RESEARCH ARTICLE Agricultural Science Digest, Volume 45 Issue 6: 924-930 (December 2025)

Mitigating Climate-induced Lodging While Sustaining Fodder Supply Through Cutting Management in Dual-purpose Barley (*Hordeum distichon* L.)

Sonia[1], Barkha[1], Kangujam Bokado[1], Heisnam Sobhana Devi[1]

10.18805/ag.D-6347

ABSTRACT

Background: Recent climate change has adversely affected global food production. Dual-purpose barley offers green fodder for livestock during lean periods and grains afterward. It's essential to identify management practices that mitigate the impacts of climate, particularly lodging, on grain yield. This study investigates cutting management in dual-purpose barley to support sustainable winter fodder production while maintaining grain yields.

Methods: The study used a randomized block design with four replications and ten treatments, including T_1: No lopping, T_2: Lopping@30 DAS + 1-inch stump height, T_3: Lopping @ 30 DAS + 2 inches stump height, T_4: Lopping @ 30 DAS + 3 inches stump height, T_5: Lopping @ 45 DAS + 1-inch stump height, T_6: Lopping @ 45 DAS + 2 inches stump height, T_7: Lopping @ 45 DAS + 3 inches stump height, T_8: Lopping @ 60 DAS + 1-inch stump height, T_9: Lopping @ 60 DAS + 2 inches stump height, T_{10}: Lopping @ 60 DAS + 3 inches stump height. Conducted during the *Rabi* seasons of 2022-24 at Lovely Professional University, Punjab, the study varied lopping time and stump heights, collecting data on phenology, yield, lodging and sustainability.

Result: The results showed that lopping at 30 DAS with a 3-inch stump height achieved the highest grain yield (40.8 q ha^{-1}), harvest index (36.38%), sustainable yield index (0.86) and shortest maturity time (114 days). Meanwhile, lopping at 60 DAS with a 1-inch stump height yielded the greenest fodder (109.7 q ha^{-1}). No lopping resulted in the highest lodging severity (2.17), followed by lopping at 30 DAS (1.60). A strong correlation (r=0.99) was observed between 50% maturity and full maturity with grain yield. Lopping at 30 DAS was the most effective for fodder and grain production.

Key words: Dual-purpose barley, Fodder, Lodging severity, Lopping, Sustainable production.

INTRODUCTION

Global temperatures have increased by around 0.4°C since 1980, with significant variations in different areas. Warming increased the yield in some regions, decreased it in others and had a minor impact on others (Lobell *et al.,* 2007). Barley is the 4th most important cereal crop after rice, wheat and maize globally. Compared to the other crops, it has more regeneration capacity, less water requirements, requires fewer external inputs, is more resistant to pests and diseases and is comparatively capable of surviving harsh climatic conditions. It is mainly grown for grain, feed and fodder purposes. However, it is prone to lodging during critical growth stages, particularly in dense canopies with excessive vegetative growth.

Only 20-25 % of the grain is used in the malt industry, while the rest is used for fodder purposes in the dairy sector to fill the gap between the demand and supply of the green fodder during the lean period of the year (Kumar *et al.,* 2013). Globally, it has grown over 123.55 million acres, with production of 150.9 million metric tons. India produced about 1.91 million metric tons of barley over 614.5 thousand hectares of land with an average productivity of 27.3 quintals per hectare in 2023 (USDA, 2023).

Lodging is a complex process that is impacted by external factors like wind speed, rain, soil and plant characteristics. The plant lodging resistance can be assessed by the weight of the upper portion and the resistance of the lower parts, which shows the importance of interaction in plant stability (Mengistie *et al.,* 2023). It also complicates the harvesting procedure and the quality of the grains is also reduced. Adopting proper lopping management before the jointing stage, *i.e.,* taking one cutting during the active vegetative growth stage, can significantly reduce the chances of lodging in barley due to its shorter height, better stability and strong root anchorage (Dhillon *et al.,* 2020) (Fig 1).

Fodder lopping is critical, as early lopping reduces fodder yield, while delayed lopping can hinder plant regeneration and grain yield (Neelam *et al.,* 2022). Stump

[1]Department of Agronomy, School of Agriculture, Lovely Professional University, Phagwara-144 411, Punjab, India.

