**FINAL STUDY REPORT, January 2026**
**Corvallis Plant Materials Center**
**Corvallis, Oregon**

# Evaluation of 20 forage plant species in a mid-rotation Douglas-fir silvopasture

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## ABSTRACT

An evaluation of forage plant species in a mid-rotation Douglas-fir (*Pseudotsuga menziesii*) silvopasture was performed in Philomath, Oregon, from fall 2022 to summer 2024. The study area consisted of three 900m$^2$ blocks located on east, west, and south aspects in a 30–60-year-old Douglas-fir dominant stand with an average of 65% canopy cover. Twenty forage species (7 legumes, 9 grasses, 4 non-leguminous forbs) were seeded in single species 2m x 15m plots after mechanical mastication of surface woody debris. Four plots per block were also seeded with a mix of 3 legumes, 3 grasses, and 3 non-leguminous forbs but with different soil preparation (mastication of woody debris vs control) and fertilization treatments. Plots within each block were randomized and replicated across all three blocks. Plots with sufficient establishment and production were harvested in June 2023 and again in June 2024 to determine dry matter production (pounds/acre). With a single exception, legumes were not harvested from single species plots because of low establishment and production. Non-leguminous forbs were minimally productive in single species plots. Annual ryegrass (*Lolium multiflorum*) produced the highest dry biomass in single species plots. Of the perennial grasses, orchardgrass (*Dactylis glomerata*) produced the most single-year dry biomass. Mixed plots showed low forage biomass production, with no significant difference between control plots and those that were masticated prior to seeding, though fertilization did improve productivity in year one. These results suggest that the heavy shade present in the study may have limited forage plant productivity, and that few species, of those evaluated, exist for forage production under these conditions.

## INTRODUCTION

A significant land base in Western Oregon and Western Washington is dominated by Douglas-fir plantation forestry in which the common practice is to harvest stands on a 30–100-year rotation, depending on management objectives (OFRI, 2026). Within this life cycle, there are potentially multiple points where the integration of forage species and livestock may be possible to provide opportunities for ecological and environmental benefit, short-term financial gain for a landowner, as well as to provide perennial herbaceous cover for soil health, forage utilization, and wildlife habitat. One point in the rotation for integration of trees and forages is during the earlier years of tree growth, when trees are small and sunlight is ample for forage growth. Another point is after tree thinning. Many Douglas-fir stands require a thinning in which subdominant, misshapen,

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unhealthy, and otherwise lower performing trees are removed to improve growing conditions for the other remaining trees. After this thinning, sunlight penetration through the canopy to the forest floor increases for several years until the tree canopy closes in again. Little is known about forage species and their performance in the understory of a Douglas-fir forest after thinning.

Silvopasture is the intentional integration of livestock, forages, and trees into a single integrated system (Sharrow, 1999). It is one of a larger suite of agroforestry practices. Some benefits of silvopasture are an extension of the season of fresh forage availability, improved animal welfare from shade access during heat and shelter during high winds and cold, improved tree growth, and carbon sequestration. An additional benefit to a tree producer is the ability to have an income source from livestock prior to mature tree harvest (Smith et al., 2022).

Forage quality can be increased in semi-shaded situations as compared to forages grown in the open sun. Warm temperatures during growth can increase the portion of plant cells composed of structural molecules, which can decrease their digestibility by animals (Henderson & Robinson, 1982). Flowering of herbaceous plants may be delayed because of growing in the shade, keeping plants in a greener and more digestible form for a longer portion of the year (Krueger, 1981). Shade promotes the nutritional quality and crude protein levels of grasses and legumes (Buergler et al., 2006; Santiago-Hernandez et al., 2016; Pang et al., 2017).

