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RESEARCH ARTICLE

Residual effect of cropping system and nutrient sources on growth, yield and quality of fodder oat (*Avena sativa* L.)

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Abstract

Residual effects of intercropping in maize-soybean systems on subsequent crop growth, yield and quality are highly significant. This study was conducted to evaluate the influence of maize + soybean intercropping and various nutrient management strategies on fodder oat(*Avena sativa* L.) production. The experiment, established at Lovely Professional University's agricultural research farm, utilized a split-plot design with three replications. Treatments comprised sole maize, sole soybean and maize-soybean intercrops at different row proportions, each combined with distinct nutrient sources. Results demonstrated that the residual effect of sole soybean as the preceding crop with 100 % RDFproduced the most favorable outcomes across all measured parameters. This treatment enhanced plant height by 23.65 %, dry matter accumulation by 44.04 %, fodder quality by 40.0 % and biomass yield by 39.87 %, compared to other treatment combinations. Among nutrient management strategies, alternatives such as 70 % RDF combined with two foliar applications of nano-NPK, homemade NPK and plant extracts proved to be effective supplements to conventional fertilization. Correlation analyses revealed that biomass yield was strongly and positively linked to improvements in fodder oat quality and various crop growth parameters. This study indicates the potential of sustainable intercropping systems with optimized nutrient management to maximize agricultural resource use, reduce dependence on synthetic fertilizers and enhance fodder productivity. These findings support the adoption of more effective and environmentally friendly agricultural practices and contribute valuable insights toward addressing challenges in fodder production as well as soil health.

Keywords: dry matter; fodder yield; quality; residue; synthetic fertilizer; soil fertility; soil health

Introduction

Sustainable resource development has become a critical focus in recent years, addressing global challenges such as ensuring food and fodder security, mitigating the threats posed by climate change and meeting the rising energy demands (1). Agriculture adopted sustainable production strategies for food-fodder systems because of increasing environmental problems (2). Fodder plays a critical role in India's agricultural and rural economy by serving as the fundamental feed source for the country's vast livestock population, which includes over 500 million cattle, buffalo, sheep and goats. Healthy livestock depend on nutritionally rich fodder, primarily green fodder and crop residues, for good milk and meat production, enhanced reproductive efficiency and disease resistance. The livestock sector contributes significantly to farmers' income, rural employment and national food security by providing milk, meat and other animal products. Thus, fodder forms a direct bridge between crop agriculture and the animal food supply system (3). Inadequate or poor-quality fodder leads to lower animal productivity, health issues and financial losses for small farmers who rely on livestock for their livelihoods. Furthermore, fodder cultivation improves soil health, aids in crop rotation and increases biodiversity, contributing to sustainable agriculture. *Avena sativa* serves as Oat "Jai" an essential cereal crop for Indian livestock feeding operations (4). Green fodder oat contains essential fiber and proteins and minerals to fortify the nutrition that livestock depend on. Green fodder offers animals 10-12 % protein and vitamins A, calcium and iron, together with necessary energy, while providing them with these vital nutrients. The nation of India experiences a major shortage of manufactured fodders in its agricultural fields. The current deficit of 35.6 % represents a gap between green fodder demand at 851 MT and supply at 590 MT (3). Dry fodder production is currently lagging behind expected demand by 10.95 % demonstrating an immediate requirement for better cultivation systems that preserve resources (5). The use of legume crops fulfils sustainability criteria as they bring benefits to both the natural environment and social economy (6). The integration of legume crops into agriculture increases land diversity, minimizes external input needs and achieves balanced nitrogen cycles by means of root water vapour release and harvestable organic substances (7). Cropping systems benefit through improved multiple advantages when farmers mix legumes with their existing crops, like maize and soybean, through intercropping practices (8). Intercropping contributes to pest outbreaks management and disease protection, together with stable farm finances, while enhancing soil conditions and preserving biodiversity (9). Research indicates that the maize + soybean intercropping (MSI) system optimizes land management as it reduces resource depletion and helps achieve sustainable ecological practices (10). The optimized nitrogen management approach within this system delivers superior crop yields of succeeding fodder oat plants and maintains plot quality alongside decreased dependence on synthetic fertilizers (1).

The expense of chemical fertilizers alongside increased irrigation and labor costs has created a feed shortage problem for Indian farmers (11). Cultivation methods that promote sustainable intercropping systems enable more efficient fodder production and reduced procedural expenses (12). The sequential cultivation system of maize and soybeans with subsequent oat production provides farmers with a workable alternative that uses leftover effects to boost fodder productivity and enhance nutritional value. The practice enables improved resource utilization together with decreased environmental runoff from excessive fertilizer applications (13, 14). Previous studies showed that maize + soybean intercropping leads to better land efficiency alongside improved soil quality and better-quality animal feed. Legume-generated residual nitrogen, which primarily stems from rhizodeposition, drives crop growth and subsequent crop quality (5). The combination of maize and soybeans improves the protein levels in fodder oats, although it decreases production expenses in future cultivation seasons (15). These cropping systems combine efficient land management with soil care practices and increased biodiversity to create sustainable farming systems (16). The character of nitrogen application controls both crop yield levels and nitrogen use efficiency (NUE) performance in mixed crop farming systems. Proper nitrogen quantities lead to superior production while eliminating resource squandering and lessening ecological impact (17). Research shows that matching nitrogen inputs to unique cropping demands within Multi-Striga Interactions systems creates a stable growth environment combined with improved nitrogen replenishment that benefits subsequent crops (5). Agricultural operations in India's Indo-Gangetic territory rely almost entirely on cereal farming methods, where they use large synthetic fertilizer to boost harvest output. Soil degradation and environmental risks and financial difficulties emerged as side effects when farmers adopted this method (12).