Corresponding Author: Barkha, Department of Agronomy, School of Agriculture, Lovely Professional University, Phagwara-144 411, Punjab, India. Email: barkhasingh57@gmail.com

ORCIDs: 0009-0004-2221-9334; 0000-0002-0715-0285; 0000-0003-3242-8960; 0009-0003-1615-2076

How to cite this article: Sonia, Barkha, Bokado, K. and Devi, H.S. (2025). Mitigating Climate-induced Lodging While Sustaining Fodder Supply Through Cutting Management in Dual-purpose Barley (*Hordeum distichon* L). *Agricultural Science Digest.* **45(6):** 924-930. doi: 10.18805/ag.D-6347.

Submitted: 09-04-2025 **Accepted:** 05-05-2025 **Online:** 12-06-2025

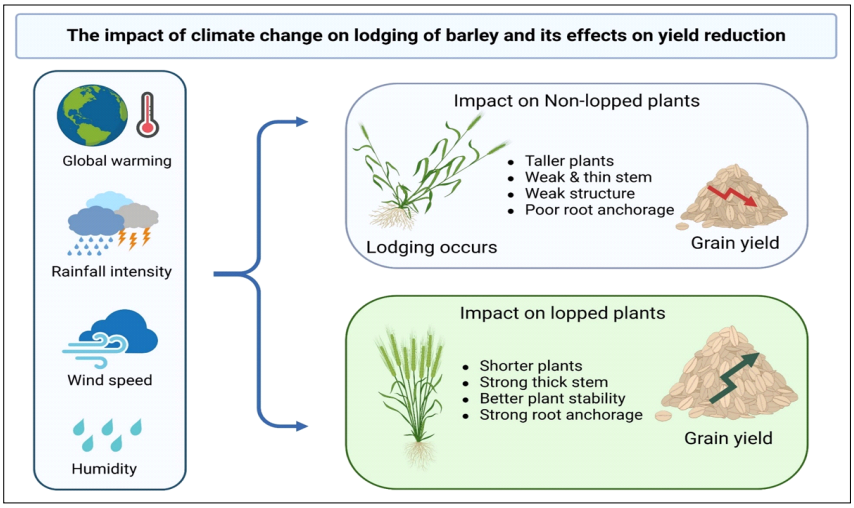


Fig 1: Impact of climate change on lodging of barley and its effects on yield reduction (Wilke *et al.,* 2019).

height during lopping impacts nutrient availability, regeneration and grain production, ensuring effective photosynthesis and productivity. Additionally, the number of leaves left on the stump affects sunlight capture and regrowth capacity, influencing both green fodder and grain yields (Atis *et al.,* 2018).

To address this issue, proper lopping time and stump height management are essential for enhancing both grain and fodder yield of dual-purpose barley in Punjab. This study aims to optimize these factors to achieve a balanced supply of fodder and grain by maximizing resource usage, enhancing food security and promoting agricultural sustainability while addressing challenges like lodging from changing weather patterns.

MATERIALS AND METHODS

A field experiment was conducted at Lovely Professional University in Phagwara, Punjab, during the *rabi* seasons of 2022-23 and 2023-24. The site is located at 31.08810 N latitude and 75.51700 E longitude at 233 meters above sea level. The soil is sandy loam with a pH of 0.41 and 0.44 and low in available nitrogen (223, 231 kg/ha), high in available phosphorus (29.3, 32.5 kg/ha) and medium in available potassium (160, 184 kg/ha).

Meteorological data

Meteorological parameters from the cropping seasons of 2022-23 and 2023-24 are shown in Table 1. While overall seasons were normal, the second season had higher total rainfall and relative humidity. Increased wind speed in March raised the risk of lodging, leading to reduced grain filling, photosynthesis, quality and yield.

Preliminary information

The experiment was laid out in a randomized block design with ten treatments and four replications. The treatments include- T_1: Control (No lopping), T_2: Lopping at 30 DAS + 1 inch stump height, T_3: Lopping at 30 DAS + 2 inches stump height, T_4: Lopping at 30 DAS + 3 inches stump height, T_5: Lopping at 45 DAS + 1-inch stump height, T_6: Lopping at 45 DAS + 2 inches stump height, T_7: Lopping at 45 DAS + 3 inches stump height, T_8: Lopping at 60 DAS + 1-inch stump height, T_9: Lopping at 60 DAS + 2 inches stump height, T_{10}: Lopping at 60 DAS + 3 inches stump height. DWRUB-52 barley was sown on November 19, 2022 and November 18, 2023, at a 5 cm depth and 22.5 cm row spacing, using 100 kg/ha seed. Fertilizer (75:30:20 NPK kg/ha) was applied, with P and K at sowing and N in three split doses. Necessary agronomic practices, like irrigation and weeding, were followed.

