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**Pullman Plant Materials Center**

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## **Effect of Fall Planting Date on Biomass Production of Cool-Season Cover Crops in Eastern Washington**

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### **ABSTRACT**

Cover crop success depends on numerous, complex factors. While producers have little influence over climate and environmental factors, they can adjust crop management practices to simplify the challenges of establishing an effective cover crop. Early fall planting is widely recommended for cool-season cover crops in the Inland Pacific Northwest but regional data quantifying this effect has been limited. This study evaluated twelve cultivars representing six species under two fall planting dates. Early plantings produced 46 to 64% greater biomass than late plantings in all three years with available harvest data, and the effect remained statistically significant even in a year when a severe freeze killed all brassica plots outright. This consistency across highly variable growing seasons, including one severe winterkill event, makes planting date the single most dependable management factor identified in this study. Triticale (*× Triticosecale Wittmack*) cultivars 'Fx1001' and 'Tulus' ranked highest for biomass across all years and planting dates and species-level analysis confirmed that triticale produced significantly more biomass than both brassica and hairy vetch species groups. Mustard (*Brassica juncea*), turnip (*Brassica rapa*), and rapeseed (*Brassica rapa*) are not recommended for overwintering systems in the Palouse region given complete winterkill in the 2022-2023 season. Spring green canopy cover was the strongest field-measurable predictor of final biomass ( $\rho = 0.46$  to  $0.76$ ) and is recommended as a practical pre-termination assessment tool for producers and conservation planners. These results provide a direct, quantified basis for updating fall cover crop planting-date guidance under NRCS Conservation Practice Standard 340 in the Inland Pacific Northwest, where a target planting window of mid-to-late September is recommended over later fall planting dates in the Palouse dryland region.

### **INTRODUCTION**

The Plant Materials Program continues to evaluate cover crops to help farmers choose the appropriate species, variety, seeding rate, and planting date to maximize cover crop benefits in their rotation. According to Bergtold and Sailus (2020), planting date and termination date are probably the most important factors for integrating cover crops into different cropping systems. Specific regional information relating planting and termination dates to cover crop performance and biomass is lacking. Prior work in the region evaluated cool-season cover crop cultivar performance (Casey & Spellman, 2020) and cover crop planting dates under irrigated (USDA-NRCS, 2014a) and dryland (USDA-NRCS, 2014b) rotations in Central Washington, as well as under broader northwest conditions (USDA-NRCS, 2020), but a direct, quantified link between planting date and biomass production specific to the Palouse dryland region has not been established.

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One challenge to successfully grow cool-season cover crops in the Inland PNW is timely seeding for crop establishment. Key constraints on timely crop establishment are sufficient rainfall to initiate cover-crop germination and enough days for growth before hard frost. Cover crop benefits such as reduced erosion, weed suppression, enhanced soil fertility, and improved water retention (Clark, 2007; Abdalla et al., 2019) are limited if the crop is not established before fall or winter frost (Kruger et al., 2017; Lawson et al., 2015).

Planting timing can vary each season based on weather conditions, soil moisture, crop rotation, and other logistics. Understanding which species and varieties have the potential to perform well will increase the likelihood of cover crop adoption in this region and improve conservation practices in agricultural settings. Our objectives for this study were to (1) compare biomass production of cool-season cover crop cultivars at early (PD1) and late (PD2) fall planting dates; (2) evaluate the effect of planting date on cover crop establishment (emergence), spring green canopy cover, and biomass; (3) identify cultivars with consistent performance across years suitable for NRCS recommendation; and (4) provide data to support updates to NRCS cover crop practice standards for the Inland PNW.

## **MATERIALS AND METHODS**

### *Site Description*

This study was conducted at the USDA-NRCS Pullman Plant Materials Center, Pullman, WA (46°42'58" N, 117°08'14" W; elevation 2,600 ft) for 3 seasons between 2021 and 2025. The Pullman PMC is in MLRA 9 of Land Resource designation B and is characterized by a Palouse silt loam soil. The climate is typical of the Palouse region, with average annual precipitation of 13 to 28 inches and average temperatures between 47 and 54 degrees, with an average freeze-free period of 165 days. About 70% of annual precipitation falls between October and March, while 25% falls between April and June. July through September is the driest period. Winter temperatures are cool to cold and can drop to -11°F, with occasional Arctic cold winds from Canada.

### *Experimental Design*

This trial included 12 cover crop cultivars (Table 1) and two planting dates, arranged in a randomized block split-plot design with three replications. Individual plots were 8 ft by 60 ft and seeded with a Great Plains no-till drill equipped with a Kincaid cone seeder (Kincaid Equipment, Haven, KS) on 7.5" row spacing. Seeding rates for all species were based on industry recommendations (USDA-NRCS, 2010) and all treatments were planted on a pure live seed (PLS) basis. Before planting, legume seeds were inoculated with appropriate rhizobial bacteria. Weeds were spot-treated with selective and non-selective herbicides or hand-rouged.

Early-date (PD1) plots were planted on September 29, 2021, September 20, 2022, and September 15, 2024; late-date (PD2) plots were planted 14 to 26 days later, on October 13, 2021, October 16, 2022, and September 29, 2024, respectively, depending on rainfall. No supplemental irrigation was applied throughout the trial. Precipitation and temperature were monitored using data from our on-site ClimaVUE 50 weather station (Campbell Scientific, Logan, UT). Plots were terminated using either chemical or mechanical methods when 50% or more of the plants reached 50% bloom. Plots were moved to a new field location each year to avoid contamination from the previous year.

**Table 1:** Cultivars and seeding rates of annual, cool-season cover crops planted at the USDA NRCS Pullman, Washington Plant Materials Center (WAPMC). All twelve cultivars were fall-planted on two dates in each of the three trial years (2021, 2022, and 2024), producing harvests in 2022, 2023, and 2025.

| Cultivar      | Common Name         | Species                | Seeding Rate (lb/ac) |
|---------------|---------------------|------------------------|----------------------|
| Survivor 15   | Austrian winter pea | <i>Pisum sativum</i>   | 70                   |
| Wyo Winter    | Austrian winter pea | <i>Pisum sativum</i>   | 70                   |
| Cosaque       | black seeded oats   | <i>Avena strigosa</i>  | 84                   |
| AUMerit       | hairy vetch         | <i>Vicia villosa</i>   | 24                   |
| Purple Bounty | hairy vetch         | <i>Vicia villosa</i>   | 24                   |
| Villana       | hairy vetch         | <i>Vicia villosa</i>   | 24                   |
| Winter King   | hairy vetch         | <i>Vicia villosa</i>   | 24                   |
| Kodiak        | mustard             | <i>Brassica juncea</i> | 10                   |
| Winfred       | rapeseed            | <i>Brassica rapa</i>   | 10                   |
| Fx1001        | triticale           | × <i>Triticosecale</i> | 84                   |
| Tulus         | triticale           | × <i>Triticosecale</i> | 84                   |
| Vivant Hybrid | turnip              | <i>Brassica rapa</i>   | 10                   |

#### Field Measurements:

**Emergence:** To evaluate stand establishment and seedling vigor across species, we recorded the date of plant emergence and expressed total emergence as a percentage of the total plot based on ocular assessment.

