Legume Establishment in Native Warm-Season Grass Pastures

Carter Bradley Phillips

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Kathryn M. Payne, Committee Chair
A. Ozzie Abaye, Co-Chair
Scott P. Greiner
Benjamin F. Tracy

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Academic Abstract

Interseeding legumes in native warm-season grasses (NWSG) may improve the nutritive value of the stand, result in more consistent forage availability throughout the growing season, and increase forage yield. These benefits are often not realized due to difficulties in establishing legumes in existing NWSG stands. The objective of this study was to investigate the effect of planting method of legume interseeding, timing of legume interseeding, and the efficacy of burning plant residue on legume establishment in NWSG. Two forage legumes, 'Alice' white clover (*Trifolium repens* L.) and 'Freedom HR' red clover (*Trifolium pratense* L.), were interseeded into mixed 'Niagara' big bluestem (*Andropogon gerardii* Vitman), 'GA Ecotype' Indiangrass (*Sorghastrum nutans* Nash), and 'Camper' little bluestem (*Schizachyrium scoparium*) pasture in 2022 and 2023 at the Southern Piedmont AREC in Blackstone, Virginia. Planting method at three levels (no-till drill, broadcast, and non-planted control) were evaluated at three planting timing levels (fall planting, winter planting, and winter planting with burned residue). Among the treatment combinations, burned plots that were drilled resulted with the greatest spring clover count of 236 plants m^{-2}, followed by winter drill (146 plants m^{-2}) and burn broadcast (133 plants m^{-2}). All fall plantings and all control plots were similar with a mean of 21 plants m^{-2}. As a result of greater initial clover emergence, plots that were burned or seeded in the winter had greater clover content throughout the experiment; burned and drilled plots had over 90% clover ground cover throughout the second year. Domination of plots by clover in the second year caused yields and the proportion of NWSG in the stand to decline, with burned plots yielding 5,757 kg ha^{-1} compared to a winter-fall mean of 7,429 kg ha^{-1}. Plots with greater clover content were able to sustain higher crude protein content

and lower neutral detergent fiber content in both the establishment year and the second year. Though interseeding legumes benefitted nutritive values, these results suggest that red clover may be incompatible with the NWSG evaluated. Burned plots were especially affected by excessive competition. Further research is needed to evaluate forage legume species which complement NWSG in mixture rather than compete with them.

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General Audience Abstract

Native warm-season grasses are well adapted to much of the US and are able to provide nutritious forage for livestock while requiring lower soil fertility and moisture, in temperatures high enough to render most imported cool-season grasses unproductive. Despite this, farmers are hesitant to use NWSG as a forage crop in part due to their lower nutritive value than imported cool-season species and their lower forage productivity early and late in the growing season, when temperatures are cooler. Planting cool-season legumes in NWSG pasture, or interseeding, could increase the available forage early and late in the season and improve the nutritional value of the forage. Establishing legumes in existing NWSG pasture can be difficult, with multiple choices affecting the ultimate outcome, such as the method of planting, the timing of planting, and the removal of plant residue on the soil surface. The objective of this study was to investigate the effect of planting method of legume interseeding, timing of legume interseeding, and the burning of plant residue on legume establishment in NWSG. Two forage legumes, 'Alice' white clover (*Trifolium repens* L.) and 'Freedom HR' red clover (*Trifolium pratense* L.), were interseeded into mixed 'Niagara' big bluestem (*Andropogon gerardii* Vitman), 'GA Ecotype' Indiangrass (*Sorghastrum nutans* Nash), and 'Camper' little bluestem (*Schizachyrium scoparium*) pasture in 2022 and 2023 at the Southern Piedmont AREC in Blackstone, Virginia. Three variations of planting method (no-till drill, broadcast, and non-planted control) were evaluated in combination with three variation of planting timing (fall planting, winter planting, and winter planting with burned residue). Among the treatment combinations, burned and drilled plots produced more clover plants in spring at 236 plants m^{-2}, followed by winter drilled (146 plants m^{-2}) and burned and broadcasted (133 plants m^{-}

^{2}). All fall plantings and all control plots were similar with a mean of 21 plants m^{-2}. Because plots that were burned or seeded in the winter had greater clover seedling emergence at the start of the experiment, they had greater clover content throughout the experiment; burned and drilled plots had over 90% clover ground cover throughout the second year. Excessive red clover growth in the second year overshadowed NWSG plants, causing forage yields and the proportion of NWSG in the stand to decline, with burned plots yielding 5,757 kg ha^{-1} compared to a winter-fall mean of 7,429 kg ha^{-1}. Plots with greater clover content were able to sustain higher crude protein content and lower neutral detergent fiber content in both the establishment year and the second year, benefitting forage nutritive values. Despite this benefit, these results suggest that red clover may be incompatible with the NWSG which were evaluated, as it competed with NWSG and limited their growth. Burned plots were especially affected by excessive competition. Further research is needed to evaluate forage legume species which complement NWSG in mixture rather than compete with them.

Dedication

This work is dedicated to my great grandfather, James Gowen. He told me that he probably won't ever read a word of this. He might be busy mowing the lawn, planting trees, reading the Bible, or shooting crows. I know he's proud nonetheless.

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Chapter 1

Introduction

Native warm-season grasses (NWSG), such as big bluestem (*Andropogon gerardii* Vitman), little bluestem (*Schizachyrium scoparium*), Indiangrass (*Sorghastrum nutans* Nash), switchgrass (*Panicum virgatum*), and eastern gamagrass (*Tripsacum dactyloides* L.) are uniquely adapted to the eastern United States (Harper et al., 2007). They can maintain a high level of productivity with high nitrogen (N) efficiency, lowering reliance on fertilizer inputs; in one study conducted in Illinois, eastern gamagrass-dominated mixed NWSG pastures averaged 61% greater herbage mass than tall fescue (*Schedonorus arundinaceus* [Schreb.] Dumort) pasture at 493 g m^{-2} (Tracy et al., 2010). When managed properly, these grasses may support nutrient requirements of livestock, relaying to body weight gain. Researchers have reported gains for yearling steers (*Bos taurus*) on Indiangrass pasture at 1.08 kg day^{-1} (Krueger and Curtis, 1979), for feeder steers on big bluestem pasture at 0.85 kg day^{-1} (Burns and Fisher, 2013), and for weaned steers on mixed big bluestem and Indiangrass pasture at 1.03 kg day^{-1} (Backus et al., 2017). Able to be grazed by livestock or harvested as hay, baleage, or biomass for energy production, their utility to farm systems can be versatile (Burns and Fisher, 2012; Lowe et al., 2015; Brazil et al., 2020). Native grasses can be continuously grazed (Monroe et al., 2017; Brazil et al., 2020) but there is greater interest is the possibility of incorporating these species into rotational grazing systems.

