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# EVALUATION OF COCKSFOOT GRASS (*DACTYLIS GLOMERATA* L.) AND RYEGRASS (*LOLIUM* SPP.) CULTIVARS FOR FORAGE BIOMASS AND SEED PRODUCTIVITY IN THE NEPALI HILLS

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**SUMMARY**

Hill pastures play a vital role in sustaining ruminant production systems in Nepal, yet adoption of improved forages remains limited. To address this, 11 cultivars of Cocksfoot grass (*Dactylis glomerata* L.), Hybrid ryegrass, Italian ryegrass (*Lolium multiflorum* Lam.) and Perennial ryegrass (*Lolium perenne* L.) were evaluated for forage and seed yield during 2018-2020. Multi-location trials were conducted at Khumaltar, Lalitpur (mid-hill ecology) and Dhunche, Rasuwa (high-hill ecology). At Khumaltar, the Perennial ryegrass cultivar Base produced significantly higher ($p<0.05$) forage dry matter yield than others. At Dhunche, cultivars Base, One$^{50}$, and Dhunche consistently performed better in first to third harvests and total forage yield, also showing higher plant height and tiller number. For seed yield, Asset, Winter Star II, and Dhunche were superior at Khumaltar, while Base and Winter Star II were better at Dhunche. These findings highlight the potential of selected ryegrass cultivars to enhance both forage and seed productivity under mid- and high-hill conditions. Their promotion and adoption could substantially strengthen hill pasture-based livestock systems in Nepal.

**Key words:** Ecological regions, genotypes, plant height, number of tillers, temporal and spatial effects, yield and yield attributes

Nepali hill pastures in the Himalayan foothills are crucial for sustaining local livelihoods. These grazing lands contribute significant amounts of Total Digestible Nutrients (approximately 433,000 tons) and other essential nutrients to ruminant livestock (NAFLQML, 2019). They are rich in biodiversity, range from alpine meadows to shrub lands, supporting the diverse plant species. Unfortunately, the sustainability of these pastures is jeopardized by overgrazing, land-use changes, and climate variability (MoFSC, 2002).

Recognizing the need for improved forage resources, various germplasms have been imported and evaluated across different regions of Nepal over time (Ghimire, 2021). Forage cultivars from countries such as India, New Zealand, the USA, Denmark, the UK, Germany, Australia, China, and the Netherlands have been introduced and tested in research stations and pasturelands across Nepal (Ghimire, 2021; Pande, 2024). However, despite these efforts, only a limited number of forage genotypes have been recommended for hill pastures. Current research system in Nepal is focussing to identify high-yielding forage genotypes to enhance biomass production and seed yield in ruminant production systems (Ghimire *et al.*, 2022).

Past introductions to Nepali high-altitude pasturelands include Cocksfoot grass, Italian ryegrass and Perennial ryegrass with hybrid ryegrass being a recent addition. Cocksfoot grass (*Dactylis glomerata* L.) is a long-lived perennial grass well-adapted to temperate zones, displaying good regrowth characteristics and adaptability to diverse environmental conditions. Widely distributed across Europe, North and South America, Australia, New Zealand, and Asia, it serves various purposes such as hay, silage, and grazing. Cocksfoot grass is often mixed with alfalfa (*Medicago sativa* L.) or red clover (*Trifolium pratense* L.) for hay or white clover

(*Trifolium repens* L.) for grazing (Sanada, 2010). Likewise, Perennial ryegrass (*Lolium perenne* L.), growing 1 to 2 feet tall, is a valuable forage and soil stabilization plant, predominant in Europe and widely used in the United States. Tetraploid cultivars are typically used for forage, while diploid cultivars are preferred for lawns and conservation plantings (USDA, 2002). Likely, Italian ryegrass (*Lolium multiflorum* Lam.) similar to perennial ryegrass, is an annual or biennial, reaching 2 to 3 feet tall. Thriving on dark rich soils in mild climates, it is primarily used for quick cover in erosion control plantings (USDA, 2002). Likely, Hybrid ryegrass, a cross between perennial and Italian ryegrass, combines yield, quality, and persistence. Mainly used for conservation, newer perennial types demonstrate improved suitability in grazing, providing better yield and high-quality forage in spring. Polyploidy and interspecific hybridization are common breeding methods for ryegrass, leading to highly appreciated tetraploid cultivars and synthesis cultivars obtained from hybridization (Schitea and Varga, 1995).