Observations recorded

Growth parameters

Dry matter accumulation is determined by oven drying plant samples at 60-70°C until a constant weight is reached. For the leaf stem ratio, samples are collected at harvest, dried at 60°C and separated into leaf and stem. The leaf stem ratio is calculated by dividing leaf dry weight by stem dry weight.

Phenological studies

For crop phenological studies, days were counted from sowing to tillering, booting, 50% spike initiation, 50% maturity and full maturity.

Crop yield

Fodder was lopped from plots, leaving stump heights of 1, 2 and 3 inches for regeneration. Green fodder yield was measured in q ha^{-1}. The crop was harvested and threshed, with grain weights recorded. Straw yield was calculated by subtracting grain yield from total biological yield and the harvest index (HI) was the percentage of grain yield to biological yield.

Lodging and sustainability-related indices

Parameters to assess lodging's impact on crop yield and treatment sustainability are detailed in Table 2.

Statistical analysis

The data of individual years was pooled and analysed using Excel software with ANOVA for randomized block design. Two-way ANOVA was used to determine the statistical significance of the difference between mean treatment values. Treatment means are compared at a 5% level of significance using the least significant difference test to decode the significance of the treatment effect (Gomez and Gomez, 1984).

RESULTS AND DISCUSSION

Phenological studies of dual-purpose barley in Table 3 showed significant effects from varying lopping times and stump heights at post-tillering stages. The time taken for tillering was consistent across treatments, ranging from 25 to 27 days, indicating that genetic and environmental factors influence tillering. Previous studies by Lal *et al.* (2017) and Singh *et al.* (2017) support these findings. Variations in booting times were

Table 1: Mean monthly meteorological data during the *rabi* seasons of 2022-23 and 2023-24.

Months	Max temp (°C)		Min temp (°C)		Max relative humidit (%)		Total rainfall (mm)		Wind speed (km/hr.)	
	2022-23	2023-24	2022-23	2023-24	2022-23	2023-24	2022-23	2023-24	2022-23	2023-24
November	29.0	26.6	17.0	11.5	64.0	92.8	0.2	8.0	13.0	4.8
December	24.8	21.3	10.3	6.3	90.2	94.1	0.0	0.6	5.6	3.8
January	15.6	13.6	7.1	6.3	91.5	94.5	49.1	2.4	7.8	3.6
February	25.4	21.5	11.9	6.2	81.2	91.9	0.0	8.3	10.1	6.5
March	27.5	26.7	15.0	11.4	73.1	89.9	55.6	78.0	7.8	7.0
April	33.1	33.8	16.4	15.9	74.4	84.7	11.7	44.9	5.5	5.9

Table 2: Lodging and sustainability formulae used.

Parameter	Formula	Reference
Lodging percentage	By the quadrant method	Rabieyan *et al.,* 2023
Lodging score	= (%plot area lodged*angle of lodging from the vertical)/90	Kumar *et al.,* 2020
Lodging index	= (1/6 (% at 0°-15°) +2/6 (%at 15°-30°) +3/6 (% at 30°-45°) +4/6 (%at 45°-60°) +5/6 (% at 60°-75°) +6/6 (% at 75°-90°)	Caierão *et al.,* 2006
Lodging score index	= Lodged area/lodging angle*100	Rabieyan *et al.,* 2023
Lodging severity index	=Lodging score*lodging percentage	Wilke *et al.,* 2019
Grain fodder ratio	= Grain yield/Fodder yield	Neelam *et al.,* 2022
Dual-purpose crop yield index	= Grain yield + Fodder yield/2	Kumar *et al.,* 2024
Sustainable yield index grain and fodder	= y-/y max	Sarangi *et al.,* 2020
Combined sustainable yield index (grain+fodder)	= (wg *SYlg + wf * SYlg)/wg +wf	

Table 3: Impact of varying lopping schedules and stump height management on different phenological stages of dual-purpose barley (Data pooled over 2 years).