Native warm-season grasses enter their period of peak forage production when cool-season species production begins to decline during a period known as the “summer slump” (Tracy et al., 2010). Due to the costs associated with re-planting annual warm-season grasses (WSG) each growing season, planting acreage in NWSG can provide a long-term solution to the “summer slump” at a lower cost than annual WSG; in Illinois, NWSG cost \$93.40 ha^{-1} to establish and manage over three years of forage production versus \$119.20 ha^{-1} for annual WSG (Tracy et al., 2010). The primary obstacles to grower adoption of NWSG have been the limited forage availability both early and late in the season and the lower nutritive value of NWSG forage compared to cool-season grasses (CSG) like tall fescue (Moore et al., 2004; Hudson et al., 2010; Tilhou et al., 2018). It is possible that these drawbacks could be improved with the incorporation of legumes into NWSG stands.

One potential benefit of interseeding legumes into NWSG is improvement of forage nutritional value (Posler et al., 1993; Springer et al., 2001; Keyser et al., 2016b; Jakubowski et al., 2017). Interseeding cool-season legumes into warm-season grasses has been explored as a possible method of extending the grazing season, as cool-season plants are productive while NWSG is dormant (Springer et al., 2001; Ashworth et al., 2015).

Research has suggested that pastures with greater species richness may produce greater forage yields and suppress weed species more effectively (Allan et al., 2011; Bonin and Tracy, 2012). In a study evaluating the effect of plant diversity on forage yield, Bonin and Tracy (2012) report that 71% of multi-species perennial prairie plant forage plots yielded more than their respective monoculture plots. This study also found that in one year of the study, weed biomass reached a proportion of nearly 30% in monoculture plots compared to less than 1% of biomass in multi-species plots; however, they did note that this was largely due to unproductive legume monocultures failing to compete with weeds (Bonin and Tracy, 2012). Sleugh et al. (2000) found that mixtures of legumes and grasses yielded more than grass monocultures; intermediate wheatgrass (*Thinopyrum intermedium* (Host.) Barkw. & D.R. Dewey) and smooth bromegrass (*Bromus inermis* Leyss.) grown in mixture with alfalfa (*Medicago sativa* L.) yielded more than their respective grass monocultures. In this study, the intermediate wheatgrass-alfalfa mixture yielded 12,736 kg ha^{-1} compared to 4012 kg ha^{-1} for the monoculture, and the smooth bromegrass-alfalfa mixture yielded 12,614 kg ha^{-1} compared to 4,002 kg ha^{-1} for the monoculture. This may be partially explained by various factors, including differences in root structure that allow greater whole stand exploitation of water resources, grass exploitation of the nitrogen (N) that legumes fix in the soil and the ability of legumes to procure their own atmospheric nitrogen, reducing competition for resources (Sleugh et al., 2000; Springer et al., 2001; Temperton et al., 2007; Ashworth et al., 2015).

One factor that limits the benefit of interseeding legumes into NWSG is the difficulty of establishment (Bartholomew and Williams, 2010; Keyser et al., 2016b). Research has shown that greater grass height and ground cover suppress legume establishment (Wilsey, 2010). Seeding method may influence interseeding outcomes (Mueller and Chamblee, 1984; Byers and Templeton, 1988; Schlueter and Tracy, 2012), as well as the suppression of the dominant forage species before interseeding through chemical, physical, and other means (Cuomo et al, 1996; Gettle et al., 1996). Additional research is needed to determine the effect that these and other factors have on legume establishment in NWSG.

Chapter 2

Literature Review

2.1 Native Warm-Season Grasses

Native warm-season grasses are, as implied by the name, warm-season bunchgrasses which populated North America prior to the arrival of European settlers. Though these grasses once dominated the eastern United States, they have been largely replaced by tall fescue and other introduced species in forage production settings. Five native warm-season grasses (NWSG) are most used in forage production: big bluestem, little bluestem, Indiangrass, switchgrass, and eastern gamagrass (Keyser et al., 2011a). These species are most productive when cool-season grasses (CSG) enter what is known as the “summer slump”, a period of lower productivity in the hottest months of the year (Tracy et al., 2010). Due to this difference in peak growth periods for NWSG and CSG, integrating both into the same livestock operation can have a complementary effect as livestock are rotated from CSG to WSG when each species begins peak production (Moore et al., 2004).

Native warm-season grasses are more productive in the summer months because they use the C_4 photosynthetic pathway, rather than the C_3 photosynthetic pathway used by CSGs; their use of the C_4 pathway allows NWSG to utilize CO_2, water, nitrogen (N), and solar radiation more efficiently (Brejda, 2000). The C_4 pathway is more efficient at CO_2 assimilation than the C_3 pathway because of an adaptation in C_4 plants that positions Rubisco, the most important and often most limiting enzyme in CO_2 assimilation, in the bundle sheath cells, where C_4 plants maintain a CO_2 concentration 10-100 times greater than that of ambient air; this isolates Rubisco from oxygen, avoiding the wasteful process of photorespiration, thus increasing photosynthetic efficiency (Furbank and Hatch, 1987; Jenkins et al., 1989). This adaptation is absent in C_3 plants, and because photorespiration increases with oxygen concentration and leaf temperature, C_3 plants perform photosynthesis less efficiently than C_4 plants at higher temperatures (Ehleringer and Björkman, 1977; Ehleringer and Pearcy, 1983). Ku and Edwards (1978) found that the C_3 crop wheat (*Triticum aestivum* L.) and the C_4 crop corn (*Zea mays* L.) have similar quantum yields for photosynthesis at 15°C at 0.062 mol CO_2 mol^{-1} quanta and 0.059 mol CO_2 mol^{-1} quanta, respectively; when temperatures increased to 35°C the quantum yield for wheat declined to 0.046 mol CO_2 mol^{-1} quanta while the quantum yield for corn remained essentially constant.

