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EVALUATING THE EFFECTS OF NUTRIENT EXCLUSION ON GROWTH PERFORMANCE, YIELD, AND NUTRIENT EFFICIENCY IN WINTER RAPESEED (BRASSICA NAPUS L.) IN RAINFED CONDITIONS

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ABSTRACT
Rapeseed (Brassica napus L.) is one of the world's most important oilseed plants, although it is the yield in the rain-fed ecosystems, especially under arid and semi-arid environments, which remains low due to inadequate nutrient management. This research was conducted to evaluate the effect of nutrient omission on the growth, yield and nutrient use efficiency of winter rapeseed in Chakwal, Pakistan. The goal was to assess how nutrient sources could be better used for increasing yields, especially with the incorporation of FYM. A field experiment was conducted over two consecutive rabi seasons at the PMAS Arid Agriculture University Research Farm using a randomized block design with seven treatments: control, PK (-N), NK (-P), NP (-K), NPK (-S), NPKFYM (-FYM), and NPKS + FYM. Nutrient application rates were 80:50:40:30 kg ha^{-1} for N, P, K, and S, with 10 t ha^{-1} of FYM. Treatments were thus assessed in terms of yield, yield components, seed/straw nutrient content, agronomic utilization efficiency and nutrient use efficiency. The findings revealed that the NPKS + FYM treatment improved yield and nutrient uptake to the highest level, with a seed yield of 1265 kg ha^{-1}. This treatment also increased nutrient utilization, plant use efficiency, and partial factor productivity, thus indicating the advantages of using organic plus inorganic nutrients. However, exclusions of nutrients resulted in yield declines, and out of these, nitrogen and potassium had the greatest decline. Therefore, from the present investigation, it revealed the role of balanced nutrient supply and organic inputs to maximize the rapeseed production under rainfed environments. It satisfies a knowledge gap because it blends organic materials with chemical fertilizers that were not often incorporated before. The research benefits current and advancing sustainable agriculture practices as it enlightens nutrient management relating to the climatic zone of the study area.

Keywords: *Brassica, Nutrient, Rapseed, Rainfed, Yield*

INTRODUCTION
Winter rapeseed or British rapeseed (Brassica napus L.) is an oilseed crop belonging to Cruciferae family and has ambitious global importance as the second largest contender for edible oil after soybean (Sainger et al.,

2017). The rainfed agricultural regions of Pakistan, including Chakwal, is the winter rapeseed where crop yield regulation and nutrient use efficiency poses a prospect and a threat under marginal soil nutrient supply (Sajjad et al., 2024). Due to the share of rainfall and low fertilizer use in the regions' agro-climatic map, rapeseed productivity in the region does not reach potential yield levels typical for highly fertilized systems (Basra et al., 2018; Ali et al., 2022).
In the context of Pakistan, rapeseed is a major source of income for the agrarian economy and an important component of the rabi cropping season, following the major cereals, notably wheat, in the rain-fed zone (Rana et al., 2022). Derived from rainfall's instability and temperature changes during its winter season characterized Chakwal as a semi-arid region affect its nutrient and crop growing patterns. Still, this crop is adaptable to temperature changes and still it will have low yield due to uneven distribution of fertilizers (Sajjad et al., 2021). Lack of proper input nutrients and their poor indexing, especially of N, P, and K hampers the efforts to have improved reduction of yield gap and efficiency of nutrient utilization leading to sustainable agricultural growth in the region (Sajjad & Fatima, 2023). Fertilizers have for long been said to be pivotal in increasing the yield of a crop, thus a yield boost more often than not ranges from 30 to 50%. However, the nutrient status of the soil is a serious constraint to crop production in most of the rainfed areas where soil is inherently low in nutrients and the use of fertilizers including organic manure is not adequate (Liliane & Charles, 2020). Nitrogen an important constituent in the process of photosynthesis and plant protein synthesis is very important in vegetative growth and crop establishment process (Zenda et al., 2021). Therefore nitrogen supply should be managed effectively as rapeseed suffers from poor chlorophyll content when nitrogen is low and NDVI is low, due to lack of appropriate vegetative growth, the yield potential is low (Skendžić et al., 2023). Phosphorus is similarly essential for energy transfer and root formation; nonetheless, in most of Chakwal's soils, P usability is constrained by reactions that immobilize the nutrients, so simply ensuring adequate uptake by the crop is critical (Jewan et al., 2022). Besides, it is an extracellular electrolyte, needed in large quantities and has various important physiological and biochemical activities with reference to water balance and activation of various enzymes that may be beneficial under rainfed environment (Timachi et al., 2020).
Mentioned nutrient management scenario is normatively often enshrouded in Chakwal having biased use of fertilizers. The farmers, because of the low resource endowment and inadequate knowledge, splash far more nitrogen and phosphorus on the field while potassium and sulfur get completely overlooked, which means that the plants get unbalanced nutrients that negatively impact their health and fluctuating yields (Kianira, 2021). Applications of nutrients in this widespread manner hampers growth and yield of rapeseed besides causing vulnerability to environmental pollution through soil degradation and possibility of water pollution through nutrient leaching (Dhaliwal et al., 2022). In the first place, imbalances of nutrient supply complicate the issue of NUE which is extremely important in the rainfed systems because nutrient uptake with limited access to the water depends on moisture availability. Recent studies recommended the need for integrated optimum fertilizer application for increasing NUE that remains a contentious factor in rainfed agriculture productivity improvement in the tropics (Yan et al., 2022).
Considering these difficulties, nutrient omission plot technique is useful and systematic in estimating the role of specific nutrients in crop production. In this method all the requisite nutrients excluding one are supplied to the plants in order to compare and analyse the effect of the deficiency on the growth, yield or NUE of the crop (Bojtor et al., 2022). By following this approach, the researchers can determine the sequenced limiting nutrients, and develop suitable fertilizer management that can improve the crop growth rate and nutrients utilization efficiency. They are especially rather helpful whenever the area under consideration is as mechanized as Chakwal where input resource optimization coupled with sustainable agriculture forms the basis of farmers' planning and practice. The purpose of this research was to investigate the impact of nutrient omission on yield and nutrient use, growth and performance of the winter rapeseed under rainfed in Chakwal. By using the nutrient omission plot technique which will be applied in this study, the research seeks to determine nutrient specific deficiencies and even express the effects in terms of productivity of the crops. The outcomes will enable users to gain an appreciation of the nutrients involved in stimulating rapeseed growth and the ways and manner in which efficient use of each nutrient will enhance yield and operational efficiency

in rainfed areas. Therefore, this study advances the plethora of nutrient management practices conceived for rainfed cropping systems of Pakistan's semi-arid environment in Chakwal region.

