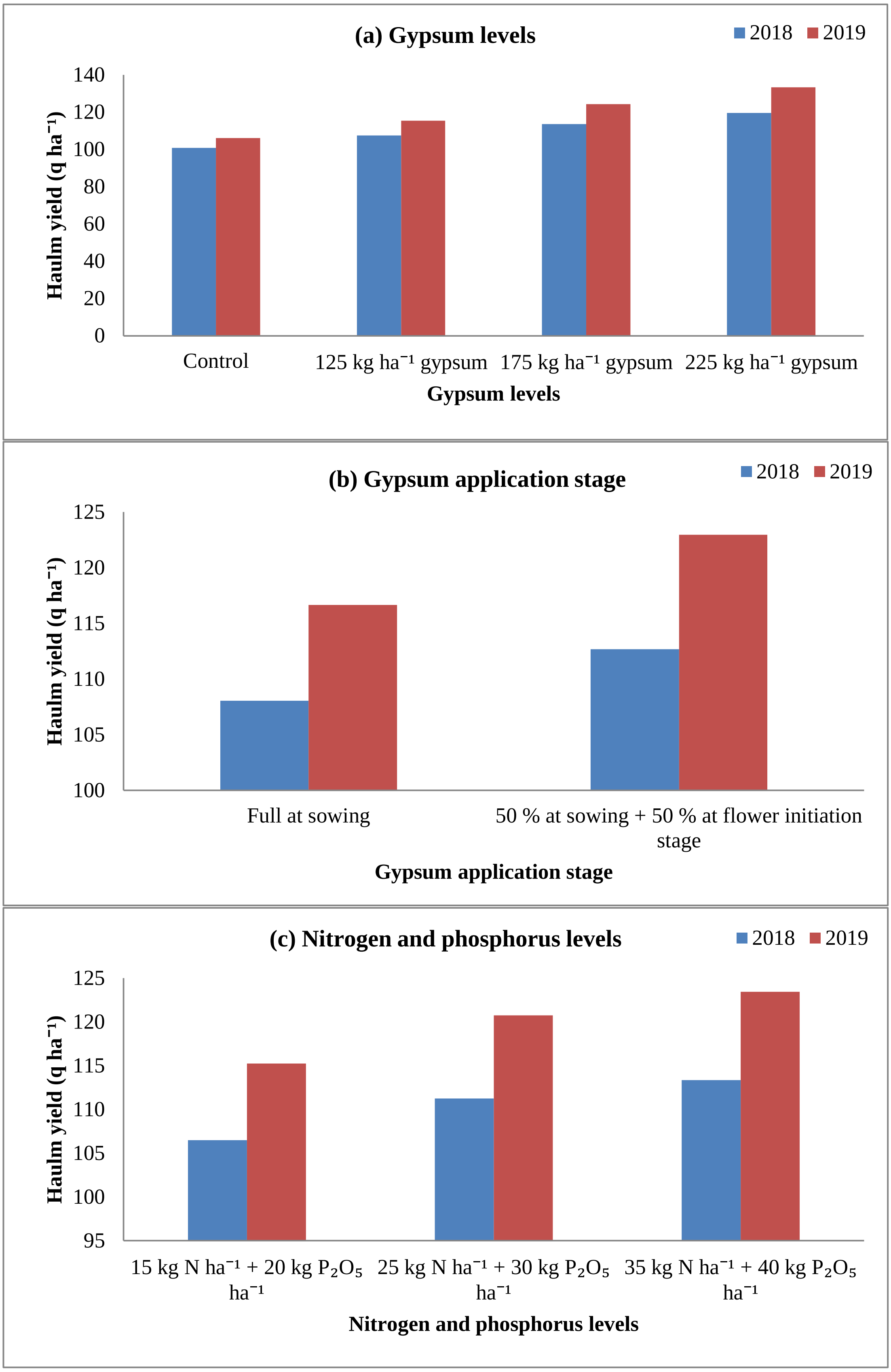

Fig. 4.9: Haulm yield of groundnut as influenced by (a) gypsum levels, (b) gypsum application stage and (c) nitrogen and phosphorus levels

at par with that of 25 kg N ha^{-1} + 30 kg P_2O_5 ha^{-1} (111.25 q ha^{-1} in 2018 and 120.75 q ha^{-1} in 2019) but significantly higher than that of 15 kg N ha^{-1} + 20 kg P_2O_5 ha^{-1} (106.5 q ha^{-1} in 2018 and 115.25 q ha^{-1} in 2019) during both the years. The results are in confirmation with the findings of Meena *et al* (2013) and Meena and Yadav (2015) who reported that the application of 30 kg N ha^{-1} + 60 kg P_2O_5 ha^{-1} resulted in significantly higher haulm yield of groundnut as compared to control and other lower doses of nitrogen and phosphorus. Increase in haulm yield might be due to increased growth and development in terms of plant height, number of branches and dry matter due to improvement in the nutritional environment of rhizosphere and plant system leading to higher plant metabolism, leaf area and photosynthetic activity.

4.3.7 Kernel yield

The data regarding the effect of various treatments on kernel yield of groundnut are presented in table 4.7 and depicted in figure 4.10.

Different gypsum levels exerted a significant influence on the kernel yield of groundnut in both the years. An increase in the kernel yield was observed with the increasing levels of gypsum in both the years. Maximum kernel yield of 29.17 q ha^{-1} in 2018 and 32.34 q ha^{-1} in 2019 was obtained with the application of 225 kg ha^{-1} gypsum and it was significantly higher as compared to the other doses (Control, 125 and 175 kg ha^{-1}) of applied gypsum. The results are in accordance with the findings of Kabir *et al* (2013) who concluded that application of 472 kg gypsum ha^{-1} resulted in an increase of kernel yield of groundnut by 64% over control. Gashti *et al* (2012) and Pancholi *et al* (2017) also observed that 300-400 kg gypsum ha^{-1} significantly increased the kernel yield of groundnut over lower doses of gypsum. Increasing of the 100-kernel weight, shelling percentage and directly high nutrient absorption by the pods could lead to increase of kernel yield at the higher levels of calcium (Gashti *et al* 2012). According to Tabatabai (1986), application of sulphur increases the seed yield because it improves the rhizosphere conditions that causes an increase in the absorption of nutrients from the soil.

Gypsum application stage also had a significant influence on the kernel yield in both the years. The split application of gypsum (50% at sowing + 50% at flower initiation stage) gave significantly higher kernel yield (26.48 q ha^{-1} in 2018 and 29.52 q ha^{-1} in 2019) as compared to the application of full dose of gypsum at sowing during both the years. Similar results were given by Jat and Singh (2006) who reported that the application of 250 kg gypsum ha^{-1} at sowing + 125 kg gypsum ha^{-1} at flowering significantly increased the kernel yield over gypsum application at the time of sowing. The increase in the kernel yield due to split application of gypsum might be the outcome of increased shelling percentage and pod yield (Table 4.6 and 4.7).

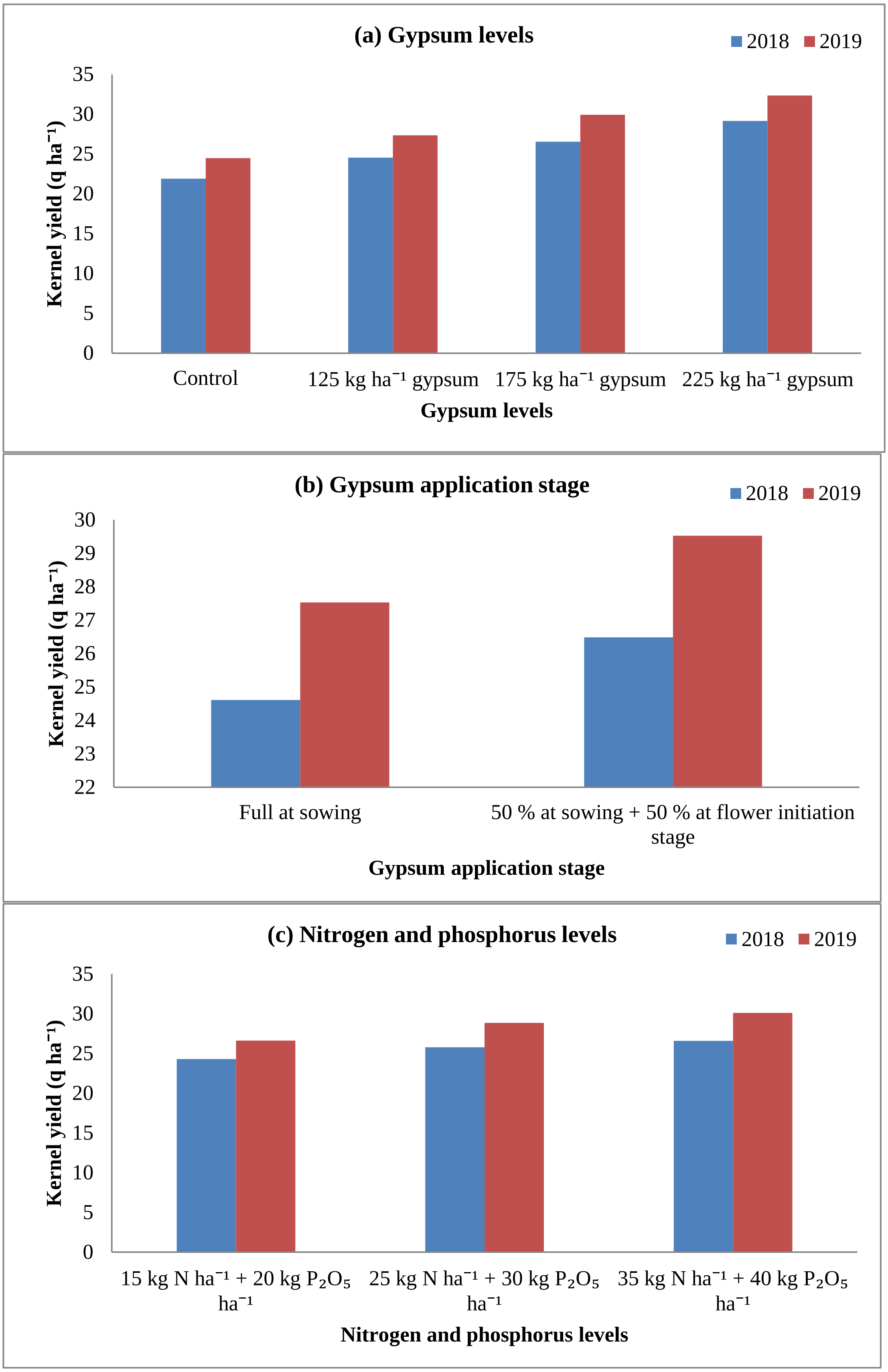

Fig. 4.10: Kernel yield of groundnut as influenced by (a) gypsum levels, (b) gypsum application stage and (c) nitrogen and phosphorus levels

Nitrogen and phosphorus levels also exerted a significant influence on the kernel yield during both the years. Maximum kernel yield of 26.59 q ha^{-1} in 2018 and 30.09 q ha^{-1} in 2019 was observed with the application of 35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1} and it was at par with that of 25 kg N ha^{-1} + 30 kg P_2O_5 ha^{-1} (25.76 q ha^{-1} in 2018 and 28.85 q ha^{-1} in 2019) while significantly higher than that of 15 kg N ha^{-1} + 20 kg P_2O_5 ha^{-1} (24.29 q ha^{-1} in 2018 and 26.62 q ha^{-1} in 2019) during both the years. Data are supported by the findings of Meena *et al* (2013), Meena and Yadav (2015) and Sagvekar *et al* (2017) who found that the application of 30 kg N ha^{-1} + 60 to 70 kg P_2O_5 ha^{-1} significantly increased the kernel yield of groundnut over lower doses. It is because application of nitrogen fertilizer helps in the better growth and development of vegetative and reproductive organs of groundnut and with increase in photosynthesis rate and photosynthetic matters production, seed yield and yield components of groundnut were increased (Gohari and Amiri 2010, Vishkaee 1999). Application of phosphorus resulted in greater production of assimilates and their partition to the reproductive sink represented by the pods, which in turn was reflected in the higher seed yield.