Taylor et al. (2009) found, at a mean temperature of 20°C, that twenty-two C_4 grasses from five clades (Aristidoideae, Chloridoideae, Micrairoideae, Andropogoneae, and Paniceae) had a significantly higher mean net leaf photosynthetic CO_2 assimilation rate (19.1 μmol CO_2 m^{-2} s^{-1} ± 0.6) than twelve C_3 grasses from three clades (Arundinoideae, Danthonioideae, and Paniceae) (13.2 μmol CO_2 m^{-2} s^{-1} ± 0.6); the experiment was phylogenetically controlled so that species were primarily compared based on their photosynthetic pathway. This study also found a difference in greater mean intrinsic water use efficiency, which is the ratio of net leaf photosynthetic CO_2 assimilation rate to stomatal conductance; C_4 grasses had significantly greater values (173 ± 3) than C_3 grasses (80 ± 4), assimilating much more CO_2 per unit of water expended. Brown (1978) theorized that C_4 plants have greater nitrogen use efficiency, allowing them to maintain equal photosynthetic capacity with lower leaf N content than C_3 plants. Confirming this theory, Sage and Pearcy (1987) showed that the C_4 plant *Amaranthus retroflexus* (L.) had a greater rate of photosynthesis than similarly adapted C_3 plant *Chenopodium album* (L.) at identical leaf N content, and that *A. retroflexus* maintained a lower leaf N content than *C. album*. They noted that greater nitrogen use efficiency may allow C_4 species to allocate more N into new leaf production or the root system, contributing to greater whole plant carbon gain. Taylor et al. (2009) also found C_4 species to have greater photosynthetic N-use efficiency, but found a smaller, statistically insignificant difference in leaf N content. As global temperatures and atmospheric CO_2 levels rise in tandem, some C_4 grass species are expected to thrive at the expense of C_3 species due to their superior adaptation to high temperatures and drought conditions (Sage and Kubien, 2003). The unique adaptations of NWSGs that allow high productivity in conditions considered suboptimal for CSGs combined with efficient resource utilization make them a valuable option for forage producers.

2.2 Establishment of NWSG

Establishment of NWSG has shown to be more inconsistent and complex than establishment of popular CSGs, so attention to detail and proper planning is imperative (Sadeghpour et al., 2014; Richwine et al., 2021; Keyser and Ashworth, 2022). Researchers have established that satisfactory establishment of NWSG is dependent on the elimination of existing vegetation with herbicides or tillage (Barnes, 2004), the use of high-quality seed well adapted to the location being seeded (Wilson et al., 2016), good seed-soil contact by planting at the right depth (Newman and Moser, 1988), and providing residual weed control while the stand is still in the seedling stage through chemical means (Washburn and Barnes, 2000) and possibly with the assistance of a companion crop (Hintz et al., 1998).

2.2.1 NWSG Species and Cultivars

Even within NWSG species, there is variation in their suitability to be grazed, harvested as hay, or even harvested as biomass for bioenergy production (Tracy et al., 2010; Burns and Fisher, 2013; Lowe et al., 2013; McIntosh et al., 2016). Mixtures of these grasses are often planted together, and higher species diversity in NWSG stands has been linked to higher yields and more effective weed suppression (DeHaan et al., 2010; Bonin and Tracy, 2012). Big bluestem, LB, and IG are commonly planted in mixtures (McIntosh et al., 2016; Brazil et al., 2020). Big bluestem and IG may perform better when planted in mixture because BB matures earlier than IG, and this temporal separation of peak growth between the species could have a complementary effect on whole stand productivity (Allan et al., 2011). The BB+LB+IG mixture is high yielding with high nutritional quality, and these grasses maintain forage nutritional quality for more of the growing season than with SG or EG (McIntosh et al., 2016). Switchgrass and EG can produce large quantities of high-quality forage, generally yielding more than BB, LB, and IG, but there is also interest in using these species for biomass feedstock production (McIntosh et al., 2016; Kieffer et al., 2023). Due to the various differences between NWSG species, the characteristics and objectives of the forage system should be taken into account when selecting which NWSG species to establish.

Native warm-season grass seed is available in multiple forms, including commercial cultivars that have been bred for improved agronomic qualities and local ecotypes that are presumably naturally adapted to the region of origin (Chamberlain et al. 2012). There is debate regarding the relative merits of commercial cultivars and local ecotypes; in Kansas, Klopf and Baer (2011) have reported that BB and IG cultivars had greater root length, surface area, and volume than local ecotypes of the same species. Flint et al. (2019) found that SG cultivars and commercially produced, but not deliberately selected, ecotypes were more competitive with weeds than seed collected in the wild, possibly reflecting a combination of genetic improvement and the effects of cultural practices, such as greater seed plumpness in commercially harvested seed. In contrast, Chamberlain et al. (2012) in their Wisconsin study found that differences between commercial cultivars and locally harvested seed for BB and IG were inconsistent, and that both provided acceptable pasture. Similarly, Wilsey (2010) found in Iowa that there was no difference in aboveground net primary productivity between cultivars and local seed sources of BB, LB, IG, and SG. In Kansas and Illinois, Wilson et al. (2016) found that BB and IG ecotypes performed better when planted closer to their point of origin, with increased distance from their point of origin along a precipitation gradient decreasing the dominance of seeded grasses. As both ecotypes and cultivars have demonstrated the ability to perform well as forage grasses, either may be acceptable depending on the circumstances of their utilization.

