Research Article:

EVALUATION OF EARLY GROWTH TRAITS AND HERBAGE BIOMASS PRODUCTION OF SELECTED OAT GENOTYPES UNDER DIFFERENT SOWING DATES

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ABSTRACT

Early growth traits are important indicators of plant vigor and potential herbage yield. Lack of knowledge on how early growth traits respond to different sowing dates and their influence on herbage biomass is limiting oat fodder production in the Terai region. Optimum sowing date can enhance livestock feed availability and quality through higher herbage biomass production. The objective of this study was to evaluate early-stage growth attributes and herbage yield under different sowing dates. A field experiment was conducted using a two-factor factorial randomized complete block design with four replications at Rampur, Chitwan. Four oat genotypes (Nandini, Amritdhara, Swan Pak, and Longford) were sown on three dates: 1 November, 15 November, and 30 November. Significant differences ($p<0.05$) were observed among genotypes and sowing dates for all the studied traits. Nandini, Swan Pak, and Amritdhara showed the highest tillering, while leaf number and leaf area were greatest at 15 November sowing. Longford had the highest chlorophyll content. Amritdhara produced the highest dry matter yield (2.53 t ha^{-1}), followed by Swan Pak (2.49 t ha^{-1}), with maximum yield observed at 15 November sowing (2.64 t ha^{-1}). Plant height and tiller number contributed most positively to dry matter yield. Sowing Swan Pak and Amritdhara on November 15 holds potential for higher fodder production under the agro-climatic conditions of the Inner Terai region of Nepal. Further multi-year trials are recommended to validate these findings and utilize them in agronomic practices.

Keywords: Early vegetative, fodder yield, growth attributes, sowing time

INTRODUCTION

Livestock plays a vital role in sustaining rural livelihoods and contributes 24% to the agricultural gross domestic product (AGDP) of Nepal (MoALD, 2025). Availability of nutrient-rich fodder is essential for improving livestock productivity (Surje et al., 2015). However, feed scarcity and the limited availability of high-quality fodder remain a major problem for livestock development in Nepal. Poor quality and inadequate feed negatively affect animal health, resulting in reduced weight gain, milk production, and reproductive efficiency (Baris, 2023). To address these problems, the production of fodder crops such as oats should be increased through scientific management practices. However, high variation exists in varietal selection, sowing dates, and management practices of oat cultivars across different regions.

Oat (*Avena sativa* L.), locally known as *jai*, belongs to the family Poaceae, and is one of the most important winter-season fodder crops grown throughout the country. It is well recognized for its high fodder yield and nutritional value. Oats are highly palatable and promote good digestion and nutrient absorption in ruminants (Li et al., 2022). Owing to its use as fodder, grain, grazing, hay, haylage, and silage, oat is gaining popularity as an important multi-cut fodder (FAO, 2020). However, their herbage mass producing abilities during different phenological growth stage varies due to varietal differences, sowing date, and other agronomical practices (Gondal et al., 2020; Xue et al., 2025).

Sowing date is a key detrimental factor affecting the growth attributes and herbage yield (Liu et al., 2021). In Nepal, oat is generally sown in November. The recent climatic variability alteration in rice sowing and harvesting schedules, which subsequently affected the sowing time of winter crops, including oat and wheat, in a rice-wheat/oats cropping system (Lamsal & Khadka, 2019). As a result, identifying location-specific adapting cultivars along with suitable sowing dates becomes a critical aspect to consider in higher herbage mass per unit area during different phenological stages. As a multi-cut fodder crop, oat can be harvested even during the early vegetative as well as at later growth stages. Vegetative growth plays a crucial role in the herbage mass and grain seed yield and adaptability to diverse agro-climatic conditions (West et al., 2023).

Early growth vigor and seedling establishment are key traits influencing herbage mass production (Khokhar et al., 2025). Evaluating these traits during early growth stages would help to understand the herbage yield potential and support the high herbage-yielding genotypes with respect to appropriate sowing dates. Early rapid vegetative growth also reduces the weed interference and reduces soil moisture loss through soil surface coverage (Zhao et al., 2006; Lemerle et al., 2001). However, limited studies have studied the early growth performance of oat genotypes under different sowing dates, as most studies emphasized herbage yield at later growth stages. Therefore, the present study was conducted in the inner terai region of Nepal to assess the growth attributes and herbage biomass production of four oat genotypes under three sowing dates at early growth stages.

RESEARCH METHODS

Genetic materials

Four Oat genotypes, namely, Nandini (V1), Amritdhara (V2), Swan Pak (V3) and Longford (V4), were used in this study. The genotypes were obtained from the Fodder and Pasture Research Center, Nepal Agricultural Research Council, Khumaltar, Lalitpur, Nepal.