In many Douglas-fir forests of the Pacific Northwest, light penetration to the forest floor is limited year-round. As such, there are tree canopy cover levels that are unlikely to support sufficient herbaceous forage production on the forest floor. However, the photosynthetic rate of understory plants depends on the amount of light reaching the leaves until the plant reaches the light saturation point, and photosynthetic rate does not increase after that (Gardner et al., 1985). Photosynthetic light saturation levels for plants vary from 20-50% light exposure (Krueger, 1981; Gardner et al., 1985), suggesting that there are canopy cover levels that can balance both tree and forage production. Sharrow (1999) suggests that cool season pasture production is unlikely to be negatively impacted by tree canopy until trees intercept over half of the total incoming sunlight. Productivity of understory forages increased significantly when nitrogen and phosphorus fertilizer were applied to a thinned *Pinus pinaster* agroforest when 30% of the sunlight reached the understory, but at 11% sunlight penetration, understory forages did not respond to fertilization (Braziotis & Papanastasis, 1995). This suggests that silvopastures are not entirely limited by light, even at light levels as low as 30%.

## MATERIALS AND METHODS

This study occurred at a farm and ranch located west of Corvallis and north of Philomath, Oregon. The property is managed for timber, livestock, and wildlife habitat. Monthly precipitation totals and mean minimum and maximum temperature data for the study location and duration are displayed in Figure 1. Study design included three blocks of $900m^2$ each (Figure 2). Blocks were on slopes with aspects reflected by their names. Douglas-fir is the dominant tree species in the study area, and ranges in age from approximately 30-60 years. There is a small representation of Oregon white oak (*Quercus garryana*) in the study area.

Soil samples were collected on September 28, 2022 in each study block prior to study