MATERIALS AND METHODS

Experimental Site

The present field experiment was carried out at the Research farm of PMAS Arid Agriculture University is situated at Rawalpindi Chakwal Road Punjab Pakistan. The experimental location is at the centre of the Potohar Plateau within the arid climate region and experiences semi-arid climate with reliance on rainfall for crop production. The survey was carried out during two successive Rabi seasons, 2022-23 and 2023-24 as the site had been cropped with maize in kharif season. The whole experiment was conducted on the same piece of land every year as this way the conditions did not changed much for different seasons. Before the starting of the experiment, five soil samples were collected at five random points of the field at 20 cm intervals. These samples were oven dried, mixed and analyzed chemically for basic fertility status of the soil. The outcome of this analysis showed that the soil type was silt clay loam and nutrient supply was found low for nitrogen at 210 kg ha^{-1}, moderate for phosphor at 15 kg ha^{-1}, potassium at 250 kg ha^{-1} and sulphur at 10 mg kg^{-1}. From these basic measurements it is possible to determine the native fertility of the plot soils and from this basis construct the nutrient treatments for the experimental area.

Treatments and experimental design

For preparing the experimental field the main implements used were one disking and two harrowing to achieve the best tilt that is suitable for rapeseed planting. After the last plowing, a preliminary level of chemical and organic fertilizer was applied on the plot according to the treatment plan of the study. The field was then subdivided into 21 plots of 12 m^2 each deployed in a randomized complete block design replicated three times to reduce spatial variance and increase the accuracy of the results. The treatments were developed using the nutrient omission plot technique to assess the effects of nutrient exclusion on rapeseed performance. The specific treatments included: control (no fertilization), PK, NK, NP, NPK, NPKS, and NPKS + farmyard manure (FYM). Nutrients were applied at rates of 80 kg N ha^{-1}, 50 kg P ha^{-1}, 40 kg K ha^{-1}, and 30 kg S ha^{-1}, with FYM applied at 10 t ha^{-1}. The sources of nitrogen, phosphorus, potassium, and sulfur were urea, triple super phosphate, muriate of potash, and gypsum, respectively. Nitrogen was applied in three equal splits: as a basal dose, at stem elongation, and during the flowering stage, to synchronize nutrient availability with the plant's growth requirements. All other nutrients were applied as basal doses according to the assigned treatments. For effective weed management, a pre-emergence herbicide, pendimethalin, was applied at 1 kg active ingredient ha^{-1}.

Measurement of yield attributes and yield

Yield attributes and yield measurements followed standard agronomic procedures. In the first week of March, five randomly selected plants were tagged from each plot for yield attribute assessment. The primary yield attributes recorded were the number of pods per plant, seeds per pod, and test weight. The tagged plants were harvested, and the seeds were manually threshed. Following threshing, a random sample of seeds from each plot was collected to determine the thousand-seed weight. Seed yield per plot was recorded and then converted to a standard yield measure of quintals per hectare (q ha^{-1}) to facilitate comparative analysis.

Calculations

To determine the Nitrogen Content (%), Phosphorus Content (%), Potassium Content (%), and Sulfur Content (%) in winter rapeseed (Brassica napus L.) grown under rainfed conditions, you can follow these standard laboratory methods:

Nitrogen Content (%):

Sample preparation includes the digestion of the plant tissue in sulphuric acid with a catalyst to release ammonium from the organic nitrogen content of the Plant. The ammonium is then distilled and titrated to find the nitrogenous content of the solution.

Using the **Kjeldahl Method**, the formula is:

$$\text{Nittrogen content\%} = \left(\frac{(Vb - Vs) \times N \times 14}{W}\right) \times 100$$

Where:

- Vb: Volume of acid used for the blank (mL)
- Vs: Volume of acid used for the sample (mL)
- N: Normality of the acid
- 14: Atomic weight of nitrogen
- W: Weight of the plant sample (g)

Phosphorus Content (%):

Carry out an acid digestion of the plant material on the nitric and perchloric acids in a 3:1 ratio. Determine the missing phosphate by using spectrophotometer with colorimetric moiety or by using a technique such as the ICP-OES (Inductively Coupled Plasma Optical Emission Spectroscopy).

Using **Colorimetric Analysis**, the formula is:

$$\text{Phosphorus content\%} = \left(\frac{C \times V}{W \times 10}\right)$$

Where:

- C: Concentration of phosphorus in the sample (mg/L) determined from a standard curve
- V: Total volume of the digest (mL)
- W: Weight of the plant sample (g)

Potassium Content (%):

As with phosphorus treat the plant tissue accordingly Digest Plant Tissue as described above. Assay for potassium using a flame photometer or ICP-OES since potassium has a propensity to fluoresce in flame, being directly proportional to the intensity of light at a certain wavelength emitted by potassium when it is excited.

Using **Flame Photometry**, the formula is:

$$\text{Potassium content\%} = \left(\frac{C \times V}{W \times 10}\right)$$

Where:

- C: Concentration of potassium in the digest (mg/L)
- V: Total volume of the digest (mL)
- W: Weight of the plant sample (g)

Sulfur Content (%):

Turbidimetric analysis of digested plant tissue should be further used to determine the content of sulfate ions. Instead, use ICP-OES for the determination of the sulfur concentration within the same digest as P and K.

Using **Turbidimetric Analysis**, the formula is:

$$\text{Sulfur content\%} = \left(\frac{C \times V}{W \times 10}\right)$$

Where:

- C: Concentration of sulfur in the sample (mg/L) from a standard curve
- V: Total volume of the digest (mL)
- W: Weight of the plant sample (g)

These methods facilitate precise determination of the nutrient concentrations that are required in defining growth performance and nutrient utilization.

Statistical analysis

The results of the experiments were statistically evaluated by applying simple analysis of variance (SANOVA) to measure the impact of the treatment. All statistical analyses were conducted using the Minitab statistical software with a 5% level of significance (P ≤ 0.05) for analysis of variance (ANOVA). To achieve this a comparison of means test through the use of Tukey's test and least significant difference was done so that impacts of the treatments could be effectively compared. Since the analysis of year by treatment interaction showed no significant effect, the data of the two years were combined and analyzed in order to reinforce the existing treatment impacts on the rapeseed yield and nutrient use efficiency. This methodology offers a general approach to assessment of nutrient contributions to rapeseed growth under rainfed environments and helps in identification of nutrient specific constraints thus improve recommendation for appropriate plant nutrient supply for the specific situation in the SSA semi-arid agro-ecologies.