Farmer integration of legumes within their cropping system allows them to reduce dependency on chemical fertilizer with environmental sustainability and sustainable agricultural development over the long term (15). Despite the evident advantages, the combined effects of cropping systems and nutrient sources on succeeding crops remain underexplored. Most studies have focused on the individual impacts of nitrogen applications or specific intercropping benefits (1). Comprehensive research is needed to evaluate the residual effects of intercropping systems on the growth, yield and quality of succeeding crops, particularly under different nutrient management regimes. Understanding these dynamics can provide valuable insights for optimizing sustainable farming practices. We hypothesize that the integration of maize + soybean intercropping with optimized nutrient management practices, including the use of organic and nano-based inputs, can significantly enhance the growth, yield and quality of succeeding fodder oat (*Avena sativa* L.). This improvement is anticipated through increased residual nitrogen availability and better soil health contributed by legumes. Such integrated systems are expected to optimize resource utilization, improve nutrient cycling and minimize dependence on synthetic fertilizers. Consequently, this approach may reduce input costs, mitigate environmental risks and promote sustainable agricultural practices, thereby contributing to long-term productivity and ecological stability in fodder-based cropping systems.

Materials and Methods

Description of the experimental site

The research was conducted at the research farm of Lovely Professional University in Punjab during the 2023-24 rabi season. During the cropping season, the maximum and minimum temperatures range from 11.76 °C to 30.27 °C and 4.33 °C to 15.46 °C, respectively. Similarly, the maximum and minimum relative humidity range from 91.56 % to 95.0 % and 46.67 % to 85.86 %, respectively. The wind speed ranges from 2.68 to 5.5 km/hr. The cropping season was almost dry except for 0.29 mm of rainfall in the 3rd week of October, 0.09 mm in the 1st week of November, 0.94mm in the 1st week of December and 1.26 mm in the 4th week of January 2024. The evaporation ranges from 0.44 mm to 2.90 mm and the sunshine hours range from 1.89 to 8.79 hr/day, which were recorded during the entire cropping period (Fig. 1). The oat variety OL 15 was used with a spacing of 20 cm row to row distance and sown on 15th November 2024. The soil at the experimental site was sandy loam, with a medium organic carbon content (0.52 %), low available nitrogen (216 kg ha^{-1}), medium phosphorus (P_2O_5 at 24 kg ha^{-1}) and medium potassium (K_2O at 210 kg ha^{-1}). The experiment was conducted using a split-plot design (SPD) with five main plot factors and five subplot factors, each replicated three times. Each plot was maintained at a size of 25 m^2, with further details provided in Table 1.

Sampling and measurement

Crude protein content (%)

The nitrogen content of oven-dried plant samples was determined using the modified Kjeldahl method and crude protein content was calculated as per formula (18).

$$\text{Nitrogen content (\%)} = \frac{\text{N x Volume of 0.1N } H_2SO_4 \text{ used x Dilution factor}}{\text{1000 x weight of sample (g)}} \qquad \text{(Eqn. 1)}$$

For calculating the crude protein content, the % t nitrogen was multiplied by 6.25.

$$\text{Crude protein (\%)} = \text{Percent Nitrogen content x 6.25} \qquad \text{(Eqn. 2)}$$

Ether extract (%)

The standard procedure was followed and the extraction was done by using a Soxhlet apparatus (19, 20). The formula to calculate the ether extract was given below.

$$\text{Ether extract (\%)} = \frac{W_3\text{ (g)} - W_2\text{ (g)}}{W_1\text{ (g)}} \times 100 \qquad \text{(Eqn. 3)}$$

Where, Weight of sample = W_1g, Weight of oil flask (empty) = W_2g, Weight of oil flask and fat after extraction= W_3g.

Table 1. Treatment details of the preceding cropping system and nutrient management impact on succeeding fodder oat