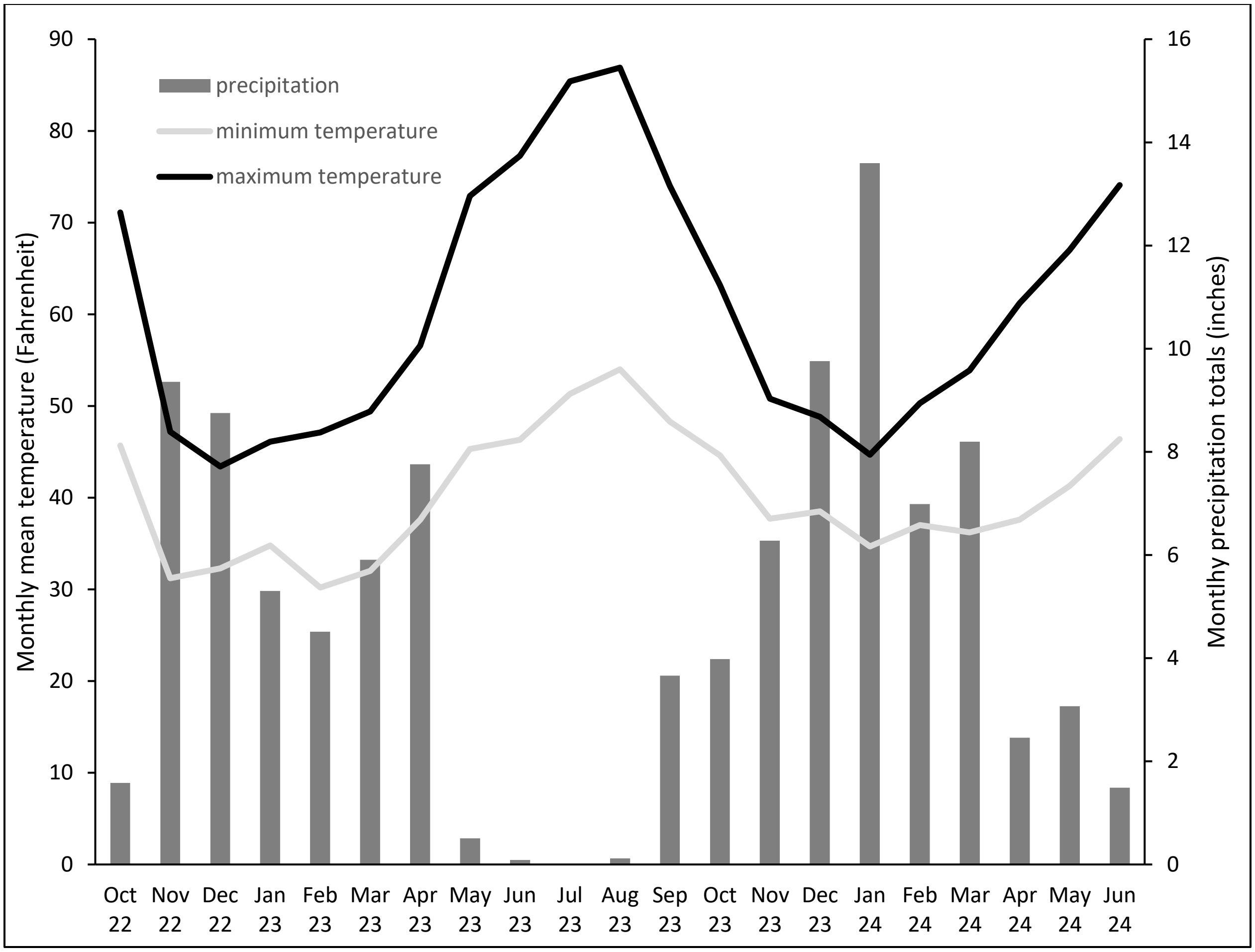


*Figure 1: Monthly mean temperature (F) and precipitation totals (in) at the study site located between Corvallis and Philomath, Oregon, October 2022-June 2024. PRISM/NACSE, Oregon State University.*

establishment and evaluated for basic chemical properties by Kuo Testing Labs in Othello, Washington. A single soil sample for analysis was composed of a composite of 10 6-inch-deep samples collected throughout an entire block. Prior to planting, surface woody debris in the study area was masticated with a forestry mulcher attachment on a skid steer. Within each block, twenty forage species that performed well in other trials at the Plant Materials Center and Oregon State University were seeded with a hand broadcast seeder in single-species plots on October 20, 2022 (Figure 3). Pre-weighed quantities of seed were spread without the addition of an inert carrier.


*Figure 2: Relative locations of forage plant species study blocks in a mid-rotation Douglas-fir silvopasture near Philomath, OR.*

Each plot was 2m x 15m and plots within each block were randomized and replicated across all three blocks. All plots were fertilized after seeding in late February with a granulated 33-0-0 product (with 12% sulfur) at 50 pounds/acre nitrogen. Study species and seeding rates are listed below in Table 1.

*Figure 3: Seeding forage plant species into mid-rotation Douglas-fir silvopasture study plotsOctober 20, 2022.*

*Table 1: Forage plant species, cultivars/varieties, and seeding rates used in a mid-rotation Douglas-fir silvopasture study, fall 2022-summer 2024, near Philomath, OR. PLS= Pure live seed. *VNS=Variety not stated.*

| Common Name | Scientific Name | Cultivar or Variety | Category | Duration | Seeding rate (lb/acre PLS) |
|---|---|---|---|---|---|
| **birdsfoot trefoil** | *Lotus corniculatus* | 'Bull'-year 1, 'Bruce'-year 2 | legume | perennial | 9.8 |
| **burnet, small** | *Sanguisorba minor* | 'Delar' | forb | perennial | 37.5 |
| **chicory** | *Cichorium intybus* | 'Oasis' | forb | perennial | 10.5 |
| **clover, white x kura** | *Trifolium ambiguum X T. repens* | 'AberLasting' | legume | perennial | 12.0 |
| **clover, arrowleaf** | *Trifolium vesiculosum* | 'Zulu' | legume | annual | 18.8 |
| **clover, balansa** | *Trifolium michelianum* | 'Viper' | legume | annual | 9.8 |
| **clover, red** | *Trifolium pratense* | 'Medium' | legume | perennial | 16.5 |
| **clover, sub** | *Trifolium subterraneum* | 'Campeda' | legume | annual | 37.5 |
| **clover, white** | *Trifolium repens* | 'Haifa' | legume | perennial | 4.5 |
| **creeping red fescue** | *Festuca rubra* | *VNS | grass | perennial | 40.0 |
| **festulolium** | *Festuca x Lolium* | 'Sugarcrest' | grass | perennial | 30.0 |
| **orchardgrass** | *Dactylis glomerata* | 'Tekapo' | grass | perennial | 18.8 |
| **plantain** | *Plantago lanceolata* | 'Boston' | forb | perennial | 15.0 |
| **roughstalk bluegrass** | *Poa trivialis* | *VNS | grass | perennial | 11.3 |
| **rye, blue wild** | *Elymus glaucus* | Arlington | grass | perennial | 12 |
| **ryegrass, annual** | *Lolium multiflorum* | 'Rival'-year 1, 'Bounty'-year 2 | grass | annual | 45 |
| **ryegrass, perennial** | *Lolium perenne* | 'Power' | grass | perennial | 48.8 |
| **self-heal** | *Prunella vulgaris var. lanceolata* | *VNS | forb | perennial | 7.5 |
| **Sitka brome** | *Bromus sitchensis* | *VNS | grass | perennial | 33 |
| **tall fescue** | *Schedonorus arundinaceus* | 'Bronson' | grass | perennial | 33.8 |