RESULTS

Effect of nutrient management practices on yield attributing characters, seed yield, and nutrient uptake in Brassica napus L. grown at PMAS Arid Agriculture University research farm is presented in Table 1. Both treatments influenced growth yields aspect of the plant such as pod per plant, seed pod, 1000 seed weight, and seed yield based on the inclusion or exclusion of specific nutrients as well as plant at harvest stage.

Effect of nutrient omission on yield attributes and seed yield

Comprehensive nutrient applications enhanced pod numbers with the best figure of 200 pods per plant produced in the NPKS + FYM treatment. The lowest pod yields of 85 pods per plant were obtained from the control (unfertilized) treatment suggesting a direct relationship between nutrient balance and pod setting. Out of nutrient-omission treatments, PK treatment which lacked nitrogen greatly affected the pod count and yielded 108 pods per plant while treatments with nitrogen emphasized nitrogen as essential nutrient in rapeseed's reproductive development and pod formation. Of the remaining treatments, the NK (-P) and NP (-K) cuts a fairly modest decrease in pod count of, respectively, 135 and 140 pods per plant.

In the same way, the seed per pod measurement also showed an upward trend as nutrient were added, and a downward trend when certain nutrients were withdrawn. Maximum seed number per pod (16.5) was recorded in the NPKS+ FYM treatment while minimum (7.8 seeds per pod) in the control. Less notably, PK treatment which excluded nitrogen decreased the number seeds per pod (8.8), which points to role of nitrogen in ringing seeds effectiveness and set. The exclusion of phosphorus (NK treatment) and potassium (NP treatment) recorded comparatively higher seed counts per pod (12.4 and 13.8 respectively) but both were significantly below fully fertilized treatment suggesting that nutrient interaction has a liner cumulative add on on reproductive yield attributes.

The 1000-seed weight another important factor determining seed quality and market value also differed according to treatments. It was also possible to verify that the biggest 1000-seed weight (3.55 g) occurred in the treatment NPKS + FYM while the lowest value (2.53 g) was observed in the PK treatment, where the exclusion of nitrogen generated a consequent reductions in seed mass. The absentiation of sulfur (treatment NPK) and farmyard manure (treatment NPKS) resulted to slight decline in thousand seed weight this perhaps more so indicates the importance of sulfur and organic nutrient sources in seeding and weight enhancement.

Seed yield and yield reduction

The seed yield data indicates the summation effects of nutrient management practices on yield potentiality the NPKS + FYM treatment provided 1265 kg/ha seed yield. On the other hand the unfertilized control treatment gave the least amount of seed yield at 530 kg/ha, this is 57 % less than the NPK treatment which was used as standard. Treatments with no mode specific nutrient were also significantly lower in yield compared to the highest yielding treatment NPKS + FYM. For example, PK treatmentypsum had -N; 24% yield reduction and gave yield of 890 kg/ha; here, nitrogen is central to realizing greatest seed yield under rainfed. Reducing the phosphorus in nitrogen and potassium treatment reduced the yield to 1020 kg/ha, 13% less than the control; removing the potassium (NP treatment) reduced the yield only slightly, 2.7% less than the control, 1130 kg/ha indicating that potassium may not be nearly as limiting as nitrogen and phosphorus in this agro-climatic zone. When the effect of sulfur omission treatment (NPK) was compared with that of NPKS the yield reduction recorded was 4.6 per cent over NPKS treatment It means that although sulfur is not as important as nitrogen, phosphorus, or potassium it has positive influence to the yield potential. The NPKS (-FYM) treatment had the similar decline in yield, which was 4.4 percent of reduction, that supported that the inclusion of organic matter (FYM) is helpful in the enhancement in nutrient [availability and the soil health especially in arid rainfed Agriculture . The outcome of the study points out that nitrogen was the most important nutrient in boosting the yield of rapeseed in this environment as the lack of it had the largest impact in form of yield loss. Phosphorus and potassium also entered the model though the absence of them led to slightly smaller but still significant drops in yields. Sulfur and FYM added progressively to the yield but were crucial to attaining the optimum productivity in this research.

Table 1. Effect of nutrient management practices on yield attributes and yield of winter rapeseed (Brassica napus L.) under rainfed conditions (Pooled Data of 2 Years)

Treatments	Pods/plant	Seeds/pod	1000 Seed wt. (g)	Seed yield (kg/ha)	Percent Decrement (%)
Control	85e	7.8c	2.55c	530f	Over NPK −57
PK (-N)	108d	8.8bc	2.53c	890e	−24
NK (-P)	135cd	12.4b	2.50c	1020d	−13
NP (-K)	140c	13.8b	2.60c	1130c	−2.7
NPK (-S)	155b	14.8b	2.75b	1160bc	Over NPKS −4.6
NPKS (-FYM)	170b	15.7ab	2.70b	1205b	Over NPKS + FYM −4.4
NPKS + FYM	200a	16.5a	3.55a	1265a	-

It was also observed that the nutrient concentration in rapeseed seeds received different nutrient management treatments was significantly different (Table 2). A gradual rise in the nitrogen content of seeds was recorded corresponding to the adoption of a rational nutrient regime. Treatment NPKS + FYM stand the highest nitrogen concentration of 3.75 % while it is the lowest in the control treatment of 3.10 %. The PK treatment reduced nitrogen concentration that was however low at 3.35% when nitrogen was omitted in a way implying its importance in stimulating proteins synthesis within seeds. Total phosphorus content in seeds showed significant difference means of treatments and its highest value was recorded in PK (-N) treatment i.e. 0.60%. In the seed, the nutrient like phosphorus appeared to be effective when Nitrogen and potassium were presented with the treatments such as NPK, NP and NK where phosphorus omissions were obvious and had concentration of between 0.58-0.59% respectively. However, the control treatment yielded the least phosphorus value (0.50%), indicating that post-harvest phosphorus-containing treatments enhance seed phosphorus content. The results indicate that the mineral nutrient caused potassium accumulation and reached the maximum value of 0.63 percent K in NPKS/FYM treatment and NP(-K). This goes to support the potential role of potassium in seed formation and general nutrition value of the seeds. They established that sulfur content in the vegetation was highest (0.31 %) in plants grown with NPKS+FYM treatment; while the plants grown in the control plots had the lowest (0.24%). These values focus on the essentiality of the chemical element, sulfur, in increasing seed quality, and how it operates to influence the organic matter, FYM to make S easily available to be taken up by plants.