Experimental design details.		
Sr. No.	**Preceded Treatment**	**Fodder oat cultivation details**
M_1S_1	Residue of Sole maize with control	
M_1S_2	Residue of Sole maize with 100 % RDF	
M_1S_3	Residue of Sole maize with 70 % RDF and Nano NPK	
M_1S_4	Residue of Sole maize with 70 % RDF and Homemade NPK	
M_1S_5	Residue of Sole maize with 70 % RDF + plant extract	
M_2S_1	Residue of Sole Soybean with control	
M_2S_2	Residue of Sole maize with 100 % RDF	
M_2S_3	Residue of Sole Soybean with 70 % RDF and Nano NPK	
M_2S_4	Residue of Sole Soybean with 70 % RDF and Homemade NPK	
M_2S_5	Residue of Sole Soybean with 70 %RDF+ plant extract	
M_3S_1	Residue of Residue of Maize + Soybean (1:1) with control	
M_3S_2	Residue of Maize + Soybean (1:1) with 100 % RDF	
M_3S_3	Residue of Maize + Soybean (1:1) with 70 % RDF and Nano NPK	Fodder oats are planted with a spacing of 20 cm between rows and 5 cm between individual plants. Notably, no fertilizer is applied during this cultivation process
M_3S_4	Residue of Maize + Soybean (1:1) with 70 % RDF and Homemade NPK	
M_3S_5	Residue of Maize + Soybean (1:1) with 70 % RDF and plant extract	
M_4S_1	Residue of Maize + Soybean (1:2) with control	
M_4S_2	Residue of Maize + Soybean (1:2) with 100 % RDF	
M_4S_3	Residue of Maize + Soybean (1:2) with 70 % RDF and Nano NPK	
M_4S_4	Residue of Maize + Soybean (1:2) with 70 % RDF and Homemade NPK	
M_4S_5	Residue of Maize + Soybean (1:2) with 70 % RDF+ plant extract	
M_5S_1	Residue of Maize + Soybean (2:3) with control	
M_5S_2	Residue of Maize + Soybean (2:3) with 100 % RDF	
M_5S_3	Residue of Maize + Soybean (2:3) with 70 % RDF and Nano NPK	
M_5S_4	Residue of Maize + Soybean (2:3) with 70 % RDF and Homemade NPK	
M_5S_5	Residue of Maize + Soybean (2:3) with 70 % RDF+ plant extract	

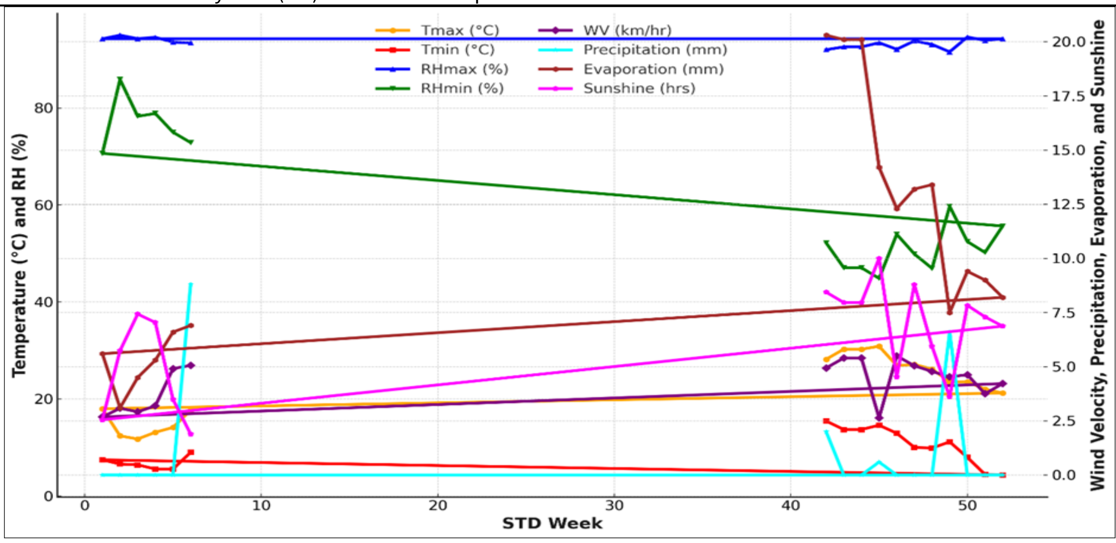

Fig. 1. Meteorological observations during experiment Oct to Jan 2023-24.

Neutral detergent fiber (NDF %), acid detergent fiber (ADF %) and hemicellulose

For NDF and ADF, analyses were done by using the standard (21). Hemicellulose was calculated by subtracting ADF content from NDF content.

$$\text{NDF (\%)} = \frac{\text{wt. of the crucible with residue - wt. of the crucible with residual ash}}{\text{1000 x weight of samweight of the dried sample (g)}} \times 100 \quad \text{(Eqn. 4)}$$

$$\text{ADF (\%)} = \frac{\text{wt. of the crucible with residue (g) - wt. of the empty crucible (g)}}{\text{Wt. of the dried sample (g)}} \times 100 \quad \text{(Eqn. 5)}$$

$$\text{Hemicellulose (\%)} = \text{NDF (\%)} - \text{ADF (\%)} \quad \text{(Eqn. 6)}$$

Statistical methods

The data collection from different studied characters followed the methodology (22). A significance level of p = 0.05 was utilized for both F and t tests. Critical differences were computed whenever the F tests yielded significant results. Statistix 10 software was used to calculate the means of treatments. The RStudio software was used to depict a graphical representation of the data.