Implementing effective management strategies and assessing resilient forage genotypes are essential to enhance biomass and seed productivity, ensuring the ecological integrity and overall productivity of these vital landscapes. Therefore, cultivar screening is crucial for the development of forages in these pastures within Nepali hill ruminant production systems. In the context, a study was conducted to evaluate the biomass and seed yield of different cultivars of Cocksfoot grass, Italian ryegrass, Perennial ryegrass and Hybrid ryegrass species.

## MATERIALS AND METHODS

The experiments were carried out during two consecutive years at two research stations of the Nepal Agricultural Research Council, each representing distinct ecological zones. The National Pasture and Fodder Research Program (NPFRP) in Khumaltar, Lalitpur (27.65555N, 85.32536E) is situated at an altitude of 1,330 meters above sea level (masl) and represents the middle hill ecology. Meanwhile, the Pasture and Fodder Research Station (PFRS) in Dhunche, Rasuwa (28.11264N, 85.30239E) is located at 2,030 masl, representing the high hill ecology. The experiment followed a Split-Split Plot Design. The main plot represented the years, while the sub-plots were assigned to locations. Forage cultivars were allocated to sub-subplots using a Randomized Complete Block Design (RCBD). It was replicated three times at each location during both seasons from 2018 to 2020. The experimental plot size was 5m × 4m at Khumaltar, Lalitpur and 4m × 3m at Dhuche, Rasuwa. Each plot was divided into two halves. One half was used for forage yield observation, while the other half was used for seed yield observation. A total of 11 cultivars were used for forage observation. These included: Rasuwa and Savvy cultivars of Cocksfoot grass (*Dactylis glomerata* L.), Mavarick GII and Prospect 2 cultivars of hybrid ryegrass, Asset, Winterstar II and Makhangrass of Italian ryegrass (*Lolium multiflorum* Lam.), One[50], Base, Dhunche and Rely cultivars of Perennial ryegrass (*Lolium perenne* L.). Rasuwa cultivar of Cocksfoot grass and Dhunche cultivar of Perennial ryegrass were used as check cultivars in both experiments each year. For seed yield observation, two hybrid ryegrass cultivars were excluded. For forage production, the first cut was taken 60 days after sowing. Subsequent two cuts were taken in 30-day interval. The cutting height was maintained at 5 cm above ground level at both locations during both years. No cut was taken from seed plants. The soil was silty clay loam at Khumaltar site and sandy loam at Rasuwa with moderate fertility status in both locations. The recommended $N:P_2O_5:K_2O$ dose of 100:60:40 was applied at both locations during both years. The seed rate was 10 kg/ha for Cocksfoot grass cultivars and 15 kg/ha for ryegrass cultivars. Plant height and the number of tillers/plant were recorded during defoliation in each cut for forage plants and at the time of seed maturity for seed plants. Dry matter content of green forage and straw was determined by drying samples in a hot air oven at 72°C for 24 hours.

The seeds of the tested genotypes, except for Rasuwa cocksfoot grass and Dhunche ryegrass were obtained through the Cool Season Crop Improvement Project- a collaborative effort involving Lincoln University, NZ; the NZ Aid Program under the Ministry of Foreign Affairs and Trade; and the Government of Nepal. These materials were sourced from Lincoln University, New Zealand; Plant Research, New Zealand; AgResearch, New Zealand; Global Oats Limited, New Zealand; and the Foundation for Arable Research, New Zealand.

The data collected from the experiments were statistically analyzed using Analysis of Variance (ANOVA) in a Split-Split Plot Design. Data analysis was carried out using the R-Package (R-Core Team, 2013). To compare means between treatments at the 5% significance level, Tukey's Honest Significant Difference (HSD) Test was applied. Although the interactions between year, location, and cultivar were consistently significant during data analysis, the study did not include a yield stability analysis, which remains a limitation.

## RESULTS AND DISCUSSION

### The temporal, spatial and cultivar effects on forage, seed and straw yield

The results presented in Table (1) indicate that the effects of year, location and cultivar significantly influenced forage dry matter yield, seed yield and straw yield. The significant effect of year on forage yield ($p<0.01$), seed yield ($p<0.001$), and straw yield ($p<0.001$) suggests that climatic variations and seasonal conditions play a critical role in the productivity of these grasses. Similar findings have been reported by Xie *et al.* (2020), where environmental fluctuations significantly influenced perennial ryegrass performance.