4.3.8 Harvest Index

The data on harvest index are presented in table 4.7. Harvest index is an important parameter indicating the efficiency of partitioning of dry matter to the economic part of the crop. Higher value of harvest index indicates that plant is more efficient in producing economic yield.

The effect of gypsum levels on harvest index was non-significant in both the years. However, numerically highest value of harvest index was obtained with the application of 225 kg ha^{-1} gypsum (26.49 in 2018 and 26.02 in 2019) while the lowest value was observed with the control treatment (25.06 in 2018 and 25.85 in 2019) although the difference was non-significant during both the years. Parallel findings were observed by Kabir *et al* (2013) who concluded that maximum harvest index (26.02%) was obtained with the application of 708 kg gypsum ha^{-1} which was significantly higher as compared to lower doses. The increase in harvest index with gypsum application seems to be due to its favourable effect on number of pods, pod weight, kernel weight, shelling percentage and pod yield (Jat and Singh 2006).

The effect of gypsum application stage on the harvest index was found to be non-significant during both the years. The maximum harvest index was found with the split application of gypsum (25.99 in 2018 and 25.94 in 2019) during both the years. Similar results were noticed by Jat and Singh (2006) who reported that the application of gypsum @ 250 kg ha^{-1} at sowing + 125 kg ha^{-1} at flowering increased the harvest index of groundnut as compared to the gypsum application at the time of sowing. The split application of gypsum might have increased the number of pods, 100-kernel weight and the pod yield which was ultimately reflected in the higher harvest index.

Similarly, nitrogen and phosphorus levels also had non-significant influence on the harvest index during both the years. However, highest harvest index was obtained with the application of 35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1} (25.94 in 2018 and 26.11 in 2019) whereas, lowest value of harvest index was obtained with that of 15 kg N ha^{-1} + 20 kg P_2O_5 ha^{-1} (25.58 in 2018 and 25.65 in 2019) during both the years. Kabir *et al* (2013) confirmed the above results and observed that the application of 50 kg P_2O_5 ha^{-1} resulted in significantly higher harvest index of groundnut as compared to 25 kg P_2O_5 ha^{-1}. Improved fertilization with higher levels of nitrogen and phosphorus might have resulted in improved yield attributes and the pod yield which consequently increased the harvest index.

4.4 Economics

4.4.1 Cost of cultivation

The cost of cultivation per hectare for various treatments is given in the table 4.8. Cost of cultivation for different treatments was calculated on the basis of the enterprise budget of groundnut crop for the year 2018 and 2019 as given in Appendix III.

4.4.2 Gross returns

The data on the effect of various treatments on gross returns are given in the table 4.8. Gypsum levels influenced gross returns significantly during both the years. Application of 225 kg ha^{-1} gypsum resulted in maximum gross returns (₹157573 ha^{-1} in 2018 and ₹188001 ha^{-1} in 2019) and these were significantly higher than other levels of gypsum during both the years. Mandal *et al* (2005) also advocated that the higher dose of gypsum resulted in higher gross returns over lower levels of gypsum. Higher dose of gypsum resulted in improved pod and haulm yield of groundnut, which resulted in higher gross returns.

Gypsum application stage also significantly influenced the gross returns in both the years. Split application of gypsum (50% at sowing + 50% at flower initiation stage) gave significantly higher gross returns (₹144710 ha^{-1} in 2018 and ₹172581 ha^{-1} in 2019) as compared to the application of full dose of gypsum at sowing during both the years. Higher gross returns might be the outcome of higher pod and haulm yield obtained with split application of gypsum.

Nitrogen and phosphorus levels influenced gross returns significantly during both the years. Application of 35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1} gave maximum gross returns (₹145331 ha^{-1} in 2018 and ₹175275 ha^{-1} in 2019) which were at par with 25 kg N ha^{-1} + 30 kg P_2O_5 ha^{-1} (₹141770 ha^{-1} in 2018 and ₹170023 ha^{-1} in 2019), but significantly higher than 15 kg N ha^{-1} + 20 kg P_2O_5 ha^{-1} (₹134181 ha^{-1} in 2018 and ₹158381 ha^{-1} in 2019) during both the years. Higher levels of nitrogen and phosphorus might have resulted in higher pod and haulm yield of groundnut, thus leading to increased gross returns.

Table 4.8: Cost of cultivation, gross returns, net returns and benefit cost ratio of spring groundnut as influenced by gypsum, nitrogen and phosphorus

Treatments	Cost of cultivation (₹ ha^{-1})		Gross returns (₹ ha^{-1})		Net returns (₹ ha^{-1})		Benefit cost ratio	
	2018	**2019**	**2018**	**2019**	**2018**	**2019**	**2018**	**2019**
Gypsum levels								
Control	49858	53152	123643	147480	73785	94328	2.48	2.78
125 kg ha^{-1}	51111	54426	134897	161156	83785	106730	2.64	2.96
175 kg ha^{-1}	51549	54864	145596	174934	94048	120071	2.83	3.18
225 kg ha^{-1}	51986	55301	157573	188001	105587	132700	3.03	3.40
CD (p=0.05)	-	-	9359	12018	9359	12018	0.18	0.22
Gypsum application stage								
Full at sowing	51006	54301	136145	163205	85138	108904	2.67	3.00
50% at sowing + 50% at flower initiation stage	51246	54571	144710	172581	93464	118010	2.82	3.16
CD (p=0.05)	-	-	6618	8498	6618	8498	0.13	NS
Nitrogen and phosphorus levels								
15 kg N ha^{-1} + 20 kg P_2O_5 ha^{-1}	49628	52720	134181	158381	84553	105660	2.70	3.00
25 kg N ha^{-1} + 30 kg P_2O_5 ha^{-1}	51126	54436	141770	170023	90644	115587	2.77	3.12
35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1}	52624	56151	145331	175275	92707	119124	2.77	3.12
CD (p=0.05)	-	-	4858	10757	4858	10757	NS	NS
Interaction	-	-	NS	NS	NS	NS	NS	NS

4.4.3 Net returns

The data on the effect of different treatments on net returns are given in the table 4.8. Gypsum levels influenced net returns significantly during both the years. Application of 225 kg ha^{-1} gypsum resulted in maximum net returns (₹105587 ha^{-1} in 2018 and ₹132700 ha^{-1} in 2019) and these were significantly higher than other levels of gypsum during both the years. The findings are in line with the results of Adhikari *et al* (2003) who reported that the application of higher dose of gypsum resulted in higher net returns over lower doses of gypsum. This could be primarily due to higher pod and haulm yields with comparatively less additional cost of gypsum with higher gypsum levels.

Gypsum application stage also significantly influenced the net returns in both the years. Split application of gypsum (50% at sowing + 50% at flower initiation stage) gave significantly higher net returns (₹93464 ha^{-1} in 2018 and ₹118010 ha^{-1} in 2019) as compared to the application of full dose of gypsum at sowing during both the years.

Nitrogen and phosphorus levels influenced net returns significantly during both the years. Application of 35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1} gave maximum net returns (₹92707 ha^{-1} in 2018 and ₹119124 ha^{-1} in 2019) which were statistically at par with those of 25 kg N ha^{-1} + 30 kg P_2O_5 ha^{-1} (₹90644 ha^{-1} in 2018 and ₹115587 ha^{-1} in 2019), while significantly higher than those of 15 kg N ha^{-1} + 20 kg P_2O_5 ha^{-1} (₹84553 ha^{-1} in 2018 and ₹105660 ha^{-1} in 2019) during both the years. The results were confirmed by Sagvekar *et al* (2017) who reported that the application of 30 kg N ha^{-1} + 75 kg P_2O_5 ha^{-1} resulted in significantly higher net returns as compared to lower doses of nitrogen and phosphorus. Kumar *et al* (2014) also reported parallel results. Patel *et al* (2014) advocated that the increase in net returns by the application of nitrogen and phosphorus might be due to the positive effect of these nutrients on the pod yield.

4.4.4 Benefit cost ratio

The data on the effect of various treatments on benefit cost ratio are given in the table 4.8. Gypsum levels influenced the benefit cost ratio significantly during both the years. In 2018, application of 225 kg ha^{-1} gypsum gave significantly higher value of benefit cost ratio (3.03) as compared to other gypsum levels. In the year 2019, 225 kg ha^{-1} gypsum resulted in highest benefit cost ratio (3.40), which was statistically at par with 175 kg ha^{-1} gypsum (3.18), but significantly higher over other gypsum levels. Mandal *et al* (2005) and Adhikari *et al* (2003) confirmed the results of the present study and reported that the application of 400 kg ha^{-1} gypsum resulted in highest benefit cost ratio as compared to lower doses of gypsum.

The stage of application of gypsum exerted a significant influence on the benefit cost ratio of groundnut in 2018. Split application of gypsum gave significantly higher benefit cost ratio (2.82) as compared to the application of full dose of gypsum at sowing (2.67) in 2018. In 2019, split application of gypsum resulted in higher benefit cost ratio (3.16) as compared to basal application of gypsum (3.00), though the difference was non-significant.

Nitrogen and phosphorus levels influenced the benefit cost ratio non-significantly during both the years. However, an increasing trend in the value of benefit cost ratio was observed with increase in the levels of nitrogen and phosphorus. Application of 35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1} and 25 kg N ha^{-1} + 30 kg P_2O_5 ha^{-1} resulted in maximum benefit cost ratio (2.77 with each of them in 2018 and 3.12 with each of them in 2019), which was higher than 15 kg N ha^{-1} + 20 kg P_2O_5 ha^{-1} (2.70 in 2018 and 3.00 in 2019). Sagvekar *et al* (2017) supported the findings of the current study and reported that the application of 30 N kg ha^{-1} + 75 P_2O_5 kg ha^{-1} resulted in higher benefit cost ratio as compared to lower doses of fertilizer. Similarly, Kumar *et al* (2014) reported an increase in benefit cost ratio with increase in the level of applied nitrogen and phosphorus.

4.5 Quality characteristics

4.5.1 Protein content in kernels

The data on the effect of various treatments on the protein content of kernels are presented in table 4.9. The protein content of the seeds is directly related to the nitrogen content of the seed.

Different gypsum levels exerted a significant influence on the protein content of kernels during both the years. Application of 225 kg ha^{-1} gypsum resulted in maximum protein content (27.02% in 2018 and 27.23% in 2019) which was statistically at par with that of 175 kg ha^{-1} and 125 kg ha^{-1} gypsum, but significantly higher than control during both the years. The results are similar as documented by Thilakarathna *et al* (2014) who concluded that gypsum application improved protein content with the increasing rate of gypsum up to 250 kg ha^{-1}. Rao and Shaktawat (2001) and Rao and Shaktawat (2005) also reported that application of 250 kg gypsum ha^{-1} significantly improved the protein content as compared to control. Manaf *et al* (2017) also obtained similar results and observed that the application of 400 kg ha^{-1} gypsum significantly increased protein content of groundnut over the lower doses. The improvement in protein content due to gypsum might be on account of increased sulphur content in the kernel, which is required for synthesis of sulphur containing amino acids in groundnut as they are the building blocks of proteins (Badiger *et al* 1992).

The effect of gypsum application stage on the protein content was non-significant in both the years. The maximum protein content was observed with the split application of gypsum as compared to full gypsum application at sowing time though the difference was non-significant during both the years.