Results and Discussion

Growth attributes

The mean values of the growth attributes showed significant differences among treatments, influenced by the residual effects of the cropping system and nutrient sources during 2023-24 (Table 2). The highest plant height was recorded in M_2 (79.87 cm), followed by M_4 (77.60 cm), which was on par with M_5 (75.60 cm) and M_3 (74.80 cm). This represents an increase in plant height of 8.2 % over sole maize (M_1). This improvement may be attributed to the symbiotic relationship between *Rhizobium* bacteria and

Table 2. Residual effect of maize + soybean intercropping and nutrient management on the growth and yield of fodder oat

Treatments	Plant height (cm)	DMA (g)	Biomass yield (t ha^{-1})
Factor A			
M$_1$	73.80d ± 4.88	76.38e ± 7.14	64.40c ± 5.84
M$_2$	79.87a ± 6.57	91.86a ± 5.56	73.69a ± 5.22
M$_3$	74.80cd ± 4.74	80.66d ± 7.35	72.38b ± 7.54
M$_4$	77.60b ± 5.69	89.54b ± 6.41	73.12ab ± 6.45
M$_5$	75.76c ± 4.95	86.08c ± 8.93	72.56b ± 6.44
CD (p ≤ 0.05)	1.42	1.85	0.92
Factor B			
S$_1$	66.87d ± 1.09	72.36d ± 7.58	60.06c ± 3.68
S$_2$	79.75a ± 2.57	89.19a ± 6.01	74.68a ± 2.74
S$_3$	78.87b ± 2.67	88.33ab ± 6.36	74.01b ± 4.09
S$_4$	78.54b ± 2.69	87.85bc ± 5.92	73.93b ± 4.23
S$_5$	77.82c ± 3.11	86.78c ± 6.38	73.47b ± 4.93
CD (p ≤ 0.05)	0.48	1.17	0.56
Interaction			
M$_1$S$_1$	65.27l ± 3.33	63.73l ± 0.83	54.47g ± 0.58
M$_1$S$_2$	77.18kl ± 3.57	80.95ghi ± 4.00	69.79b ± 1.07
M$_1$S$_3$	76.36jk ± 4.03	79.47hij ± 3.08	66.70c ± 0.78
M$_1$S$_4$	75.88jk ± 4.00	79.64hij ± 4.00	66.36c ± 2.34
M$_1$S$_5$	74.31j ± 3.58	78.09j ± 3.60	64.67d ± 1.87
M$_2$S$_1$	68.17i ± 2.86	82.00fgh ±5.16	64.35d ± 0.12
M$_2$S$_2$	83.55hi ± 2.86	95.32a ± 2.86	76.19a ± 0.17
M$_2$S$_3$	83.05gh ± 2.86	94.80a ± 2.86	76.08a ± 0.21
M$_2$S$_4$	82.55fgh ± 2.86	93.33ab ± 2.94	76.04a ± 1.23
M$_2$S$_5$	82.05fgh ± 2.86	93.82ab ± 2.89	75.78a ± 1.25
M$_3$S$_1$	66.47fgh ± 2.86	67.64k ± 1.12	58.88f ± 0.04
M$_3$S$_2$	78.01fgh ± 2.54	85.11e ± 2.87	75.76a ± 0.11
M$_3$S$_3$	77.18efg ± 2.60	84.32ef ± 2.79	75.76a ± 0.10
M$_3$S$_4$	76.71ef ± 2.54	83.82efg ± 2.87	75.74a ± 1.27
M$_3$S$_5$	75.65ef ± 2.86	82.40fgh ± 2.87	75.75a ± 0.08
M$_4$S$_1$	67.47ef ± 2.86	78.30ij ± 4.17	61.57e ± 0.07
M$_4$S$_2$	81.08 de ± 2.33	93.51ab ± 2.87	76.03a ± 0.09
M$_4$S$_3$	79.86cd ± 2.85	93.04ab ± 2.89	75.99a ± 1.73
M$_4$S$_4$	79.85cd ± 2.89	92.61abc ± 2.86	76.00a ± 0.37
M$_4$S$_5$	79.74cd ± 2.26	90.26cd ± 3.32	76.03a ± 0.04
M$_5$S$_1$	66.97bc ± 2.86	70.14k ± 1.72	61.05e ± 0.10
M$_5$S$_2$	78.91ab ± 2.54	91.06bcd ± 2.92	75.66a ± 0.01
M$_5$S$_3$	77.88 ab ± 2.60	90.04cd ± 2.91	75.50a ± 0.06
M$_5$S$_4$	77.71a ± 2.54	89.84cd ± 2.88	75.50a ± 0.06
M$_5$S$_5$	77.35 a± 2.66	89.32d ± 2.86	75.12a ± 0.10
CD (p ≤ 0.05)	1.19	2.76	1.36

*Figures not sharing the same letters in the same column differ significantly at p < 0.05. ± SD standard deviation of the treatments

the soybean plant, which fixes atmospheric nitrogen and supplies additional nutrients to the succeeding crop (23). Similarly, M$_2$ (91.86 g) occupied significantly maximum dry-matter accumulation (DMA), followed by M$_4$ (89.54 g), which was on par with M$_5$ (86.08 g) and M$_3$ (80.66 g). The residual effect of sole soybean (M$_2$) increased the DMA by 20.2 %, while the lowest DMA was recorded under the M$_1$ treatment. It might have happened due to the high nitrogen demand of maize, which depletes the nutrients from the soil (23, 24). In contrast, soybean contributes to soil nitrogen pools through symbiotic nitrogen fixation, thereby benefiting the succeeding fodder oat (24).