**Green Canopy Cover:** Green Canopy cover was measured to assess plant growth rates, soil protection potential, and overall plot success. Percent green canopy cover was measured using the Canopeo app (Patrignani and Ochsner, 2015) on an Apple iPhone at 30 days after planting (DAP), 60 DAP, and at crop termination. Canopeo estimates the fraction of green canopy from a vertically oriented overhead photograph and has been validated for accuracy in cover crop and forage systems (Patrignani and Ochsner, 2015).

**Phenology:** We monitored the phenological development of summer cover crops to identify initial and 50% bloom dates, characterizing the cultivars to optimize field management practices. Days to initial bloom and 50% bloom were calculated from planting date to estimate how long the crop could remain on the soil for cover or potential forage.

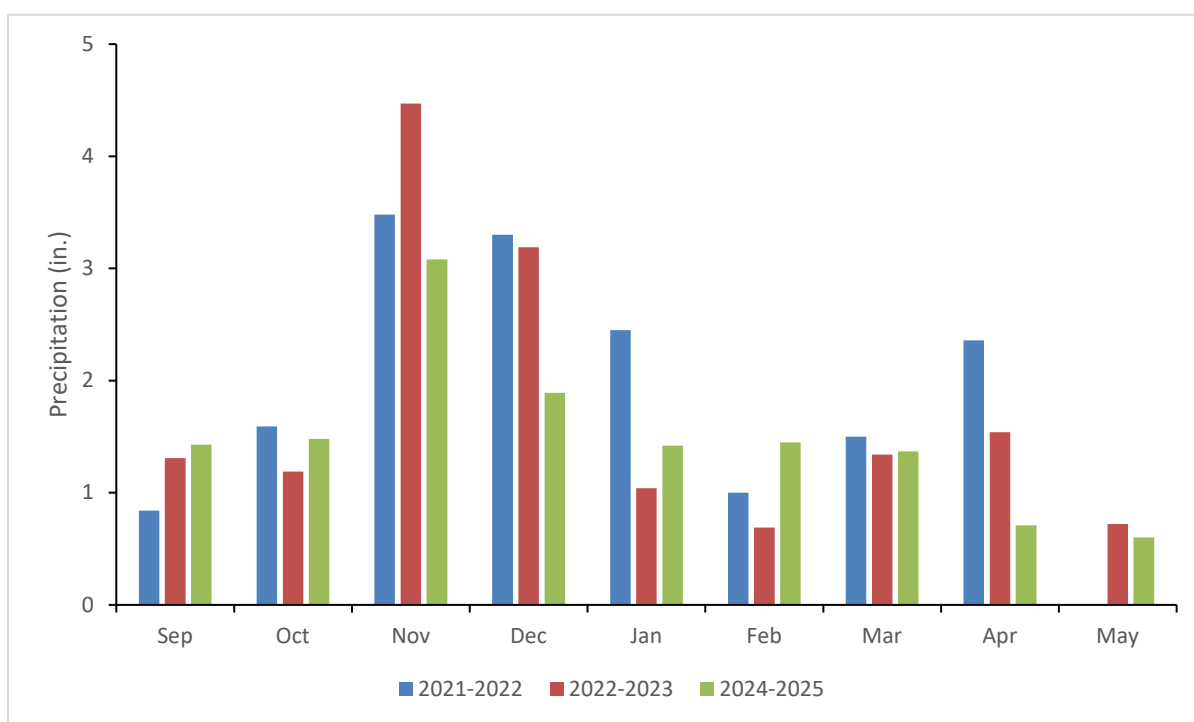
**Soil Moisture:** Volumetric water content (VWC) is the volume of liquid water per volume of soil. We measured VWC to track seasonal water usage for each species. It is usually expressed as a percentage. For example, 25% VWC means 0.25 cubic inch of water per cubic inch of soil. We measured %VWC at planting and termination for each cultivar using a HydroSense II Handheld Soil Moisture Sensor (Campbell Scientific, Logan, UT) to estimate water use.

**Biomass:** Above-ground biomass was harvested from a 1 by 1 m square from interior rows of the plot. Biomass was dried at 60°C for one week, then weighed. Dates varied per year.

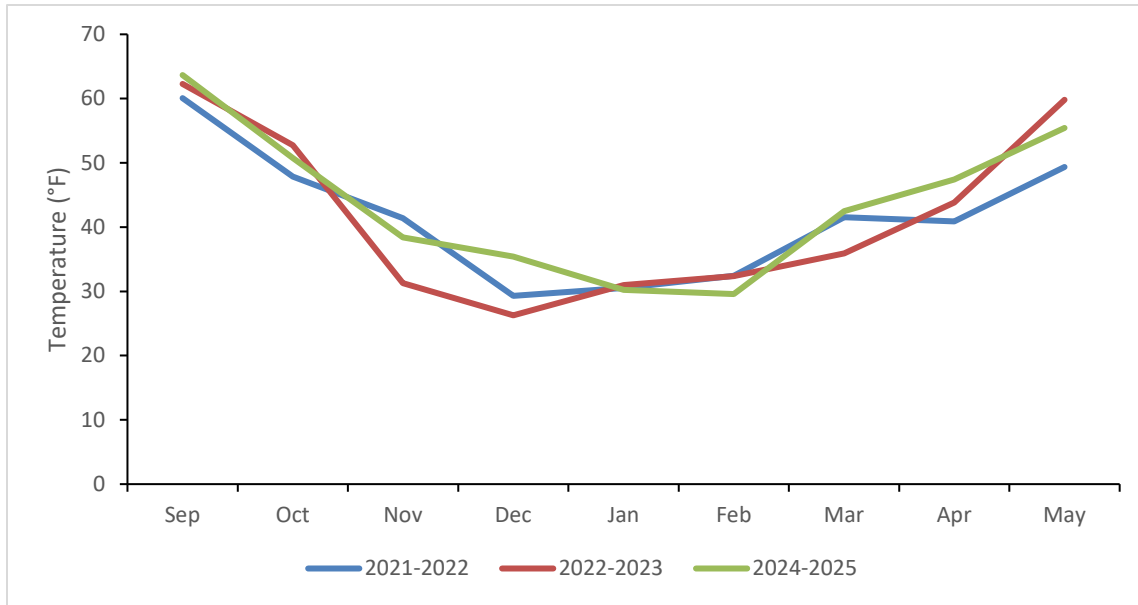
### Statistical Analysis:

We assessed all variables for normality using the Shapiro-Wilk test. All key agronomic variables were determined to be non-normal (Shapiro-Wilk,  $p < 0.05$ ; Warton & Hui, 2011). Because normality was not met, we used non-parametric tests throughout. We evaluated cultivar effects using the Kruskal-Wallis test and applied Dunn's test with Bonferroni correction for pairwise comparisons. We assessed planting date effects using the Wilcoxon rank-sum test and determined predictor relationships using Spearman rank correlation. Descriptive statistics are reported as medians and 25th-75th percentiles. For the multivariate analysis, we applied rank-based PCA by extracting eigenvectors and eigenvalues from a Spearman correlation matrix. We conducted all analyses in R (R Core Team, 2024).

## RESULTS AND DISCUSSION



**Figure 1a:** Weather data for September 2021 to May 2025 at the Pullman, Washington PMC during the cool-season cover crops trial measured with an on-site ClimaVUE 50 weather station. Precipitation is presented in inches.