Table 2. Effect of nutrient management practices on nutrient concentration in rapeseed seeds under rainfed conditions

Treatments	Nitrogen Content (%)	Phosphorus Content (%)	Potassium Content (%)	Sulfur Content (%)
Control	3.10f	0.50c	0.52c	0.24c
PK (-N)	3.35e	0.60a	0.57b	0.28b
NK (-P)	3.42d	0.53c	0.60a	0.25c
NP (-K)	3.55c	0.58b	0.63a	0.26b
NPK (-S)	3.52c	0.59b	0.61a	0.27b
NPKS (-FYM)	3.68b	0.61b	0.62a	0.30a
NPKS + FYM	3.75a	0.60b	0.63a	0.31a

It was also found that nutrient concentration in rapeseed straw was changed significantly due to different nutrient treatments (Table 3). Significant difference was observed in nitrogen content of straw with inclusion of nitrogen the grain yield was observed maximum with NPKS + FYM with nitrogen concentration of 0.68% as against control was only 0.50 %. This is in concordance with the trend seen in seeds further highlighting the importance of nitrogen in biomass formation and nutrient storage in straw. The NPKS + FYM treatment's phosphorus concentration 0.110% revealed the benefits of complete nutrient management incorporating FYM on phosphorus content in straw. For most of the omission treatments especially NK (-P) the phosphorus content was significantly higher at 0.075 % supporting the need to fertilize phosphorus for better straw quality.
The straw yield showed variation in NPKS + FYM treatment had highest potassium content (1.25 %) to proved that potassium is important for structural biomass in rapeseed. The treatments that excluded nitrogen had lower potassium values; it indicates that efficiency of potassium uptake is poor when potassium availability is low or not sufficient. As observed earlier, both sulfur and organic amendments were significant for higher sulfur accumulation in straw tissue under rainfed environment because straw contained the maximum sulfur in NPKS + FYM to 0.68%.

Table 3. Effect of nutrient management practices on nutrient concentration in rapeseed straw under rainfed conditions

Treatments	Nitrogen Content (%)	Phosphorus Content (%)	Potassium Content (%)	Sulfur Content (%)
Control	0.50c	0.045d	0.78d	0.42d
PK (-N)	0.61b	0.085b	1.15b	0.47c
NK (-P)	0.62b	0.075c	1.20a	0.48bc
NP (-K)	0.65b	0.080b	0.95c	0.50b
NPK (-S)	0.64b	0.085b	1.22a	0.52b
NPKS (-FYM)	0.67a	0.090b	1.22a	0.68a
NPKS + FYM	0.68a	0.110a	1.25a	0.68a

The findings above show that extensive nutrient management practices affect the concentrations of nutrients in seed and straw positively through effecting seed NPKS plus FYM negatively. This brings to prominence on balanced fertilization regime in synergy with organic amendments with regard to optimizing nutrient utilization and plant nutrient uptake in rainfed rapeseed at PMAS Arid Agriculture University research farm.
In this study, the agronomic and physiological use efficiency of N, P, K, and S in rapeseed were determined with varying nutrient management treatments to achieve maximum yield and nutrient use under Chakwal rainfed conditions due to limited nutrient availability (Table 4). Agronomic efficiency compares the yield of each unit of nutrient applied to the amount of that nutrient required to produce this crop, while physiological efficiency reflects the yield increase per unit of nutrient uptake. Both parameters were higher in the comprehensive NPKS + FYM treatment probably due to good nutrient availability with organic inputs.
The agronomic efficiency of nitrogen was optimum in the NPKS + FYM treatment (8.30 kg grain/kg N applied) only indicating the significance of N for biomass production and seed formation. Conversely, PK treatment by nitrogen omission reduced efficiency to 6.70 kg grain/kg N showing that a poor nitrogen supply is deleterious. Agronomic use efficiency of phosphorus also showed maximum in the combination with NPKS and FYM 13.50 kg grain/kg P applied revealing its potent aspects of increasing root formation and energy transferring in the low mobility of nutrient solution under the rain-fed stress.
The maximum potassium Agronomic Efficiency of 16.50 kg grain/kg K applied was recorded with the NPKS + FYM treatment. NP treatment clearly demonstrated reduced efficiency when potassium was omitted, an indication that potassium enhances water use efficiency and guard cell turgor in Chakwal environments. Among all the treatments, the NPKS + FYM also gave the highest agronomic efficiency (22.40 kg grain/kg S applied) underscoring the role of sulfur in amino acid synthesis and improving crop performance under low irrigation condition. As with the case physiologic efficiency was also increased in the treatment which was applied as NPKS + FYM. The nitrogen use efficiency was recorded at highest level of 23.60 kg grain/kg

nutrient uptake and phosphorus at the level of 158.00 kg grain /kg nutrient uptake which revealed that when all the PNEU's along with FYM were provided in optimum quantity, the highest nutrient conversion efficiency was achieved. Same trend occurs with efficiency where NPKS + FYM treatment record highest potassium and sulfur efficiencies of 148.00 and 365.00 kg grain/kg nutrient uptake, respectively confirming the importance of sulfur in plant protein synthesis and potassium in stress tolerance due to water-stress. These efficiencies highlight why adequate nutrient applications in relation to their uptake and utilization should be used in rainfed rapeseed production in this area.

Table 4. Agronomic and physiological efficiency of nutrients in rapeseed under nutrient management practices in rainfed chakwal conditions

Treatments	N (kg/kg)	P (kg/kg)	K (kg/kg)	S (kg/kg)	N (kg grain/kg nutrient uptake)	P (kg grain/kg nutrient uptake)	K (kg grain/kg nutrient uptake)	S (kg grain/kg nutrient uptake)
Control	5.50	0.30	1.20	0.15	95.00	108.00	118.00	95.00
PK (-N)	6.70	8.50	10.90	–	–	110.50	130.00	–
NK (-P)	5.90	–	11.80	15.20	20.80	–	165.00	–
NP (-K)	6.80	11.20	–	17.60	21.80	148.00	–	–
NPK (-S)	7.50	11.90	14.20	–	22.70	150.40	143.50	–
NPKS (-FYM)	8.10	12.90	15.80	21.90	23.10	152.80	146.00	358.00
NPKS + FYM	8.30	13.50	16.50	22.40	23.60	158.00	148.00	365.00
LSD (p 0.05)	0.50	0.30	1.00	0.40	7.80	0.75	23.50	1.25