Similarly, S$_2$ (79.75 cm and 89.19 g) achieved significantly the maximum plant height and DMA, which were on par with S$_3$ (78.87 cm and 88.33g), S$_4$ (78.54 cm and 87.85 g) and S$_5$ (77.82 cm and 86.78 g), while significantly the lowest plant height and DMA were found in S$_1$. Further, the Residual effect of 100 % RDF (S$_2$) recorded 19.2 and 23.25 % plant height and DMA compared to the control (S$_1$). It might be attributed to the higher residual nutrients present in the S$_2$ treatment compared to the other treatments. When fertilizer is applied as a basal dose, a significant portion often converts to unavailable forms. However, the inclusion of legume plants promotes the activity of *Rhizobium* bacteria, which convert these nutrients into available forms, thereby supplying essential nutrients to the succeeding crop (25, 26).

The interaction effect of the residual effect of intercropping and nutrient management had a positive impact on the growth attributes of fodder oat. Except for the cropping system in combination with control, the residual impact of cropping system and nutrient source combinations showed significantly higher plant height and DMA. The M$_2$S$_3$, M$_2$S$_4$ and M$_2$S$_5$ enhanced plant height by 0.59 % to 1.79 % and DMA by 0.54 to 1.57 %. Significantly higher plant height and DMA were found in M$_2$S$_2$ and the lowest was in M$_1$S$_1$. It might be due to better nutrient supply by the legumes with 100 % RDF treatment combination (27, 28).

Biomass yield

Residual effect of cropping system and nutrient management significantly influenced on biomass yield of fodder oat during 2023-24 (Table 1). The significantly highest biomass production was recorded in M$_2$ (73.69 T ha^{-1}) treatment. The sole soybean recorded 14.28 % higher biomass yield over sole maize (M$_1$). Maize + soybean intercropping combinations (M$_3$-M$_5$) increased biomass yield by 12.39 to 12.67 % over M$_1$. Similarly residual effect of 100 % RDF (S$_2$) recorded significantly higher biomass yield. Various nutrient sources (S$_3$-S$_5$) increased biomass yield by 22.32 - 23.22 % over the S$_1$ treatment. The superior performance of the cropping system (M$_2$- M$_5$) can be attributed to the residual nitrogen fixed by legumes during the preceding cropping cycle (29, 23). Soybean, through symbiotic nitrogen fixation, improves soil nitrogen levels, leading to enhanced growth and nutritional parameters in the succeeding fodder oat (30, 31).

Further, a significant interaction effect was found between the cropping system and nutrient management. M_2S_2 combination achieved significantly maximum biomass yield, which was at par with M_2, M_3, M_4, M_5 combined with S_3, S_4 and S_5. While sole maize and its combinations found lower biomass yield. Maize + soybean intercropping with various row proportions performed better than sole maize and its nutrient combinations. It might be due to better nutrient availability in the M_2S_2 treatment combination (32).

Quality parameter of fodder oat

Total ash content

The total ash content in fodder oat was significantly influenced by the residual effects of cropping systems and nutrient management (Fig. 2). The significantly highest ash content (8.75 %) was observed under M_2 (maize-soybean intercropping), reflecting the enhanced soil mineralization due to nitrogen fixation and organic matter contribution by legumes. In contrast, significantly the lowest ash content (7.42 %) was recorded in M_1 (sole maize), attributed to its high nutrient demand and lack of legume residues for nitrogen replenishment. Intercropping systems (M_3- M_5) improved ash content by 3.9 - 9.97 % over sole maize, highlighting the benefits of incorporating legumes in cropping systems (33). Similarly, nutrient management practices significantly impacted ash content. S_2 (100 % RDF) recorded the significantly highest ash content (9.43 %), emphasizing the role of balanced fertilization in mineral retention, while the control (S_1) had the lowest ash content (5.60 %). Nutrient-enriched treatments (S_3-S_5) with 70 % RDF and Nano NPK, weed extract and homemade NPK increased ash content by 46.07-55.71 % over S_1 that nutrient-rich treatments enhance mineral availability (34).

Extract content

The extract content was significantly highest in M_2 (2.51 %) due to the nutrient-rich legume residues, while M_1 (2 %) had the lowest value, reflecting the reduced nutrient enrichment in the absence of legumes (Fig. 2). Intercropping (M_3-M_5) further significantly increased extractable content by 9-15.5 % over sole maize, emphasizing the role of legumes in nutrient availability. Among nutrient treatments, S_2 (2.80 %) achieved significantly the highest extract content, while S_1 (1.45 %) had the lowest, indicating the nutrient-deficient conditions in control plots. Residual effects of S_3-S_5 improved extract content by 52.41-76.55 % over S_1 treatment. Research indicates that enhanced nutrient availability and extractable content in legume-integrated and nutrient-enriched systems (26).