Treatment	Days taken for tillering	Days taken for the booting stage after lopping	Days taken for 50% spike initiation	Days taken for 50% maturity	Days taken for full maturity
T_1: Control (No lopping)	26	53	84	108	118
T_2: Lopping at 30 DAS + 1-inch stump height	26	67	89	114	124
T_3: Lopping at 30 DAS + 2 inches stump height	26	63	84	109	117
T_4: Lopping at 30 DAS + 3 inches stump height	26	61	81	105	114
T_5: Lopping at 45 DAS + 1-inch stump height	26	67	102	126	136
T_6: Lopping at 45 DAS + 2 inches stump height	25	64	96	122	131
T_7: Lopping at 45 DAS + 3 inches stump height	27	62	93	116	127
T_8: Lopping at 60 DAS + 1-inch stump height	25	71	108	134	144
T_9: Lopping at 60 DAS + 2 inches stump height	26	67	103	128	138
T_{10}: Lopping at 60 DAS + 3 inches stump height	26	64	99	124	134
SE(m)±	0.6	0.9	0.4	0.7	0.8
CD (P=0.05)	NS	2.3	1.0	2.1	1.8

significant, with T_1: Control (No lopping) booting first at 53 days, followed by T_4: Lopping at 30 DAS + 3 inches stump height at 61 days and T_8: Lopping at 60 DAS + 1-inch stump height at 71 days. The delays in T_8: Lopping at 60 DAS + 1-inch stump height and T_5: Lopping at 45 DAS + 1-inch stump height may be attributed to lower stump heights and prolonged vegetative growth, as higher stump heights are associated with increased photosynthesis and carbohydrate storage (Atis *et al.,* 2018).

The 50% spike initiation occurred first in T_4: Lopping at 30 DAS + 3 inches stump height at 81 days, followed by T_1: Control (No lopping) and T_3: Lopping at 30 DAS + 2 inches stump height at 84 days, likely due to lopping at early vegetative growth redirects assimilates and hormonal signals (like cytokinin flow) from shoot expansion to reproductive development. In contrast, T_8: Lopping at 60 DAS + 1-inch stump height took 108 days, possibly due to extended vegetative growth and greater residual biomass (Sharma *et al.,* 2023).

T_4: Lopping at 30 DAS + 3 inches stump height reached 50% maturity in just 105 days, followed by T_1: Control (No lopping), while T_8: Lopping at 60 DAS + 1-inch stump height took longer at 134 days. Throughout the experiment, T_4: Lopping at 30 DAS + 3 inches stump height progressed through stages faster than other treatments, with T_8: Lopping at 60 DAS + 1-inch stump height showing slow growth after tillering. Delayed lopping increases residual biomass, extending grain-filling duration and lengthening the crop cycle. It significantly affects crop physiology and phenology, causing delays in booting and spike initiation. Early lopping leads to faster maturation due to reduced regeneration and photosynthesis, while delayed lopping lengthens the maturity period (Patel *et al.,* 2024; Lal *et al.,* 2017).

The data in Table 4 shows that T^7: Lopping at 45 DAS + 3 inches stump height has the highest dry matter accumulation (75.3 g/m²), followed by T_6: Lopping at 45 DAS + 2 inches stump height (74.4 g/m²), while T_2: Lopping at 30 DAS + 1-inch stump height has the least (62.8 g/m²) during growth. T_5: Lopping at 45 DAS + 1-inch stump height has the maximum leaf stem ratio (2.37) and T_1: Control (No lopping) has the lowest (1.68). Lower stump height lopping resulted in the highest fodder yield, whereas grain yield was highest during 30 DAS lopping. Highest grain yields were noted in T_4: Lopping at 30 DAS + 3 inches stump height (40.8 q/ha) and T_3: Lopping at 30 DAS + 2 inches stump height (38.8 q/ha) from 30 DAS lopping, outperforming no lopping and other treatments. Heavy lodging with no cutting reduced yields compared to 30 DAS lopping. A delay in lopping decreases the grain yield but increases fodder yield. The lowest straw yield was in T_2: Lopping at 30 DAS + 1-inch stump height (69.44 q/ha), while T_7: Lopping at 45 DAS + 3 inches stump height had the maximum (74.56 q/ha).