*Table 2: Study species, sowing rates, and percent representation in mixed species plots. Cultivars were the same as shown in Table 1.*

| Common Name | Seeding rate (lbs/acre PLS) | Percent of mix |
|---|---|---|
| **burnet, small** | 5 | 9.4 |
| **chicory** | 2 | 3.8 |
| **clover, red** | 3 | 5.7 |
| **clover, subterranean** | 5 | 9.4 |
| **clover, white** | 1 | 1.9 |
| **orchardgrass** | 8 | 15.1 |
| **plantain** | 4 | 7.5 |
| **ryegrass, perennial** | 15 | 28.3 |
| **tall fescue** | 10 | 18.9 |

Five species were resown in October 2023 either because they were annual: annual ryegrass, arrowleaf clover (*Trifolium vesiculosum*), balansa clover (*Trifolium michelianum*), subterranean clover (*Trifolium subterraneum*), or because they were not observed in the plots in year 1: birdsfoot trefoil (*Lotus corniculatus).* Seeding rates and cultivars were the same as in year 1, except where noted in Table 1.

Plots with sufficient establishment and production were harvested one time per year, on June 21, 2023 and on June 28, 2024. In each plot, two randomly placed 30cm x 30cm quadrats were hand cut at two inches for biomass analysis. Prior to sample collection, developmental stage was recorded. Developmental stages included vegetative, bud (legumes/forbs), transition (grasses), flowering, and fruiting. Each sample was dried and pounds per acre of dry matter was calculated. After harvest, the plot was cut with a weed whacker and raked to remove any remaining plant residue. Biomass data was analyzed using an ANOVA test.

In addition to the single species plots, four plots per block were seeded with a species mix that had shown functionality in a pasture mix in other settings studied by the Plant Materials Center and Oregon State University (Table 2). Species and cultivars used were the same as those in the single species plots. The percentages of each species in the mix were constant between plots but fertilizer and mechanical mulching treatments varied. Treatments included mulched/fertilized, mulched/unfertilized, unmulched/fertilized, and unmulched/unfertilized. Harvest methods were the same as for the single species plots. Data was analyzed using a t-test.

Tree canopy cover was measured using the smartphone application Percentage Cover Canopy Assessment Tool (Public Interest Enterprises) by taking 5 photographs per block of the tree canopy at random locations within the block and averaging the measured percentage of canopy leaf cover.

## RESULTS AND DISCUSSION

A full soil analysis report is included in Appendix 1. No additional amendments were applied to experimental blocks other than the previously mentioned fertilizer. Eleven of the 20 forage species evaluated produced measurable biomass in single species plots (Table 4). Nine produced insufficient material to harvest; this may be due at least in part to the circumstances during establishment. In fall 2022, plots were not seeded until October 20 because of the lack of rain. Additionally, freezing temperatures began three weeks after seeding. This combination of factors likely impacted establishment, especially of legumes that often require warmer establishment