Table 4.9: Protein content and oil content in kernels of spring groundnut as influenced by gypsum levels, gypsum application stage and nitrogen and phosphorus levels

Treatments	**Protein content in kernels**		**Oil content in kernels**	
	2018	**2019**	**2018**	**2019**
Gypsum levels				
Control	26.03	26.12	46.82	46.86
125 kg ha^{-1}	26.94	26.99	47.19	47.22
175 kg ha^{-1}	26.99	27.06	47.55	47.58
225 kg ha^{-1}	27.02	27.23	47.92	47.94
CD (p=0.05)	0.79	0.80	0.35	0.34
Gypsum application stage				
Full at sowing	26.53	26.76	47.31	47.32
50% at sowing + 50% at flower initiation stage	26.96	26.94	47.43	47.48
CD (p=0.05)	NS	NS	NS	NS
Nitrogen and phosphorus levels				
15 kg N ha^{-1} + 20 kg P_2O_5 ha^{-1}	26.33	26.05	47.05	47.08
25 kg N ha^{-1} + 30 kg P_2O_5 ha^{-1}	26.76	26.82	47.36	47.40
35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1}	27.14	27.68	47.70	47.72
CD (p=0.05)	0.32	0.71	0.24	0.27
Interaction	NS	NS	NS	NS

Different levels of nitrogen and phosphorus exerted a significant effect on the protein content of groundnut kernels in both the years. Application of 35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1} gave maximum protein content of 27.14% in 2018 and 27.68% in 2019, which was significantly higher than the other two levels of nitrogen and phosphorus during both the years. Shinde *et al* (2000) confirmed the findings of the current study and noticed that 25 kg N ha^{-1} + 50 kg P_2O_5 ha^{-1} recorded significantly higher protein content (21.58%) in kernels of groundnut as compared to control. Similarly, Hasan and Sahid (2016) revealed that the increase in levels of nitrogen and phosphorus increased the protein content in the kernels of groundnut. Protein content is essentially the manifestation of N content in kernels, hence increased N content might have increased the protein content. This increase in protein content might be due to the enhanced absorption of nutrients from the soil solution resulting from higher application rates, and hence promoted better assimilation leading to higher protein content in kernels of groundnut. Increase in protein content with N might be attributed to the fact that the nitrogen is the main constituent of protein and is involved in the synthesis of amino acids and accumulation of protein in the seed (Singh and Singh 2005).

4.5.2 Oil content in kernels

The data on the effect of various treatments on the oil content of kernels are presented in table 4.9. The oil content of the seeds is an important character for determining the quality of the groundnut crop.

Gypsum levels had a significant effect on the oil content in both the years. Application of 225 kg ha^{-1} gypsum gave maximum oil content of 47.92% in 2018 and 47.94% in 2019, which was significantly higher as compared to the other doses of gypsum. The findings of Thilakarathna *et al* (2014) corroborate with the present study as it was concluded that gypsum application improved oil content with the increasing rate of gypsum up to 250 kg ha^{-1}. Rao and Shaktawat (2001) and Rao and Shaktawat (2005) also obtained parallel results. Likewise, Adhikari *et al* (2003) reported that the application of 400 kg ha^{-1} gypsum resulted in significantly higher oil content in kernels of groundnut over 200 kg ha^{-1}. As sulphur is an integral part of oil, the increased availability of sulphur through gypsum application might have favourably influenced the synthesis of essential metabolism responsible for higher oil content. Addition of sulphur through gypsum creates favourable nutritional environment both in root zone and in the plant system and thereby favours greater development, biomass production and higher uptake of nutrients, which favoured oil synthesis in groundnut. This could be due to involvement of sulphur in the biosynthetic pathway of fatty acids. Application of sulphur increases the supply of sulphur containing amino acids such as cysteine, cystine and methionine which play a vital role in synthesis of oils (Verma and Bajpai 1974).

Gypsum application stage had a non-significant effect on the oil content of the groundnut kernels although maximum oil content was observed with split application of gypsum during both the years.

Nitrogen and phosphorus levels exerted a significant influence on the oil content during both the years. Application of 35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1} gave maximum oil content of 47.70% in 2018 and 47.72% in 2019 and it was significantly better than the other two levels of nitrogen and phosphorus. Shinde *et al* (2000) supported the findings of the present study and revealed that 25 kg N ha^{-1} + 50 kg P_2O_5 ha^{-1} recorded significantly higher oil content (51.70%) in groundnut kernels as compared to control. Hasan and Sahid (2016) also witnessed parallel results. Nitrogen might have increased oil content in seed by increasing vegetative growth and higher production of carbohydrate in the plant. Also, phosphorus is a major constituent of fatty acids and higher accumulation of phosphorus might have resulted in higher oil content in the seeds.

4.6 Plant analysis

4.6.1 Nitrogen content in plant (haulm and kernel) at harvest

The data on the nitrogen content in the haulm and kernel of the spring groundnut are presented in table 4.10. The N content of haulm of spring groundnut was not affected significantly by the application of different gypsum levels during both the years. However, an increasing trend in the N content of haulm in both the years was seen with the increasing levels of the applied gypsum. Gypsum levels had a significant effect on the N content of kernels. In 2018, application of 225 kg ha^{-1} gypsum and 175 kg ha^{-1} gypsum resulted in maximum nitrogen content in kernel (4.32% with each of them), which was statistically at par with 125 kg ha^{-1} gypsum, while significantly higher than control. In 2019, application of 225 kg ha^{-1} gypsum resulted in maximum nitrogen content in kernel (4.36%), which was statistically at par with 175 kg ha^{-1} and 125 kg ha^{-1} gypsum, while significantly higher than control. Similar findings were reported by Rao and Shaktawat (2005) who concluded that the application of 250 kg ha^{-1} gypsum increased the nitrogen concentration in kernel and haulm of groundnut over control. The increase in nitrogen content due to gypsum application might be due to improved nutritional environment in the rhizosphere as well as in the plant system which leads to translocation of N to reproductive parts which ultimately increased the N concentration in the kernel of groundnut (Alcordo and Recheigl 1993). Also, sulphur and nitrogen are said to increase the uptake and concentration of each other in groundnut (Mishra *et al* 1986).

The effect of gypsum application stage on the N content of haulm and kernel was found to be non-significant during both the years. The maximum nitrogen content of haulm and kernel was found in split application of gypsum though the difference was observed to be non-significant.

However, nitrogen and phosphorus levels exerted a significant influence on the N content of haulm and kernel in both the years. The maximum nitrogen content in haulm was observed with the application of 35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1} and 25 kg N ha^{-1} + 30 kg P_2O_5 ha^{-1} (1.77% in each of them during both the years), which was significantly higher than that of 15 kg N ha^{-1} + 20 kg P_2O_5 ha^{-1}. The maximum nitrogen content in kernels was obtained with the application of 35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1} (4.34% in 2018 and 4.43% in 2019), which was significantly higher as compared to the other two doses of nitrogen and phosphorus. El-Habbasha *et al* (2013) reported similar observations and reported that the increase in N levels significantly increased nitrogen content in seeds and haulm of groundnut. Likewise, Gobarah *et al* (2006) reported that increasing the dose of phosphorus fertilizer significantly increased nitrogen content in plants of groundnut. Rao and Shaktawat (2005) also reported that the application of 60 kg P_2O_5 ha^{-1} significantly increased the nitrogen concentration in kernel and haulm of groundnut over 20 kg P_2O_5 ha^{-1}. This may be due to the fact that the plants accumulated more nitrogen with increasing levels of nitrogen, thus ultimately showing more N content in haulm and kernels.

4.6.2 Total nitrogen uptake in plant at harvest

The data on total nitrogen uptake by the spring groundnut are presented in the table 4.10. Gypsum levels were observed to have a significant effect on the total nitrogen uptake by the groundnut plants in both the years. Application of 225 kg ha^{-1} gypsum resulted in maximum nitrogen uptake by the plant (336.43 kg ha^{-1} in 2018 and 377.17 kg ha^{-1} in 2019) in both the years, which was significantly higher than other levels of gypsum. Parallel findings were reported by Rao and Shaktawat (2005) who reported that the application of 250 kg ha^{-1} gypsum significantly increased the total N uptake by groundnut plant over control. This increase in nutrient uptake could be attributed to increased availability of sulphur to plants by the application of gypsum, which in turn might have resulted in profuse shoot and root growth thereby activating greater absorption of N, P and S from the soil.

The stage of gypsum application also exerted a significant influence on the total nitrogen uptake by the plant in both the years. Split application of gypsum (50% at sowing + 50% at flower initiation stage) gave significantly higher nitrogen uptake (310.94 kg ha^{-1} in 2018 and 344.12 kg ha^{-1} in 2019) as compared to the application of full dose of gypsum at the time of sowing during both the years.

Total nitrogen uptake was also significantly affected by the application of different levels of nitrogen and phosphorus during both the years. In 2018, application of 35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1} recorded maximum nitrogen uptake (316.7 kg ha^{-1}), which was at par with 25 kg N ha^{-1} + 30 kg P_2O_5 ha^{-1} but significantly higher than 15 kg N ha^{-1} + 20 kg P_2O_5 ha^{-1}. In 2019, 35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1} gave maximum nitrogen uptake (352.49 kg ha^{-1}) which was significantly higher as compared to the other two levels of nitrogen and phosphorus. The results were confirmed by Kumar *et al* (2000) who noticed that the application of 30 kg N ha^{-1} + 60 kg P_2O_5 ha^{-1} resulted in the higher uptake of N in groundnut as compared to the lower levels of nitrogen and phosphorus fertilizer. Hossain *et al* (2007) and Veerabhadrappa *et al* (2000) also found that the application of 60 kg N ha^{-1} along with 60 kg P_2O_5 ha^{-1} resulted in a higher uptake of nitrogen by seed and haulm of groundnut as compared to the control. The increased uptake may be accounted for synergistic effect between N and P. Higher uptake of nutrients at higher levels of nitrogen and phosphorus fertilizer may be due to increased nitrogen availability to plants for higher biomass production. Further, phosphorus enhanced the root growth which helps in better absorption of nitrogen through symbiotic nitrogen fixation process.

Table 4.10: Haulm and kernel nitrogen content and total nitrogen uptake as influenced by gypsum levels, gypsum application stage and nitrogen and phosphorus levels

Treatments	N content (%)				Total N uptake (kg ha^{-1})	
	Haulm		Kernel			
	2018	2019	2018	2019	2018	2019
Gypsum levels						
Control	1.75	1.73	4.16	4.18	267.85	286.46
125 kg ha^{-1}	1.75	1.75	4.31	4.32	294.11	320.13
175 kg ha^{-1}	1.76	1.76	4.32	4.33	313.96	349.10
225 kg ha^{-1}	1.76	1.77	4.32	4.36	336.43	377.17
CD (p=0.05)	NS	NS	0.13	0.13	11.96	16.80
Gypsum application stage						
Full at sowing	1.74	1.75	4.24	4.28	295.24	322.31
50% at sowing + 50% at flower initiation stage	1.76	1.76	4.31	4.31	310.94	344.12
CD (p=0.05)	NS	NS	NS	NS	8.46	11.88
Nitrogen and phosphorus levels (N)						
15 kg N ha^{-1} + 20 kg P_2O_5 ha^{-1}	1.72	1.72	4.21	4.17	285.57	309.13
25 kg N ha^{-1} + 30 kg P_2O_5 ha^{-1}	1.77	1.77	4.28	4.29	307.00	338.03
35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1}	1.77	1.77	4.34	4.43	316.70	352.49
CD (p=0.05)	0.04	0.05	0.05	0.11	11.81	10.48
Interaction	NS	NS	NS	NS	NS	NS

4.6.3 Phosphorus content in plant (haulm and kernel) at harvest

The data on the phosphorus content in the haulm and kernel of the spring groundnut are presented in table 4.11. The phosphorus content in the haulm and kernel of the spring groundnut was significantly influenced by the use of different gypsum levels in both the years. In 2018, maximum phosphorus content in haulm (0.28%) was observed with the application of 225 kg ha^{-1} gypsum, which was statistically at par with those of 175 kg ha^{-1} and 125 kg ha^{-1} gypsum while significantly higher than the control. In 2019, both 225 kg ha^{-1} and 175 kg ha^{-1} gypsum gave highest phosphorus content in haulm (0.281% with each of them), which was statistically at par with that of 125 kg ha^{-1} gypsum while significantly higher than the control. In 2018, maximum phosphorus content in kernel (0.564%) was observed with the application of 225 kg ha^{-1} gypsum, which was at par with 175 kg ha^{-1} and 125 kg ha^{-1} gypsum while significantly higher than the control. In 2019, both 225 kg ha^{-1} and 175 kg ha^{-1} gypsum gave highest phosphorus content in kernel (0.567% with each of them), which was statistically at par with that of 125 kg ha^{-1} gypsum while significantly higher than the control. Parallel findings were observed by Ismail *et al* (1998) and Rao and Shaktawat (2005) who noticed that the application of 250 kg ha^{-1} gypsum increased the concentration of phosphorus in the kernels and haulm of groundnut over control. The increase in phosphorus content due to gypsum application might be due to improved nutritional environment in the rhizosphere as well as in the plant system which leads to translocation of P to the reproductive parts which ultimately increased the P concentration in the kernels of groundnut (Alcordo and Recheigl 1993).