Experiment location and climate

A field experiment was done from November 2023 to January 2024 at the research field of the National Cattle Research Program (NCRP), Chitwan, Nepal (27º65′ N latitude; 84º35′ E longitude and 187 meters above sea level. The soil texture of the experiment site was sandy loam. The mean maximum temperature rises to 39ºC during summer, while the minimum temperature during the winter drops to 8ºC. The research area receives 1500 mm of rainfall annually. The details on weathers parameters throughout the research period is presented in Fig. 1.

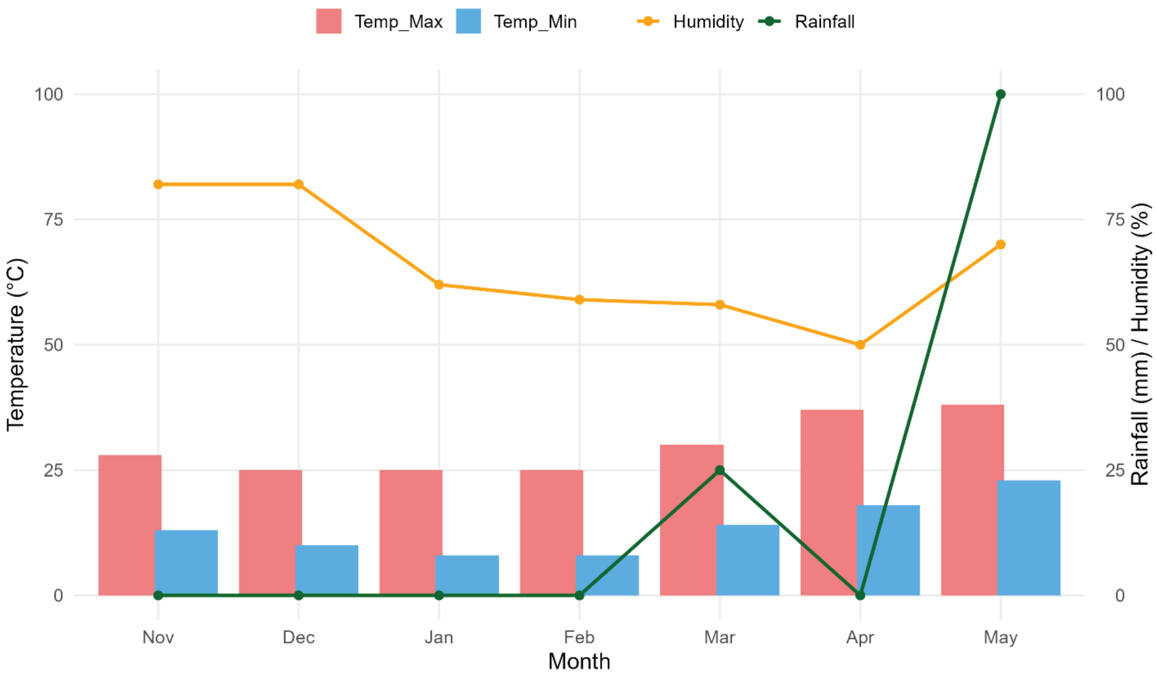

Fig. 1. Monthly variation in maximum and minimum temperatures (°C), relative humidity (%), and rainfall (mm) throughout the research period

Experimental design and treatment details

The experiment was laid out using a Randomized Complete Block Design (RCBD) with two factors arrangement of the treatments. Each treatment was replicated four times. The first factor consisted of four genotypes, namely Nandini, Amritdhara, Swan Pak, and Longford, while the second factor included three sowing dates: November 1 (D1), November 15 (D2), and November 30 (D3). Each plot measured 3 m × 4 m and consisted of 10 rows spaced at 30 cm apart.

Crop establishment

Continuous line sowing was done at a seed rate of 80 kg/ha manually. Farmyard manure (10 t/ha) and chemical fertilizer at the recommended dose of 80:60:30 kg/ha N: P_2O_5: K_2O were applied. The full dose of phosphorus, potassium, and half the dose of nitrogen were applied at the time of field preparation, while the rest of the nitrogen was applied in two splitting doses. All other agronomical practices were kept constant and were followed as per the standard procedure recommended by the National Pasture Fodder Research Program (NPFRP).

Data collection

Ten random plants from each plot were selected at 15, 30, 45, and 60 days after sowing (DAS) to record growth and physiological traits, including plant height, number of tillers per plant, number of leaves per plant, leaf area, and chlorophyll content. Plant height was measured from the soil surface to the tip of the longest leaf using a measuring scale and expressed in centimeters. The number of tillers and leaves per plant was counted manually from each selected plant, and mean values were computed. Leaf area was estimated indirectly by measuring leaf length and maximum width and applying the formula: leaf area = length × width × 0.75 (Aldesuquy et al., 2014), where 0.75 is a correction factor accounting for leaf shape. Chlorophyll content was recorded using a SPAD chlorophyll meter (SPAD 502 Plus, Minolta, Japan), where three readings were taken from different positions of each leaf and the average was expressed in SPAD units.