The significant location effects on forage yield ($p<0.001$), seed yield ($p<0.01$) and straw yield ($p<0.01$) indicate that site-specific environmental factors such as soil fertility, precipitation, and temperature variations directly affect the productivity. These results align with those of Reddy *et al.* (2021), who found that variations in temperature and soil conditions influence grass growth and yield components. Similarly, significant cultivar effects on forage yield ($p<0.01$), seed yield ($p<0.001$) and straw yield ($p<0.001$) emphasize the genetic variability among different cultivars, supporting previous findings by Kemesyte *et al.* (2017) that tetraploid perennial ryegrass genotypes exhibited higher adaptability and productivity under different climatic conditions. Dhunche site experiences lower winter and spring temperatures than Khumaltar, which could have induced cold stress. Such stress is known to negatively impact turf quality, regrowth, dry weight, and tiller density in perennial ryegrass (Xie *et al.*, 2020). The study revealed a strong correlation between plant growth parameters (Table 2), forage yields (Table 3), and straw yields (Fig. 1) with seed yield. Cultivars that exhibited superior forage and seed components also demonstrated higher overall seed yields, aligning with findings by Sartie *et al.* (2018).

The interaction effects between year × cultivar, location × cultivar, and the three-way interaction of year × location × cultivar were all significant, reinforcing the impression that cultivar performance varies under different environmental conditions. The year × cultivar interaction significantly affected forage yield ($p<0.05$), seed yield ($p<0.01$), and straw yield ($p<0.05$), indicating the impact of yearly climatic variations on specific cultivar performances. Likewise, the location × cultivar interaction showed strong significance ($p<0.01$ for forage yield, $p<0.001$ for seed yield and straw yield), suggesting that certain cultivars performed better in specific locations due to site-specific factors. These findings are in agreement with studies by Minner *et al.* (1983) and Harrison *et al.* (1997), which highlight the importance of genotype-environment interactions in forage productivity.

TABLE 1
Table of significance of temporal, spatial and genotype effects on forage dry matter and seed yield

| Factors | Total forage dry matter yield | Seed yield | Straw yield |
|---|---|---|---|
| Year effect | <0.01 | <0.001 | <0.001 |
| Location effect | <0.001 | <0.01 | <0.01 |
| Cultivar effect | <0.01 | <0.001 | <0.001 |
| Year × cultivar | <0.05 | <0.01 | <0.05 |
| Location × cultivar effect | <0.01 | <0.001 | <0.001 |
| Year × location × cultivar effect | <0.01 | <0.001 | <0.001 |

### Growth parameters in forage plants: Plant height and number of tillers

The Base cultivar of perennial ryegrass consistently exhibited greater plant height across all defoliations at both Khumaltar and Dhunche ($p<0.05$, Table 2). Additionally, it produced a higher number of tillers plant$^{-1}$ in the high-altitude conditions of Dhunche.

At Khumaltar, during the first and second cuts, the Winter Star II and Asset cultivars of Italian ryegrass, along with the Base cultivar of perennial ryegrass, attained the greatest plant heights (Table 2). In the third cut, the Rasuwa cultivar of Cocksfoot grass, the Makhangrass cultivar of Italian ryegrass, and the Dhunche and Base cultivars of perennial ryegrass exhibited the tallest ($p<0.05$) plant heights in the mid-hill ecological conditions of Khumaltar. Italian ryegrass and Cocksfoot grass cultivars had significantly higher ($p<0.05$) number of tillers plant$^{-1}$ during the first cut at Khumaltar, but this declined sharply in the third cut. The reduction in forage yield components in later defoliations suggests a decline in grass persistency. Notably, the Hybrid ryegrass cultivar Prospect 2 and the Perennial ryegrass cultivar One$^{50}$ exhibited significantly lower ($p<0.05$) tiller numbers plant$^{-1}$.

At Dhunche, the Base cultivar of perennial ryegrass and the Maverick GII cultivar of Hybrid ryegrass consistently exhibited superior ($p<0.05$) plant heights across all three cuts in the high hills. However, plant height decreased progressively from the first to subsequent cuts. Overall, the number of tillers plant$^{-1}$ was lower at Dhunche compared to Khumaltar. Nevertheless, the Base cultivar of perennial ryegrass at Dhunche, along with the Hybrid ryegrass cultivars Maverick GII and Prospect 2, consistently maintained higher number of tillers plant$^{-1}$ across all three cuts in the high-altitude environment.