**Figure 1b:** Weather data for September 2021 to May 2025 at the Pullman, Washington PMC during the cool-season cover crops trial measured with an on-site ClimaVUE 50 weather station. Temperature is presented in degrees Fahrenheit.

## RESULTS

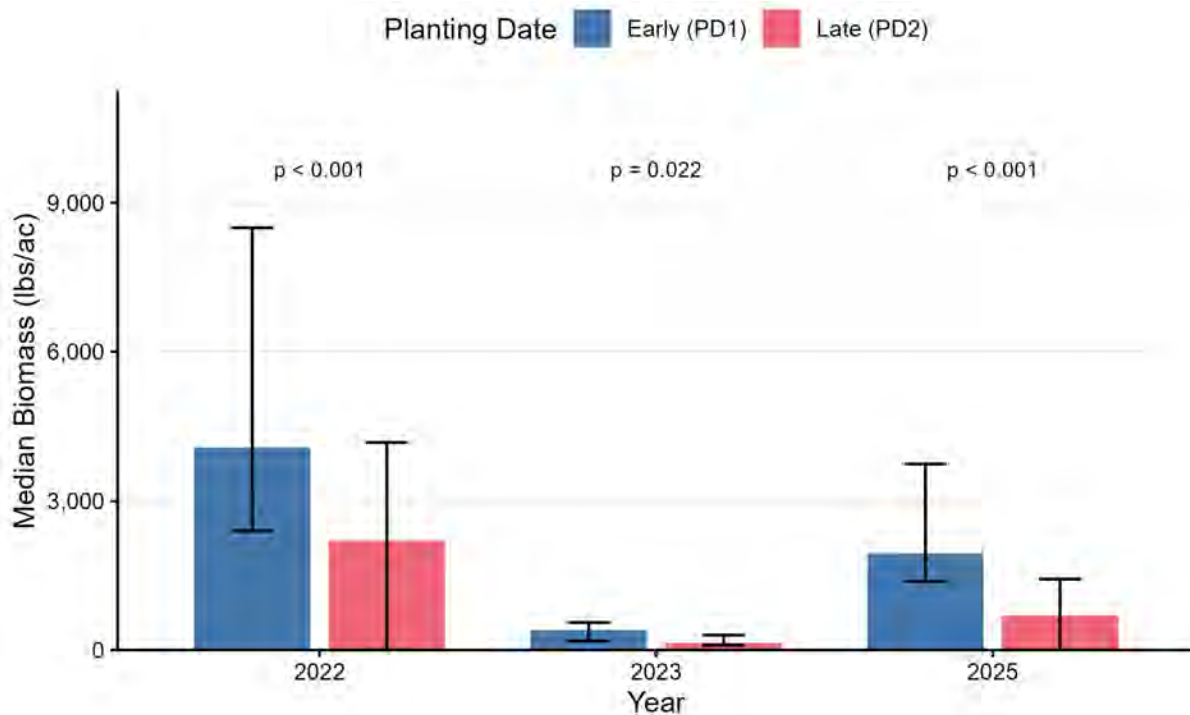
### *Planting Date Effect on Biomass*

Planting date significantly affected biomass production in all three years (Table 2, Figure 2). In 2022, early planting produced a median biomass of 4,095 lb/ac compared with 2,222 lb/ac under late planting, a 46% reduction in biomass accumulation ( $W=955$ ,  $p<0.001$ ). While the median biomass was substantially lower in 2023 for both planting dates (early: 224 lb/ac; late: 110 lb/ac) due to a severe freeze event during the establishment phase, the early planting still produced 51% greater median biomass than the late planting ( $W=413$ ,  $p=0.022$ ). In 2025, early planting produced 1,963 lb/ac compared to 714 lb/ac under late planting. Late planting was associated with a 64% reduction ( $W=1021$ ,  $p<0.001$ ). The planting date effect was statistically significant in all three years, with the advantage ranging from 46% to 64%. Consistency of this effect across years with very different weather conditions, including a year with severe freeze kill, indicates a robust and reliable response.

**Table 2.** Median biomass (lb/ac) by planting date (PD), year, and percent reduction from early PD to late PD in the 2021-2025 fall-planted cover crop trial at the Pullman, Washington PMC.

| Year | Early PD (lb/ac) | Late PD (lb/ac) | Reduction (%) | Wilcoxon ( $p$ -value) |
|------|------------------|-----------------|---------------|------------------------|
| 2022 | 4,095            | 2,222           | 46%           | $W=955$ , $p<0.001$    |
| 2023 | 224              | 110             | 51%           | $W=413$ , $p=0.022$    |
| 2025 | 1,963            | 714             | 64%           | $W=1021$ , $p<0.001$   |

Wilcoxon rank-sum test.  $n=36$  plots per planting date in 2022 and 2025 (12 cultivars  $\times$  3 replications);  $n=35$  (early) and  $n=32$  (late) in 2023 due to missing harvest data for winter-killed Brassica plots.



**Figure 2.** Median biomass (lb/ac) by planting date and year in the 2021-2025 fall-planted cover crop trial at the Pullman, Washington PMC. Error bars = 25<sup>th</sup>-75<sup>th</sup> percentile (IQR). Wilcoxon rank-sum p-values shown.

#### *Planting Date Effect on Establishment and Spring Green Canopy*

Table 3 shows the effect of planting date on cover crop emergence and spring green canopy cover of all evaluated varieties. Emergence at 15 days after planting (DAP) did not differ significantly between planting dates in any of the years ( $p=0.11-0.93$ ), and the direction of the non-significant difference was inconsistent across years: early planting showed higher median emergence in 2022 (51.5% vs. 43.5%) but lower median emergence in 2023 and 2025 (31.5% vs. 49.5%; 35% vs. 48.5%). Emergence at 30 DAP reached significance in two of three years, but with opposite directions: the late planting had significantly higher 30-DAP emergence in 2023 (88% vs. 80%,  $p=0.014$ ), while the early planting had substantially higher 30-DAP emergence in 2025 (88% vs. 70%,  $p<0.001$ ).

This inconsistency, both direction and significance varying by year, indicates that emergence timing in this study was driven more by year-specific fall weather conditions than by planting date itself and is an important caveat to the emergence-biomass predictor relationships reported in the Multivariate Analysis section below: emergence is not a metric producers can expect planting date alone to shift in a predictable direction.

Spring green canopy showed a more consistent pattern. Median canopy was higher under early planting in all three years (2022: 62.4% vs. 29.6%; 2023: 18.4% vs. 0.9%; 2025: 77.5% vs. 67%). This difference reached statistical significance only in 2023 ( $p<0.001$ ), the year of the brassica winterkill event, in which later planting and a severe freeze appear to have compounded to produce a particularly large gap. The 2022 and 2025 differences, while directionally consistent with 2023, did not reach significance ( $p=0.089$  and  $p=0.074$ , respectively). Taken together, these results offer partial support for the hypothesis that planting date affects early-season metrics beyond biomass: planting date reliably shifts the direction of spring green canopy development, but this shift reaches

formal statistical significance only under added winter stress. Planting date does not produce a consistent, predictable effect on emergence timing at either 15 or 30 DAP in this dataset.