The results revealed significant differences in grain and straw yield across treatments compared to the control group (T_1: No lopping). Treatment T_4, with lopping at 30 DAS and a 3-inch stump height, yielded a 6.25% increase in grain yield and a minor 2.0% decrease in straw yield. In contrast, T_8 (lopping at 60 DAS with a 1-inch stump height) experienced the largest grain yield drop of 26.0%. T_7 (Lopping at 45 DAS + 3 inches stump height 3-inch stump height) and T_6 (2-inch stump height) also showed declines in grain yield of 11.7% and 8.1%, respectively, but had modest increases in straw yield of 1.6% and 2.5%.

Slow initial vegetative growth and reduced stem biomass result in a better leaf-to-stem ratio. Delayed lopping increases stem biomass, leading to more dry matter in stems than leaves (Kumar *et al.,* 2021). Lower stump heights capture less solar radiation due to greater leaf area removal. Early lopping at 30 DAS allows time for regeneration, enhancing grain production, with results showing 4.89 t/ha for grain and 5.91 t/ha for both grain and fodder at a 7.5 cm cutting height (Atis *et al.,* 2018). Delaying fodder lopping increases vegetative growth,

Table 4: Impact of varying lopping schedules and stump height management on various yield-related parameters of dual-purpose barley (Data pooled over 2 years).

Treatment	Dry matter accumulation (g/m^2)	Leaf stem yield ratio	Green fodder (q ha^{-1})	Grain yield (q ha^{-1})	Straw yield (q ha^{-1})	Harvest index (%)
T_1: Control (No lopping)	63.7	1.68	-	38.4	72.73	34.60
T_2: Lopping at 30 DAS + 1-inch stump height	62.8	2.21	29.1	37.6	69.44	35.04
T_3: Lopping at 30 DAS + 2 inches stump height	65.0	1.97	27.7	38.8	69.85	35.67
T_4: Lopping at 30 DAS + 3 inches stump height	66.3	1.89	25.7	40.8	71.26	36.38
T_5: Lopping at 45 DAS + 1-inch stump height	73.1	2.37	79.7	31.9	72.61	30.48
T_6: Lopping at 45 DAS + 2 inches stump height	74.4	2.17	59.7	33.9	73.89	31.46
T_7: Lopping at 45 DAS + 3 inches stump height	75.3	1.92	45.4	35.3	74.56	32.07
T_8: Lopping at 60 DAS + 1-inch stump height	69.4	1.83	109.7	28.4	71.48	28.42
T_9: Lopping at 60 DAS + 2 inches stump height	70.5	1.70	96.1	29.8	72.55	29.11
T_{10}: Lopping at 60 DAS + 3 inches stump height	71.6	1.50	86.2	31.4	73.94	29.81
SE(m)±	0.1	0.03	1.9	0.7	0.5	0.2
CD (P=0.05)	0.4	0.09	6.2	1.4	1.1	0.6

Table 5: Impact of varying lopping schedules and stump height management on lodging with different indices on dual-purpose barley (Data pooled over 2 years).

Treatment	Grain fodder ratio	Lodging percentage %	Lodging score (0-9)	Lodging index	Lodging score index	Lodging severity index
T_1: Control (No lopping)	-	34	6.4	4.8	0.24	2.17
T_2: Lopping at 30 DAS + 1-inch stump height	1.3	9	0.5	0.8	0.02	0.04
T_3: Lopping at 30 DAS + 2 inches stump height	1.4	18	1.9	1.6	0.07	0.35
T_4: Lopping at 30 DAS + 3 inches stump height	1.6	29	5.2	4.3	0.16	1.60
T_5: Lopping at 45 DAS + 1-inch stump height	0.4	-	-	-	-	-
T_6: Lopping at 45 DAS + 2 inches stump height	0.6	-	-	-	-	-
T_7: Lopping at 45 DAS + 3 inches stump height	0.8	-	-	-	-	-
T_8: Lopping at 60 DAS + 1-inch stump height	0.3	-	-	-	-	-
T_9: Lopping at 60 DAS + 2 inches stump height	0.3	-	-	-	-	-
T_{10}: Lopping at 60 DAS + 3 inches stump height	0.4	-	-	-	-	-
SE(m)±	0.03	2.2	1.1	1.6	0.01	0.4
CD (P=0.05)	0.10	9.8	NS	NS	0.02	NS