For dry matter biomass determination, plants were harvested at 60 DAS from a 1 m² area in each plot by cutting at a uniform height of 10 cm above ground level. The harvested plant material was first weighed for fresh weight and then oven-dried at a constant temperature (65–70°C) until a constant weight was achieved to determine dry matter. The dry biomass was calculated as described by Ninama et al. (2022). Dry matter yield was calculated and expressed in tons per hectare (t ha^{-1}) by converting the dry weight obtained from the 1 m² sampling area.

Statistical analysis

All the recorded data were analyzed in R Studio version 4.2.3. Data were statistically analyzed by using analysis of variance (ANOVA) (Gomez and Gomez, 1984), followed by Duncan's Multiple Range Test (DMRT) for mean comparison at 5% level of significance ($p < 0.05$). Similarly, for regression analysis, growth attributes recorded at 15, 30, 45, and 60 days after sowing were standardized using Z-score transformation. Multiple linear regression was performed to evaluate the relationship between dry matter yield at 60 DAS (DMY 60) and growth attributing traits using equation (1). The regression model included plant height (PH), number of tillers per plant (TIL), chlorophyll content (CHL), number of leaves per plant (NOL), and leaf area (LA) as individual variables. The regression model was determined as:

$DMY60=\beta0+\beta1(PH)+\beta2(TIL)+\beta3(CHL)+\beta4(LA)+\beta5(NOL)+\varepsilon$ (Eqn. 1)

Where, β0 is the intercept, β1 to β5 are regression coefficients and ε represents the error term.

RESULTS AND DISCUSSION

Plant height

Significant differences in plant height were observed for oat genotypes ($p < 0.05$) and sowing dates ($p<0.001$), but non-significant between genotype × sowing interaction at 15DAS (Table 1). Longford recorded the highest plant height which was statistically similar to Amritdhara and Swan Pak and the lowest plant height was recorded for Nandini. Among the sowing dates, oat genotypes sown on November 15 recorded the highest plant height, whereas the lowest plant height was observed in the November 1 sowing (Table 1). Similarly, at 30 DAS, only sowing date had a significant effect on plant height ($p < 0.05$). Highest plant height was observed on November 1, which was statistically similar to November 15, and lowest on November 30 (Table 1).

Sowing dates and genotype × sowing interaction were highly significant effects ($p < 0.001$) at 45DAS (Table 1). Highest plant height was observed on November 1, and lowest on November 30, which was statistically similar to November 15. There was a significant effect for genotypes, sowing dates, as well as the case for treatment combination ($p<0.001$) at 60 DAS (Table 1). Amritdhara, Swan Pak and Longford recorded statistically similar and highest plant height, while Nandini recorded the lowest plant height. Sowing on November 1 resulted in tall plants, followed by November 15 and November 30 at 60DAS (Table 1).

Plant height is the most important indicator of vegetative growth and vitality (Sarkar et al., 2022). The observed variation in plant height among the genotypes and sowing dates might be the effect of differences in physiological response, cell division, and phenotypic plasticity (Milach et al., 2002). Delayed sowing of oats often exposes the crop to cold temperature and frost, as a result, chilling stress limits the production and expression of gibberellic acid (Thakur et al., 2010). The non-significant difference observed in plant height at 30 and 45 DAS might be because the plants were at the tillering stage, which might have resulted in a similar plant height during vegetative growth among the genotypes. Taller plant tends to accumulate high biomass (Chapagain et al., 2025). Amritdhara, Swan Pak, and Longford recorded statistically similar plant heights and are therefore considered desirable genotypes for herbage production. Dwarf genotypes have the dominant dwarfing genes Dw6 and Dw7, which resulted in low height genotypes (Yan et al., 2021). These genotypes are beneficial under lodging-prone conditions.