This research assesses the above-ground biomass and partial factor nutrient recovery of N, P, K and S in B. napus L. across nutrient levels, with a special emphasis on the retention and efficiency of nutrients as influenced by the rain-fed conditions of Chakwal (Table 5). Apparent nutrient recovery (ANR) is another aspect that shows the capability of the crop to recover the applied nutrient and the partial factor productivity (PFP), which estimates the yield per unit of nutrient applied, gives an indication of the efficiency of nutrient use in every treatment. The maximum apparent nutrient recovery out of nitrogen (N) was recorded 35.00 per cent in NPKS + FYM indicating the use and importance of both organic and inorganic sources of nutrient for good plant growth under rainfed conditions. In phosphorus, the highest recovery efficiency was recorded to be 9.00% followed by the NPKS + FYM treatment since phosphorus plays an important role in root formation, energy transfer in crops especially those that grow in dry areas. The highest potassium recovery was also obtained in the NPKS + FYM treatment (12.00%) which established the importance of potassium in Enhancing drought resistance through ability to control osmotic adjustment and efficient water use.

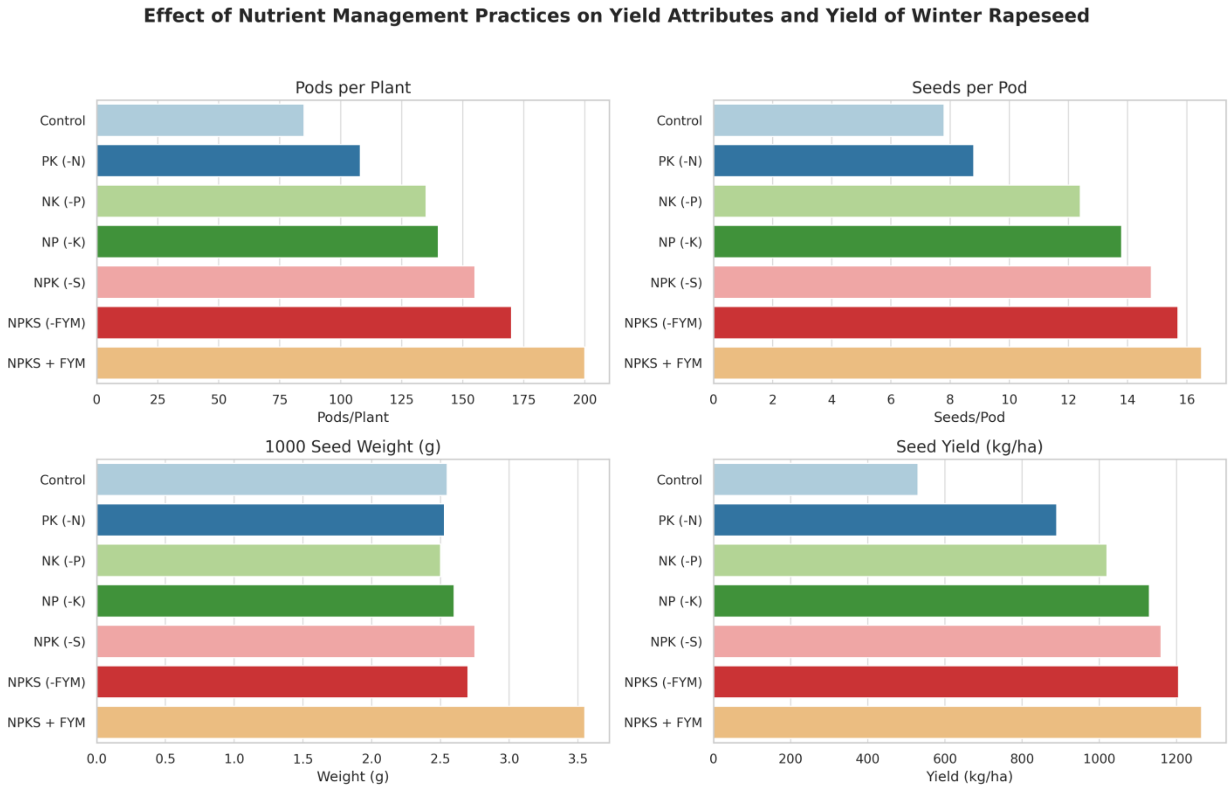
Overall there was an improvement of partial factor productivity values in treatments with full nitrogen and phosphorus application. The nitrogen PFP across all the treatments was however highest with NPKS + FYM, giving a figure of 16.00 kg grain/kg N confirming that while N supply in any agro–ecosystem is important, FYM is equally important in complementing N for optimum growth and yield. Similarly, phosphorus PFP was highest (24.50 kg grain/kg P), revealing that rapeseed brought potential benefit to improve its nutrient uptake under condition of balanced nutrient supply. The NPKS + FYM treatment showed the highest potassium PFP at 30.00 kg grain/kg K illustrating the need for optimum nutrient use. Sulfur PFP was also highest being 12.00 kg grain/kg S in the treatment NPKS + FYM The reaction of sulfur in chlorophyll formation and protein synthesis, which go a long way in yield optimization is important in arid environments.

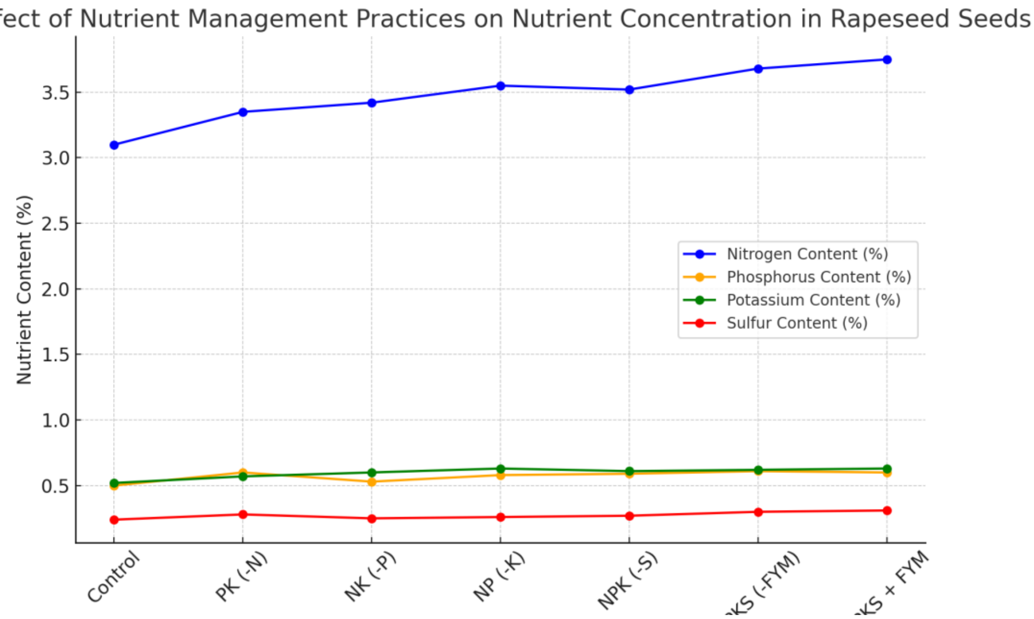
Table 5. Apparent Nutrient Recovery and Partial Factor Productivity of Nutrients in Brassica napus in Rainfed Chakwal Conditions