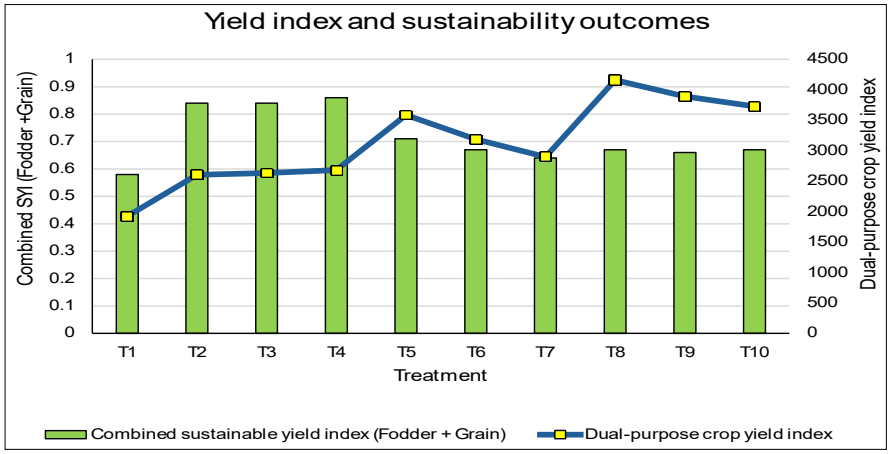


Fig 2: Crop yield index and combined sustainability index (Fodder + Grain) of dual-purpose barley.

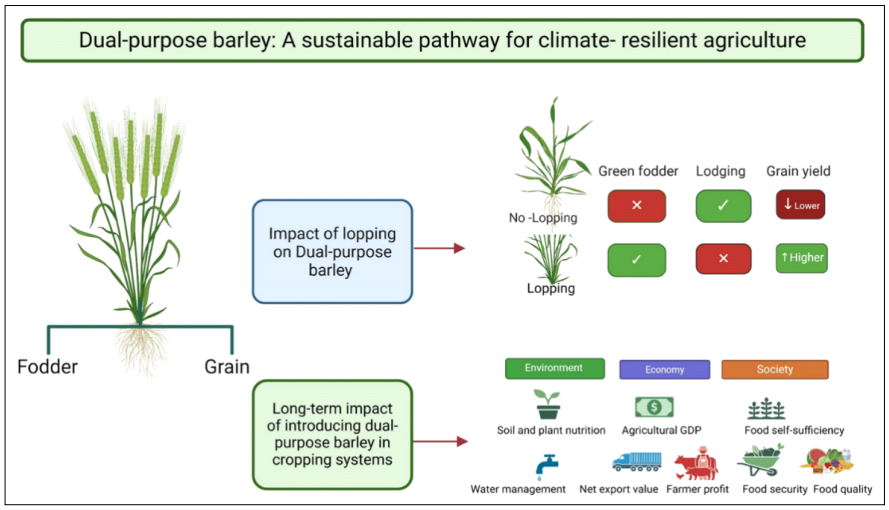


Fig 3: The long-term impact of varying lopping time and stump heights on the productivity of dual-purpose barley.

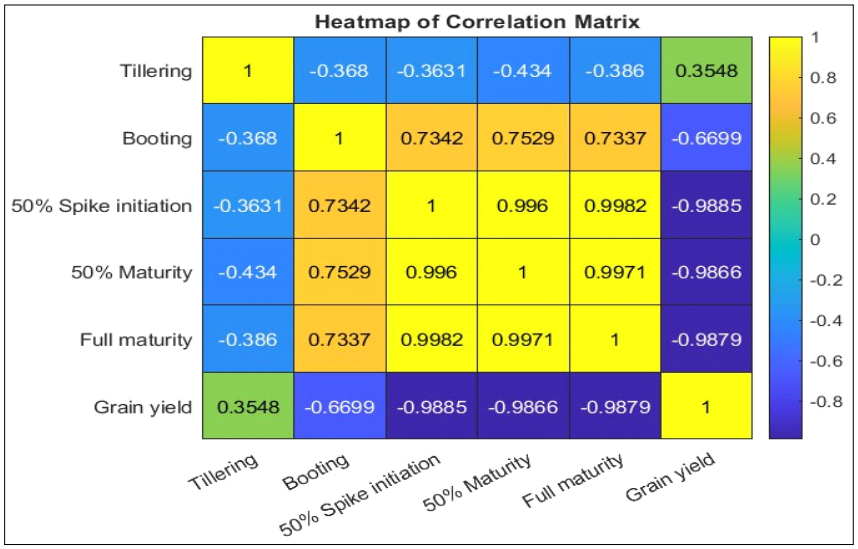


Fig 4: Correlation studies among the phenological studies and the grain yield of the dual-purpose barley.