The greater overall number of tillers plant$^{-1}$ observed in ryegrass cultivars at the Khumaltar research station, compared to Dhunche, may be attributed to differences in climate and soil nutrient availability between these two ecological regions, as noted by Gislum and Griffith (2005). In this study, while elevated temperatures likely contributed to increased plant height and tiller production, genotypic variations in response to high temperatures were evident, consistent with findings by Reddy *et al.* (2021). Previous research on another poaceae species demonstrated that low temperatures significantly inhibited shoot growth and developmental traits, with the exception of number of leaves, when compared to optimal temperature conditions. For instance, plant height decreased by 73% under cold stress relative to control treatments, while tiller number- an essential component of grain yield- declined by 61.5 percentage. Temperature directly affects the shoot meristem and can also reduce nutrient uptake through the roots, both of which may limit shoot development under suboptimal soil temperatures (Reddy *et al.*, 2021).

## Forage yield

The middle hill altitude exhibited significantly higher ($p<0.001$) total forage dry matter (DM) yield compared to the high hill altitude (Table 3). At Khumaltar, located in the middle hills, forage DM yield during the first cut was statistically similar among all tested cultivars except for the Base cultivar of Perennial ryegrass, which outperformed the others. The second cut showed mixed results, while the third cut revealed significantly lower ($p<0.05$) yields from the Asset cultivar of Italian ryegrass, One$^{50}$ and Dhunche cultivars of Perennial ryegrass, Maverick GII cultivar of Hybrid ryegrass, and Savvy cultivar of Cocksfoot grass. However, the Base cultivar of Perennial ryegrass produced the highest ($p<0.05$) forage DM yield during the third cut and in terms of total forage DM at Khumaltar. This superior yield may be attributed to its consistently greater plant height across all three cuts and a higher number of tillers plant$^{-1}$ during the third cut (Table 3). In contradiction, the Asset cultivar of

TABLE 2

Growth parameters of different Cocksfoot grass, Hybrid ryegrass, Italian ryegrass and Perennial ryegrass cultivars at middle hill and high hill ecologies