Crude protein (CP) content

Crude protein content was significantly highest in M_2 (12.74 %) due to nitrogen fixation and the contribution of soybean residues, which increased nitrogen availability for the succeeding oat crop (Fig. 3). Sole maize (M_1) recorded the significantly lowest crude protein content (11.02 %), as maize depleted soil nitrogen without replenishment. Intercropping (M_3-M_5) increased crude protein content by 1.99 - 4.80 % over M_1

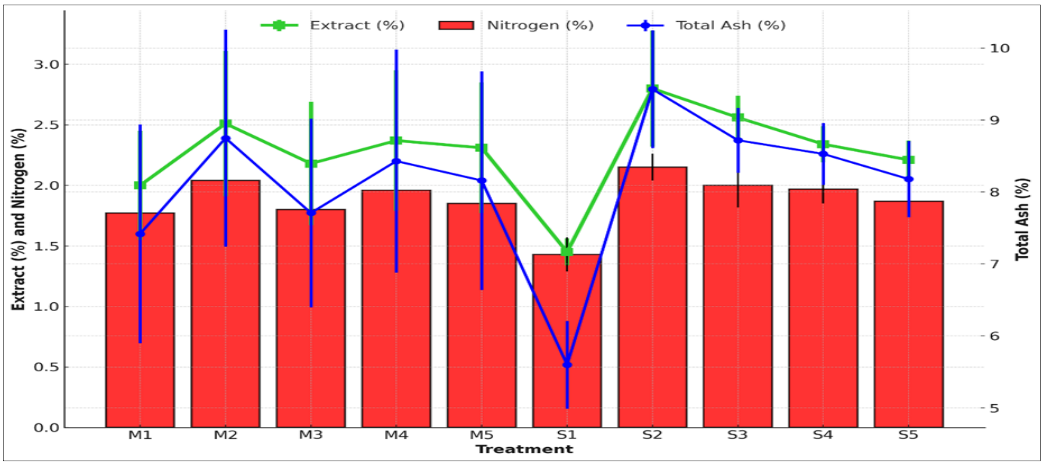

Fig. 2. Total ash, nitrogen and ether extract of fodder oat influenced by residual impact of maize + soybean intercropping with different nutrient management.

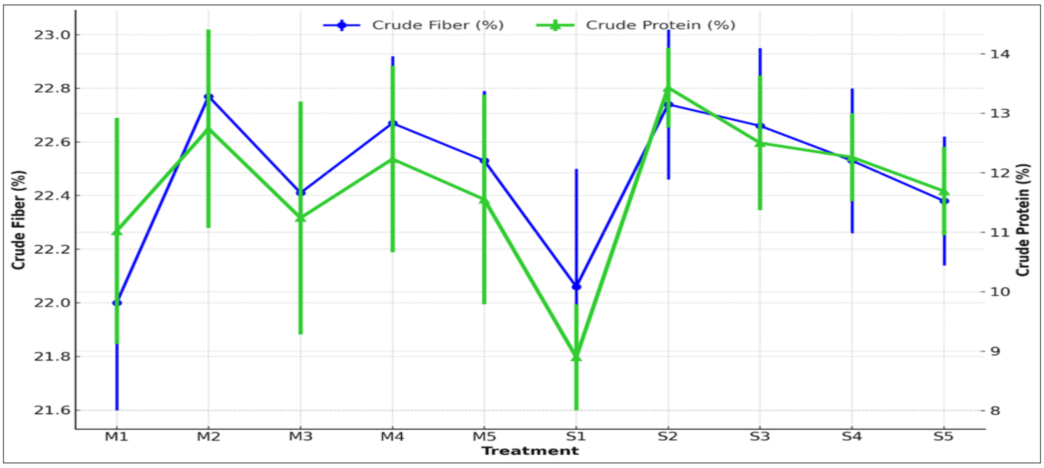

Fig. 3. Crude protein and crude fibre content of fodder oat influenced by residual impact of maize + soybean intercropping with different nutrient management.

treatment, showcasing the role of legumes in improving fodder quality. Nutrient management also significantly influenced crude protein content. S_2 (13.43 %) had the highest protein content due to optimal nitrogen availability, while S_1 (8.90 %) showed the lowest. S_3-S_5 treatments improved crude protein content by 31.34 - 40.44 % over S_1, which balanced fertilization enhances nitrogen availability and protein synthesis (25).

Fiber content

Fiber content showed minimal variations across treatments, ranging from 22 % (M_1) to 22.77 % (M_2) (Fig. 3). Intercropping systems (M_3-M_5) significantly increased fiber content marginally, indicating a limited influence of cropping patterns on this parameter. Similarly, nutrient management had a negligible impact, with S_2 recording the highest fiber content (22.74 %). Research reported that minimal variations in fiber content under different cropping and nutrient treatments (28).

Nitrogen content

Nitrogen content in fodder oat was significantly influenced by cropping systems and nutrient management (Fig. 2). Residue of sole soybean (M_2) recorded (2.04 %), significantly the highest nitrogen content in fodder oat. It might be due to better nutrients and providing sufficient nutrients to the succeeding crop, while the lowest nitrogen content was recorded under t M_1 treatment (1.77 %). Intercropping (M_3-M_5) increased nitrogen content by 1.69 - 4.5 % over sole maize. Among the nutrient management treatments, 100 % RDF (S_2) showed the highest nitrogen content, 2.15 %, while the lowest (1.43 %) was found in the S_1 treatment. Residual effects of S_3-S_5 increased the nitrogen content by 30.76 - 39.86 % over S_1 treatment (35).

NDF and ADF

The NDF and ADF were significantly maximum in sole soybean (56.62 % and 34.33 %, respectively) due to the structural benefits of legume residues (Fig. 4). Sole maize recorded the lowest NDF (54.02 %) and ADF (33.13 %), reflecting lower-quality fodder. Intercropping systems (M_3-M_5) significantly increased NDF and ADF by 4.46 - 4.55 % and 3.32 - 3.44 %, respectively, over sole maize. Among nutrient sources, 100 % RDF fertilization recorded the highest NDF (56.71 %) and ADF (34.30 %), while S_1 had the lowest. Residual effects of nutrient sources (S_3-S_5) improved NDF and ADF by 5 - 5.14 % and 2.85 - 3.06 % (36).