This asymmetry reinforces the recommendation to prioritize spring green canopy over emergence counts as a field decision-support metric. Spring green canopy not only predicts eventual biomass but also responds more reliably to planting dates. Emergence depends more on specific fall conditions than planting dates.

**Table 3.** Planting date (PD) effect on percent median emergence and spring green canopy in the 2021-2025 fall-planted cover crop trial at the Pullman, Washington PMC.

| <b>Metric</b>       | <b>Year</b> | <b>Early PD<br/>Median (%)</b> | <b>Late PD<br/>Median (%)</b> | <b>Wilcoxon<br/>Statistic</b> | <b>p-value</b> |
|---------------------|-------------|--------------------------------|-------------------------------|-------------------------------|----------------|
| Emergence 15 DAP    | 2022        | 51.5                           | 43.5                          | W=639.5                       | 0.926          |
| Emergence 15 DAP    | 2023        | 31.5                           | 49.5                          | W=416.5                       | 0.113          |
| Emergence 15 DAP    | 2025        | 35.0                           | 48.5                          | W=677.5                       | 0.743          |
| Emergence 30 DAP    | 2022        | 79.5                           | 81.0                          | W=616.5                       | 0.726          |
| Emergence 30 DAP    | 2023        | 80.0                           | 88.0                          | W=350.0                       | 0.014          |
| Emergence 30 DAP    | 2025        | 88.0                           | 70.0                          | W=1088.5                      | <0.001         |
| Spring green canopy | 2022        | 62.4                           | 29.6                          | W=799.5                       | 0.089          |
| Spring green canopy | 2023        | 18.4                           | 0.9                           | W=955.5                       | <0.001         |
| Spring green canopy | 2025        | 77.5                           | 67.0                          | W=541.5                       | 0.074          |

Wilcoxon rank-sum test, early planting date vs. late planting date, within year. Maximum possible n=36 per planting date-year combination (12 cultivars × 3 replications); realized sample sizes are lower in some year-metric combinations due to missing field assessments.

#### *Winter Kill in the 2022-2023 season*

In the 2022-2023 growing season, 56 days after the early planting date and 30 days after the late planting date, low temperatures were below 20 degrees F for five days. This freezing event caused complete winterkill of all three brassica species: mustard (Kodiak), turnip (Vivant Hybrid), and rapeseed (Winfred). Fall emergence and canopy data confirm that all three had established adequate fall stands before the freezing event. Spring canopy for frost-killed plots was 0–3%, and biomass was coded as zero for all affected plots and both planting dates. The 3% spring canopy was from delayed seed germination in the spring.

Eight cultivars survived the winter of 2022-2023 and produced measurable spring canopy and biomass under both planting dates. Cosaque (black seeded oats) was a partial exception under late planting; this is discussed together with a second, similar event below. Our results show that the brassica species evaluated in this study are not reliable as overwintering cover crops at the Pullman site under the planting dates evaluated. This is consistent with the known frost sensitivity of brassica species at temperatures below approximately -8 to -12°C (Pessotto et al., 2023). The 2022 event represents a meaningful agronomic risk that producers should weigh when considering brassica species for fall-planted overwintering systems in the Inland Pacific Northwest.

Cosaque (black seeded oats) showed a similar partial, replicate-specific winterkill pattern in two separate seasons, distinct from the uniform, stand-wide brassica losses described above. In the 2022-2023 season, under late planting only, two of three replicates were severely reduced by the same freezing event that killed the brassicas outright (1% and 0.7% spring canopy; 100 and 85 lb/ac biomass), while the third replicate remained healthy (72% spring canopy; 3,542 lb/ac biomass). In the 2024-2025 season, at both the early and late planting dates, two replicates were lost outright (0% spring canopy; 0 lb/ac biomass), while the third replicate at each date survived and produced measurable spring canopy and biomass (51% canopy and 1,428 lb/ac at the early date; 43% canopy and 714 lb/ac at the late date). In both seasons, the losses were partial and replicate-specific rather than stand-wide, suggesting a more localized cause (e.g., microsite drainage or snow cover differences) rather than a uniform freeze event of the severity documented for the brassicas. Because only one replicate survived to produce biomass in the affected cells, the corresponding Table 4 values for Cosaque (3,542 lb/ac in 2023 late; 1,428 lb/ac and 714 lb/ac in 2025 early and late) are single-replicate estimates and should be interpreted with reduced confidence relative to other cells in the table.

### *Cultivar Biomass Performance*

Table 4 presents median biomass for each cultivar by year and planting date, alongside the combined-year medians. A Kruskal-Wallis test revealed significant differences in overall biomass ranking among the 12 cultivars ( $X^2(11) = 28.34, p = 0.0029$ ). However, Dunn's post-hoc pairwise comparison detected no significance among specific cultivar pairs ( $p > 0.05, n = 66$ ). This discrepancy stems from high interannual variability within individual cultivars. Specifically, the stark contrast between high-biomass conditions in 2022 and frost-kill conditions in 2023 widened confidence intervals, thereby reducing the statistical power of pairwise tests.

**Table 4.** Median biomass (lb/ac) by cultivar, year, and planting date in the 2021-2025 fall-planted cover crop trial at the Pullman, Washington PMC.

| Cultivar    | Common Name         | Median Biomass (lb/ac) |           |            |           |            |           | Median for all years |
|-------------|---------------------|------------------------|-----------|------------|-----------|------------|-----------|----------------------|
|             |                     | 2022 Early             | 2022 Late | 2023 Early | 2023 Late | 2025 Early | 2025 Late |                      |
| Fx1001      | triticale           | 15,899                 | 5,584     | 783        | 828       | 3,925      | 3,212     | 3,926                |
| Tulus       | triticale           | 8,494                  | 7,405     | 979        | 488       | 3,925      | 3,212     | 3,569                |
| Survivor 15 | Austrian winter pea | 9,801                  | 7,187     | 405        | 171       | 1,784      | 713       | 639                  |
| AUMerit     | hairy vetch         | 2,178                  | 1,306     | 91         | 110       | 2,855      | 2,676     | 1,307                |

| Cultivar      | Common Name         | Median Biomass (lb/ac) |           |            |           |            |                    | Median for all years |
|---------------|---------------------|------------------------|-----------|------------|-----------|------------|--------------------|----------------------|
|               |                     | 2022 Early             | 2022 Late | 2023 Early | 2023 Late | 2025 Early | 2025 Late          |                      |
| Winter King   | hairy vetch         | 2,831                  | 1,960     | 210        | 82        | 1,427      | 1,427 <sup>#</sup> | 1,249                |
| Wyo Winter    | Austrian winter pea | 4,051                  | 3,702     | 488        | 185       | 1,070      | 1,070              | 1,071                |
| Purple Bounty | hairy vetch         | 3,179                  | 2,221     | 431        | 148       | 1,962      | 535                | 892                  |
| Villana       | hairy vetch         | 2,395                  | 2,221     | 410        | 89        | 1,784      | 892                | 1,249                |
| Kodiak        | mustard             | 4,325                  | 0         | 0          | 0         | 4,639      | 0                  | 1,089                |
| Cosaque       | black seeded oats   | 6,534                  | 3,092     | 358        | 3,542*    | 1,428*     | 714*               | 573                  |
| Winfred       | rapeseed            | 3,789                  | 0         | 0          | 0         | 1,784      | 0                  | 625                  |
| Vivant Hybrid | turnip              | 2,178                  | 0         | 0          | 0         | 3,747      | 0                  | 348                  |

0 = no biomass data collected due to complete winterkill (all three replicates lost); Kodiak, Vivant Hybrid, and Winfred experienced complete winterkill in the 2022-2023 season. \* = partial winterkill; two of three replicates were lost to winter injury and the reported value reflects the surviving replicate only. # = reduced replication of these cells was due to poor emergence in fall.