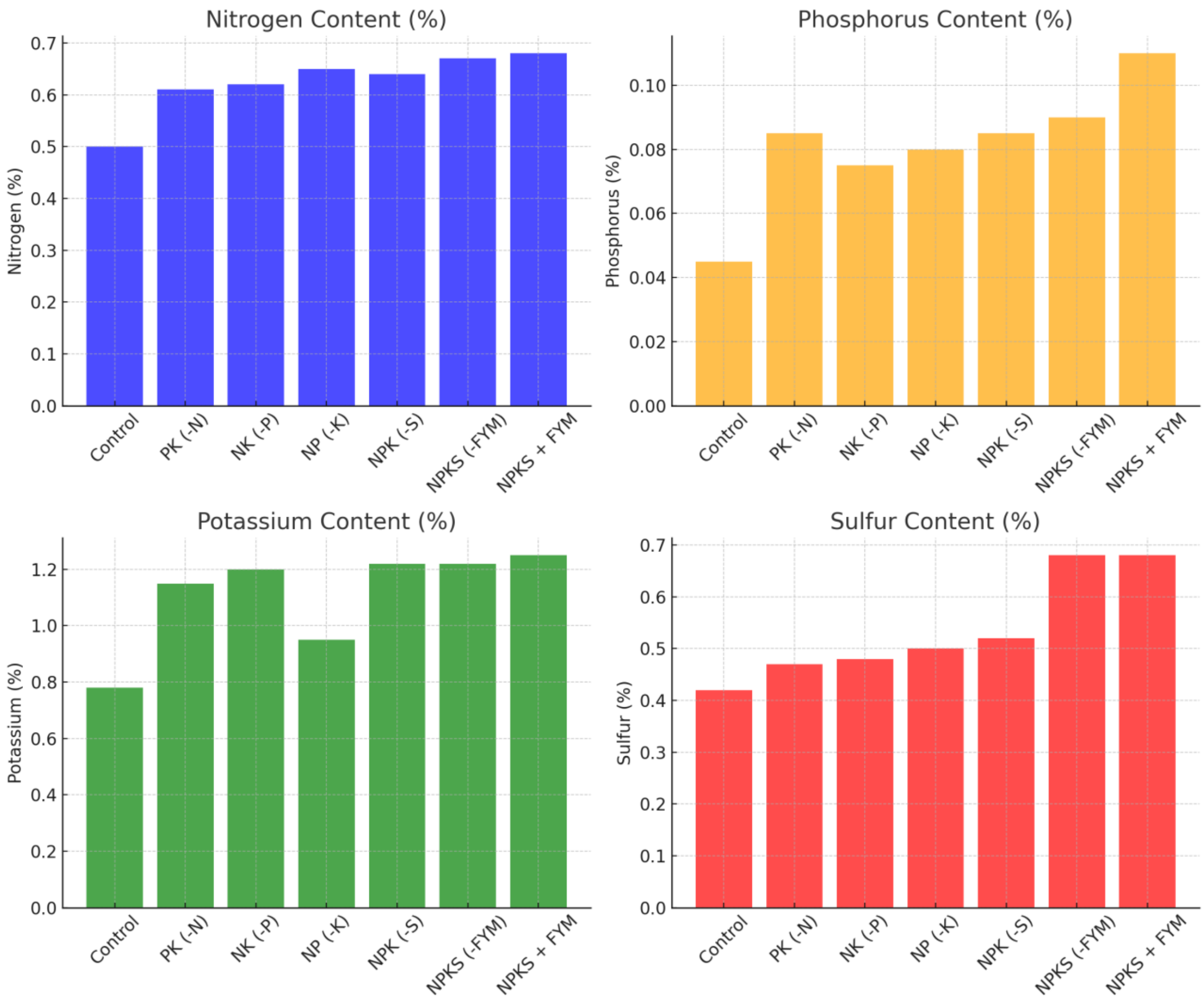
Treatments	N (kg/kg)	P (kg/kg)	K (kg/kg)	S (kg/kg)	N (%)	P (%)	K (%)	S (%)
Control	10.00	15.00	18.50	5.00	–	–	–	–
PK (-N)	11.80	16.80	21.50	–	–	5.50	6.00	–

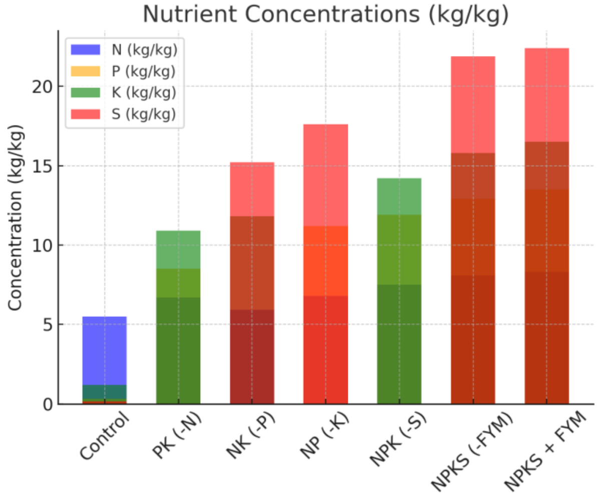
NK (-P)	13.20	–	24.20	7.00	22.50	–	8.00	–
NP (-K)	14.00	21.00	–	8.00	28.50	7.00	–	–
NPK (-S)	14.50	22.00	27.50	–	30.00	7.80	10.00	10.00
NPKS (-FYM)	15.20	23.00	29.20	11.00	33.00	8.20	11.00	11.00
NPKS + FYM	16.00	24.50	30.00	12.00	35.00	9.00	12.00	12.00
LSD (p 0.05)	0.80	1.00	1.50	0.90	2.50	0.50	1.00	0.50