yielding higher fodder at 60 DAS compared to 45 and 30 DAS, benefiting from additional growth (Dhillon *et al.,* 2020). Early lopping improves the harvest index at 30 DAS, while delaying it favors taller stumps for better outcomes.

The performance of dual-purpose barley showcased in Fig 2, which displays the crop yield index and combined sustainability index. Treatment T_4, which involves lopping at 30 DAS with a stump height of 3 inches, stands out for its superior agronomic and environmental benefits in terms of both grain and fodder production.

Data in Table 5 shows that T_4: Lopping at 30 DAS + 3 inches stump height has a better grain fodder ratio (1.6) and T_1: Control (No lopping) had the highest lodging severity at 2.17%, while T_2: Lopping at 30 DAS + 1-inch stump height (0.04%), T_3: Lopping at 30 DAS + 2 inches stump height (0.35%) and T_4: Lopping at 30 DAS + 3 inches stump height (1.60%) had lower rates. No lopping increased vulnerability to wind and rain, while delayed cutting improved stem strength and reduced lodging. Early lopping weakened root anchorage and increased lodging risk during heavy rain. Barley cell walls consist of 30-31% cellulose, 27% hemicellulose, 16-19% lignin and 3.9% ash, with variations contributing to lodging. Plants sustain gravity along with strong opposing wind speeds by accumulating cell walls around each cell (Mengistie *et al.,* 2023). The seasons were normal, but rainfall and humidity were higher in the second season compared to the first, as shown in Table 1. Increased wind speed in March raises the risk of lodging due to stem bending and breakage, leading to reduced grain filling, photosynthesis, grain quality and yield. The long-term impact of varying lopping time and stump heights on dual-purpose barley productivity is illustrated in Fig 3.

Tillering negatively correlated with all phenological stages but had a weak positive correlation with grain yield (r =0.3548) in Fig 4. The booting stage was strongly correlated with later stages (50% spike initiation r =0.7342; 50% maturity r =0.7529) but negatively impacted grain yield (r =-0.6699). The stages of 50% spike initiation, 50% maturity and full maturity had high correlations (r =0.99) while also being negatively correlated with yield (r =-0.98). Maintaining optimal phenological through proper lopping and stump height is essential for grain productivity (Lal *et al.,* 2017).

CONCLUSION

Based on the above findings, it may be concluded that the impact of lopping time and stump height on crop physiological maturity was significant; a delay in lopping time and higher stump height will lead to delayed maturity. Lopping time and stump height significantly impact crop maturity; delays in lopping and higher stumps result in later maturity. Although late lopping can reduce lodging in barley, it may harm fodder and grain yields. Early lopping at 30 DAS with a 3-inch stump height is promising for improving stability and sustainability in Punjab's grain and fodder production, also lowering lodging compared to no lopping. These practices align with SDG 2 (Zero Hunger) and SDG 13 (Climate Action).

This study has limitations, including a focus on a single variety and the absence of an economic analysis to evaluate the cost-benefit ratio of management practices, which is essential for farmer adoption. Future research should address these issues by studying long-term effects on nutrient cycling, soil health and crop resilience across various environments and cropping patterns, along with economic feasibility for farmers.

ACKNOWLEDGEMENT

The authors acknowledge the Department of Agronomy, Lovely Professional University, for the research facilities provided.

Disclaimers

The views and conclusions expressed in this article are solely those of the authors and do not necessarily represent the views of their affiliated institutions. The authors are responsible for the accuracy and completeness of the information provided, but do not accept any liability for any direct or indirect losses resulting from the use of this content.

Informed consent

All animal procedures for experiments were approved by the Committee of Experimental Animal Care and Handling Techniques were approved by the University of Animal Care Committee.

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this article. No funding or sponsorship influenced the design of the study, data collection, analysis, decision to publish, or preparation of the manuscript.