Although pairwise differences were not significant, the cultivar rankings provided practical insights. Table 4 shows that over the three-year study, triticale cultivars Fx1001 and Tulus, ranked first and second in overall median biomass (3,926 and 3,569 lb/ac, respectively). They performed reliably under both early and late planting, and across varying winter conditions, confirming triticale as the most reliable high-yielding species group in this study. Hairy vetch cultivars (AU Merit, Villana, Winter King, Purple Bounty), occupied the middle range of biomass performance with combined-year medians ranging from 892 to 1,307 lb/ac. AU Merit ranked highest among hairy vetch (1,307 lb/ac), followed by Villana and Winter King (both 1,249 lb/ac) and Purple Bounty (892 lb/ac). All four hairy vetch cultivars survived the 2022-2023 winter, distinguishing them from the brassica species and confirming their reliability under Palouse conditions.

Austrian winter pea cultivars also showed mid-range performance (Survivor 15: 639 lb/ac; Wyo Winter: 1,071 lb/ac) with complete winter survival in all years. Wyo Winter ranked notably higher than Survivor 15 in combined-year median biomass. Cosaque (black seeded oats) showed high 2022 biomass (3,092 lb/ac under late planting) but a recurring partial winterkill response in both subsequent winters: in 2023, two of three late-planted replicates were severely reduced by the same freezing event that caused complete winterkill in the brassica species that winter, while the third replicate remained healthy (3,542 lb/ac; early-planted Cosaque was unaffected that year at 358 lb/ac); in 2025, two of three replicates were lost to winter injury at both planting dates, with reported values (1,428 lb/ac early; 714 lb/ac late) reflecting the single surviving replicate at each date. This recurring, replicate-level pattern pulled Cosaque's combined-year median down to 573 lb/ac, placing it among the lowest-ranked cultivars in the study alongside the brassicas, despite its strong performance in years and plantings where it was unaffected. This variability suggests susceptibility

to late-season stress in certain years and warrants caution when recommending Cosaque for late planting dates. Brassica species Kodiak (mustard; 1,089 lb/ac), Vivant Hybrid (turnip; 348 lb/ac), and Winfred (rapeseed; 625 lb/ac) ranked among the lowest in combined-year median biomass, primarily because their 2023 frost-kill zeros substantially reduced their pooled medians. In years without freeze kill, Kodiak and Winfred showed moderate biomass potential (4,325 and 3,789 lb/ac in 2022, respectively), while Vivant Hybrid remained the lowest-producing cultivar across all years and conditions (2,178 lb/ac in 2022; 3,747 lb/ac in 2025).

Producers should interpret the cultivar rankings in Table 4 alongside the planting date effects shown in Figure 2. Cultivar selection and planting timing are codependent; even top-tier cultivars underperform when planted late. This timing is especially critical for brassica species, as early planting significantly enhances winter survival compared to later dates.

Because the cultivar-level comparison was not significant, we grouped cultivars into their six constituent species to see whether this clarified overall biomass performance. The species-level Kruskal-Wallis test remained highly significant ( $X^2(4) = 27.17$ ,  $p < 0.0001$ ), and three pairwise comparisons survived Bonferroni correction (Table 5). Triticale produced significantly greater biomass than both brassica ( $p = 0.0001$ ) and hairy vetch ( $p = 0.0168$ ), and brassica produced significantly lower biomass than Austrian winter pea ( $p = 0.0033$ ). No other species-level pairs differed significantly. This confirms, at the species level, the same ranking pattern visible in Figure 2: triticale performed best and brassicas performed worst, with statistical support that a cultivar-level test alone could not provide.

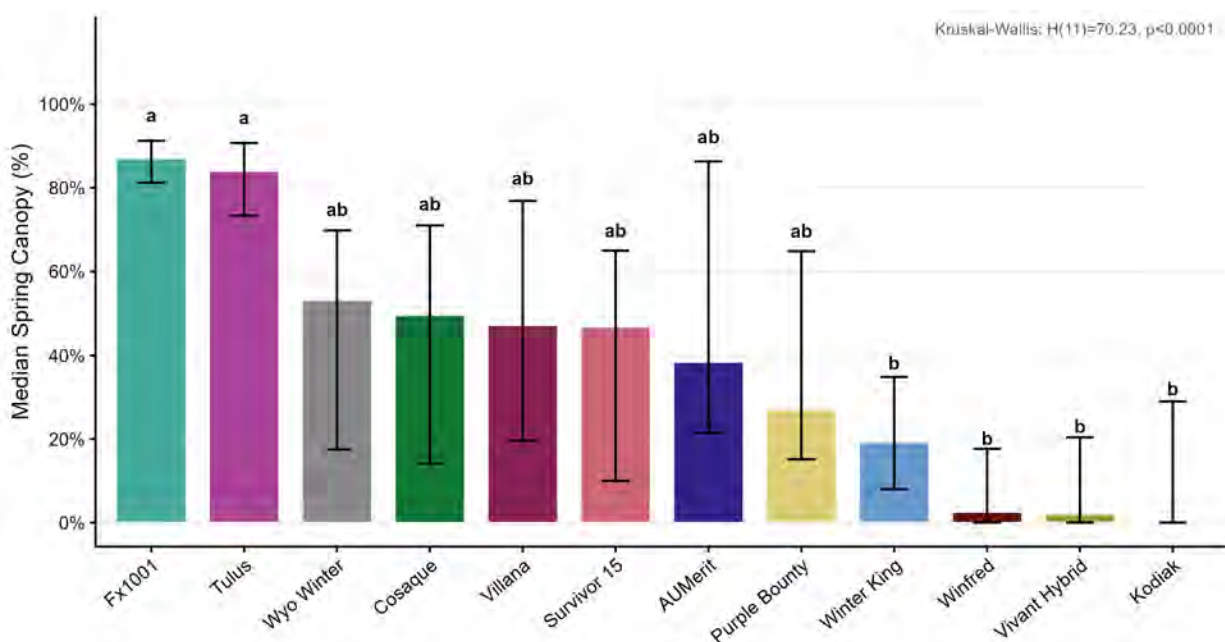
**Table 5.** Species-level pairwise comparisons of combined-year biomass for the 2021-2025 fall-planted cover crop trial at the Pullman, Washington PMC.

| Comparison                              | Z      | p_adj  | Significant |
|-----------------------------------------|--------|--------|-------------|
| Brassica – Triticale                    | -4.492 | 0.0001 | Yes         |
| Austrian winter pea – Brassica          | 3.590  | 0.0033 | Yes         |
| Hairy vetch – Triticale                 | -3.141 | 0.0168 | Yes         |
| Black seeded oats – Brassica            | 2.156  | 0.3111 | No          |
| Austrian winter pea – Hairy vetch       | 2.084  | 0.3716 | No          |
| Brassica – Hairy vetch                  | -2.061 | 0.3931 | No          |
| Austrian winter pea – Black seeded oats | 0.597  | 1.000  | No          |
| Black seeded oats – Hairy vetch         | 0.852  | 1.000  | No          |
| Austrian winter pea – Triticale         | -0.955 | 1.000  | No          |
| Black seeded oats – Triticale           | -1.329 | 1.000  | No          |

Dunn's test with Bonferroni correction;  $n=10$  pairwise comparisons among five species groups (Triticale, Brassica [Kodiak, Vivant Hybrid, Winfred], Austrian winter pea, Hairy vetch, Black seeded oats;  $C(5,2) = 10$ ). Z = Dunn's test statistic; p adj = Bonferroni-adjusted p-value.