Gypsum application stage had non-significant effect on the phosphorus content of haulm and kernel in both the years though the maximum content of phosphorus was observed with the split application of gypsum.

Nitrogen and phosphorus levels, however resulted in a significant influence on the phosphorus content of haulm and kernel of groundnut during both the years. In the year 2018, maximum phosphorus content in haulm (0.279%) was observed with the application of each of 35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1} and 25 kg N ha^{-1} + 30 kg P_2O_5 ha^{-1} but significantly higher than that of 15 kg N ha^{-1} + 20 kg P_2O_5 ha^{-1}. In the year 2019, 35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1} gave highest phosphorus content in haulm (0.280%), which was statistically at par with 25 kg N ha^{-1} + 30 kg P_2O_5 ha^{-1} (0.279%) while significantly higher than the use of 15 kg N ha^{-1} + 20 kg P_2O_5 ha^{-1}. Maximum phosphorus content in kernel was observed with the treatment receiving 35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1} (0.564% in 2018 and 0.568% in 2019) which was at par with 25 kg N ha^{-1} + 30 kg P_2O_5 ha^{-1} (0.562% in 2018 and 0.564% in 2019), while significantly higher than that of 15 kg N ha^{-1} + 20 kg P_2O_5 ha^{-1} (0.545% in 2018 and 0.556% in 2019). These results were supported by Rao and Shaktawat (2005) who reported that the application of 60 kg P_2O_5 ha^{-1} significantly increased the phosphorus concentration in kernel and haulm of groundnut over 20 kg P_2O_5 ha^{-1}. Gobarah *et al* (2006) also reported that increasing the dose of phosphorus fertilizer significantly increased phosphorus content in plants of groundnut. Greater uptake of phosphorus due to application of higher dose of phosphatic fertilizer may be the reason for improved P concentration in groundnut plants.

Nitrogen application might have also increased the P content in plant because improved N availability in the root zone as well as N content in plant may lead to enhanced translocation of P to reproductive structures and other plant parts.

4.6.4 Total phosphorus uptake in plant at harvest

The data on total phosphorus uptake by the groundnut plants are presented in the table 4.11. Total phosphorus uptake was significantly influenced by the application of different levels of gypsum in both years. 225 kg ha^{-1} gypsum gave maximum total phosphorus uptake in both the years (49.8 kg ha^{-1} in 2018 and 55.81 kg ha^{-1} in 2019), which was significantly better as compared to other two doses of gypsum as well as control.

Table 4.11: Haulm and kernel phosphorus content and total phosphorus uptake as influenced by gypsum levels, gypsum application stage and nitrogen and phosphorus levels

Treatments	P content (%)				Total P uptake (kg ha^{-1})	
	Haulm		Kernel			
	2018	2019	2018	2019	2018	2019
Gypsum levels						
Control	0.268	0.268	0.540	0.551	38.94	42.00
125 kg ha^{-1}	0.278	0.279	0.561	0.566	43.61	47.55
175 kg ha^{-1}	0.278	0.281	0.562	0.567	46.48	51.91
225 kg ha^{-1}	0.280	0.281	0.564	0.567	49.80	55.81
CD (p=0.05)	0.008	0.009	0.019	0.012	1.39	2.60
Gypsum application stage						
Full at sowing	0.276	0.276	0.556	0.560	43.47	47.67
50% at sowing + 50% at flower initiation stage	0.277	0.278	0.558	0.566	45.95	50.97
CD (p=0.05)	NS	NS	NS	NS	0.98	1.84
Nitrogen and phosphorus levels						
15 kg N ha^{-1} + 20 kg P_2O_5 ha^{-1}	0.271	0.273	0.545	0.556	42.03	46.29
25 kg N ha^{-1} + 30 kg P_2O_5 ha^{-1}	0.279	0.279	0.562	0.564	45.44	50.01
35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1}	0.279	0.280	0.564	0.568	46.66	51.66
CD (p=0.05)	0.006	0.005	0.012	0.008	1.77	1.54
Interaction	NS	NS	NS	NS	NS	NS

Rao and Shaktawat (2005) confirmed the findings of the present study and reported that the application of 250 kg ha^{-1} gypsum significantly increased the total P uptake by groundnut plant as compared to control. This increase in nutrient uptake could be attributed to increased availability of S to plants through the application of gypsum, which in turn might have resulted in profuse shoot and root growth thereby activating greater absorption of N, P and S from the soil.

Gypsum application stage also had a significant influence on the total phosphorus uptake in both the years. Split application of gypsum recorded significantly higher phosphorus uptake (45.95 kg ha^{-1} in 2018 and 50.97 kg ha^{-1} in 2019) over full dose application of gypsum at sowing during both the years.

Nitrogen and phosphorus levels also had a significant effect on the total phosphorus uptake in both the years. In 2018, 35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1} recorded maximum phosphorus uptake (46.66 kg ha^{-1}), which was at par with 25 kg N ha^{-1} + 30 kg P_2O_5 ha^{-1} (45.44 kg ha^{-1}) while significantly higher than 15 kg N ha^{-1} + 20 kg P_2O_5 ha^{-1} (42.03 kg ha^{-1}). In 2019, 35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1} recorded highest phosphorus uptake (51.66 kg ha^{-1}) and it was significantly higher than the other doses of nitrogen and phosphorus. Data are supported by the findings of Hossain *et al* (2007) who observed that the application of 60 kg N ha^{-1} + 60 kg P_2O_5 ha^{-1} resulted in a higher uptake of phosphorus as compared to the control. Kumar *et al* (2000) also concluded that the application of 30 kg N ha^{-1} + 60 kg P_2O_5 ha^{-1} resulted in the highest uptake of P in groundnut as compared to the lower levels of the nitrogen and phosphorus. Likewise, Rao and Shaktawat (2005) and Veerabhadrappa *et al* (2000) reported that the application of 60 kg P_2O_5 ha^{-1} significantly increased the total P uptake by groundnut plant over 20 kg P_2O_5 ha^{-1}. This increased P uptake may be due to the increased dry matter production and synergistic effect between N and P. Also, there was an increase in P availability from the applied fertilizer and inherent soil source. Higher uptake of nutrients at higher levels of nitrogen and phosphorus fertilizer may be due to increased nitrogen availability to plants for higher biomass production. The greater mobilization of phosphorus in the presence of nitrogen may be another reason for its higher uptake.

4.6.5 Potassium content in plant (haulm and kernel) at harvest

The data on effect of various treatments on the potassium content in the haulm and kernel of the spring groundnut are presented in table 4.12. Gypsum levels exerted a significant influence on the potassium content of both haulm and kernel in both the years. In 2018, 225 kg ha^{-1} and 175 kg ha^{-1} gypsum resulted in maximum haulm potassium content (1.57% with each of them), which was statistically at par with that of 125 kg ha^{-1} gypsum (1.56%) while significantly higher over control (1.53%). In the year 2019, application of 225 kg ha^{-1} gypsum gave maximum haulm potassium content (1.58%), which was at par with that of 175 kg ha^{-1} (1.57%) and 125 kg ha^{-1} (1.57%) gypsum while significantly higher than the control (1.54%). Maximum potassium content in kernel was obtained with the use of 225 kg ha^{-1} gypsum (0.763% in 2018 and 0.768% in 2019), which was statistically at par with that of 175 kg ha^{-1} (0.762% in 2018 and 0.763% in 2019) and 125 kg ha^{-1} gypsum (0.761% in 2018 and 0.756% in 2019), while significantly higher than the control (0.732% in 2018 and 0.727% in 2019). Ismail *et al* (1998) and Rao and Shaktawat (2005) also reported similar results and observed that the application of 250 kg ha^{-1} gypsum raised the concentration of K in the kernels and above ground parts of groundnut over control. The application of gypsum might have improved the rhizosphere conditions and thus increased the absorption of nutrients including potassium. Gypsum application stage had non-significant effect on potassium content of haulm and kernels of groundnut during both the years.

Potassium content of haulm was significantly influenced by the different levels of nitrogen and phosphorus in both the years. In 2018, 35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1} gave maximum haulm potassium content (1.58%), which was statistically at par with the application of 25 kg N ha^{-1} + 30 kg P_2O_5 ha^{-1} (1.56%), while significantly higher than that of 15 kg N ha^{-1} + 20 kg P_2O_5 ha^{-1} (1.52%). In the year 2019, both 35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1} and 25 kg N ha^{-1} + 30 kg P_2O_5 ha^{-1} gave highest value of potassium content in haulm (1.58% with each of them), while significantly higher than that of 15 kg N ha^{-1} + 20 kg P_2O_5 ha^{-1} (1.55%). The effect of nitrogen and phosphorus levels on the potassium content in kernels was non-significant in both the years. The results are in coherence with the findings of El-Habbasha *et al* (2013) who reported that the increase in N levels significantly increased potassium content in seeds and haulm of groundnut. Rao and Shaktawat (2005) obtained similar results and reported that the application of 60 kg P_2O_5 ha^{-1} significantly increased the potassium concentration in kernel and haulm of groundnut over 20 kg P_2O_5 ha^{-1}. Elayaraja and Singaravel (2012) reported that the increase of potassium content in haulm with the application of higher levels of nitrogen might be attributed to the balanced and continuous supply of nitrogen through fertilizer. Further, improved nodulation and nodule activity might have increased nutrient availability and content in haulm.

4.6.6 Total potassium uptake in plant at harvest

The data on the effect of various treatments on the total potassium uptake by the spring groundnut are presented in the table 4.12. Total potassium uptake in spring groundnut was significantly influenced by the use of different gypsum levels in both the years. Maximum potassium uptake was recorded with application of 225 kg ha^{-1} gypsum (209.72 kg ha^{-1} in 2018 and 235.59 kg ha^{-1} in 2019) and it was significantly higher than the other levels of gypsum. The findings of the current study are supported by Rao and Shaktawat (2005) who reported that the application of 250 kg ha^{-1} gypsum significantly increased the total K uptake by groundnut plant over control. The increase in potassium uptake might be due to the gypsum application, which creates favourable nutritional environment both in root zone and in the plant system and thereby favours greater development, biomass production and higher uptake of nutrients. Total potassium uptake was also significantly affected by the stage of gypsum application in both years. Split application resulted in significantly better potassium uptake (196.31 kg ha^{-1} in 2018 and 215.66 kg ha^{-1} in 2019) as compared to the application of full dose of gypsum at sowing during both the years though the differences were non-significant.