2.2.2 Seed Dormancy

Seed dormancy is a significant obstacle in planting NWSG. Seed must often go through a significant period of after-ripening to germinate without treatment; of the commonly used treatments, cold stratification has generally served as an effective method of breaking seed dormancy, while chemical and mechanical methods have achieved mixed results (Emal and Conard, 1973; Beckman et al., 1993; Rogis et al., 2004; Keyser et al., 2016a). Emal and Conard (1973) found that new IG seed maintained near complete dormancy for seven months of storage, with germination improving afterward; seed pre-soaked and chilled at 4-6°C for four weeks always achieved near 100% germination, while seed exposed to gibberellic acid or sodium hypochlorite had improved germination when exposed to sunlight. Beckman et al. (1993) found that BB seed moistened for two days at 17°C and seed pre-soaked and then chilled for two weeks at 4°C both improved germination by 7% over the dry control treatment; they also found that SG seed pre-soaked and chilled for two weeks at 4°C had 150% greater emergence than the dry control treatment, and 85% greater emergence than the moistened treatment. Rogis et al. (2004) found that stratifying EG seed at 4°C for six weeks resulted in 40% germination, compared to the 18%

germination attained from priming with gibberellic acid for one week and 13% without gibberellic acid. These examples show the beneficial effect cold stratification has on germination and emergence in NWSG seed.

2.2.3 Planting Date

The date of planting can affect the success of NWSG plantings. Hsu et al. (1985) estimated base emergence temperatures of 8.9, 8.6, and 10.3℃ for BB, IG, and SG; Hsu and Nelson (1986a) estimated similar base emergence temperatures of 9.9, 9.4, and 10.8℃ for BB, IG, and SG respectively. Hsu et al. (1985) found that maximal emergence occurred for BB, IG, and SG between 20 and 30℃ for cold stratified seeds and between 12 and 20℃ for seeds that were not cold stratified; greater emergence at lower temperatures among unstratified seed was attributed to a partial fulfillment of the chilling requirement by those lower temperatures. Hsu and Nelson (1986a) found that plantings made in late April and mid-May in Missouri resulted in the highest emergence rates and were planted early enough to minimize exposure to high temperature and moisture stress; late plantings in June had reduced seedling survival to 70% compared to the average of 90% when soil conditions became dry. Hsu and Nelson (1986b) also found that seedlings performed well in June plantings when rainfall was frequent until early July, but performed best when planted in May if rainfall was infrequent, reinforcing the value of earlier plantings in avoiding soil moisture stress. In Tennessee, Keyser et al. (2016a) found that mid-March SG planting stand densities were similar or greater than early December, February, and May plantings, when using seed with a dormancy level of 45-75%. Among planting dates there was no difference in second year yields, clustering around 4 Mg ha^{-1}, suggesting that all treatments had plant densities that passed a threshold above which yields are less sensitive to density in the long term.

2.2.4 Planting Method

Native warm-season grasses may be established using a seed drill or a broadcast seeder, into tilled or untilled soil; the adaptation of no-till drill technology to NWSG seeding has made this a preferred establishment method, involving the drilling of NWSG seed into herbicide-killed sod from the previous forage stand (Barnes, 2004). Drilling NWSG seed as opposed to broadcasting it has been observed to result in greater grass abundance with more even distribution (Yurkonis et al., 2010b), and drilled canopies have also been observed to capture more light than broadcast canopies (Yurkonis et al., 2010a). In a Tennessee experiment, Harper et al. (2002) found that no-till drilling resulted in greater BB (12.9 vs. 3.8 plants m^{-2}), LB (8.1 vs. 2.8 m^{-2}), and IG (15.5 vs. 4.5 m^{-2}) seedling counts compared to conventional tillage followed by top-sowing at one location, finding no difference at another location and no difference for SG. Due to its larger seed, EG is planted in wider rows using a corn planter, with 76.2 cm being a typical row width (Aberle et al., 2003).

2.2.5 Planting Depth

Native warm-season grasses are sensitive to planting depth in part due to the small size of their seed; Newman and Moser (1988) seeded BB, IG, and SG at depths of 1.5, 3.0, 4.5, and 6.0 cm and found that BB and IG emergence decreased as planting depth exceeded 1.5 cm while SG emergence decreased as planting depth exceeded 3.0 cm. The emergence for BB and IG was low even at depths of 1.5 cm, suggesting that this depth was too deep for this environment and soil type (Newman and Moser, 1988). This is reflected in the recommended planting depth for these grasses at 1 cm (Moser and Vogel, 1995). Butler et al. (2016) found that planting SG at 0.635 cm and 1.27 cm generally resulted in a greater number of seedlings and yield than planting at 2.54 cm, though all three depths produced seedling counts exceeding 10.8 plants m^{-2}. Eastern gamagrass has much larger seeds than the other NWSG species and as such can be planted much deeper in the soil; Aberle et al. (2003) found that EG seeded at depths of 2.5 and 5.0 cm very infrequently differed in terms of net seedling survival, showing that this species can be planted deeper than the other NWSG.

2.2.6 Companion Crops

The loss of forage production in the year of NWSG establishment represents a significant short-term cost to producers. This shortage may be alleviated via the use of a companion crop, which may also serve to reduce the proliferation of weedy species during the establishment year. In their Iowa study, Hintz et al. (1998) found that BB and SG could be established in a corn (*Zea mays*) companion crop with the application of atrazine to control early cool-season weed species; BB had plant counts of 31.7 and 5.2 plants m^{-2} in the first and second year respectively, while SG had plant counts of 26.3 and 46.4 plants m^{-2}. Additionally, short- or long-season corn hybrids could be planted with plant densities between 12,400 and 49,400 plants ha^{-1}, without reducing NWSG stands; stands planted in corn with atrazine were greater than stands without corn or atrazine in one year, at 26.3 plants m^{-2} vs. 14.0 plants m^{-2} for SG and 31.7 plants m^{-2} vs. 10.8 plants m^{-2} for BB. In this study, corn could be harvested for grain or silage, reducing the loss in production. Richwine et al. (2021) found similar results when employing browntop millet (*Urochloa ramosa* (L.) Nguyen) as a companion crop while establishing BB and SG in Tennessee; browntop millet impeded BB and SG establishment, as controls had greater stand counts in all cases, but all treatments still resulted in acceptable stands of over 5.4 plants m^{-2}. Harvesting browntop millet for hay produced a mean DM yield of 3.15 Mg ha^{-1} in one year and 2.68 Mg ha^{-1} in another, providing ample forage using land that would otherwise be unproductive during NWSG establishment. In an additional Tennessee study, Keyser and Ashworth (2022) found that SG was more successful in establishing under a winter wheat (*Triticum aestivum* L.) cover crop than BB or EG, with poor weed control contributing to the collapse in stand counts among all species in some years and locations.