| Forage | Khumaltar | | | | | | Dhunche | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Plant height, cm | | | No of tillers/plant | | | Plant height, cm | | | No of tillers/plant | | |
| | Cut1 | Cut2 | Cut3 | Cut1 | Cut2 | Cut3 | Cut1 | Cut2 | Cut3 | Cut1 | Cut2 | Cut3 |
| CF- Rasuwa | 64.00$^{de}$ | 64.20$^{ab}$ | 61.87$^{a}$ | 13.07$^{ab}$ | 16.67$^{a}$ | 9.13$^{a}$ | 62.7$^{cd}$ | 49.8$^{cd}$ | 40.5$^{bc}$ | 8.96$^{bcd}$ | 12.83$^{bc}$ | 9.80$^{bc}$ |
| CF- Savvy | 63.27$^{de}$ | 61.67$^{d}$ | 56.8$^{b}$ | 14.07$^{a}$ | 14.40$^{bc}$ | 8.93$^{abc}$ | 59.85$^{d}$ | 47.1$^{d}$ | 37.75$^{c}$ | 8.34$^{cdf}$ | 13.03$^{bc}$ | 8.97$^{c}$ |
| HR- Maverick GII | 70.53$^{cd}$ | 65.20$^{c}$ | 58.67$^{ab}$ | 13.67$^{a}$ | 12.40$^{c}$ | 8.20$^{abc}$ | 65.19$^{abc}$ | 54.78$^{b}$ | 43.65$^{ab}$ | 9.31$^{bc}$ | 16.79$^{a}$ | 11.31$^{ab}$ |
| HR- Prospect 2 | 66.60$^{cde}$ | 64.07$^{cd}$ | 54.2$^{b}$ | 11.93$^{bc}$ | 13.40$^{bc}$ | 7.73$^{bc}$ | 63.87$^{bc}$ | 55.74$^{b}$ | 42.45$^{b}$ | 9.67$^{ab}$ | 17.13$^{a}$ | 12.39$^{a}$ |
| IR- Asset | 80.87$^{a}$ | 64.87$^{c}$ | 56.4$^{b}$ | 14.13$^{a}$ | 14.07$^{bc}$ | 9.13$^{a}$ | 61.2$^{cd}$ | 47.4$^{d}$ | 37.00$^{cd}$ | 8.31$^{cdef}$ | 12.85$^{bc}$ | 8.72$^{cd}$ |
| IR- Winter Star II | 83.40$^{ab}$ | 68.27$^{b}$ | 57.8$^{ab}$ | 14.93$^{a}$ | 17.47$^{a}$ | 9.13$^{a}$ | 64.95$^{abc}$ | 51.3$^{bc}$ | 40.25$^{bc}$ | 8.94$^{bcd}$ | 13.21$^{b}$ | 9.77$^{bc}$ |
| IR- Makhangrass | 61.67$^{e}$ | 64.00$^{cd}$ | 60.13$^{a}$ | 13.27$^{ab}$ | 14.73$^{abc}$ | 8.53$^{ab}$ | 59.7$^{d}$ | 43.2$^{e}$ | 35.50$^{d}$ | 6.81$^{f}$ | 9.71$^{e}$ | 6.82$^{d}$ |
| PR- One$^{50}$ | 61.60$^{e}$ | 65.13$^{c}$ | 53$^{b}$ | 10.73$^{c}$ | 13.27$^{c}$ | 7.87$^{bc}$ | 60.96$^{d}$ | 49.32$^{cd}$ | 36.6$^{cd}$ | 7.81$^{cdef}$ | 12.37$^{bc}$ | 9.14$^{c}$ |
| PR- Base | 78.13$^{ab}$ | 77.33$^{a}$ | 60$^{a}$ | 10.60$^{c}$ | 13.20$^{c}$ | 8.53$^{ab}$ | 68.19$^{a}$ | 61.98$^{a}$ | 46.65$^{a}$ | 10.55$^{a}$ | 17.56$^{a}$ | 13.05$^{a}$ |
| PR- Dhunche | 69.27$^{cd}$ | 64.93$^{c}$ | 62.93$^{a}$ | 11.27$^{bc}$ | 14.87$^{abc}$ | 8.27$^{ab}$ | 67.62$^{ab}$ | 46.44$^{de}$ | 37.7$^{cd}$ | 8.01$^{cdef}$ | 11.87$^{cd}$ | 9.08$^{c}$ |
| PR- Rely | 76.13$^{bc}$ | 63.53$^{cd}$ | 55.47$^{b}$ | 12.27$^{abc}$ | 15.87$^{ab}$ | 8.40$^{ab}$ | 59.7$^{d}$ | 54.6$^{b}$ | 35.5$^{d}$ | 7.66$^{ef}$ | 10.91$^{de}$ | 8.36$^{c}$ |
| SEM | 2.88 | 1.03 | 2.29 | 0.96 | 1.13 | 0.33 | 1.31 | 1.63 | 1.15 | 0.40 | 0.38 | 0.34 |
| F-Probability | <0.001 | <0.01 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.001 | <0.05 | <0.05 | <0.01 | <0.01 |

The mean with the similar superscript letters in a column are not significantly different at 5% level of significance. HR= Hybrid ryegrass, IR= Italian ryegrass, PR= Perennial ryegrass, SEM= Standard error of mean, SEM= Standard error of mean.

Italian ryegrass exhibited one of the lowest forage DM yields at Khumaltar (Table 4), suggesting its limited suitability for middle hill ecology. In this study, Winter Star II and Base were tetraploid cultivars of ryegrass, with the Base cultivar yielding the highest forage DM in both locations. These findings align with Kemesyte *et al.* (2017), who reported that tetraploid perennial ryegrass genotypes exhibit greater tolerance to cold stress, improved spring growth and regrowth after cutting, and higher DM yields compared to diploid genotypes.

At Dhunche in the high hill ecology, the Base, One$^{50}$, and Dhunche cultivars consistently demonstrated superior forage DM yields across all three harvests and in total DM production. These cultivars also showed moderate to superior plant height and tiller numbers/plant in Dhunche (Table 3). Temperature is a key factor influencing plant growth, with perennial ryegrass thriving at an optimal temperature of approximately 20°C but being sensitive to both high (30-40°C) and low (-20 to 0°C) temperatures (Minner *et al.*, 1983; Harrison *et al.*, 1997). Studies indicate that temperature stress causes morphological and physiological damage in plants, with genotype-specific responses to these stresses (Xie *et al.*, 2020). Low temperatures, in particular, are a major factor limiting the persistence of perennial ryegrass in high-altitude environments. The Makhangrass cultivar of Italian ryegrass exhibited extremely poor forage dry matter (DM) yield at Dhunche, a high-altitude ecology. This yield reduction can likely be attributed to the lower temperatures at Dhunche, as Makhangrass thrives in temperatures ranging from 24-27°C but experiences significant yield declines below 18°C (Nutrifeed, 2015; Shital *et al.*, 2022). Notably, the Makhangrass cultivar demonstrated a sharp decline in forage DM yield during the third cut. This trend aligns with the findings of Meena *et al.* (2017), who reported a substantial reduction in forage DM yield during the third cut across all seeding rates.