Table 4.12: Haulm and kernel potassium content and total potassium uptake as influenced by gypsum levels, gypsum application stage and nitrogen and phosphorus levels

Treatments	K content (%)				Total K uptake (kg ha^{-1})	
	Haulm		Kernel			
	2018	2019	2018	2019	2018	2019
Gypsum levels						
Control	1.53	1.54	0.732	0.727	170.21	180.69
125 kg ha^{-1}	1.56	1.57	0.761	0.756	186.38	202.48
175 kg ha^{-1}	1.57	1.57	0.762	0.763	198.37	218.46
225 kg ha^{-1}	1.57	1.58	0.763	0.768	209.72	235.59
CD (p=0.05)	0.03	0.03	0.024	0.023	8.18	15.60
Gypsum application stage						
Full at sowing	1.55	1.56	0.753	0.747	186.03	202.95
50% at sowing + 50% at flower initiation stage	1.56	1.57	0.756	0.759	196.31	215.66
CD (p=0.05)	NS	NS	NS	NS	5.79	11.03
Nitrogen and phosphorus levels						
15 kg N ha^{-1} + 20 kg P_2O_5 ha^{-1}	1.52	1.55	0.746	0.749	180.42	198.53
25 kg N ha^{-1} + 30 kg P_2O_5 ha^{-1}	1.56	1.58	0.758	0.754	193.17	212.06
35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1}	1.58	1.58	0.760	0.756	199.92	217.32
CD (p=0.05)	0.03	0.02	NS	NS	7.84	7.88
Interaction	NS	NS	NS	NS	NS	NS

Nitrogen and phosphorus levels also had significant influence on the total potassium uptake in both the years. Application of 35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1} recorded highest potassium uptake (199.92 kg ha^{-1} in 2018 and 217.32 kg ha^{-1} in 2019), which was statistically at par with 25 kg N ha^{-1} + 30 kg P_2O_5 ha^{-1} (193.17 kg ha^{-1} in 2018 and 212.06 kg ha^{-1} in 2019), while significantly higher than 15 kg N ha^{-1} + 20 kg P_2O_5 ha^{-1} (180.42 kg ha^{-1} in 2018 and 198.53 kg ha^{-1} in 2019) during both the years. Kumar *et al* (2000) reported similar findings and concluded that the application of 30 kg N ha^{-1} + 60 kg P_2O_5 ha^{-1} resulted in the highest uptake of K (34.89 kg ha^{-1}) in groundnut as compared to the lower doses of the fertilizer. Likewise, Singh and Chaudri (2007) and Manoharan *et al* (1994) reported an increase in the uptake of potassium by groundnut plants with an increase in the levels of applied nitrogen. Rao and Shaktawat (2005) also reported that the application of 60 kg P_2O_5 ha^{-1} significantly increased the total K uptake by groundnut plant over 20 kg P_2O_5 ha^{-1}. This increase in K uptake might be attributed to significantly higher dry matter accumulation as a result of application of higher doses of other nutrients such as nitrogen and phosphorus.

4.6.7 Calcium content in plant (haulm and kernel) at harvest

The data on the effect of various treatments on the calcium content of haulm and kernel of spring groundnut are presented in table 4.13. Gypsum levels significantly influenced the calcium content in both haulm and kernel of groundnut in both the years. In the year 2018, 225 kg ha^{-1} and 175 kg ha^{-1} gypsum gave highest haulm calcium content (1.19% with each of them) and it was statistically at par with that of 125 kg ha^{-1} gypsum (1.16%) while significantly higher than the control (1.11%). In 2019, 225 kg ha^{-1} gypsum gave highest haulm calcium content of 1.19%, which was at par with 175 kg ha^{-1} (1.18%) and 125 kg ha^{-1} (1.16%) gypsum, while significantly higher than the control (1.11%). 225 kg ha^{-1} gypsum gave maximum kernel calcium content of 0.377% in 2018, which was at par with that of 175 kg ha^{-1} (0.376%) and 125 kg ha^{-1} (0.376%) gypsum, but significantly higher than the control (0.36%). In 2019, both 225 kg ha^{-1} gypsum and 175 kg ha^{-1} gypsum gave highest kernel calcium content (0.378% with each of them), which was at par with 125 kg ha^{-1} gypsum (0.376%), while significantly higher than the control (0.364%). Rao and Shaktawat (2005) supported the findings of the present study and reported that the application of 250 kg ha^{-1} gypsum significantly increased the calcium concentration in kernel and haulm of groundnut over control. Likewise, Arnold et al (2017), Pathak *et al* (2013) and Howe *et al* (2012) reported that seed Ca concentration increased with increase in the rates of gypsum application. The influence of gypsum application stage on calcium content of haulm and kernel of groundnut was non-significant during both the years.

Nitrogen and phosphorus levels had a significant effect on the calcium content of haulm but a non-significant effect on the calcium content of kernels during both the years. In 2018, both 35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1} and 25 kg N ha^{-1} + 30 kg P_2O_5 ha^{-1} resulted in highest calcium content of haulm (1.18% with each of them), which was significantly higher than that of 15 kg N ha^{-1} + 20 kg P_2O_5 ha^{-1} (1.14%). In the year 2019, 35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1} gave maximum haulm calcium content of 1.18% which was significantly higher as compared to the other two levels of nitrogen and phosphorus. Similarly, Rao and Shaktawat (2005) reported that the application of 60 kg P_2O_5 ha^{-1} significantly increased the calcium concentration in the above ground part of groundnut as compared to 20 kg P_2O_5 ha^{-1}. Application of phosphorus might have led to the development of extensive root system, thus resulting in the improved absorption of nutrients from the soil including calcium.

4.6.8 Total calcium uptake in plant at harvest

The data on the effect of various treatments on the total calcium uptake by the groundnut are presented in the table 4.13. Total calcium uptake by the groundnut plants was significantly influenced by the different gypsum levels in both the years. In 2018, application of 225 kg ha^{-1} gypsum recorded maximum calcium uptake (153.59 kg ha^{-1}), which was statistically at par with 175 kg ha^{-1} gypsum (145.45 kg ha^{-1}) while significantly higher than 125 kg ha^{-1} gypsum (134.23 kg ha^{-1}) as well as control (119.9 kg ha^{-1}). In the year 2019, 225 kg ha^{-1} gypsum recorded maximum calcium uptake (171.47 kg ha^{-1}) and it was significantly higher as compared to the other doses of gypsum. Rao and Shaktawat (2005) reported parallel results and observed that the application of 250 kg ha^{-1} gypsum significantly increased the total Ca uptake by groundnut plant over control. This increase in calcium uptake might be due to the improvement in rhizosphere conditions with gypsum application, which led to increased absorption of nutrients. Gypsum application stage also had a significant influence on the total calcium uptake during both the years. Split application of gypsum recorded significantly higher calcium uptake (141.88 kg ha^{-1} in 2018 and 154.78 kg ha^{-1} in 2019) as compared to the application of full dose of gypsum at the time of sowing during both the years.

Nitrogen and phosphorus levels also exerted a significant influence on the total calcium uptake in both the years. In both the years, application of 35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1} gave highest calcium uptake (143.97 kg ha^{-1} in 2018 and 156.66 kg ha^{-1} in 2019), which was at par with 25 kg N ha^{-1} + 30 kg P_2O_5 ha^{-1} (140.62 kg ha^{-1} in 2018 and 151.46 kg ha^{-1} in 2019), while significantly higher than 15 kg N ha^{-1} + 20 kg P_2O_5 ha^{-1} (130.29 kg ha^{-1} in 2018 and 141.89 kg ha^{-1} in 2019). Similar findings were supported by Singh and Chaudri (2007)

Table 4.13: Haulm and kernel calcium content and total calcium uptake as influenced by gypsum levels, gypsum application stage and nitrogen and phosphorus levels

Treatments	Ca content (%)				Total Ca uptake ($kg\ ha^{-1}$)	
	Haulm		Kernel			
	2018	2019	2018	2019	2018	2019
Gypsum levels						
Control	1.11	1.11	0.360	0.364	119.90	126.44
125 $kg\ ha^{-1}$	1.16	1.16	0.376	0.376	134.23	144.23
175 $kg\ ha^{-1}$	1.19	1.18	0.376	0.378	145.45	157.88
225 $kg\ ha^{-1}$	1.19	1.19	0.377	0.378	153.59	171.47
CD (p=0.05)	0.04	0.05	0.010	0.010	8.16	11.72
Gypsum application stage						
Full at sowing	1.16	1.16	0.372	0.372	134.71	145.22
50% at sowing + 50% at flower initiation stage	1.17	1.17	0.372	0.376	141.88	154.78
CD (p=0.05)	NS	NS	NS	NS	5.77	8.29
Nitrogen and phosphorus levels						
15 $kg\ N\ ha^{-1}$ + 20 $kg\ P_2O_5\ ha^{-1}$	1.14	1.14	0.370	0.371	130.29	141.89
25 $kg\ N\ ha^{-1}$ + 30 $kg\ P_2O_5\ ha^{-1}$	1.18	1.16	0.372	0.374	140.62	151.46
35 $kg\ N\ ha^{-1}$ + 40 $kg\ P_2O_5\ ha^{-1}$	1.18	1.18	0.375	0.377	143.97	156.66
CD (p=0.05)	0.03	0.02	NS	NS	4.89	5.22
Interaction	NS	NS	NS	NS	NS	NS

who advocated an increase in the uptake of calcium by groundnut plants with increased levels of applied nitrogen. Likewise, Rao and Shaktawat (2005) reported that the application of 60 kg $P_2O_5\ ha^{-1}$ significantly increased the total Ca uptake by groundnut plant over 20 kg $P_2O_5\ ha^{-1}$. Phosphorus might have improved the uptake of various nutrients including calcium due to development of extensive root system.

4.6.9 Sulphur content in plant (haulm and kernel) at harvest

The data on the effect of various treatments on sulphur content in the haulm and kernel of the spring groundnut are presented in table 4.14. Sulphur content in the haulm and kernel of groundnut was significantly influenced by different gypsum levels during both the years. Application of 225 $kg\ ha^{-1}$ gypsum resulted in maximum sulphur content in haulm (0.257% in 2018 and 0.258% in 2019) as well as maximum sulphur content in kernel (0.365%

in 2018 and 0.367% in 2019), which was statistically at par with the application of 175 kg ha^{-1} and 125 kg ha^{-1} gypsum, while significantly greater than control. The current findings are supported by Pathak *et al* (2013) who revealed that the application of gypsum resulted in a significant increase of 29.3% in S concentration in kernels of groundnut over control. Rao and Shaktawat (2005) also reported that the application of 250 kg ha^{-1} gypsum significantly increased the sulphur concentration in kernel and haulm of groundnut over control. The increase in sulphur content due to gypsum application may be due to improved nutritional environment in the rhizosphere as well as in the plant system which leads to translocation of S to reproductive parts which ultimately increased the S concentration in kernels of groundnut (Alcordo and Recheigl 1993). Different gypsum application stages had a non-significant effect on the sulphur content of haulm and kernel in both the years.

Table 4.14: Haulm and kernel sulphur content and total sulphur uptake as influenced by gypsum levels, gypsum application stage and nitrogen and phosphorus levels

Treatments	**S content (%)**				**Total S uptake (kg ha^{-1})**	
	Haulm		**Kernel**			
	2018	**2019**	**2018**	**2019**	**2018**	**2019**
Gypsum levels						
Control	0.245	0.248	0.347	0.352	32.28	34.89
125 kg ha^{-1}	0.254	0.255	0.362	0.364	36.15	39.43
175 kg ha^{-1}	0.255	0.257	0.364	0.366	38.63	42.96
225 kg ha^{-1}	0.257	0.258	0.365	0.367	41.34	46.39
CD (p=0.05)	0.008	0.007	0.012	0.010	1.32	2.76
Gypsum application stage						
Full at sowing	0.252	0.252	0.357	0.360	36.07	39.42
50% at sowing + 50% at flower initiation stage	0.253	0.257	0.362	0.365	38.12	42.42
CD (p=0.05)	NS	NS	NS	NS	0.93	1.95
Nitrogen and phosphorus levels (N)						
15 kg N ha^{-1} + 20 kg P_2O_5 ha^{-1}	0.248	0.251	0.352	0.356	35.01	38.52
25 kg N ha^{-1} + 30 kg P_2O_5 ha^{-1}	0.254	0.255	0.362	0.365	37.61	41.38
35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1}	0.256	0.258	0.364	0.366	38.68	42.85
CD (p=0.05)	0.005	0.004	0.008	0.006	1.33	1.51
Interaction	NS	NS	NS	NS	NS	NS

Nitrogen and phosphorus levels exerted a significant influence on the sulphur content of haulm and kernel of groundnut during both the years. Application of 35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1} resulted in maximum sulphur content in haulm (0.256% in 2018 and 0.258% in 2019) as well as in kernel (0.364% in 2018 and 0.366% in 2019), which was statistically at par with 25 kg N ha^{-1} + 30 kg P_2O_5 ha^{-1}, while significantly higher than the application of 15 kg N ha^{-1} + 20 kg P_2O_5 ha^{-1} during both the years. Rao and Shaktawat (2005) advocated that the application of 60 kg P_2O_5 ha^{-1} significantly increased the sulphur concentration in the above ground parts of groundnut in comparison to 20 kg P_2O_5 ha^{-1}. Nitrogen fertilization may increase the cation exchange capacity of plant roots and thus makes them more efficient in absorbing nutrient ions. The application of higher doses of nitrogen was responsible for better root and shoot development and resulted in greater absorption of sulphur in haulm and kernel (Patel *et al* 2014). Also the increase in S uptake because of N application could be due to the synergistic effect of N and S in plants. The increased availability of nutrients in root zone coupled with increased metabolic activity at cellular level might have increased nutrient uptake and their accumulation in vegetative plant parts (Sharma *et al* 2013).