2.2.7 Herbicide

Herbicide can be sprayed in the year prior to planting to attain adequate weed control during establishment; in the spring of the second growing season following herbicide treatment, Bahm et al. (2011a) found that an application of imazapic at 0.10 kg a.i. ha^{-1} with imazapyr at 0.16 kg a.i. ha^{-1} resulted in a smooth brome cover of 12% and a Kentucky bluegrass (*Poa pratensis* L.) cover of 13%, compared to 39% smooth brome and 27% Kentucky bluegrass in the untreated control. Burning the undesirable plant population and letting it regrow to a short height before spraying may improve NWSG establishment, but fire can be paired with herbicide for the improved results (Barnes, 2004; Bahm et al., 2011a). A pre-emergence application of imazapic is typically employed to provide residual weed control; Washburn and Barnes (2000) report that a pre-emergence application of 0.07 kg a.i. ha^{-1} imazapic reduced weed cover to <5% during the first growing season, compared to >95% in the control, resulting in second year NWSG plant density 4.5x that of the control. Washburn et al. (2002) report that a post emergence application of imazapic at 0.21 kg a.i. ha^{-1} two to three seasons after seeding NWSG is highly effective at controlling reemerging tall fescue and other weedy species, though Ghajar et al. (2022) note that imazapic can also decrease desirable forb populations such as native wildflowers. Mixtures of imazapic and glyphosate may also be employed as a pre-emergent herbicide; Bahm et al. (2015) found that an application of 0.07 kg a.i. ha^{-1} imazapic and 0.18 kg a.i. ha^{-1} glyphosate resulted in planted native grass cover of 70% after three years, compared to 1% in the untreated control.

2.3 Forage production

Native warm-season grasses may be ready for utilization in their second growing season, a year after their planting (Keyser et al., 2011b), though they may need more time if establishment was difficult (Henning, 1993). These grasses can be grazed (Tracy et al., 2010), harvested as hay (Burns and Fisher, 2012), or harvested as biomass for bioenergy production (McIntosh et al., 2016). Of the high yielding varieties, EG matures earliest, followed by SG, BB, and finally IG (Moser and Vogel, 1995; Keyser et al., 2011b). As NWSG matures, forage quality rapidly declines while forage mass increases (Mitchell et al., 2001; Backus et al., 2017; Brazil et al., 2020).

2.3.1 Grazing Height and Stocking Rate

It is possible to utilize NWSG using rotational or continuous grazing (Burns and Fisher, 2010; Brazil et al., 2020). Grazing NWSG too short can damage plant vigor, decrease the amount of carbohydrate reserves, and decrease the odds of winter survival (Owensby et al., 1970; Owensby et al., 1974); the growing points of NWSG are higher from the ground than traditional CSG forages, and therefore defoliation must be more carefully managed to avoid injury (Temu and Kering, 2023). Forwood and Magai (1992) found that BB clipped to 10 cm remained similar in ground cover over two years while BB clipped to 20 cm improved significantly from 22% ground cover to 61% ground cover over two years. Though grazing the grass to a lower height may seem to guarantee improved animal gain at the cost of long term stand health, Burns and Fisher (2010) found in North Carolina that continuously grazed EG produced the best ADG of 0.90 kg d^{-1} while supporting 6.1 steers ha^{-1} with a target height of 36 to 46 cm. Balancing stand health and animal gains, Burns and Fisher (2013) targeted stand heights between 20 and 30 cm for BB, SG, and EG. Keyser et al. (2022) targeted canopy heights of 40-46 cm for BB+IG, 60-76 cm for SG, and 45-60 cm for EG, maintaining these targets through a put-and-take method, changing the number of grazing animals to change the level of grazing pressure. Native warm-season grass species can differ in the stocking rates they can support; in Tennessee, Keyser et al. (2016b) found that BB+IG supported a per-year average of 199 animal days (AD) ha^{-1} over three years while SG supported 262 AD ha^{-1}, though total gain was not significantly different. In contrast, Burns and Fisher (2013) found in their North Carolina study that BB, SG, and EG supported similar stocking rates, with a mean of 5.7 steers ha^{-1}. In an additional three-year Tennessee study, Keyser et al. (2022) found that the stocking rate for each species declined over the growing season, reporting that BB+IG declined from a mean stocking rate of 6.4 head of weaned heifers ha^{-1} in May to 3.7 head ha^{-1} in August; SG declined from 11.6 to 4.0, and EG declined from 11.6 to 4.9 over the same time scale.

2.3.2 Harvest Timing

Native warm-season grasses should be harvested for hay at the early-boot growing stage to optimize nutritive value and yield. McIntosh et al. (2016) found that the crude protein (CP) of SG decreased from 106.8 g kg^{-1} at the early-boot stage to 86.8 g kg^{-1} at the early-seedhead stage while acid detergent fiber (ADF) increased from 403.1 to 435.4; in the case of BB+IG, CP decreased from 114.7 g kg^{-1} to 93.1 g kg^{-1} and ADF increased from 391.7 g kg^{-1} to 401.7 g kg^{-1}. A period of regrowth is necessary between harvests to allow the stand to recover and produce more forage; in Virginia, Temu et al. (2014) found that 30-40 day harvest intervals for BB, LB, and IG maximized first production year yields and did not seem to compromise post-season stand recovery in comparison to longer intervals. In Mississippi, Rushing et al. (2019a) found that cutting BB, LB, IG, SG, and EG at 30 day intervals resulted in the greatest mean dry matter yield in the first year at 5,416 kg ha^{-1}, compared to 4,994 kg ha^{-1} for the 40 day interval and 3,611 kg ha^{-1} for the 120 day interval; in the second year, yields were similar and had declined for all intervals except the 120 day interval, which yielded 3,708 kg ha^{-1}. Rushing et al. (2019a) recommend that allowing up to 60 days between harvests will balance the competing interests of maximizing yield in the short term and managing stand health in the long term. As with grazing, care must be taken to avoid harvesting to too low a height, because the growing points of NWSG are above the common cutting heights for CSG; Temu and Kering (2023) employed a cutting height of 18 cm, while Rushing et al. (2019a) employed a cutting height of 30 cm.