In overall, Cocksfoot grass cultivars produced lower forage DM yields compared to Hybrid ryegrass, Italian ryegrass, and Perennial ryegrass cultivars in this study. Similar results have been observed in previous study, where ryegrass pastures exhibited faster growth than Cocksfoot grass during autumn (Ates *et al.*, 2010). In their study, the authors established a correlation between pasture growth rates and accumulated thermal time, quantifying the seasonal response. Their findings highlighted significant seasonal effects on pasture grasses, aligning with the results of our study. This alignment is likely due to the November sowing of pasture grasses, with forage harvested during winter and spring and seed harvesting occurring in spring.

**Seed yield seed attributing traits**

At Khumaltar, the Italian ryegrass cultivars Asset, Winter Star II, and Makhangrass, along with

TABLE 3

Forage dry matter yield of different cultivars of Cocksfoot grass, Hybrid ryegrass, Italian ryegrass and Perennial ryegrass at middle hill and high hill ecologies

| Cultivars | Khumaltar, t/ha | | | | Dhunche, t/ha | | | |
|---|---|---|---|---|---|---|---|---|
| | Cut 1 | Cut 2 | Cut 3 | Total | Cut 1 | Cut 2 | Cut 3 | Total |
| CF- Rasuwa | 3.87$^{b}$ | 2.93$^{ab}$ | 2.67$^{a}$ | 9.47$^{b}$ | 3.05$^{de}$ | 1.26$^{f}$ | 1.55$^{e}$ | 6.16$^{de}$ |
| CF- Savvy | 3.4$^{b}$ | 2.43$^{b}$ | 1.90$^{c}$ | 7.73$^{de}$ | 2.90$^{de}$ | 1.69$^{def}$ | 1.45$^{e}$ | 5.43$^{ef}$ |
| HR- Maverick GII | 3.9$^{b}$ | 2.97$^{ab}$ | 1.83$^{c}$ | 8.70$^{bcd}$ | 5.04$^{bc}$ | 3.25$^{bc}$ | 2.13$^{de}$ | 8.96$^{c}$ |
| HR- Prospect 2 | 4.5$^{b}$ | 2.77$^{b}$ | 2.1$^{bc}$ | 9.37$^{b}$ | 5.08$^{bc}$ | 3.69$^{abc}$ | 2.94$^{bcd}$ | 10.32$^{bc}$ |
| IR- Asset | 2.87$^{b}$ | 2.37$^{b}$ | 1.87$^{c}$ | 7.11$^{e}$ | 4.92$^{bc}$ | 3.03$^{bc}$ | 2.40$^{cd}$ | 9.22$^{c}$ |
| IR- Winter Star II | 3.83$^{b}$ | 3.83$^{a}$ | 2.37$^{ab}$ | 9.73$^{b}$ | 4.23$^{cd}$ | 2.82$^{cd}$ | 2.63$^{bcd}$ | 8.65$^{cd}$ |
| IR- Makhangrass | 3.6$^{b}$ | 3.00$^{ab}$ | 2.33$^{ab}$ | 8.93$^{bc}$ | 1.87$^{e}$ | 1.53$^{ef}$ | 0.78$^{f}$ | 3.31$^{f}$ |
| PR- One$^{50}$ | 3.57$^{b}$ | 2.54$^{b}$ | 1.89$^{c}$ | 8.00$^{cde}$ | 6.27$^{ab}$ | 4.22$^{ab}$ | 3.33$^{ab}$ | 11.90$^{ab}$ |
| PR- Base | 6.29$^{a}$ | 2.89$^{b}$ | 2.51$^{ab}$ | 11.69$^{a}$ | 7.03$^{a}$ | 4.65$^{a}$ | 3.89$^{a}$ | 13.44$^{a}$ |
| PR- Dhunche | 4.5$^{b}$ | 3.17$^{ab}$ | 1.93$^{c}$ | 9.60$^{b}$ | 5.51$^{ab}$ | 3.51$^{ab}$ | 3.13$^{abc}$ | 11.02$^{abc}$ |
| PR- Rely | 4.34$^{b}$ | 3.05$^{b}$ | 2.37$^{ab}$ | 9.76$^{b}$ | 4.17$^{c}$ | 2.70$^{cde}$ | 2.58$^{bcd}$ | 8.34$^{cd}$ |
| SEM | 0.85 | 0.77 | 0.28 | 0.78 | 0.46 | 0.33 | 0.28 | 0.89 |
| F-Probability | <0.05 | <0.05 | <0.05 | <0.05 | <0.001 | <0.01 | <0.01 | <0.001 |