4.6.10 Total sulphur uptake in plant at harvest

The data on the effect of different treatments on total sulphur uptake by groundnut plants are presented in the table 4.14. Gypsum levels exerted a significant influence on the total sulphur uptake by groundnut plants during both the years. Application of 225 kg ha^{-1} gypsum gave maximum sulphur uptake (41.34 kg ha^{-1} in 2018 and 46.39 kg ha^{-1} in 2019), which was significantly higher as compared to the other doses of gypsum. The results are in accordance with the findings of Pancholi *et al* (2017) who observed that the application of 324 kg gypsum ha^{-1} resulted in significantly higher total S uptake (15.37 kg ha^{-1}) over control. Rao and Shaktawat (2005) also reported that the application of 250 kg ha^{-1} gypsum significantly increased the total S uptake by groundnut plant over control. This increase in nutrient uptake could be attributed to increased availability of S to plants through application of gypsum, which in turn might have resulted in profuse shoot and root growth thereby activating greater absorption of N, P and S from the soil.

Gypsum application stage also significantly influenced the total sulphur uptake during both the years. Split application of gypsum (50% at sowing + 50% at flower initiation stage) gave significantly higher sulphur uptake (38.12 kg ha^{-1} in 2018 and 42.42 kg ha^{-1} in 2019) over the application of full dose of gypsum at sowing during both the years.

Nitrogen and phosphorus levels also had a significant influence on the total sulphur uptake in both the years. In both the years, application of 35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1}

recorded maximum sulphur uptake (38.68 kg ha^{-1} in 2018 and 42.85 kg ha^{-1} in 2019), which was statistically at par with 25 kg N ha^{-1} + 30 kg P_2O_5 ha^{-1} (37.61 kg ha^{-1} in 2018 and 41.38 kg ha^{-1} in 2019), while significantly higher than that of 15 kg N ha^{-1} + 20 kg P_2O_5 ha^{-1} (35.01 kg ha^{-1} in 2018 and 38.52 kg ha^{-1} in 2019). Similar findings were reported by Singh and Chaudri (2007) who observed an increase in the uptake of sulphur by groundnut plants with an increase in the levels of applied nitrogen. Similarly, Rao and Shaktawat (2005) reported that the application of 60 kg P_2O_5 ha^{-1} significantly increased the total S uptake by groundnut plant over 20 kg P_2O_5 ha^{-1}. The application of nitrogen increased sulphur uptake at higher level of N, which would be attributed to the fact that application of nitrogen caused increased requirement for S and accordingly the uptake of S (Srinidhi 2000).

4.7 Soil analysis

4.7.1 pH of soil after harvest of crop

The data on the effect of different treatments on pH of soil after the harvest of crop are presented in the table 4.15. Gypsum levels were observed to have a non-significant effect on the soil reaction during both the years. However, the range of pH observed was 8.22 to

Table 4.15: pH, EC and OC of soil (after harvest of crop) as influenced by gypsum levels, gypsum application stage and nitrogen and phosphorus levels

Treatments	pH		EC (dS m^{-1})		OC (%)	
	2018	2019	2018	2019	2018	2019
Gypsum levels						
Control	8.24	8.19	0.61	0.62	0.33	0.35
125 kg ha^{-1}	8.25	8.28	0.62	0.63	0.34	0.34
175 kg ha^{-1}	8.24	8.33	0.64	0.63	0.35	0.34
225 kg ha^{-1}	8.22	8.31	0.63	0.63	0.35	0.35
CD (p=0.05)	NS	NS	NS	NS	NS	NS
Gypsum application stage						
Full at sowing	8.24	8.27	0.62	0.62	0.34	0.35
50% at sowing + 50% at flower initiation stage	8.24	8.28	0.62	0.63	0.35	0.35
CD (p=0.05)	NS	NS	NS	NS	NS	NS
Nitrogen and phosphorus levels						
15 kg N ha^{-1} + 20 kg P_2O_5 ha^{-1}	8.25	8.28	0.62	0.62	0.34	0.34
25 kg N ha^{-1} + 30 kg P_2O_5 ha^{-1}	8.23	8.27	0.63	0.63	0.34	0.35
35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1}	8.23	8.28	0.62	0.63	0.35	0.35
CD (p=0.05)	NS	NS	NS	NS	NS	NS
Interaction	NS	NS	NS	NS	NS	NS

8.25 in 2018 and 8.19 to 8.33 in 2019 varying non-significantly between various gypsum levels. These results were supported by Warren (2011) who observed that gypsum application improves the pod filling of groundnut without changing the soil pH. Chakrabarti (1990) also reported that the soil characteristics such as pH, EC and organic carbon did not show significant variation in gypsum applied soil. The effect of gypsum application stage on pH of soil was non-significant during both the years. Nitrogen and phosphorus levels also had a non-significant effect on soil reaction during both the years. In 2018, pH value of 8.25 was observed with 15 kg N ha^{-1} + 20 kg P_2O_5 ha^{-1} whereas 25 kg N ha^{-1} + 30 kg P_2O_5 ha^{-1} and 35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1}, both gave pH value of 8.23. In 2019, pH value of 8.28 was obtained with 15 kg N ha^{-1} + 20 kg P_2O_5 ha^{-1} and 35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1} whereas, a pH value of 8.27 was observed with the application of 25 kg N ha^{-1} + 30 kg P_2O_5 ha^{-1}. Kharade (2009) also suggested that the application of different levels of nitrogen did not affect soil pH.

4.7.2 Electrical conductivity of soil after harvest of crop

The data on the effect of various treatments on the electrical conductivity of soil after harvest of the crop are presented in the table 4.15. A non-significant effect of gypsum levels was noticed on the EC of soil after the harvest of groundnut crop during both the years. EC value of soil varied non-significantly between various gypsum levels ranging between 0.61 to 0.64 dS m^{-1} in 2018 and 0.62 to 0.63 dS m^{-1} in 2019. Similarly, Chakrabarti (1990) reported that the electrical conductivity of soil did not show significant variation in gypsum applied soil. EC of the soil was non-significantly influenced by the stage of application of gypsum during both the years. Nitrogen and phosphorus levels also had a non-significant effect on the electrical conductivity of soil. EC value of soil varied non-significantly between various nitrogen and phosphorus levels ranging between 0.62 to 0.63 dS m^{-1} in 2018 as well as in 2019.

4.7.3 Organic carbon of soil after harvest of crop

The data on the effect of various treatments on the organic carbon of soil after harvest of the crop are presented in the table 4.15. Gypsum levels had a non-significant effect on the organic carbon of soil. The values of organic carbon ranged between 0.33 to 0.35% in 2018 and 0.34 to 0.35% in 2019. Chakrabarti (1990) advocated that the soil organic carbon did not show significant variation in gypsum applied soil. Gypsum application stage also had a non-significant effect on the organic carbon of soil. Nitrogen and phosphorus levels exerted a non-significant influence on the organic carbon of soil. However, a non-significant increase in the organic carbon of soil was observed with increase in the levels of applied nitrogen and phosphorus.

4.7.4 Available nitrogen of soil after harvest of crop

The data on the influence of various treatments on the available nitrogen of soil after harvest of the crop are presented in the table 4.16. The available nitrogen in the soil was influenced non-significantly by various gypsum levels during both the years. However, an increasing trend in the available nitrogen of soil was seen with increase in the gypsum levels. Lowest value of available nitrogen was obtained with control (206 kg ha^{-1} in 2018 and 205.6 kg ha^{-1} in 2019) while highest value was observed with 225 kg ha^{-1} gypsum (227.7 kg ha^{-1} in 2018 and 224.6 kg ha^{-1} in 2019) during both the years. These findings are in corroboration with the results of Aulakh *et al* (1980) who reported that N availability increased with the

Table 4.16: Available N, P, K, Ca and S of soil (after harvest of crop) as influenced by gypsum levels, gypsum application stage and nitrogen and phosphorus levels

Treatments	Available N (kg ha^{-1})		Available P (kg ha^{-1})		Available K (kg ha^{-1})		Available Ca (ppm)		Available S (kg ha^{-1})	
	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019
Gypsum levels										
Control	206.0	205.6	18.70	19.82	252.3	253.6	100.3	102.1	23.57	24.42
125 kg ha^{-1}	211.1	211.6	20.76	22.44	259.9	257.9	105.5	107.9	27.94	28.62
175 kg ha^{-1}	226.1	217.5	21.92	22.86	264.8	259.5	107.0	109.2	29.03	29.81
225 kg ha^{-1}	227.7	224.6	22.10	23.56	269.4	260.5	108.1	110.6	30.04	30.68
CD (p=0.05)	NS	NS	1.56	1.27	NS	NS	2.5	2.6	1.93	1.82
Gypsum application stage										
Full at sowing	216.4	210.2	20.52	21.91	261.3	256.2	104.4	106.6	27.06	27.97
50% at sowing + 50% at flower initiation stage	219.1	219.5	21.22	22.43	261.9	259.6	106.1	108.3	28.24	28.80
CD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Nitrogen and phosphorus levels										
15 kg N ha^{-1} + 20 kg P_2O_5 ha^{-1}	206.3	200.5	18.95	19.59	249.6	247.4	104.4	107.0	27.00	27.85
25 kg N ha^{-1} + 30 kg P_2O_5 ha^{-1}	217.8	215.1	20.90	22.54	263.6	262.1	105.3	107.4	27.62	28.45
35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1}	229.1	228.9	22.75	24.37	271.6	264.1	106.0	108.0	28.32	28.85
CD (p=0.05)	10.6	13.2	1.75	1.66	12.7	12.9	NS	NS	NS	NS
Interaction	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

application of sulphur through gypsum. The increase in available nitrogen may be due to increased supply of sulphur as sulphur may enhance the nodulation by increasing the supply of sulphur containing proteins, which are essential for multiplication and growth of rhizobia, which fix atmospheric nitrogen. Available nitrogen of soil differed non-significantly with different gypsum application stages during both the years. However, split application of gypsum resulted in higher available nitrogen as compared to application of full dose of gypsum at sowing during both the years.

Nitrogen and phosphorus levels exerted a significant influence on the available nitrogen of soil during both the years. Application of 35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1} resulted in maximum available nitrogen (229.1 kg ha^{-1} in 2018 and 228.9 kg ha^{-1} in 2019), which was significantly higher as compared to the other two levels of nitrogen and phosphorus during both the years. Mohapatra and Dixit (2010) reported that the increase in available nitrogen in soil could be due to higher amount of N fixation by *Rhizobium* under more favourable conditions of soil and lysis of nodules and secretion of N from these nodules. Also, application of phosphorus may enhance N_2-fixation in groundnut which in turn, improved the N status of the soil (Agboola and Fayemi 1972).

4.7.5 Available phosphorus of soil after harvest of crop

The data on the effect of different treatments on the available phosphorus of soil after harvest of the crop are presented in the table 4.16. Gypsum levels exerted a significant influence on the available phosphorus of soil during both the years. Application of 225 kg ha^{-1} gypsum gave maximum available phosphorus (22.1 kg ha^{-1} in 2018 and 23.56 kg ha^{-1} in 2019), which was statistically at par with 175 kg ha^{-1} (21.92 kg ha^{-1} in 2018 and 22.86 kg ha^{-1} in 2019) and 125 kg ha^{-1} (20.76 kg ha^{-1} in 2018 and 22.44 kg ha^{-1} in 2019) gypsum, while significantly higher than control (18.7 kg ha^{-1} in 2018 and 19.82 kg ha^{-1} in 2019). The effect of gypsum application stage on available phosphorus was non-significant during both the years. Split application of gypsum resulted in higher available P of soil as compared to basal application of gypsum during both the years, although the difference was non-significant.