2.3.3 Big Bluestem, Little Bluestem, and Indiangrass Forage Yield

In a grazing study conducted in Iowa, Moore et al. (2004) found BB to have available forage averaging 3.70 Mg ha^{-1} (clipped to 2.5 cm) over five years, with yearly values ranging from 1.76 to 5.34 Mg ha^{-1}. In a North Carolina grazing study, a BB pasture cut to the soil surface was found to have a forage mass averaging 4.54 Mg ha^{-1} over three summers, supporting a season-long average stocking rate of 5.4 steers ha^{-1} (Burns and Fisher, 2013). In a Tennessee grazing study, a BB+IG blend had an average total forage mass of 2.79 Mg ha^{-1} over three years, when samples were clipped to 7.6 cm; interseeded clover did not affect yield (Keyser et al., 2016b). In a multi-location study in Tennessee, a study focusing on a 30-day early grazing period in May found that a BB+IG blend produced a forage mass of 4.28 Mg ha^{-1} at one experimental location and 3.03 Mg ha^{-1} at another over three years, with plots clipped to 2.5 cm (Backus et al., 2017). Additional research in a Tennessee study resulted in a BB+LB+IG mixture yielding a three-year average forage mass of 3.21 Mg ha^{-1} on continuously grazed pasture clipped at 5 cm averaged among grazing treatments, forage mass increased from a 7 May value of 2.34 Mg ha^{-1} to a 1 July high of 3.91, and declined back to 2.36 Mg ha^{-1} by 23 Aug. in a pattern typical for these species (Brazil et al., 2020). The Tennessee study conducted by Keyser et al. (2022) found an abnormally low three-year mean forage mass of 0.91 Mg ha^{-1} for a BB+IG blend supporting a stocking rate of 5 weaned heifers ha^{-1}, with forage mass declining from a May value of 1.87 Mg ha^{-1} to an August value of 0.51 Mg ha^{-1}.

2.3.4 Switchgrass Forage Yield

In an Iowa grazing study, Moore et al. (2004) found that SG had a mean forage mass of 3.68 Mg ha^{-1} (clipped to 2.5 cm) over five years, with yearly values ranging from 1.74 to 5.99 Mg ha^{-1}. In a North Carolina grazing study, SG had a mean summer forage mass of 4.94 Mg ha^{-1} over six years, supporting a stocking rate of 6.1 steers ha^{-1} (Burns and Fisher, 2013). In one Tennessee grazing study, SG had a mean total forage mass of 3.61 Mg ha^{-1} over three years, with interseeded red clover (*Trifolium pratense* L.) not affecting yield (Keyser et al., 2016b). A multi-location Tennessee grazing study focusing on an early 30-day grazing period in May found that SG produced a mean forage mass of 6.31 Mg ha^{-1} at one experimental location and 4.04 Mg ha^{-1} at another, averaged over three years with plots clipped to 2.5 cm (Backus et al., 2017). An additional Tennessee grazing study resulted in SG yielding an abnormally low three-year mean forage mass of 1.68 Mg ha^{-1}, supporting a stocking rate of 7 weaned heifers ha^{-1}; during the growing seasons, average forage mass dropped from a May value of 2.63 Mg ha^{-1} to a June value of 0.95 Mg ha^{-1}, rising to 1.81 and 1.75 Mg ha^{-1} in July and August, respectively (Keyser et al., 2022). An analysis by Wullschleger et al. (2010) of 39 field trials on SG biomass production found a mean (±SD) yield of 8.7 ± 4.2 Mg ha^{-1} for upland ecotype SG, and 12.9 ± 5.9 Mg ha^{-1} for lowland ecotype SG. Wullschleger et al. (2010) noted that ecotype, temperature, precipitation, and N fertilization were the strongest predictors of yield, and that their model predicted SG yields to be highest at the core of the natural range of SG, in mid-latitudes of the eastern US.

2.3.5 Eastern Gamagrass Forage Yield

In a North Carolina grazing study contrasting rotational and continuous stocking methods, continuously grazed EG with a target canopy height over 51 cm had an average forage mass of 1.93 Mg ha^{-1} over four years, supporting 5.8 steers ha^{-1} (Burns and Fisher, 2010). In an additional North Carolina study, EG had a mean summer forage mass of 5.18 Mg ha^{-1} over five years, supporting a stocking rate of 6.4 steers ha^{-1} (Burns and Fisher, 2013). A Tennessee study focusing on an early 30-day grazing period in May found EG to have a mean forage mass of 5.43 Mg ha^{-1} over three years (Backus et al., 2017). Additional grazing research in Tennessee found 'Highlander' EG to produce forage mass ranging from 8.45 Mg ha^{-1} to 1.92 Mg ha^{-1} over three years, with the decline in standing forage reflecting an improvement in grazing management; in this study EG supported a mean stocking rate of 1788 ± 514 kg ha^{-1} and 412 grazing days ha^{-1} (Keyser et al., 2020). Further research by Keyser et al. (2022) in Tennessee study found EG to have a mean forage mass of 0.66 Mg ha^{-1}, beginning with a May value of 1.35 Mg ha^{-1} and declining to an August value of 0.43 Mg ha^{-1}; the authors noted that these values are abnormally low for this forage crop compared to those reported in other studies.