### Spring green canopy

We pooled spring green canopy cover across all three years for the cultivar comparison (Figure 3). Cultivar differences in spring green canopy were highly significant (Kruskal-Wallis:  $H(11) = 70.23$ ,  $p < 0.0001$ ). Triticale cultivars, Fx1001 and Tulus, had the highest median spring green canopy (87% and 84%, respectively) and were significantly greater than the lowest-performing cultivars (letter group a vs. b). Wyo Winter (53%), Cosaque (50%), Villana (47%), and Survivor 15 (47%) were intermediate (group ab) and not significantly different from either group a or group b. AU Merit (38%) and Purple Bounty (27%) also fell in the intermediate group. Winfred (2%), Vivant Hybrid (2%), and Kodiak (0%) had the lowest spring green canopy and were significantly lower than Fx1001 and Tulus (group b), primarily because frost kill in 2023 substantially reduced their pooled medians. Winter King (19%) was also in group b, reflecting inconsistent spring recovery across years. The ranking of cultivars by spring green canopy was broadly consistent with biomass ranking, reinforcing spring green canopy as both a performance outcome and a biomass predictor.



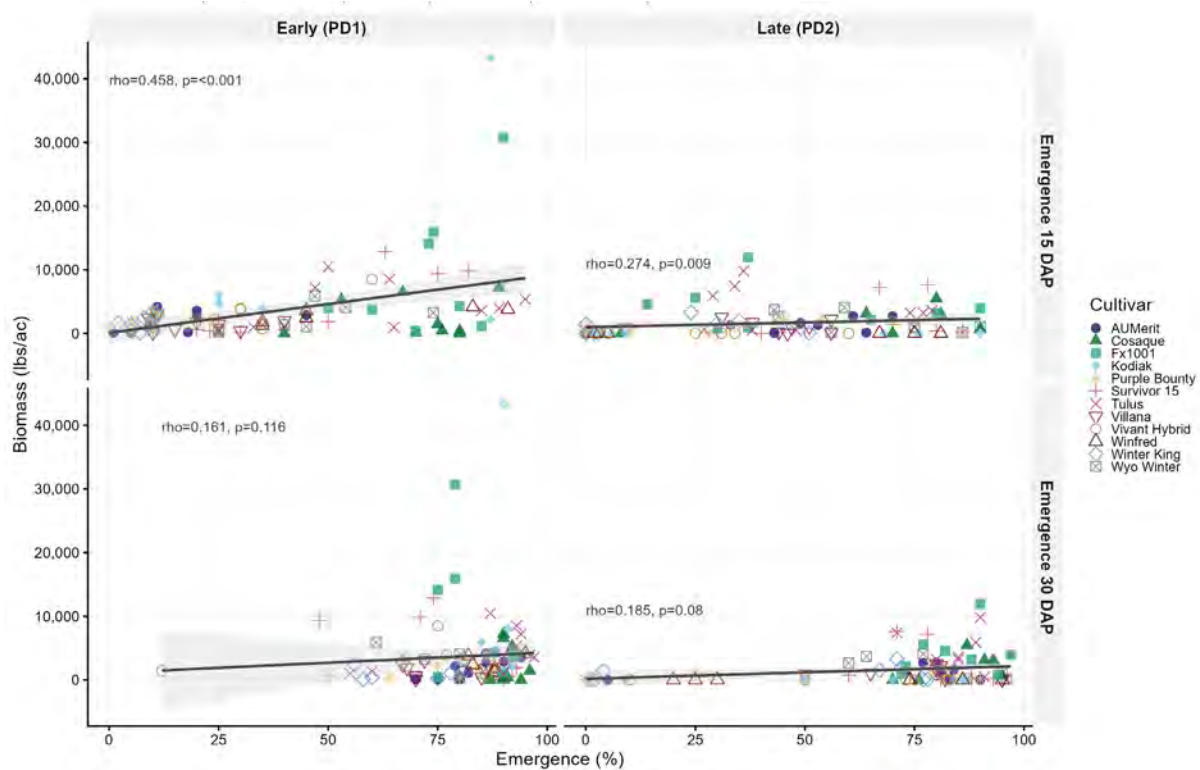
**Figure 3.** Median spring green canopy (%) by cultivar, pooled across 2022, 2023, and 2025 for fall-planted cover crop trial at the Pullman, Washington PMC. Cultivars ranked by overall median. Letters indicate significant differences (Dunn's test, Bonferroni,  $p < 0.05$ ,  $n = 203$ ). Error bars = 25<sup>th</sup>-75<sup>th</sup> percentile (IQR).

### Multivariate Analysis:

#### Emergence vs. Biomass

To evaluate the association between seedling emergence and biomass, we applied a Spearman rank correlation (Figure 4). Under early planting date, 15-DAP emergence was a moderate and significant predictor of biomass ( $\rho = 0.458$ ,  $p < 0.001$ ), while 30-DAP emergence was not a significant predictor ( $\rho = 0.161$ ,  $p = 0.116$ ). Under late planting date, 15-DAP emergence remained a weak but significant predictor ( $\rho = 0.274$ ,  $p = 0.009$ ), and 30-DAP emergence fell short of significance ( $\rho = 0.185$ ,  $p = 0.08$ ).