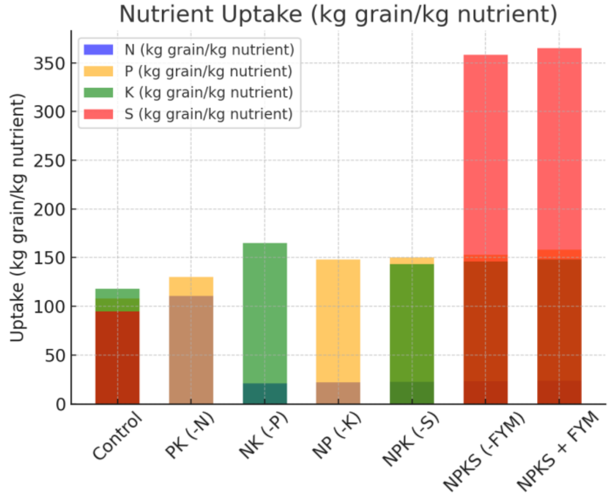
The results reveal that the nutrient recovery and productivity is significantly improved by NPKS + FYM treatment, which indicates it can be useful in maintaining productivity under nutrient constraint rainfed environments. This study brings out the importance of right use of nutrients for enhancement of nutrient utilization and yield of Brassica napus in the zone.

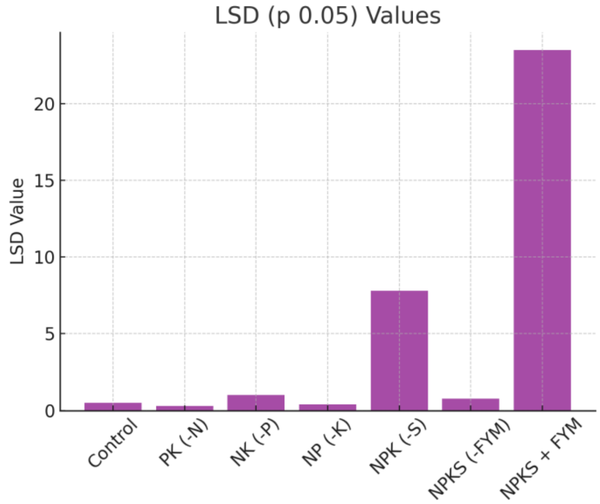


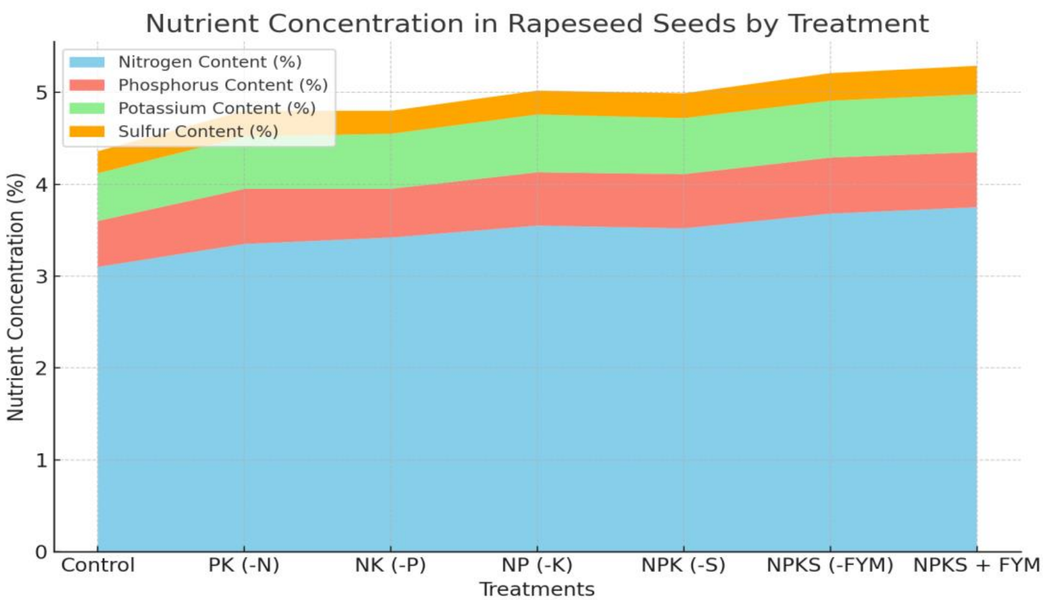

Effect of Nutrient Management Practices on Nutrient Concentration in Rapeseed Seeds
Nutrient Content (%)
Nitrogen Content (%)
Phosphorus Content (%)
Potassium Content (%)
Sulfur Content (%)
Control
PK (-N)
NK (-P)
NP (-K)
NPK (-S)


Nitrogen Content (%)
Nitrogen (%)
Phosphorus Content (%)
Phosphorus (%)
Potassium Content (%)
Potassium (%)
Sulfur Content (%)
Sulfur (%)
Control
PK (-N)
NK (-P)
NP (-K)
NPK (-S)
NPKS (-FYM)
NPKS + FYM


Nutrient Concentrations (kg/kg)
N (kg/kg)
P (kg/kg)
K (kg/kg)
S (kg/kg)
Concentration (kg/kg)
0
5
10
15
20
Control
PK (-N)
NK (-P)
NP (-K)
NPK (-S)
NPKS (-FYM)
NPKS + FYM


Nutrient Uptake (kg grain/kg nutrient)
N (kg grain/kg nutrient)
P (kg grain/kg nutrient)
K (kg grain/kg nutrient)
S (kg grain/kg nutrient)
Uptake (kg grain/kg nutrient)
0
50
100
150
200
250
300
350
Control
PK (-N)
NK (-P)
NP (-K)
NPK (-S)
NPKS (-FYM)
NPKS + FYM


LSD (p 0.05) Values
LSD Value
0
5
10
15
20
Control
PK (-N)
NK (-P)
NP (-K)
NPK (-S)
NPKS (-FYM)
NPKS + FYM


Nutrient Concentration in Rapeseed Seeds by Treatment
Nitrogen Content (%)
Phosphorus Content (%)
Potassium Content (%)
Sulfur Content (%)
Nutrient Concentration (%)
0
1
2
3
4
5
Control
PK (-N)
NK (-P)
NP (-K)
NPK (-S)
NPKS (-FYM)
NPKS + FYM
Treatments