Available phosphorus of soil was significantly influenced by the different levels of nitrogen and phosphorus in both the years. Application of 35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1} resulted in maximum available phosphorus (22.75 kg ha^{-1} in 2018 and 24.37 kg ha^{-1} in 2019), which was significantly higher over other doses of nitrogen and phosphorus during both the years. The increase in phosphorus availability might be due to synergistic effect of nitrogen with phosphorus which increased the availability of P in the soil.

4.7.6 Available potassium of soil after harvest of crop

The data on the effect of various treatments on the available potassium of soil after harvest of the crop are presented in the table 4.16. Application of different gypsum levels had non-significant influence on the available potassium of soil during both the years. The available potassium of soil displayed an increase with increased levels of gypsum, although the increase was non-significant.

Gypsum application stage also exerted a non-significant influence on the available potassium of soil. Split application of gypsum resulted in higher available potassium of soil as compared to the basal application of gypsum, although the difference was non-significant.

Nitrogen and phosphorus levels exerted a significant influence on the available potassium of soil after the harvest of crop during both the years. Maximum available potassium in soil was recorded with the treatment 35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1} (271.6 kg ha^{-1} in 2018 and 264.1 kg ha^{-1} in 2019), which was statistically at par with 25 kg N ha^{-1} + 30 kg P_2O_5 ha^{-1} (263.6 kg ha^{-1} in 2018 and 262.1 kg ha^{-1} in 2019), while significantly higher than 15 kg N ha^{-1} + 20 kg P_2O_5 ha^{-1} (249.6 kg ha^{-1} in 2018 and 247.4 kg ha^{-1} in 2019). Parallel findings were observed by Hasan (2018) who noticed that the application of 27 kg N ha^{-1}+82 kg P_2O_5 ha^{-1} resulted in higher potassium content of soil as compared to lower doses of nitrogen and phosphorus. The increase in potassium availability might be due to synergistic effect of nitrogen with potassium which increased the availability of K in the soil (Bhikane 2002).

4.7.7 Available calcium of soil after harvest of crop

The data on the effect of various treatments on the available calcium of soil after harvest of the crop are presented in the table 4.16. Application of different doses of gypsum had a significant influence on available calcium of the soil during both the years. Application of 225 kg ha^{-1} gypsum recorded maximum available calcium in soil during both the years (108.1 ppm in 2018 and 110.6 ppm in 2019), which was statistically at par with that of 175 kg ha^{-1} gypsum (107 ppm in 2018 and 109.2 ppm in 2019) while significantly higher than 125 kg ha^{-1} gypsum (105.5 ppm in 2018 and 107.9 ppm in 2019) and control (100.3 ppm in 2018 and 102.1 ppm in 2019). Similarly, Sharma *et al* (1971) and Puntamkar *et al* (1972) observed an increase in the available calcium of soil with the application of gypsum.

Gypsum application stage did not affect available calcium of soil significantly during both the years. Split application of gypsum resulted in significantly higher available calcium of soil in comparison to application of full dose of gypsum at sowing, although the difference was non-significant. Hallock and Allison (1980b) also achieved similar results and reported that the application of gypsum at early flowering stage resulted in higher calcium content in soil as compared to control.

Available calcium of soil was affected non-significantly by various doses of nitrogen and phosphorus. However, with increase in the levels of nitrogen and phosphorus, an increasing trend of soil available calcium was observed, though the difference was non-significant during both the years.

4.7.8 Available sulphur of soil after harvest of crop

The data on the effect of various treatments on the available sulphur of soil after the harvest of crop are presented in the table 4.16. Application of different doses of gypsum had a significant influence on the available sulphur of soil during both the years. Application of 225 kg ha^{-1} gypsum recorded maximum available sulphur in soil (30.04 kg ha^{-1} in 2018 and 30.68 kg ha^{-1} in 2019), which was statistically at par with that of 175 kg ha^{-1} gypsum (29.03 kg ha^{-1} in 2018 and 29.81 kg ha^{-1} in 2019) while significantly higher than 125 kg ha^{-1} gypsum (27.94 kg ha^{-1} in 2018 and 28.62 kg ha^{-1} in 2019) and control (23.57 kg ha^{-1} in 2018 and 24.42 kg ha^{-1} in 2019) during both the years. The results were confirmed by Jat and Ahlawat (2010) who reported that increasing the rate of gypsum application significantly improved the available S content in the soil.

Gypsum application stage had a non-significant influence on the available sulphur of soil during both the years. Split application of gypsum resulted in higher available sulphur in soil as compared to application of full dose of gypsum at sowing during both the years, though the differences were non-significant.

Nitrogen and phosphorus levels exerted a non-significant influence on the available sulphur of soil. However, with increase in the levels of nitrogen and phosphorus, an increasing trend of available sulphur in soil was observed though the difference was non-significant during both the years.

CHAPTER V

SUMMARY

Groundnut (*Arachis hypogaea* L.) is a major oilseed and it accounts for 25% of the total oilseed production in India. Groundnut kernels contain 48-50% edible oil, 25-34% protein, 10-20% carbohydrates, rich source of vitamins (E, K, and B complex) and minerals (phosphorus, calcium, magnesium and potassium). Groundnut kernel being highly digestible can be consumed as shelled nut or processed form like peanut sauce, flour and butter. After the extraction of oil, the residual oil cake obtained are rich in nutrients (7-8% N, 1.5% P_2O_5, 1.2% K_2O) and acts as a valuable animal feed and organic manure. Groundnut crop improved the fertility level of soil by fixing atmospheric nitrogen in its root nodules (Bairagi *et al* 2017).

Groundnut is a legume-oilseed crop, its requirement of phosphorus, calcium and sulphur is quite high. Moreover, as compared to other legume crops, groundnut is a very exhaustive crop because it removed a large amount of nutrients from the soil (Varade and Urkude 1982). Gypsum is commonly used as a source of Ca and S for groundnut. The dissolution of gypsum is quite rapid and therefore readily adds Ca and S to the podding zone. Application of gypsum improved soil structure which favoured effective pegging in groundnut (Agasimani *et al* 1992). Calcium maintains the membrane permeability, cell integrity, increases pollen germination, activates many enzymes involved in cell division, takes part in protein synthesis and carbohydrate transfer in groundnut. Calcium also increases the growth and survival of the symbiotic bacteria in groundnut which therefore has a positive influence on biological nitrogen fixation. Sulphur is a component of protein and has an important role to play in oil synthesis. It also increases chlorophyll synthesis and decreases chlorosis. It improves nodulation, pod yield and reduces the incidence of diseases (Singh and Chaudri 2007). Groundnut is a self-fertilizing crop, since its most of the nitrogen requirement is met by the nitrogen-fixing bacteria that are present in the root nodules. At very high yield levels, the nitrogen requirement of nodulated groundnut cannot be met from symbiotic N fixation alone (Williams 1979). Phosphorus plays a significant role in nodule formation and fixation of atmospheric nitrogen (Brady and Well 2002). Phosphorus is an important structural component of membrane system of the cell, the chloroplast and mitochondria. It is an essential constituent of nucleic acid, amino acids, phytin, proteins, nucleoproteins and energy rich phosphate bonds (ADP and ATP).

However, very less information on the balanced nutrition of spring groundnut is available. Therefore, there is a need to develop a nutrient management strategy to achieve the potential production of spring groundnut. Keeping all these points in view the present investigation was proposed to study the **"Effect of nitrogen, phosphorus and gypsum on growth, yield and quality of spring groundnut (*Arachis hypogaea* L.)"** with the following objectives:

- To optimize the mineral nutrition in terms of nitrogen, phosphorus and gypsum dose for optimum growth, yield and quality of spring groundnut.
- To find out the proper time for application of gypsum for optimum growth, yield and quality of spring groundnut.

The experiment was laid out in a split plot design replicated three times with four levels of gypsum (0, 125, 175 and 225 kg ha^{-1}) in combination with two gypsum application stages (Full at sowing and 50% at sowing + 50% at flower initiation stage) in the main plot and three levels of nitrogen and phosphorus (15 kg N ha^{-1} + 20 kg P_2O_5 ha^{-1}, 25 kg N ha^{-1} + 30 kg P_2O_5 ha^{-1} and 35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1}) in the sub-plot conducted during spring seasons of 2018 and 2019.

Gypsum levels

Vegetative growth parameters *viz.* plant height, number of branches plant^{-1}and dry matter accumulation were highest with the application of 225 kg ha^{-1} gypsum, which was statistically at par with 175 kg ha^{-1} gypsum, while significantly higher than 125 kg ha^{-1} gypsum as well as control during 2018 and 2019. Phenological parameters such as days to 50% flowering and days to 50% pegging were not significantly affected by different gypsum levels during both the years. During 2018 and 2019, total number of flowers plant^{-1} and total number of pegs plant^{-1} were maximum with 225 kg ha^{-1} gypsum and significantly higher as compared to other three levels of gypsum (Control, 125 kg ha^{-1}and 175 kg ha^{-1}). Yield attributes mainly 100-kernel weight, shelling percentage and sound mature kernels were reported to be highest with 225 kg ha^{-1} gypsum, which was statistically at par with 175 and 125 kg ha^{-1} gypsum while significantly higher than control during 2018 and 2019. Total number of pods plant^{-1} were observed to be highest with 225 kg ha^{-1} gypsum which was significantly higher than control, 125 kg ha^{-1} and 175 kg ha^{-1} gypsum during both the years. Pod yield, haulm yield and kernel yield were reported to be maximum with the application of 225 kg ha^{-1} gypsum which was significantly higher as compared to other gypsum levels during both the years. Although, harvest index was non-significantly affected but its highest value was found with 225 kg ha^{-1} gypsum followed by 175, 125 kg ha^{-1} gypsum and control. Gross returns, net returns and benefit cost ratio were maximum with 225 kg ha^{-1} gypsum, which were significantly higher as compared to control, 125 kg ha^{-1} and 175 kg ha^{-1} gypsum during both the years.

Protein content in kernels was highest with the application of 225 kg ha^{-1} gypsum which was at par with 175 and 125 kg ha^{-1} gypsum while significantly higher than control during both the years. Oil content was maximum with 225 kg ha^{-1} gypsum and was significantly higher than the other three levels of gypsum (Control, 125 kg ha^{-1}and 175 kg ha^{-1}) during both the years.

Nitrogen content in haulm was non-significantly affected with different gypsum levels during 2018 and 2019. Highest nitrogen content in kernel was obtained with the application of 225 kg ha^{-1} gypsum, which was statistically at par with 175 and 125 kg ha^{-1} gypsum while significantly higher than the control during both the years. Phosphorus, potassium, calcium and sulphur content in haulm and kernel was highest with the use of 225 kg ha^{-1} gypsum, which was statistically at par with 175 and 125 kg ha^{-1} gypsum while significantly higher than the control during both the years. Total N, P, K, Ca and S uptake were maximum with 225 kg ha^{-1} gypsum and was significantly higher over other levels of gypsum *viz.* control, 125 kg ha^{-1}and 175 kg ha^{-1} during both the years. Soil characteristics such as pH, EC, organic carbon, available nitrogen and potassium analysed after the harvest of crop were not significantly affected by the application of different gypsum levels during both the years. Available phosphorus in soil was highest with 225 kg ha^{-1} gypsum which was at par with 175 and 125 kg ha^{-1} gypsum, while significantly higher over control during both the years. During 2018 and 2019, available calcium and sulphur of soil were maximum with 225 kg ha^{-1} gypsum, which was at par with 175 kg ha^{-1} gypsum while significantly higher than 125 kg ha^{-1} gypsum and no application of gypsum (control).

Gypsum application stage

Vegetative growth parameters (plant height, number of branches plant^{-1} and dry matter accumulation) were significantly higher with split application of gypsum (50% at sowing + 50% at flower initiation stage) as compared to application of full dose of gypsum at sowing except at 30 DAS, where full dose at sowing resulted in significantly higher growth parameters over split application during both the years. Phenological parameters such as days to 50% flowering and days to 50% pegging remained unaffected by different gypsum application stages. Total number of flowers plant^{-1} and total number of pegs plant^{-1} were significantly higher with split application over application of full dose of gypsum at sowing during both the years. 100-kernel weight and shelling percentage were non-significantly affected by gypsum application stage during both the years. Sound mature kernels were significantly higher with split application over application of full dose of gypsum at sowing during 2018 and 2019. Total number of pods plant^{-1} were observed to be significantly higher with split application over application of full dose of gypsum at sowing during both the years. During 2018 and 2019, pod yield, haulm yield and kernel yield were observed to be significantly higher with the split application of gypsum over application of full dose of gypsum at sowing. Although, harvest index was non-significantly affected but its higher value was found with split application followed by application of full dose of gypsum at sowing during 2018 and 2019. Gross returns and net returns were observed to be significantly higher with split application over application of full dose of gypsum at sowing during 2018 and 2019. Benefit cost ratio was significantly higher with split application over application of full dose of gypsum at sowing during 2018 whereas in 2019, the difference was non-significant.