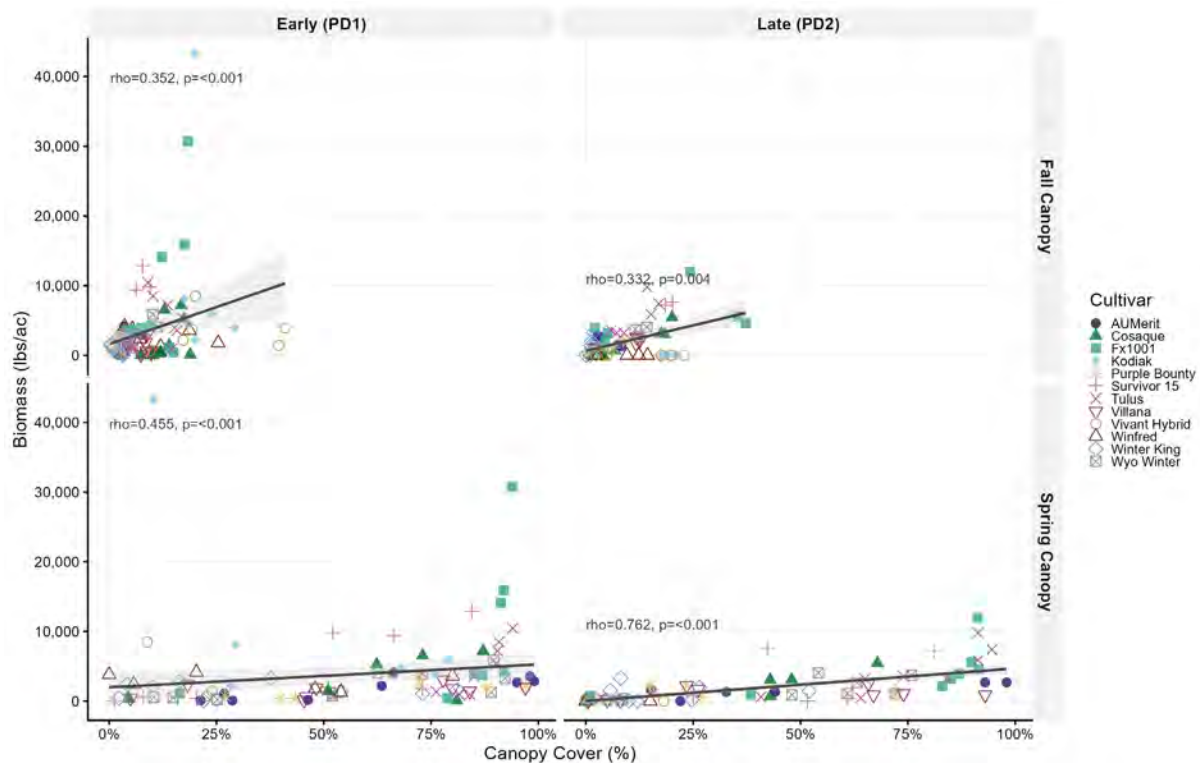
The earlier (15 DAP) assessment window shows a stronger, more reliable correlation with final biomass than 30 DAP across the planting dates, as rapid initial establishment allows for better exploitation of the growing season. While early emergence is a stronger proxy under early planting, it is not a sufficient stand-alone predictor of biomass.



**Figure 4.** Percent emergence at 15 Days after Planting (DAP and 30 DAP vs. biomass (lb/ac) by planting date for the 2021-2025 fall-planted cover crop trial at the Pullman, Washington PMC. Four panels: emergence metric × planting date. Points colored by cultivar. Trend line = linear fit with 95% CI. Spearman rho ( $\rho$ ) shown per panel. Frost-killed plots excluded.

#### *Canopy Cover vs. Biomass*

Spring green canopy showed the strongest relationship with biomass in the study ( $\rho=0.455$  early,  $p<0.001$ ;  $\rho = 0.762$  late,  $p<0.001$ , Figure 5). The relationship was stronger under late planting, where compressed growing windows may make spring green canopy a predictor of final biomass. Fall canopy showed a significant relationship under both planting dates, although the relationship was weaker in the later planting date ( $\rho=0.352$  early,  $p<0.001$ ;  $\rho=0.332$  late,  $p=0.004$ ). This establishes fall canopy as a usable secondary predictor for late-planted stands. These results support spring green canopy as the single most practical field indicator of expected cover crop biomass yield in our study, applicable across planting dates and years, and particularly valuable for late-planted stands where the cost of a wrong termination-timing call is highest.



**Figure 5.** Percent canopy cover (fall and spring) vs. biomass (lb/ac) by planting date for the 2021-2025 fall-planted cover crop trial at the Pullman, Washington PMC . Four panels: canopy metric × planting date. Points colored by cultivar. Trend line = linear fit with 95% CI. Spearman rho shown per panel.

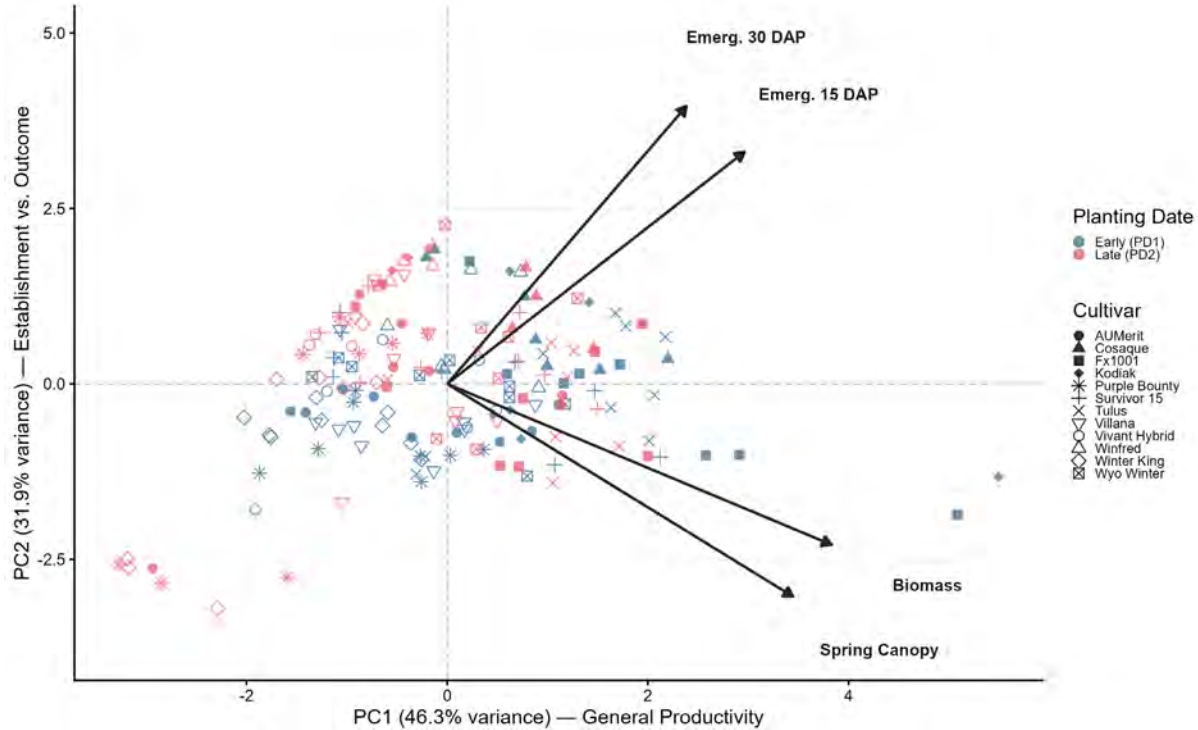
### *Principal Component Analysis*

To evaluate cover crop performance, we conducted a rank-based Principal Component analysis (PCA) using eigen-decomposition of the Spearman correlation matrix (Figure 6), an approach with established precedent for resolving genotype-by-trait relationships in multi-trait agronomic trial data (Shojaei et al., 2024) and for visualizing multi-environment trial performance via biplot (Yan & Tinker, 2006; Ebdon & Gauch, 2002). The analysis evaluated four variables across 175 complete cases pooled from the 2022, 2023, and 2025 growing seasons: 15-DAP emergence, 30-DAP emergence, spring green canopy, and biomass. We excluded frost-killed plots from this analysis, as well as canopy cover, which had missing data in 2023 and was evaluated independently in the canopy cover section. Together, the first two principal components accounted for 78.2% of the total variance.