Table 1. Effect of different oat varieties and sowing dates on plant height (cm) at Rampur, Chitwan, Nepal

Genotypes	Plant height (cm)			
	15 DAS	30 DAS	45 DAS	60 DAS
Nandini	11.24^{b}	24.84	53.81	71.15^{b}
Amritdhara	11.85^{ab}	25.99	52.47	78.20^{a}
Swan Pak	11.68^{ab}	27.26	53.34	77.41^{a}
Longford	12.36^{a}	29.13	52.85	79.38^{a}
LSD $_{(0.05)}$	0.74	3.38	3.39	2.24
SEm (±)	0.26	1.18	1.18	0.78
Level of significance	*	NS	NS	***
Date of sowing				
November 1	10.51^{c}	28.47^{a}	56.59^{a}	78.08^{a}
November 15	12.96^{a}	27.31^{ab}	52.67^{b}	79.88^{a}
November 30	11.88^{b}	24.64^{b}	50.10^{b}	71.63^{b}
LSD $_{(0.05)}$	0.64	2.93	2.94	1.94
SEm (±)	0.22	1.02	1.02	0.67
Level of significance	***	*	***	***
Interaction effect				
Level of significance	NS	NS	***	***
SEm (±)	0.45	2.04	2.04	1.35
CV%	7.56	15.2	7.68	3.52
Grand Mean	11.78	26.8	53.12	76.53

Note: LSD = least significant difference; SEm = standard error of the mean; CV = coefficient of variation. NS, *, **, and *** indicate non-significance and significance at the 5%, 1%, and 0.1% levels, respectively.

Number of tillers plant^{-1}

The genotypes and sowing dates ($p<0.001$) as well as genotype × sowing interaction showed significant differences in the number of tillers per plant ($p<0.05$) at 15 DAS (Table 2). Statistically highest number of tillers was observed for Nandini, Amritdhara, and Swan Pak, and lowest was observed for Longford (Table 2). At 15 DAS, the highest number of tillers per plant was recorded in the November 1 sowing, which was statistically similar to the November 15 sowing. The lowest number of tillers was observed in the November 30 sowing (Table 2). Similarly, significant difference was observed at 30 DAS, however different scenarios were observed for the effect of sowing dates on number of tillers per plant (Table 2). Accordingly, November 15 sowing had resulted in highest number of tillers and lowest on November 1 (Table 2). At 45 DAS, varietal differences in tiller number followed a similar trend as at 15 DAS, while the effect of sowing date was consistent with that observed at 30 DAS (Table 2). Similarly, at 60 DAS, Swan Pak had the highest number of tillers per plant, but it was statistically similar to Amritdhara. The effect of sowing date at 60 DAS on tiller number followed a similar trend as at 30 and 45 DAS, with the highest tiller numbers observed under November 1 sowing.

Tillers is an important agronomic trait influencing fodder and seed yield (Chapagain et al., 2025). Nandini, Amritdhara and Swan Pak statistically produced the highest number of tillers per plant. Longford recorded the lowest tillers among the genotypes under the study. The reduced tiller number observed could be attributed to genetic limitations in tiller formation (Chauhan &

Singh, 2019). Additionally, shorter day length and cooler temperature on November 30 might have slowed the tiller initiation and development, as tillering in cereals is influenced by cooler temperature and shorter days (Lorenzo et al., 2015). As a result, consistently low tillers were observed on November 30 sowing at all observations. 15 to 45 DAS is the critical tillering period, so this might be the reason for the observation for significant difference observed in this growth period. Moreover, genotypes with higher tillering capacity tend to maintain better canopy development and a higher leaf-to-stem ratio, which enhances light interception and contributes to high fodder yield (Wana et al., 2025).

Table 2. Effect of different oat varieties and sowing dates on the number of tillers plant^{-1} at Rampur, Chitwan, Nepal

Genotypes	Number of tillers plant^{-1}			
	15DAS	30DAS	45DAS	60 DAS
Nandini	0.93^{a}	2.32^{a}	3.51^{a}	4.38^{b}
Amritdhara	0.93^{a}	2.47^{a}	3.35^{a}	4.68^{ab}
Swan Pak	0.93^{a}	2.46^{a}	3.27^{a}	4.89^{a}
Longford	0.08^{b}	0.81^{b}	1.75^{b}	2.73^{c}
$LSD_{(0.05)}$	0.16	0.35	0.24	0.37
SEm±	0.06	0.12	0.08	0.13
Level of significance	***	***	***	***
Date of sowing				
1-Nov	0.93^{a}	2.63^{a}	3.89^{a}	4.98^{a}
15-Nov	0.82^{a}	1.94^{b}	2.62^{b}	4.47^{b}
30-Nov	0.39^{b}	1.47^{c}	2.39^{c}	3.05^{c}
$LSD_{(0.05)}$	0.14	0.31	0.21	0.32
SEm±	0.05	0.11	0.07	0.11
Level of significance	***	***	***	***
Interaction effect				
Level of significance	**	*	***	**
CV%	26.71	21.09	9.72	10.82
Grand Mean	0.71	2.01	2.97	4.17

Note: LSD = least significant difference; SEm = standard error of the mean; CV = coefficient of variation. NS, *, **, and *** indicate non-significance and significance at the 5%, 1%, and 0.1% levels, respectively.