REFERENCES

Atıs, İ. and Akar, M. (2018). Grain yield, forage yield and for age quality of dual purpose wheat as affected by cutting heights and sowing date. *Turkish Journal of Field Crops*. **23(1):** 38-48.

Caierão, E. (2006). Effect of induced lodging on grain yield and quality of brewing barley. *Crop Breeding and Applied Bio Technology*. **6(3):** 215-221.

Dhillon, B.S., Uppal, R.S. and Goyal, M. (2020). Forage quality and productivity of barley (*Hordeum vulgare* L.) as influenced by cutting management under staggered sowing in North-West India. *Archives of Agronomy and Soil Science*. **66(9):** 1244-1258.

Foreign Agricultural Service, USDA, (2023). Barley Production Data. Retrieved March 18, 2025, from https://ipad.fas.usda.gov/

Gomez, K.A. and Gomez, A.A. (1984). Statistical Procedures for Agricultural Research. International Rice Research Institute, Manila, Philippines. John Wiley and sons, New York, USA, 2nd edn. pp 20-25.

Kumar, D., Kumar, V., Verma, R.P.S., Kharub, A.S. and Sharma, I. (2013). Quality parameter requirement and standards for malt barley-A review. *Agricultural Reviews*. **34(4):** 313-317. doi: 10.5958/j.0976-0741.34.4.018.

Kumar, N., Banta, N., Chahal, A., Kantwa, S.R. and Singh, S. (2021). Production potential of dual purpose winter cereals as influenced by cutting management under Mid Hill condi tions of Himachal Pradesh. *Forage Research*. **47(2):** 187-192.

Kumar, S. and Hooda, V. (2024). Dual purpose barley (*Hordeum vulgare*) for better remunerations through higher fodder and grain production under different cutting schedules. *Indian Journal of Agronomy*. **69(1):** 65-70.

Lal, M., Saini, K.S. and Kaur, P. (2017). Phenological development and agrometeorological indices in dual purpose barley (*Hordeum vulgare* L.) as influenced by planting techniques and cutting practices in indo-gangetic plains of India. *Indian Journal of Ecology*. **44(3):** 570-574.

Lobell, D.B. and Field, C.B. (2007). Global scale climate-crop yield relationships and the impacts of recent warming. *Environmental Research Letters*. **2(1):** 014002.

Mengistie, E. and McDonald, A.G. (2023). Effect of cell wall compositions on lodging resistance of cereal crops. The Journal of Agricultural Science. **161(6):** 794-807.

Neelam, Kumar, S., Satpal, Kumar, J., Devi, U. and Hooda, V.S. (2022). Agronomic evaluation of dual-purpose barley varieties under different cutting management system. For *Age Research*. **47(4):** 449-455.

Patel, D.M., Patel, A.G., Chaudhary, M.M., Chaudhary, B.J. and Dhakar, R.L. (2024). Response of nitrogen levels and cutting management on growth and yield of dual-purpose barley. *Plant Archives*. **24(1):** 1609-1616.

Rabieyan, E., Darvishzadeh, R. and Alipour, H. (2023). Identification and estimation of lodging in bread wheat genotypes using machine learning predictive algorithms. *Plant Methods*. **19(1):** 109.

Sarangi, D., Jena, D., Santra, G.H. and Choudhury, S. (2020). Sustainable yield index (SYI) of a groundnut-maize cropping system as influenced by sources and management of phosphorus on the acid Alfisols. *Journal of Pharmacognosy and Phyto Chemistry*. **9(4):** 1732-1736.

Sharma, A., Dhaka, A.K., Singh, B., Jasht, S. and Godara, M. (2023). Yield and economics of dual purpose barley as influenced by various nitrogen dose and seed rate. *International Journal of Environment and Climate Change*. **13(8):** 2046-2054.

Singh, M., Chauhan, A., Kumar, R., Joshi, D., Soni, P.G. and Meena, V.K. (2017). Dual purpose barley as affected by date of sowing, varieties and stage of harvesting-A review. *Agricultural Reviews*. **38(2):** 159-164. doi: 10.18805/ag.v38i02.7948.

Wilke, N., Siegmann, B., Frimpong, F., Muller, O., Klingbeil, L. and Rascher, U. (2019). Quantifying lodging percentage, lodging development and lodging severity using a UAV-based canopy height model. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*. **42:** 649-655.