*Table 4: Mean dry matter yield across three blocks of forage species from single species plots. The absence of numbers indicates that a plot was not harvested because biomass production was too low to be harvested.*

| Common Name | Cultivar or Variety | Biomass production (lbs/acre) | | Average growth stage at harvest | |
|---|---|---|---|---|---|
| | | 2023 | 2024 | 2023 | 2024 |
| **birdsfoot trefoil** | 'Bull' or 'Bruce' | -- | -- | -- | -- |
| **burnet, small** | 'Delar' | -- | 656 | -- | vegetative |
| **chicory** | 'Oasis' | -- | 360 | -- | vegetative |
| **clover, white x kura** | 'Aberlasting' | -- | -- | -- | -- |
| **clover, arrowleaf** | 'Zulu' | -- | -- | -- | -- |
| **clover, balansa** | 'Viper' | -- | -- | -- | -- |
| **clover, red** | 'Medium' | -- | -- | -- | -- |
| **clover, subterranean** | 'Campeda' | -- | 128 | -- | 100% fruit |
| **clover, white** | 'Haifa' | -- | -- | -- | -- |
| **creeping red fescue** | VNS | 434 | 627 | vegetative | vegetative |
| **festulolium** | 'Sugarcrest' | 702 | 470 | transition | transition |
| **orchardgrass** | 'Tekapo' | 611 | 952 | vegetative | vegetative |
| **plantain** | 'Boston' | -- | 394 | vegetative | vegetative |
| **roughstalk bluegrass** | VNS | -- | -- | -- | -- |
| **rye, blue wild** | Arlington | 330 | 684 | vegetative | transition |
| **ryegrass, annual** | 'Rival' | 1221 | 1082 | 50% flowering | 10% fruit |
| **ryegrass, perennial** | 'Power' | 234 | 676 | vegetative | transition |
| **self-heal** | VNS | -- | -- | -- | -- |
| **Sitka brome** | VNS | 346 | -- | transition | -- |
| **tall fescue** | 'Bronson' | 672 | 428 | vegetative | vegetative |

temperatures than grasses. Harvested biomass ranged from 128 to 1221 pounds/acre in a single year, and only a legume species, 'Campeda' subterranean clover, was harvested and only in the second year. While differences were not significant across all species within a year, annual ryegrass produced the highest dry matter quantity in both years (Figure 4). While no full sun comparison planting was done at this site, yields in all cases were low compared to biomass production trials performed in full sun at the nearby Corvallis, OR, Plant Materials Center. Yield of annual ryegrass was 23% and yield of orchargrass over two years was 18% of that found in full sun at the Plant Materials Center.

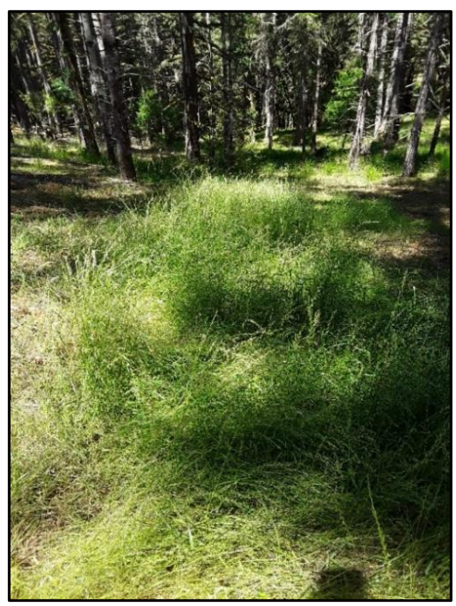

*Figure 4:* June 21, 2023. Annual ryegrass, 244 days after planting.

Canopy cover averages were as follows: South Block 70%, East Block 64%, West Block 62%, for an overall average of 65%. This level of shading affected the forage growth, as evidenced by elongated stems, smaller leaves, and reduced production. This impact was particularly evident with the legumes.

In mixed species plots, production ranged from 58 to 468 pounds/acre (Table 5). Harvested biomass was not significantly different between mechanically mulched and unmulched plots. Fertilizer application significantly increased production in year 1 (p=0.02), but not in year 2.