Leaf area

Significant effect was observed only for sowing date on leaf area at 15 DAS ($p < 0.001$). The highest leaf area was recorded for the November 15 sowing (7.66 cm^2). At 30 DAS, both genotype ($p < 0.05$) and sowing date ($p < 0.001$) significantly affect leaf area. Upon 30 DAS, largest leaf area was measured for Longford (18.77 cm^2), and the lowest was in Nandini (10.74 cm^2). Significant effects of genotype, sowing date, and their interaction were observed at 45 and 60 DAS ($p < 0.001$). Similarly, Amritdhara recorded the highest leaf area at 45 DAS, while Swan Pak had the highest leaf area at 60 DAS. Overall, November 15 sowing recorded the highest leaf area among the sowing dates. In general, Nandini showed the smallest leaf area among the genotypes under the study at 15, 30 and 60 DAS (Table 3).

Uniform leaf area among genotypes at 15 DAS is a result of slow and similar early growth stage, as morphological differentiation begins after tillering initiation (Jaffuel, 2004). Rapid leaf expansion usually occurs at the early growth stage. The variation in leaf area results from genetic variation in the genotype's leaf cell size, cell number, and their division rate (Gonzalez et al., 2012). Higher leaf area in November 15 sowing shows that optimized sowing date maximizes photoperiod and growing degree day accumulation, promoting leaf cell expansion and maximum leaf area (Samal et al., 2024). Increased leaf area improves photosynthesis and biomass accumulation (Amanullah et al., 2004). The significant genotype × sowing interaction observed at 45 and 60 DAS shows that genotypes at later growth stages shows high phenotypic plasticity in leaf area. Consistently low leaf area in Nandini reflects the low genetic potential for mesophyll cell proliferation (Sasahara, 1982).

Table 3. Effect of different oat varieties and sowing dates on leaf area at Rampur, Chitwan, Nepal

Genotypes	Leaf area (cm^2)			
	15DAS	30DAS	45DAS	60DAS
Nandini	3.78	10.74^b	31.82^b	54.29^c
Amritdhara	4.67	14.27^{ab}	36.65^a	61.89^b
Swan Pak	4.3	14.54^{ab}	33.61^{ab}	67.20^a
Longford	4.71	18.77^a	26.65^c	59.46^b
$LSD_{(0.05)}$	1.07	4.32	3.41	3.70
SEm±	0.37	1.5	1.18	1.29
Level of significance	NS	**	***	***
Date of sowing				
1-Nov	2.38^b	16.46^a	31.37^b	58.90^b
15-Nov	7.66^a	18.41^a	34.88^a	67.64^a
30-Nov	3.06^b	8.88^b	30.30^b	55.58^c
$LSD_{(0.05)}$	0.92	3.74	2.95	3.21
SEm±	0.32	1.3	1.02	1.14
Level of significance	***	***	**	***
Interaction effect				
Level of significance	NS	NS	***	**
SEm±	0.64	2.6	2.05	2.23
CV%	29.37	35.64	12.74	7.34
Grand Mean	4.37	14.58	32.18	60.71

Note: LSD = least significant difference; SEm = standard error of the mean; CV = coefficient of variation. NS, *, **, and *** indicate non-significance and significance at the 5%, 1%, and 0.1% levels, respectively.

Number of leaves plant^{-1}

Genotypes and sowing dates significantly affected the number of leaves plant^{-1}at 15 DAS ($p < 0.001$). Nandini, Amritdhara, and Swan Pak showed a high number of leaves plant^{-1}. November 15 sowing recorded the highest leaf number plant^{-1} (2.48), while the lowest in November 30 (0.54). Similarly, there were also significant effects of genotype, sowing date, and their interaction ($p < 0.001$) at 30DAS. Swan Pak recorded the highest leaf numbers plant^{-1} (7.65) while Longford recorded the lowest (1.98). November 1 sowing recorded the highest leaf number plant^{-1}, whereas November 15 and November 30 recorded the lowest leaf number plant^{-1} (Table 4).

Only significant differences in genotype and genotype × sowing interaction ($p<0.001$) were observed at 45 DAS. Amritdhara showed the highest number of leaf plant^{-1}, followed by Nandini and Swan Pak. At 60 DAS, genotype and sowing date were significant ($p<0.001$) with no interaction effect on number of leaf plant^{-1}. Statistically, Nandini, Amritdhara and Swan Pak recorded the highest number of leaves plant^{-1}. November 15 sowing produced the maximum leaf number (18.70), whereas November 30 recorded the minimum (14.88) (Table 4).