The mean with the similar superscript letters in a column are not significantly different at 5% level of significance. DM=Dry matter, CF= Cocksfoot grass, HR= Hybrid ryegrass, IR= Italian ryegrass, PR= Perennial ryegrass, SEM= Standard error of mean.

the Perennial ryegrass cultivar Dhunche, exhibited significantly taller plant heights ($p<0.001$) at the time of seed maturity. However, the number of tillers plant$^{-1}$ was notably higher ($p<0.01$) in the Cocksfoot grass cultivars, Rasuwa and Savvy, as well as the Italian ryegrass cultivar, Winter Star II. Among these, Winter Star II demonstrated both superior plant height and a higher number of tillers/plant, which likely contributed to its increased seed yield (Table 4). At middle hill ecology of Khumaltar, significantly higher seed yields ($p<0.001$) were recorded in the Italian ryegrass cultivars Winter Star II and Asset, along with the Perennial ryegrass cultivar, Dhunche. Overall, Cocksfoot grass cultivars produced lower seed yields than ryegrass cultivars in the middle hills at lower altitudes.

At Dhunche, a high-hill ecological region, significant variations were observed among cultivars. The Cocksfoot grass cultivars (Rasuwa and Savvy), Asset cultivar of Italian ryegrass, and Dhunche cultivar of Perennial ryegrass exhibited significantly greater plant heights ($p<0.001$) at seed maturity. In contrast, the Makhangrass cultivar of Italian ryegrass recorded the lowest number of tillers/plant (10.27, $p<0.001$) at seed maturity. In terms of seed yield, the Base cultivar of Perennial ryegrass and the Winter Star II cultivar of Italian ryegrass had higher yield compared to all other cultivars, while Makhangrass exhibited the lowest seed yield. Overall, the Makhangrass cultivar displayed poor performance in seed yield and seed components at Dhunche, likely due to its lower growth rate and forage yield (Table 2 and Table 3), which strongly influence seed production (Sartie *et al.*, 2018). Furthermore, at the high-altitude experimental site in Rasuwa, Makhangrass exhibited significantly lower forage and seed yields, further confirming its limited adaptability to high hill environments.

**Straw yield**

The bar graph (Fig. 1) presents straw yield of different grass cultivars following seed harvest at Khumaltar (middle hill ecology) and Dhunche (high hill ecology). In overall, higher straw yield was obtained at Khumaltar compared to Dhunche. The Winter Star II and Asset cultivars of Italian ryegrass produced the highest straw yield at Khumaltar, exceeding 25,000 kg/ha. Other cultivars, such as Cocksfoot grass- Savvy and Perennial ryegrass- Dhunche, also showed high yields, but to a lesser extent. The relatively greater plant height observed in these cultivars may have contributed to their superior straw yield. Unlike Khumaltar, straw yield at Dhunche was more evenly distributed across cultivars, indicating less variation among genotypes. However, the Makhangrass cultivar of Italian ryegrass exhibited the lowest straw yield among all cultivars at Dhunche.

The middle hill ecology (Khumaltar) generally favored higher straw production compared to the high hill ecology (Dhunche). The lower temperature and harsher climatic conditions at Dhunche may have contributed to the reduced performance of certain cultivars. The findings suggest that Italian ryegrass cultivars Winter Star II and Asset are well-suited for