2.3.6 Burning

Burning residue is a practice that has shown to benefit NWSG forage production, affecting the forage yield, nutritive value, rate of maturation and other physiological responses of NWSG (Hadley and Kieckhefer, 1963; Owensby et al., 1970; Peet et al., 1975; Mitchell et al., 1994). Burning has also improved initial establishment success of NWSG; in an Oklahoma study, Butler et al. (2016) found that no-till drilling SG after burning existing vegetation resulted in equal stand percentage at 150 days after planting to the stand percentage achieved when tilling before seeding, allowing producers to seed NWSG with decreased risk of erosion. In a study focused on exotic

CSG control in South Dakota prairies formerly dominated by BB, LB, IG, and SG, Bahm et al. (2011a and 2011b) found that fall burning reduced the amount of smooth brome vegetative cover compared to the control, though it was inferior to herbicide in this respect. In the first year, smooth brome comprised 21% of cover in burned plots compared to 28% in the control; in the second year, smooth brome comprised 19% of cover in burned plots compared to 39% in the control. In a 15-year experiment conducted in Kansas, Smith and Knapp (1999) found that burning reduced ground cover of exotic species and decreased exotic species richness by 80-90% in grasslands dominated by NWSG, including BB and IG. Mitchell et al. (1994) found in their Nebraska study that burning in early spring increased BB forage production in June by at least 52% and burning in mid- or late spring increased August forage production by at least 70%. This study also found that burning in late spring increased CP of BB in June by at least 15% compared to other burn treatments; the delay in peak yield and increase in forage quality later in the season can be attributed to a delay in BB growth caused by burning. Burning also contributes to greater NWSG seedling recruitment within established stands, allowing turnover in the grass population (Zimmermann et al., 2008). These factors make burning a potent tool to be used in managing NWSG forage production systems.

2.3.7 Soil Fertility

Due to their unique adaptations, NWSG are known to maintain a high level of productivity with less fertilization than other forage species (Jung et al., 1988; Monroe et al., 2017). In an Oklahoma study, Thomason et al. (2005) found that, though N applied at a rate of 448 kg N ha^{-1} did result in total SG yields of 18.0 Mg ha^{-1}, SG that had received no application yielded only slightly less at 16.9 Mg ha^{-1}. In a study conducted in north-central Texas, Bow et al. (2008) reported greater SG yields and greater plant phosphorus concentrations in the second year after a

30 Mg ha^{-1} compost application compared to control, with the delay potentially linked to the slower soil infiltration rate of compost. A study conducted by Muir et al. (2001) in north-central and southern Texas resulted in SG yields that decline over time if N applications are not made, and that SG biomass production was unresponsive to P applications; an application rate of 168 kg N ha^{-1} yr^{-1} was found to sustainably produce over 13 Mg ha^{-1} yr^{-1} in biomass, though production is likely to remain consistent only on soils with higher moisture retention. In an Alabama study, Mason et al. (2019) found that fertilization with 67 kg N ha^{-1} did not result in different EG yields compared to fertilization with 135 kg N ha^{-1}. Rushing et al. (2019a) evaluated monocultures of all five major NWSG species (BB, LB, IG, SG, and EG) and three variations of the BB+LB+IG mixture in Mississippi, finding that N applications had a significant but minor effect on NWSG DM yield, accounting for 2 and 4% of variation in the first and second years of the study, respectively. These inconsistent results reflect the wide variability of NWSG response to fertilization. Brejda (2000) compiled data showing a range of DM yield improvement of 0.5-6.0 Mg ha^{-1} for BB, 0-6.2 Mg ha^{-1} for SG, 0-4.9 Mg ha^{-1} for IG, and 0-8.6 Mg ha^{-1} for EG, with cultivar, year, and location all affecting the variability. N fertilization may have a positive effect on CP in BB, IG, SG, and EG, though the effect is variable (Waramit et al., 2012).

2.4 Nutritive Value

2.4.1 Nutritive Value Difference Between Species

The nutritional value of NWSG is primarily affected by species and harvest timing (Rushing et al., 2019b). In comparison to SG and EG, the commonly mixed species BB, LB, and IG are known to generally have higher nutritive value, is in part due to their later maturity and greater proportion of leaf tissue early in the season (Mitchell et al., 2001; Ball et al., 2015; McIntosh et al., 2016). McIntosh et al. (2016) found that when harvested at the early-boot stage, a BB+IG blend had a mean CP content of 114.7 g kg^{-1}, compared to 106.8 g kg^{-1} for SG; they also found BB+IG to have an neutral detergent fiber (NDF) and ADF of 648.2 g kg^{-1} and 391.7 g kg^{-1}, respectively, while SG had values of 684.9 g kg^{-1} and 403.1 g kg^{-1}. When McIntosh et al. (2016) waited until the early-seedhead stage to harvest, the differences became less pronounced, with BB+IG and SG having similar CP content values at 93.1 g kg^{-1} and 86.8 g kg^{-1} respectively; BB+IG retained lower NDF and ADF content than SG, at 668.3 g kg^{-1} and 401.7 g kg^{-1} for BB+IG compared to 729.8 g kg^{-1} and 435.4 g kg^{-1} for SG. Despite any difference in nutritive values, EG and SG often support higher stocking rates and produce more forage; Keyser et al. (2022) found that SG supported 617 grazing days ha^{-1} and EG supported 664 grazing days ha^{-1}, compared to 412 for a BB+IG mixture.

2.4.2 Big Bluestem, Little Bluestem, and Indiangrass Nutritive Value

In North Carolina, Burns and Fisher (2013) found that BB pasture had a CP content of 90 g kg^{-1}, an NDF content of 743 g kg^{-1}, and an ADF content of 418 g kg^{-1} among two replicates in one year. In Tennessee, Backus et al. (2017) found that BB+IG pasture grazed early in the season had a mean CP content of 99.6 g kg^{-1}, a mean NDF content of 679.3 g kg^{-1}, and a mean ADF content of 413.7 g kg^{-1} at one experimental location over three years. Rushing et al. (2019b) found that BB had a mean CP content of 96.5 g kg^{-1}, a mean NDF content of 700 g kg^{-1}, and a mean ADF content of 368.5 g kg^{-1} over two years in Tennessee. In an additional Tennessee study, Brazil et al. (2020) found that a continuously grazed BB+LB+IG mixture had a season-long mean CP content of 98 g kg^{-1}, a mean NDF content of 644 g kg^{-1}, and a mean ADF content of 414 g kg^{-1} over three years. In their Tennessee grazing study, Keyser et al. (2022) found that a BB+IG mixture had, within the grazing horizon above 41 cm, a mean CP content of 106 g kg^{-1}, a mean NDF content of 663 g kg^{-1}, and a mean ADF content of 411 g kg^{-1} over three years; in the subcanopy between heights of 20 and 40 cm, mean CP content was 92 g kg^{-1}, mean NDF content was 674 g kg^{-1}, and mean ADF content was 435 g kg^{-1} over three years.