Genotypic variance in the initiation of leaf primordia and phyllochron results in differences in the number of leaves among genotypes (Padilla & Otegui, 2005). Genotypes with shorter phyllochron have more leaves. This is the reason why Nandini, Amritdhara and Swan Pak maintained higher leaves per plant compared to Longford. Few leaves in Longford reflect a shorter vegetative period. Nandini might have the longest vegetative period among the genotypes under the study because it even produces new leaves after 45DAS, as a shift in the second to first position at 60 DAS. An increase in leaf area index (LAI) and leaf number contributes to aboveground biomass in the early growth stages of the plant (Zhao et al., 2019). Late sowing reduces the photo period time as the onset of cold winter, which was observed in the lowest numbers of leaves on November 30.

Table 4. Effect of different oat varieties and sowing dates on the number of leaves plant^{1} at Rampur, Chitwan, Nepal

Genotypes	Number of leaves plant^{-1}			
	15DAS	30DAS	45DAS	60DAS
Nandini	1.80^{a}	6.82^{ab}	11.65^{b}	19.67^{a}
Amritdhara	2.10^{a}	6.02^{b}	13.42^{a}	19.18^{a}
Swan Pak	2.03^{a}	7.65^{a}	10.98^{b}	20.14^{a}
Longford	0.35^{b}	1.98^{c}	7.69^{c}	9.98^{b}
LSD $_{(0.05)}$	0.53	1.17	1.45	1.93
SEm±	0.18	0.41	0.5	0.67
Level of significance	***	***	***	***
Date of sowing				
1-Nov	1.70^{b}	6.80^{a}	10.5	18.15^{a}
15-Nov	2.48^{a}	4.54^{b}	11.34	18.70^{a}
30-Nov	0.54^{c}	5.51^{b}	10.97	14.88^{b}
LSD $_{(0.05)}$	0.46	1.01	1.26	1.67
SEm±	0.16	0.35	0.44	0.58
Level of significance	***	***	NS	***
Interaction effect				
Level of significance	NS	***	***	**
SEm±	0.32	0.7	0.87	1.16
CV%	40.46	25.03	15.96	13.49
Grand Mean	1.57	5.62	10.94	17.24

Note: LSD = least significant difference; SEm = standard error of the mean; CV = coefficient of variation. NS, *, **, and *** indicate non-significance and significance at the 5%, 1%, and 0.1% levels, respectively.

Chlorophyll content

Significant effects were observed for genotypes ($p<0.05$) and sowing dates ($p<0.01$) for chlorophyll content at 15 DAS. Longford had highest chlorophyll content (36.77) and Nandini, Amritdhara, and Swan Pak had the lowest chlorophyll content which were statistically similar. November 30 sowing measured highest chlorophyll content (34.93) and lowest on November 1 sowing. At 30 DAS, only the genotypic effect showed significant differences ($p<0.001$). Longford (45.85) measured the highest chlorophyll content and the lowest in Nandini (38.08). Similarly, at 45 DAS, significant differences were observed only for genotypes and sowing dates ($p<0.001$). Longford (49.47) had highest chlorophyll content and the rest of the genotypes were statistically similar. Chlorophyll content was highest on November 1 (47.32), followed by November 15, and lowest on November 30. At 60 DAS, significant differences ($p<0.001$) were observed for genotypes and sowing dates. The highest chlorophyll content (43.42) was observed under November 1 sowing, the lowest on November 30 (40.18) In general, Longford (45.31) maintained highest chlorophyll content among the genotypes under the study.

Chlorophyll content is a genetically determined trait that is minimally affected by agronomic practices (Gao et al., 2024). Variation of chlorophyll content among the genotypes is associated with differences in expression of the gene coding for chlorophyll a and b binding proteins, which regulate chlorophyll synthesis (Tanaka & Tanaka, 2007). The higher chlorophyll content in November 1 sowing likely reflects the advantage of early sowing on nitrogen metabolism. High chlorophyll content reflects the increased photosynthetic capacity and potentially high nitrogen content in the canopy (Liu et al., 2019). The non-significant combined treatment effect at all observations indicates that genotypes responded similarly to chlorophyll variation across different sowing dates.

Table 5. Effect of different oat varieties and sowing dates on chlorophyll content at Rampur, Chitwan, Nepal

Genotypes	Chlorophyll content			
	15DAS	30DAS	45DAS	60 DAS
Nandini	32.46[b]	38.08[c]	42.44[b]	40.44[b]
Amritdhara	34.14[b]	41.65[b]	42.94[b]	41.16[b]
Swan Pak	33.92[b]	38.51[c]	42.59[b]	41.33[b]
Longford	36.77[a]	45.85[a]	49.47[a]	45.31[a]
$LSD_{(0.05)}$	2.46	2.03	1.69	1.42
SEm±	0.85	0.71	0.59	0.49
Level of significance	*	***	***	***
Date of sowing				
1-Nov	32.02[b]	42.12	47.32[a]	43.42[a]
15-Nov	34.93[a]	40.71	45.30[b]	42.59[a]
30-Nov	36.02[a]	40.25	40.46[c]	40.18[b]
$LSD_{(0.05)}$	2.13	1.76	1.46	1.23
SEm±	0.74	0.61	0.51	0.43
Level of significance	**	NS	***	***
Interaction effect				
Level of significance	NS	NS	NS	NS
SEm±	1.48	1.22	1.02	0.86
CV%	8.62	5.96	4.59	4.07
Grand Mean	34.32	41.02	44.36	42.06

Note: LSD = least significant difference; SEm = standard error of the mean; CV = coefficient of variation. NS, *, **, and *** indicate non-significance and significance at the 5%, 1%, and 0.1% levels, respectively.