DISCUSSION

This research provided a holistic approach of evaluating the impact of balanced and unbalanced nutrient management practices with particular reference to winter rapeseed (Brassica napus L.) in rainfed ecosystems. When applying an omission plot technique, we detected the main and interaction effects of N, P, K, S and FYM on yield of rapeseed, nutrient uptake and first and second order nutrient recovery efficiencies, both agronomic and physiological. The findings presented therefore pinpoint remarkable observations that extend current knowledge of nutrients availability and utilization in rainfed rapeseed production, as well as offer useful lessons for sustainable agriculture in the low-rainfall environments of arid lands. The highest seed yield of 1265 kg ha^{-1} in the NPKS + FYM treatment co-affirms the great significance of applying the organic and inorganic alone. These outcomes are in accord with those of Laub et al. (2023) and Augustine & Kalyanasundaram et al. (2021), who explained enhanced yields and nutrient use under semi conservative fertilization regimes. Nevertheless, the present research fills this gap by demonstrating that the application of FYM, which is sporadically applied in intensive farming system, improves both nutrient use efficiency and yield of rainfed rapeseed, a crop and growing environment that does not receive much attention in the literature. This finding claims special importance especially when Singh et al. (2022) reported that organic amendments have positive effects on soil health and nutrient supply though their study included mostly the irrigated area.

Yield factors & characteristics

Yield attributes including the pods per plant, seeds per pod, and thousand-seed weight recorded the highest values in the NPKS with FYM treatment, and the second-best values were recorded in the NPKS without FYM treatment. These results show that though N, P, K and S are essential macronutrients for yield enhancement, the use of FYM enhances the availability of these nutrients to the plants thus improving overall plant growth and production. This synergistic effect of organic and inorganic fertilization reported in this study was confirmed by the earlier studies conducted by Khan et al. (2022) and Ghosh et al. (2022), who mentioned that FYM increases the microbial activity and nutrient cycling and consequently improves the nutrient availability. It builds upon those findings by investigating the role of FYM on rapeseed in rainfed conditions, a comparatively overlooked aspect, to show that FYM indeed plays a decisive role in maximizing the yield and nutrient use efficiency under water deficit environments.

Protein concentration and yield in seed and straw

Data obtained from nutrient concentration study indicates that nitrogen and sulfur both in seed and straw were found highest in NPKS + FYM. The increase in nitrogen uptake in this treatment is consistent with the observation of Mustafa et al. (2022) pointing that nitrogen is very compulsory in chlorophyll synthesis and plant health. On the other hand, our findings suggest that sulfur, which is not commonly used in normal farming practices, plays a significant role in enhancing the quality of the oilseed crops, a conclusion we made in agreement with Sajjad et al., (2023); Karmakar et al., (2024). These findings of higher S concentration in both seed and straw reemphasize the necessity of this nutrient in rapeseed production especially where conditions of rainfed have a low bioavailability of the nutrients.

Notably, nutrients recovery was also the highest under NPKS + FYM treatment for measured parameters like apparent nitrogen and potassium recovery which shows that nutrients have been efficiently absorbed and there is minimal nutrient leaching. This observation agrees with Chen et al. (2024) stating that optimum nutrient inputs reduce nutrient losses in crop production. Increased nutrient recovery rates revealed by this study demonstrate the advantages of combining inorganic nutrients with organic matter as this approach decreases nutrient losses through runoff, an issue rapidly gaining importance under modern agro ecological systems.

Agronomic and physiological efficiency

Therefore, the NPKS + FYM treatment was the most efficient in terms of agronomic and physiological efficiency, testimonial to the efficient utilization of the nutrients. These yield responses are expressed in terms of agronomic efficiency for nitrogen, phosphorus, and potassium whereby a reflection of the importance of balanced fertilization. Our findings are in agreement with Midya et al. (2021) where authors revealed comparable efficiency enhancement in the field crops using integrated nutrient management practices. However, this study adds new knowledge by then applying this principle when growing rapeseed where moisture and nutrient stress is usually rife under rainfed situations. Not only does the increased agronomic efficiency and physiological efficiency enhance the value of utilizing integrated nutrient practices to improve productivity, but it also presupposes a decrease in the farmer's dependence on fertilizer, an important factor of resource-efficient farming in the arid environment (Sarkar & Baishya, 2017).

Contribution of the study to the scientific world
The overall synthesis of nutrient exclusion and addition evidence show the importance of fertilization for improving the rapeseed yield under water limited semi –arid region like Chakwal, Pakistan. This paper responds to the research questions that have arisen in earlier work by Rashmi et al. (2022), who affirmed that yield constrains in oilseed crops were associated with improper nutrition. This paper integrates FYM with NPKS to obtain materials for effective nutrient management, reducing nutrient loss, improving the nutrients in the soil, and enhancing crop resistance. In addition, the case that was analyzed applies the omission plot technique, which suggests a new perspective on assessing nutrients' interactions (Scavo et al., 2022). This technique enables evaluation of the effects of omission, thus revealing the effects of omission on yield and nutrient uptake efficiency. The study brings about a better understanding of winter rapeseed nutrient requirement in order to better enhance existing nutrient recommendations that has a focus on the local soil type and climate.
This research achieves its aims by providing strong evidence that overall nutrient management, with supplementary FYM, improves rapeseed yield, nutrient acquisition, and nutrient use effectiveness in rainfed conditions. The implications of this study are not limited to prescriptive agronomic information as it deals with the basic tenets of sustainable agriculture by promoting practices that deliver environmental multiples while minimizing harm. Information on the integration of organic and inorganic nutrients is also useful in propagating cropping similar to that which exists in other parts of the world where there is constant water shortage and low nutrient quality.

CONCLUSION
This research has achieved the goal set for it and succeeded in assessing the impacts of nutrient exclusion on growth, yield and nutrient use efficiency of Brassica napus (rapeseed) under rainfed environment of Chakwal, Pakistan. The experiment conducted using nutrient omission plot with NPKS applied along with FYM manifested influence of balanced nutrient application on yield traits, nutrient level and nutrient use efficiency. Finally, treatments with nutrient replacement were shown to be the most effective for final yields and nutrient recovery, highlighting the utility of a multiple nutrient approach. This study fills the gap in the scientific body of knowledge by focusing not just on chemical fertilizers, but by also stressing the importance of mixing FYM and inorganic fertilizers. This approach does not only increase yields but also ensures cycling of nutrients beneficial to the soil in low input, rain-fed environments. The observations yield useful information for maintaining sustainable agriculture in different climatic conditions thus making this study essential for enhancing farming practices in the arid and semi-arid areas.

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