TABLE 4
Seed attributing traits and seed yield of different genotypes of Ryegrass and Cocksfoot grass in hill ecologies of Nepal

| Cultivars | Khumaltar | | | Dhunche | | |
|---|---|---|---|---|---|---|
| | Plant height cm | No. of tillers plant | Seed yield kg/ha | Plant height cm | No. of tillers plant | Seed yield kg/ha |
| CF- Rasuwa | $62.26^{e}$ | $28.35^{a}$ | $176.36^{d}$ | $92.12^{ab}$ | $25.81^{ab}$ | $378.26^{c}$ |
| CF- Savvy | $82.29^{cd}$ | $26.47^{ab}$ | $112.39^{d}$ | $97.00^{a}$ | $18.23^{bc}$ | $256.67^{cd}$ |
| IR- Asset | $104.53^{ab}$ | $20.39c^{d}$ | $1103.61^{a}$ | $91.24^{ab}$ | $19.46^{b}$ | $839.33^{b}$ |
| IR- Winter Star II | $113.98^{a}$ | $28.96^{a}$ | $1302.27^{a}$ | $81.36^{bcd}$ | $21.33^{ab}$ | $1166.67^{a}$ |
| IR- Makhangrass | $96.96^{abc}$ | $15.68^{d}$ | $432.29^{bc}$ | $59.43^{f}$ | $10.27^{c}$ | $124.41^{d}$ |
| PR- One$^{50}$ | $76.98^{de}$ | $19.93^{cd}$ | $457.75^{bc}$ | $78.61^{cde}$ | $21.79^{ab}$ | $902.43^{b}$ |
| PR- Base | $89.67^{bcd}$ | $23.40^{bc}$ | $536.89^{b}$ | $71.26^{def}$ | $28.63^{a}$ | $1432.37^{a}$ |
| PR- Dhunche | $96.78^{abc}$ | $21.89^{bc}$ | $1016.67^{a}$ | $89.23^{abc}$ | $22.34^{ab}$ | $876.79^{b}$ |
| PR- Rely | $65.65^{e}$ | $17.02^{d}$ | $310.18^{cd}$ | $79.79^{bcd}$ | $19.33^{b}$ | $765.69^{b}$ |
| SEM | 4.70 | 1.496 | 160.71 | 3.72 | 2.68 | 122.50 |
| Probability | <0.001 | <0.01 | <0.001 | <0.05 | <0.001 | <0.001 |

The mean with the similar superscript letters in a column are not significantly different at 5% level of significance. DM=Dry matter, CF= Cocksfoot grass, HR= Hybrid ryegrass, IR= Italian ryegrass, PR= Perennial ryegrass, SEM= Standard error of mean.

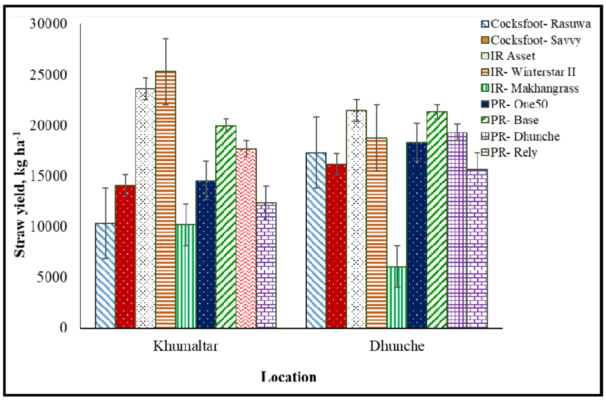


Fig. 1. Location wise straw yield (kg/ha).

straw yield production in middle hill regions, whereas straw yield in high hills is more uniform across cultivars except for the notably lower performance of Makhangrass. These results highlight the importance of site-specific cultivar selection to maximize forage straw yield.

## CONCLUSION

This study reveals the significant influence of year, location, and cultivar on the forage, seed, and straw yield of Cocksfoot grass and ryegrass. In the middle hills ecology of Khumaltar, the Base cultivar of perennial ryegrass demonstrated the highest forage dry matter yield, while Asset and Winter Star II of Italian ryegrass, along with the Dhunche cultivar of perennial ryegrass, proved superior for seed production. In the high hills of Dhunche, the Base, One[50], and Dhunche cultivars consistently produced the highest forage dry matter yields across multiple harvests, whereas Base and Winter Star II excelled in seed production. The successful introduction and promotion of these screened cultivars in their respective ecological niches can significantly enhance forage and seed productivity in the middle and high hills of Nepal. This advancement could have promising implications for hill pasture-based ruminant production systems, offering both economic and ecological benefits. The findings of the study highlight the importance of site-specific cultivar selection, particularly in diverse climatic conditions, and reinforce existing research while providing valuable insights for optimizing forage and seed production in varying agro-ecological contexts.

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