Dry matter fodder yield

There was a significant effect of genotypes, sowing dates, and combined genotype and sowing date effect ($p<0.01$) on dry matter fodder yield at 60 DAS (Table 6). Among the genotypes under the study, Amritdhara (2.53 t ha^{-1}) recorded the highest dry matter yield which is s statistically similar to Swan Pak (2.49 t ha^{-1}). Similarly, Nandini (1.84 t ha^{-1}) and Longford (2.03 t ha^{-1}) recorded the lowest and statistically similar dry matter yield. For sowing dates effect, the highest dry matter fodder yield was recorded when oat genotypes were sown on November 15 (2.64 t ha^{-1}) which was significantly at par to both November 1(2.26 t ha^{-1}) and November 30 sowings (1.76 t ha^{-1}). The mean dry matter fodder yield was 2.22 t ha^{-1}.

Table 6. Effect of different oat varieties and sowing dates on herbage dry matter yield at Rampur, Chitwan, Nepal

Genotypes	Herbage dry matter yield (t/ha)
Nandini	1.84[b]
Amritdhara	2.53[a]
Swan Pak	2.49[a]
Longford	2.03[b]
LSD $_{(0.05)}$	0.24
SEm±	0.08
Level of significance	***
Date of sowing	
November 1	2.26[b]
November 15	2.64[a]
November 30	1.76[c]
LSD $_{(0.05)}$	0.20
SEm±	0.07
Level of significance	***
Interaction effect	
SEm±	0.14
Level of significance	**
CV%	12.73
Grand Mean	2.22

Note: LSD = least significant difference; SEm = standard error of the mean; CV = coefficient of variation. NS, *, **, and *** indicate non-significance and significance at the 5%, 1%, and 0.1% levels, respectively.

Fodder yield is the most important and ultimate economic trait for fodder cultivars. The observed variation in dry matter fodder yield shows the effect of differences in physiological and morphological traits among the genotypes under study. Higher plant height, tillering ability, and leaf area contributed to accumulating high biomass in Amritdhara and Swan Pak. These genotypes efficiently partition photo assimilates to biomass. Several studies has reported that early sowing supports longer vegetative growth, greater accumulation of growing degree days, higher tillering and photosynthetic activity as a result higher herbage biomass is observed in early sown oat genotypes compared to late sowing (Jehangir et al., 2001; Kaur et al., 2022; Singh et al., 2022). Moreover, a significant genotype ×sowing date interaction indicates the importance of sowing date specific to a particular oat genotype for achieving high dry fodder yield (Table 7).