Hemicellulose content

Hemicellulose content was significantly highest in M_2 (22.28 %), reflecting improved digestibility from legume residues (Fig. 4). M_1 had the lowest hemicellulose content (20.88 %). Intercropping (M_3-M_5) increased hemicellulose by 6.32-6.36 % over M_1. Among nutrient treatments, S_2 (22.41 %) recorded the highest hemicellulose content, while S_1 (20.54 %) had the lowest. Residual effects of S_3-S_5 increased hemicellulose by 8.57 % over S_1. It might be due to higher nutrient availability in the residue of the preceding crop and nutrient residue (23, 37).

Correlation studies

Height was highly strongly correlated with DMA (r = 0.890), Ash content (r = 0.835), Ether (r = 0.759), CP (r = 0.808) and BMY (r = 0.836). Other variables, such as NDF (r = 0.779), Hemicellulose (r = 0.757) and ADF (r = 0.724), were found to have moderate correlations. DMA correlated strongly with Ash content (r = 0.842), NDF (r = 0.822), ADF (r = 0.848) and BMY (r = 0.888). These highlighted relationships between DMA and other nutritional and structural parameters. Ash content was found to be strong correlated with CP (r = 0.793), DMA (r = 842), BMY (r = 0.836), Ether observed moderate and strong correlations with CP (r = 0.653) and BMY (r = 0.750), also high correlation with NDF (r = 0.694) and ADF (r = 0.680). Crude Protein (CP) has a perfect correlation with N (r = 1.000), which is the norm for nitrogen content and crude protein levels. CP also has a high correlation with BMY (r = 0.761) and Ash content (r = 0.793). NDF exhibited high associations and strong correlations with the components ADF (r = 0.926), Hemicellulose (r = 0.975) and BMY (r = 0.916), indicating that NDF is highly characteristic of structural biomass components. BDF and Hemicellulose also had close correlations (r = 0.822), while ADF was strongly associated with BMY (r = 0.928). Unbounded BDF (UBDF) values were relatively weakly associated with other values, showing moderate correlation with BMY (r = 0.697). Biomass Yield (BMY) had positive associations with all variables, with the greatest positive strong correlation with DMA (r = 0.888), NDF (r = 0.916),

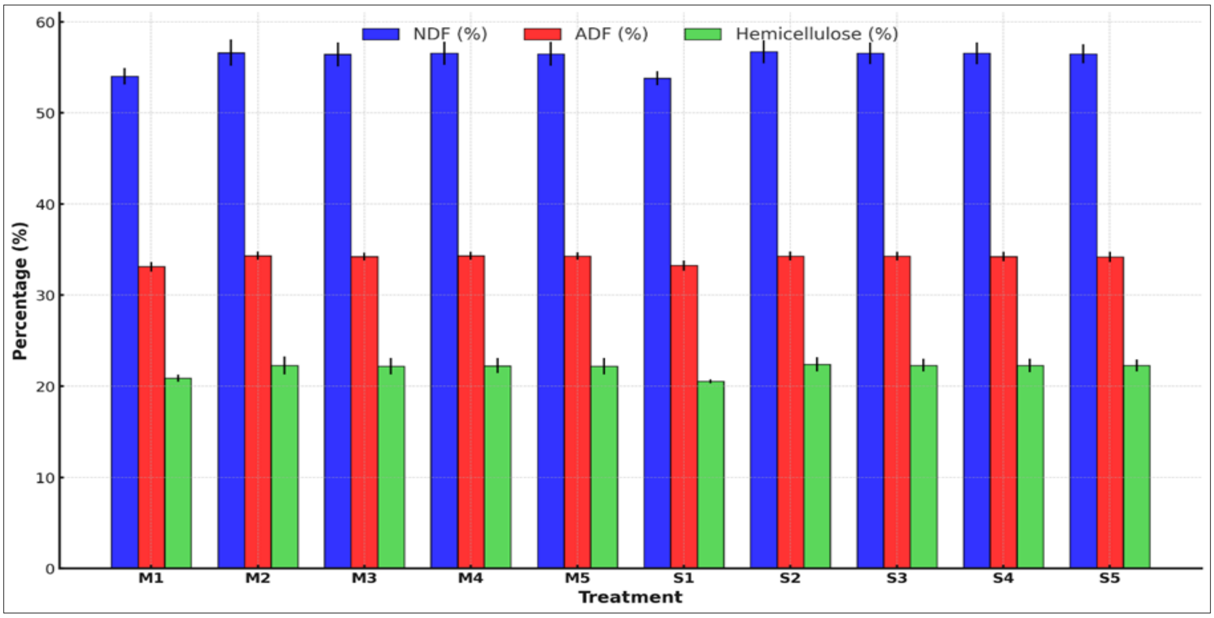

Fig. 4. Crude protein and crude fibre content of fodder oat influenced by residual impact of maize + soybean intercropping with different nutrient management.