Quality characteristics like protein content and oil content in kernels were non-significantly affected by different gypsum application stages during both the years.

N, P, K, Ca and S content in haulm and kernel were also affected non-significantly with gypsum application stage during 2018 and 2019. Total N, P, K, Ca and S uptake were observed to be significantly higher with split application of gypsum over application of full dose of gypsum at sowing during both the years. Soil characteristics such as pH, EC and organic carbon analysed after the harvest of crop were non-significantly affected by the different gypsum application stages during both the years. Available nitrogen, phosphorus, potassium, calcium and sulphur in soil were also non-significantly affected by different gypsum application stages.

Nitrogen and phosphorus levels

Vegetative growth parameters *viz.* plant height, number of branches plant^{-1} and dry matter accumulation were reported to be highest during both the years with the application of 35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1}, which was statistically at par with 25 kg N ha^{-1} + 30 kg P_2O_5 ha^{-1} and significantly higher than 15 kg N ha^{-1} + 20 kg P_2O_5 ha^{-1} during 2018 and 2019. Phenological parameters such as days to 50% flowering and days to 50% pegging were non-significantly affected by different nitrogen and phosphorus levels during 2018 and 2019. Total number of flowers plant^{-1} and total number of pegs plant^{-1} were maximum with 35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1}, while statistically at par with 25 kg N ha^{-1} + 30 kg P_2O_5 ha^{-1} and significantly higher as compared to 15 kg N ha^{-1} + 20 kg P_2O_5 ha^{-1} during both the years. Yield attributes mainly 100-kernel weight and shelling percentage were non-significantly affected by different levels of nitrogen and phosphorus during both the years. Sound mature kernels, total number of pods plant^{-1}, pod yield, haulm yield and kernel yield were reported to be maximum with the application of 35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1}, while statistically at par with 25 kg N ha^{-1} + 30 kg P_2O_5 ha^{-1} and significantly higher as compared 15 kg N ha^{-1} + 20 kg P_2O_5 ha^{-1} during 2018 and 2019. Although, harvest index was non-significantly affected by different levels of nitrogen and phosphorus but its highest value was found with 35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1} followed by 25 kg N ha^{-1} + 30 kg P_2O_5 ha^{-1} and 15 kg N ha^{-1} + 20 kg P_2O_5 ha^{-1} during both the years. Gross returns and net returns were maximum with 35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1}, while statistically at par with 25 kg N ha^{-1} + 30 kg P_2O_5 ha^{-1} and significantly higher than 15 kg N ha^{-1} + 20 kg P_2O_5 ha^{-1} during both the years. Benefit cost ratio was more with higher levels of nitrogen and phosphorus although the difference was non-significant among the different levels during both the years.

Protein content and oil content in kernels were highest with the application of 35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1} and was significantly higher than the other levels of nitrogen and phosphorus during both the years.

Nitrogen content in haulm was highest with the application of 35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1} and 25 kg N ha^{-1} + 30 kg P_2O_5 ha^{-1}, which were significantly higher over 15 kg N ha^{-1} + 20 kg P_2O_5 ha^{-1} during both the years. Nitrogen content in kernel was maximum with 35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1} and significantly higher over other doses during both the years. Phosphorus and sulphur content in haulm and kernel was highest with the use of 35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1}, while statistically at par with 25 kg N ha^{-1} + 30 kg P_2O_5 ha^{-1} and significantly higher than 15 kg N ha^{-1} + 20 kg P_2O_5 ha^{-1} during 2018 and 2019. Potassium content of haulm was highest with 35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1}, while at par with 25 kg N ha^{-1} + 30 kg P_2O_5 ha^{-1} and significantly higher than 15 kg N ha^{-1} + 20 kg P_2O_5 ha^{-1} during both the years. Potassium content in kernel was non-significantly affected by different levels of nitrogen and phosphorus. Calcium content of haulm was maximum with 35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1} and significantly higher than other doses whereas Ca content of kernel was non-significantly affected by different nitrogen and phosphorus levels during 2018 and 2019. Total N, P, K, Ca and S uptake were maximum with 35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1}, while statistically at par with 25 kg N ha^{-1} + 30 kg P_2O_5 ha^{-1} and significantly higher than 15 kg N ha^{-1} + 20 kg P_2O_5 ha^{-1} during both the years. Soil characteristics such as pH, EC and organic carbon after the harvest of crop were non-significantly affected by the application of different nitrogen and phosphorus levels during both the years. Available nitrogen and phosphorus in soil was highest with 35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1} and significantly higher over other levels of nitrogen and phosphorus. Available potassium was maximum with 35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1}, while at par with 25 kg N ha^{-1} + 30 kg P_2O_5 ha^{-1} and significantly higher than 15 kg N ha^{-1} + 20 kg P_2O_5 ha^{-1} during both the years. Available calcium and sulphur in soil were non-significantly affected by different nitrogen and phosphorus levels during both the years.

Conclusion

The application of 225 kg ha^{-1} gypsum resulted in significantly maximum yield and also improved growth and quality parameters of spring groundnut over lower levels. In spring groundnut, gypsum should be applied in two split doses *i.e.* half at sowing time and remaining half at flower initiation stage to get more growth, yield and quality of groundnut. To get maximum growth, yield and quality of spring groundnut, the crop should be applied with 25 kg N ha^{-1} + 30 kg P_2O_5 ha^{-1}.

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APPENDIX I

Weekly meteorological data recorded during *spring* season - 2018 at Meteorological Observatory, Punjab Agricultural University, Ludhiana

Standard Meteorological Week (SMW)		Temperature (^{o}C)			Relative humidity (%)			Rainfall (mm)	Total evaporation (mm)	Sun shine (hrs)	Wind speed (Km/h)
		Max.	Min.	Mean	M*	E*	Mean				
11	12 Mar – 18 Mar	29.9	14.1	22.0	85	30	58	0.0	29.8	10.0	3.0
12	19 Mar – 25 Mar	29.2	14.2	21.7	86	44	65	0.0	27.8	7.8	4.3
13	26 Mar – 01 Apr	33.1	16.5	24.8	74	29	52	0.0	38.6	10.1	4.6
14	02 Apr – 08 Apr	34.8	20.3	27.5	69	33	51	0.0	42.2	5.9	5.1
15	09 Apr – 15 Apr	33.1	18.0	25.6	73	32	53	10.0	40.5	7.4	4.7
16	16 Apr – 22 Apr	35.4	19.5	27.4	58	24	41	0.0	57.3	9.7	6.5
17	23 Apr – 29 Apr	39.6	21.5	30.5	45	19	32	0.0	62.6	11.0	5.2
18	30 Apr – 06 May	36.5	24.3	30.4	56	28	42	15.4	63.0	6.7	8.7
19	07 May–13 May	38.4	23.2	30.8	55	23	39	3.6	59.6	9.0	6.3
20	14 May–20 May	38.4	23.3	30.9	51	23	37	0.0	59	6.2	5.1
21	21 May–27 May	42.1	23.7	32.9	33	9	21	0.0	70.4	10	3.9
22	28 May – 03 Jun	40.9	27.9	34.4	45	24	35	0.0	74	7.7	10.0
23	04 Jun – 10 Jun	38.7	27.2	32.9	66	40	53	37.8	60.8	7.5	7.5
24	11 Jun – 17 Jun	37.8	23.1	32.9	61	37	49	66.8	57.8	5.2	6.0
25	18 Jun – 24 Jun	38.3	26.3	32.3	61	36	49	0.0	49.0	8.7	3.7
26	25 Jun – 01 July	34.7	27.1	30.8	67	50	58	37.2	40.2	5.1	4.7
27	02 July –08 July	33.9	26.0	29.9	85	62	73	52.8	35.7	6.9	3.9

M*- morning and E*- evening.

APPENDIX II

Weekly meteorological data recorded during *spring* season - 2019 at Meteorological Observatory, Punjab Agricultural University, Ludhiana

Standard Meteorological Week (SMW)		Temperature (°C)			Relative humidity (%)			Rainfall (mm)	Total evaporation (mm)	Sun shine (hrs)	Wind speed (Km/h)
		Max.	Min.	Mean	M*	E*	Mean				
11	12 Mar – 18 Mar	24.6	10.7	17.7	90	45	68	0.0	15.4	7.5	2.7
12	19 Mar – 25 Mar	26.9	12.9	19.9	87	42	65	0.0	23.8	7.5	3.7
13	26 Mar – 01 Apr	31.1	14.7	22.9	88	38	63	0.0	26.0	10.0	2.6
14	02 Apr – 08 Apr	34.3	18.3	26.3	83	33	59	0.0	31.2	9.4	2.6
15	09 Apr – 15 Apr	35.0	19.9	27.4	70	31	51	6.6	41.5	7.1	5.0
16	16 Apr – 22 Apr	31.3	18.1	24.7	77	37	57	31.2	30.6	8.9	3.8
17	23 Apr – 29 Apr	39.3	21.9	30.6	58	19	39	3.8	52.8	10.4	4.4
18	30 Apr – 06 May	37.7	21.3	29.5	42	15	29	4.5	53.6	9.9	4.7
19	07 May–13 May	39.4	21.9	30.7	43	17	30	3.3	62.7	9.5	4.7
20	14 May–20 May	34.5	22.1	28.3	70	34	52	11.8	48.0	7.8	4.5
21	21 May–27 May	37.7	22.4	30.0	56	24	40	0.4	52.0	10.5	5.3
22	28 May – 03 Jun	43.0	26.1	34.5	45	21	33	1.4	77.4	11.5	6.9
23	04 Jun – 10 Jun	42.7	26.6	34.6	45	26	36	0.0	74.0	11.3	4.2
24	11 Jun – 17 Jun	41	25.7	33.3	48	21	35	9.5	76.0	10.4	8.0
25	18 Jun – 24 Jun	37.2	26.0	31.6	69	39	54	19.0	54.6	8.4	5.0
26	25 Jun – 01 July	39.6	28.1	33.9	59	29	47	00	62.5	10.5	5.1
27	02 July –08 July	37.6	28.5	33.1	68	48	59	14.4	50.0	5.5	6.3

M*- morning and E*- evening.

APPENDIX III

Enterprise budget of groundnut crop (ha^{-1}) for 2018 and 2019

	Item	Year	2018	2019
		Qty.	**Value (₹)**	
A	**Gross returns**			
	i) Main product (q)	10	44500	48900
	ii) By product (q)	10	1100	1150
B	**Variable costs**	**Qty.**	**(₹ ha^{-1})**	**(₹ ha^{-1})**
1	Seed and seed treatment			
	i) Seed (kg)	80	10000	13500
	ii) Indofil M-45 (gm)	240	88	88
2	Manures and fertilizers (kg)			
	i) Urea	17.5	102.5	152.5
	ii) DAP	45	1080	1260
	iii) Muriate of potash (MOP)	42.5	807.5	852.5
	iv) Gypsum	125	875	875
3	Pesticides			
	i) Bavistin (gm)	150	135	139
4	Irrigations (No.)	4	300	300
5	Human labour (hrs)	625	24150	28000
6	Tractor hours	7.5	3375	5687
8	Marketing charges (ha^{-1})	-	315	375
9	Interest on variable costs @ 10 % for half period (ha^{-1})	-	1100	1250

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OCPA	:	8.74/10.00
Title of Master's Thesis	:	Effect of nitrogen, phosphorus and gypsum on growth, yield and quality of spring groundnut (*Arachis hypogaea* L.)
Awards/Distinctions/Fellowships	**:**	University Merit Scholarship during the period of 2018-2019 during M.Sc.