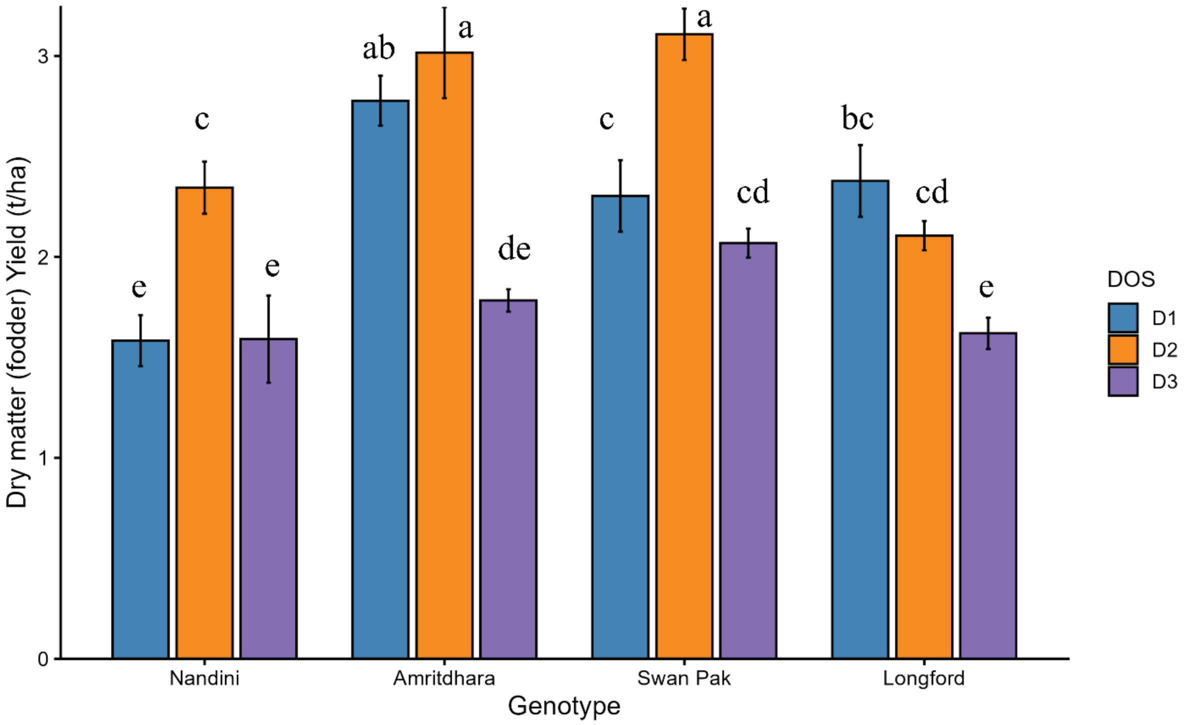

Fig. 2. Variation in dry matter yield (t/ha) among the oat genotypes under different sowing dates. Note: Superscripts indicate the genotype × sowing interaction. Values sharing the same letter are not significantly different

Measure of association of yield

Multiple linear regression analysis revealed that plant height (PH), number of tillers plant^{-1}, chlorophyll content (CHL), leaf area (LA) and number of leaves plant^{-1} together explained 56.8% of the total variation in dry matter yield at 60 DAS ($R^2 = 0.568$, and adjusted $R^2 = 0.516$).

Equation (1) explains the relationship between dry matter yield and early growth traits as:
$DMY60 = 2.223 + 0.199(PH) + 0.134(TIL) + 0.097(CHL) + 0.104(LA) - 0.176(NOL)$.
Among the traits under study, plant height contributed significantly and positively to dry matter yield at 60 DAS ($p < 0.001$). Number of tillers per plant, chlorophyll content and leaf area also showed positive but statistically non-significant association with dry matter yield. In contrast, number of leaves showed a negative and non-significant association with dry matter yield.

Table 7. Outputs of multiple linear regression between dry matter yield and growth attributes of oats varieties grown at Rampur, Chitwan, Nepal

	Estimate	Standardized β	Std. Error	t value	p-value	Level of Significance
Intercept	2.223		0.058	38.4	<0.001	***
PH	0.199	0.474	0.051	3.89	0.00035	***
TIL	0.134	0.374	0.071	1.89	0.066	NS
CHL	0.097	0.224	0.061	1.59	0.119	NS
LA	0.104	0.258	0.062	1.66	0.104	NS
NOL	-0.176	-0.433	0.089	-1.99	0.053	NS

Note: plant height (PH), number of tillers plant^{-1} (TIL), chlorophyll content (CHL), leaf area (LA), and number of leaves plant^{-1}(NOL)

Plant height showed a major role in biomass accumulation. This might be that tall genotypes have higher internode elongation, which increases structural biomass. Taller plant's has better access to photosynthetically active radiation (PAR) for photo assimilates (Wang et al., 2014). This is because higher leaf number does not necessarily mean high structural biomass, and this might have caused a reduction in overall dry matter accumulation. Chlorophyll content and leaf area had smaller positive effects on biomass accumulation. Overall, these results highlight that plant growth attributes, particularly plant height and tillering ability, are key determinants of early biomass production.

CONCLUSION

The present study evaluated the response of early growth traits under different sowing dates and their influence on herbage biomass production in the inner terai region of Nepal. Genotype and sowing date significantly affect early vegetative growth and dry matter yield. Early growth traits were found to be the important contributors to dry matter fodder yield. Amritdhara and Swan Pak showed superior performance in growth traits and biomass production, while mid-November (November 15) sowing consistently provided the most favorable conditions for early growth development and higher fodder yield. Early growth traits explained 56.8% of the variation in dry herbage biomass, with plant height contributing the most. Further in-depth multiyear trials may validate the effects of sowing dates across the prominent oats genotypes.

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AUTHOR CONTRIBUTIONS

SR: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Data curation, Resources, Writing – original draft, Writing – review & editing, Visualization; **NRD:** Validation, Resources, Writing – review & editing, Supervision; **RPG:** Writing – review & editing, Supervision; **SRB:** Validation, Writing – review & editing, Supervision.

CONFLICT OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

ETHICAL APPROVAL AND PERMITS

Not applicable.

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