*Table 5: Biomass yield in mixed species plots with different mulching and fertilizer treatments. Means not sharing a letter are significantly different at the 5% level of significance according to a t-test.*

| Mulching treatment | Fertilizer application | Biomass production (lbs/acre) | |
|---|---|---|---|
| | | 2023 | 2024 |
| **Mulched** | No | $142^{B}$ | 428 |
| | Yes | $417^{A}$ | 468 |
| **Not mulched** | No | $58^{B}$ | 339 |
| | Yes | $417^{A}$ | 312 |

## CONCLUSION

These findings suggest that heavy shade (average of 65% canopy cover) may have a large impact on forage biomass production. This impact was particularly strong with legumes, where only a single species, of seven planted, produced enough biomass to be evaluated. Additionally, forage forbs, while they established at ample density, were small and produced few leaves. Only a subset of the grass species included in this study produced agronomically significant biomass. Annual ryegrass had the highest production in both years, and orchardgrass had the highest single-year production of all perennial grasses. While no comparison was made directly with plantings in the full sun, comparison to other studies performed at the Corvallis Plant Materials Center indicate reduced productivity under shade.

In multi-species plots, forage production was also limited, and there was no significant impact on forage production of mulching of surface woody debris prior to seeding. Fertilization did improve forage production in the first year, suggesting available nutrient limitation of the soils at the study site.

These findings emphasize the value of species selection in silvopasture establishment. Several species that reliably produce harvestable biomass in full sun conditions did not produce any in this study. In Douglas-fir dominated silvopastures, it may be necessary to thin trees to a lower canopy cover than the 65% present in this study, though this need will depend on a producer’s goals. Mastication of surface woody debris may not be necessary to improve plant establishment and production, but fertilization may be useful to boost yields.

Additional evaluations should emphasize the effects of shade created by varying tree density on forage plant production, as the results of this study suggest that heavy Douglas-fir shade limits silvopasture forage growth. Evaluations of forage plant species should emphasize legumes and forbs to determine functional additions to seed mixes that include the most productive grasses in this study. Optimal seed establishment ground conditions, including further evaluations of pre-seeding woody debris mastication, should also be assessed.

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***Appendix 1:*** Soil analyses results of three study blocks prior to establishment of mid-rotation Douglas-fir silvopasture study, fall 2022-summer 2024, near Philomath, Oregon. Methods utilized for analyses are listed in italics. *OM = organic matter

| Block | NO3-N | | NH4-N | | P | K | Ca | Mg | Na | SO4-S | B | Zn | Mn | Cu | Fe |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *KCl* | | *KCl* | | *Bray* ppm | *Ammonium Acetate* | | | | *DTPA* | | | | | |
| | lbs/ac | ppm | lbs/ac | ppm | | ppm | meq/100g | | | ppm | ppm | ppm | ppm | ppm | ppm |
| **East** | 4 | 1.8 | 24 | 11.8 | 10 | 200 | 26.2 | 13.9 | 0.19 | 5 | 0.09 | 2.2 | 73 | 7.9 | 111 |
| **South** | 4 | 1.8 | 24 | 11.8 | 14 | 197 | 21.8 | 11.0 | 0.24 | 8 | 0.21 | 2.0 | 90 | 8.0 | 140 |
| **West** | 8 | 4.2 | 24 | 12.0 | 5 | 161 | 24.2 | 12.4 | 0.16 | 6 | 0.06 | 6.0 | 66 | 7.5 | 114 |

| Block | pH *1:2* | Sikora pH | Soluble Salts *1:1* | *OM *%* | Estimated CEC | Base Saturation | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | meq/100g | % Ca | % Mg | % K | % Na | % H |
| **East** | 5.5 | 6.5 | 0.14 | 7.92 | 46.8 | 56.0 | 29.7 | 1.1 | 0.4 | 12.8 |
| **South** | 5.5 | 6.5 | 0.20 | 8.40 | 39.6 | 55.0 | 27.9 | 1.3 | 0.6 | 15.2 |
| **West** | 6.6 | 6.8 | 0.14 | 7.31 | 40.1 | 60.2 | 30.8 | 1.0 | 0.4 | 7.6 |