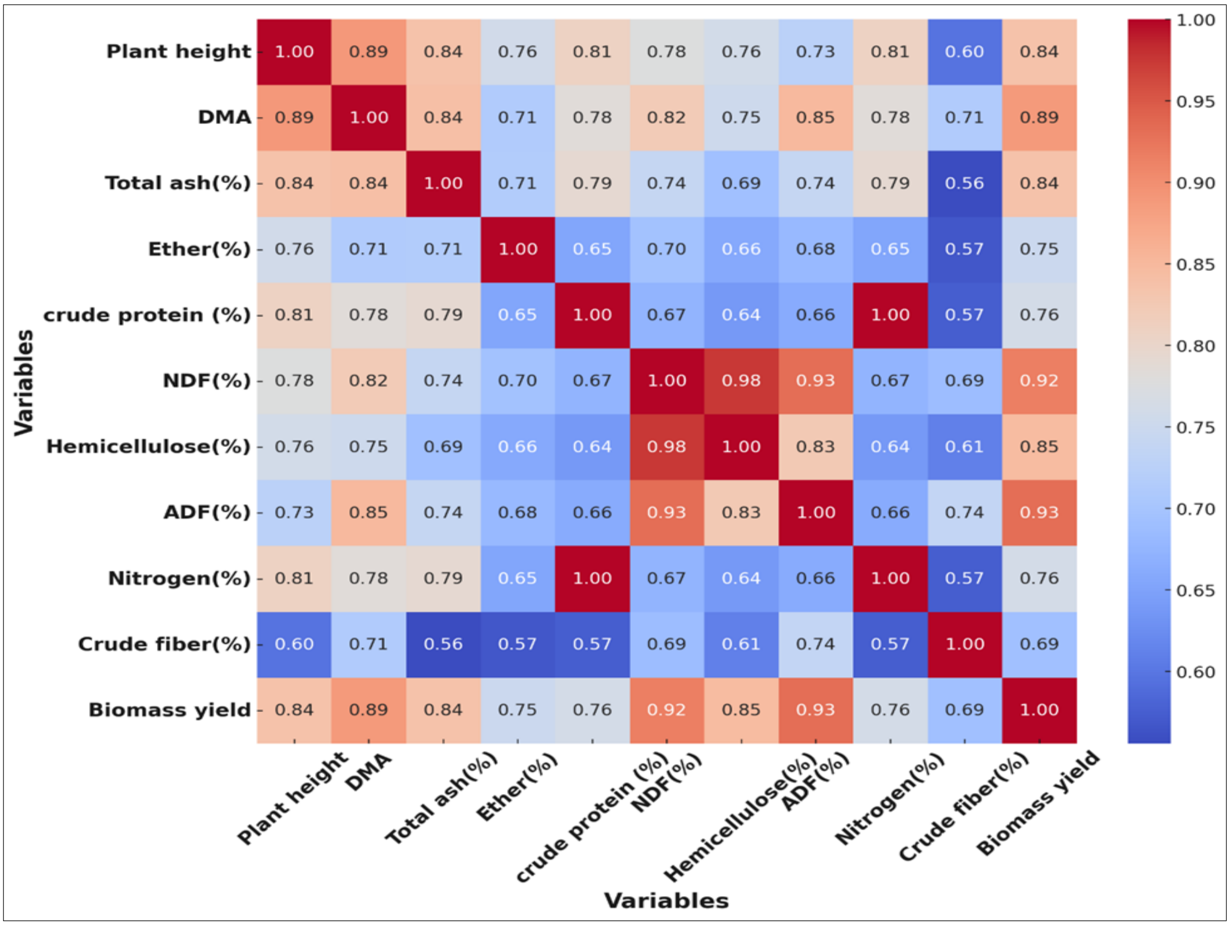

Fig. 5. Correlation studies between the variable of fodder oat during 2023-24.

ADF (r = 0.928) and Hemicellulose (r = 0.845), particularly correlated with BMY (Fig. 5).

Conclusion

The study acknowledges the impact of legume-based intercropping systems with nutrient application on enhancing the growth, development and quality of succeeding fodder oats, as well as on nitrogen cycling, soil fertility and the effective use of agricultural inputs. The use of 100 % RDF with sole soybeans as a preceding crop enhanced plant height by 23.65 %, DMA by 44.04 % and resulted in a 39.87 % increase in biomass yield. Other Altered planting systems (M_3 - M_5) and interchanging nutrient strategies (S_3 - S_5) further boosted biomass yield by 12.39-12.67 %. These methods demonstrated that the residual effect of soybean row patterns with nutrient combinations enhanced succeeding fodder oat and reduced dependency on synthetic fertilizers while sustaining productivity. A strong correlation was observed between biomass yield, growth parameters and nutritional quality. This enables farmers to integrate nitrogen-fixing legumes and improved nutrient management into their fodder production for environmental sustainability. Additionally, this study addresses significant issues, including soil degradation and high input costs, while promoting sustainable and productive agricultural practices that ensure food security and long-term environmental health.

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Authors' contributions

UKS carried out conceptualization, methodology, investigation, data curation and writing-original draft. SK and SHT carried out supervision, formal analysis, visualization, validation, writing original draft and editing, writing review and editing. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: The authors do not have any conflict of interest to declare.

Ethical issues: None

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