The first principal component (PC1) functioned as a “General Productivity Axis,” explaining 46.3% of the total variance. All four variables loaded positively on the axis, led by biomass (0.598) and spring green canopy cover (0.538), followed by 15-DAP emergence (0.462) and 30-DAP emergence (0.372). High scores along PC1 represent a dimension of comprehensive cover crop performance, identifying plots that excelled across all metrics by demonstrating strong emergence, extensive spring green canopy, and high final biomass.

The second principal component (PC2) captures an additional 31.9% of variance and revealed an “Establishment vs. Outcome Axis” (Figure 6). The component exposed a structural divergence between early and late performance metrics. Early emergence variables loaded positively on PC2 with 30-DAP emergence at 0.618 and 15-DAP emergence at 0.516, whereas spring green canopy (-

0.473) and biomass (-0.358) loaded negatively. Consequently, PC2 effectively separates two distinct scenarios: plots where robust early establishment failed to translate into heavy final biomass, and plots that achieved dense spring green canopy and high biomass despite weaker initial emergence. This opposing relationship confirms that while early emergence and final biomass are related, they are structurally distinct and should not be treated as interchangeable indicators of cover crop success.



**Figure 6.** PCA biplot for a 4-variable rank-based PCA (Spearman correlation matrix,  $n=175$ ) for the 2021-2025 fall-planted cover crop trial at the Pullman, Washington PMC . PC1 (46.3%) = general productivity; PC2 (31.9%) = establishment vs. outcome. Points colored by planting date.

## CONCLUSIONS

### *Planting Date Effect on Biomass*

The consistent and significant biomass advantage of early fall planting (46–64%) across all three years with available data is the central finding of this study and aligns with literature from adjacent regions. Lawson et al. (2015) reported roughly a 50% reduction in average biomass when planting was delayed by 2.5 weeks in the maritime Pacific Northwest. Similarly, Saini et al. (2008) found that planting and termination date strongly influenced winter cover crop biomass accumulation in a conservation-tillage corn-cotton rotation, reinforcing timing as a primary management lever across diverse cropping systems. Our study extends these findings to the semi-arid Inland PNW and confirms the pattern is robust across years, including a severe winterkill year. From a management perspective, fall planting timing is the most controllable factor affecting cover crop biomass in the Palouse region, and the penalty for delayed planting is large and consistent.

To put the data into a practical calendar format. In the 2021-2022 and 2024-2025 seasons, a 14-day gap between planting dates triggered a 46% and 64% biomass reduction, respectively. Consequently, growers lose roughly 3–5% of their biomass potential for every day planting is delayed in a typical year. The 2022-2023 season tells a different story. A 26-day gap resulted in a 51% reduction (about 2% per day), but severe winterkill suppressed that season's biomass and compressed the range for

both planting dates. Conservation planners and extension agents should use these data as a handy rule of thumb for producer conversations, not a precise yield model.

The 2023 data highlight a critical threshold. Despite a severe freeze event that eliminated all brassica plots and compressed the biomass range across surviving cultivars, the planting date effect remained statistically significant ( $W=413$ ,  $p=0.022$ ). This suggests that the early-planting advantage does not depend on favorable winter conditions. Instead, early planting dates help achieve quicker stand establishment and capture greater thermal time before winter dormancy, regardless of winter severity. Producers cannot rely on mild winters to rescue a delayed planting schedule. Producers can use these results to target mid-to-late September for fall-planted cool-season cover crops. In practice, growers should integrate cover crop planting into harvest operations or schedule dedicated planting passes before October. Under dryland conditions with variable fall moisture, early planting captures late-season rainfall for germination, providing an additional practical benefit beyond thermal time accumulation.

### *Cultivar Selection and Species Suitability*

In the Palouse region, triticale cultivars Fx1001 and Tulus consistently delivered the highest biomass across all years and planting dates. These data reveal a strong directional pattern that supports recommending both cultivars for biomass-focused cover crop systems. Their high biomass potential, reliable winter survival, and aggressive spring green canopy creation effectively buffer the variable conditions of the Inland Pacific Northwest. For producers seeking leguminous options, hairy vetch cultivars (AUMerit, Villana, Winter King, Purple Bounty) perform best. Although they produce less median biomass than triticale, they reliably survive Palouse winters and provide vital nitrogen fixation. As cover crop nitrogen fertilizer replacement value scales with aboveground biomass production (De Notaris et al., 2025), the early-planting biomass advantage documented here should further amplify the nitrogen credit hairy vetch provides to a following cash crop. In contrast, Austrian winter pea cultivars (Survivor 15, Wyo Winter) perform moderately and variably, limiting their utility to grass-legume mixtures. Finally, brassica species including Kodiak mustard, Vivant Hybrid turnip, and Winfred rapeseed fail to consistently overwinter in Pullman or similar dryland sites. A complete kill across all three species during a severe early freeze in the fall of 2022 shows these brassicas lack the winter hardiness needed for reliable fall performance. Producers should restrict use of these brassica species to spring planting or fall termination to capture their biofumigation, rapid decomposition, and deep taproot benefits. These cultivar recommendations follow a variety-trial-based selection approach consistent with guidance developed for practitioners evaluating multi-year cultivar performance data (Moseley et al., 2025).

### *Practical Use of Early-Season Metrics*

Taken together, the planting-date and predictor results support a simple, ordered decision framework for producers and conservation planners, presented here in order of how much weight each piece of evidence should carry:

1. Planting date is the primary driver. Target a mid-to-late September planting date. This is the most statistically robust finding, and producers should prioritize it over cultivar choice or any in-season performance check.
2. Choose a species by goal, not by biomass ranking alone. Triticale cultivars for maximum biomass; hairy vetch where nitrogen credit matters; and avoid brassica species for overwintering plantings due to potential winterkill.
3. Use 15-DAP emergence as an early check. A weak to moderate correlation to potential biomass is worth noting when emergence is poor. However, it is not reliable enough to justify replanting or mid-season changes.
4. Use spring green canopy cover as the primary field indicator ahead of termination. It is the strongest predictor of biomass in the dataset, especially for late-planted stands where the consequences of misjudging biomass potential before termination are the greatest.
5. The planting date recommendation remained significant throughout every year of our study. Emergence and canopy relationships are useful but have secondary correlational patterns. They should help inform, not override, planting date and species recommendations.

### *Implications for NRCS Practice Standards and Planning*

These results provide a direct evidence base for updating NRCS Conservation Practice Standard 340 (Cover Crop; USDA-NRCS, 2016) recommendations for the Palouse dryland region of the Inland Pacific Northwest. The data support: (1) an explicit early fall planting date recommendation (target: mid-to-late September) for cool-season cover crops in the Palouse dryland region; (2) triticale as the primary species recommendation for biomass-focused systems; (3) exclusion of brassica species from overwintering cover crop prescriptions at Pullman-area sites; and (4) spring green canopy as a recommended field assessment metric for evaluating cover crop performance before termination. For NRCS planners developing producer practice plans, the planting-date finding supports implementation requirements when advising producers on practice-adoption risk under time-constrained harvest schedules. More broadly, cover crop planting-date and species decisions affect not only biomass accumulation but also downstream soil nutrient status and subsequent cash crop productivity (Singh et al., 2024), reinforcing the value of the practical guidance developed here.

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