2.4.3 Switchgrass Nutritive Value

In North Carolina, Burns and Fisher (2013) found that SG pasture had a mean CP content of 103 g kg^{-1}, a mean NDF content of 694 g kg^{-1}, and a mean ADF content of 376 g kg^{-1} within two replicates over four years. In Tennessee, McIntosh et al. (2016) found that SG harvested for hay at the early boot stage had a mean CP content of 106.8 g kg^{-1}, a mean NDF content of 684.9 g kg^{-1}, and a mean ADF content of 403.1 g kg^{-1} across three locations over three years. Backus et al. (2017) found in their Tennessee study that SG grazed early in the season had a mean CP content of 66.3 g kg^{-1}, a mean NDF content of 745.5 g kg^{-1}, and a mean ADF content of 424.2 g kg^{-1} at one experimental location over three years. Additional research in Tennessee by Keyser et al. (2022) found that SG had, in the grazing horizon above 41 cm, a mean CP content of 102 g kg^{-1}, a mean NDF content of 681 g kg^{-1}, and a mean ADF content of 391 g kg^{-1} over three years; within the subcanopy between heights of 20 and 40 cm, mean CP content was 84 g kg^{-1}, mean NDF content was 699 g kg^{-1}, and mean ADF content was 419 g kg^{-1} over three years.

2.4.4 Eastern Gamagrass Nutritive Value

Burns and Fisher (2010) found in their North Carolina study that continually grazed EG managed at a canopy height between 36 and 46 cm had a mean CP content of 123 g kg^{-1}, a mean NDF content of 680 g kg^{-1}, and a mean ADF content of 343 g kg^{-1}. In Mississippi, Rushing et al. (2019b) found a mean CP content of 98.5 g kg^{-1}, a mean NDF content of 710.0 g kg^{-1}, and a mean ADF content of 375 g kg^{-1} over two years. In Tennessee, Keyser et al. (2020) found that EG had a mean CP content of 141.7 g kg^{-1}, a mean NDF content of 651.8 g kg^{-1}, and a mean ADF content of 354.2 g kg^{-1} over three years. In another Tennessee study, Keyser et al. (2022) found that EG had, in the grazing horizon above 41 cm, a mean CP content of 114 g kg^{-1}, a mean NDF content of 681 g kg^{-1}, and a mean ADF content of 418 g kg^{-1} over three years; within the subcanopy between heights of 20 and 40 cm, EG had a mean CP content of 102 g kg^{-1}, a mean NDF content of 692 g kg^{-1}, and mean ADF content of 424 g kg^{-1} over three years.

2.4.5 Nutritive Value and Harvest Timing

All NWSG nutritive values benefit from being harvested earlier in the season, around early boot stage, to maintain high nutritive value (McIntosh et al., 2016; Backus et al., 2017; Rushing et al., 2019b; Brazil et al., 2020). In Tennessee, Brazil et al. (2020) found that a BB+LB+IG mixture had a CP content of 147 g kg^{-1} on 7 May, which rapidly declined to 85 g kg^{-1} by 4 June; CP content remained at this level until the end of the season with a value of 82 g kg^{-1} on 23 August. As CP fell, NDF content increased from 557 g kg^{-1} on 7 May to 655 g kg^{-1} on 4 June, and increased further to 681 g kg^{-1} by 28 July, remaining at that level through the end of the season with a value of 683 g kg^{-1} on 23 August. Similarly to NDF, ADF rose from 347 g kg^{-1} on 7 May to 423 g kg^{-1} on 4 June, rising to 450 g kg^{-1} by 28 July, and remaining at this level for rest of the season with a value of 454 g kg^{-1} on 23 August.

2.5 Animal performance

2.5.1 Comparison with Cool-Season Species

Animal performance on NWSG is generally regarded as inferior to animal performance on tall fescue and other cool-season grasses (Moore et al., 2004; Hudson et al., 2010; Tilhou et al., 2018). In Iowa, Moore et al. (2004) found that growing cattle stocked on smooth bromegrass for the duration of the summer grazing period generally performed better than cattle rotated to BB or SG. This difference is in part due to the difference in nutritive values between species; in Michigan, Hudson et al. (2010) found that a pasture primarily composed of perennial ryegrass (*Lolium perenne* L.), tall fescue, orchardgrass (*Dactylis glomerata* L.), and various legumes generally had higher nutritive value and maintained nutritive value for longer than similar pasture with one-third of its area converted to BB or SG. Similarly, Tilhou et al. (2018) found in Tennessee that winter stockpiled BB+IG and SG forage were inferior to stockpiled tall fescue in terms of CP (32.1 and 21.0 g kg^{-1} vs. 90.3 g kg^{-1}), NDF (838 and 877 g kg^{-1} vs. 736 g kg^{-1}), and in vitro total dry matter digestibility (IVTDMD) (410 and 366 g kg^{-1} vs. 488 g kg^{-1}). Nonetheless, NWSG can serve as a valuable component of a grazing system that provides flexibility to producers; in Illinois, Tracy et al. (2010) found that calves rotated to EG+BB+LB pasture from pasture dominated by tall fescue, Kentucky bluegrass, and orchardgrass gained 0.87 kg d^{-1} over 27 days in one year and gained 0.94 kg d^{-1} over 23 days in another, despite the NWSG being allowed to become overly mature before grazing initiation. In Mississippi, Monroe et al. (2017) found that steer calves grazing BB+LB+IG in July had an average daily gain of 0.76 kg d^{-1} over two years compared to 0.57 kg d^{-1} for cattle grazing tall fescue and bermudagrass (*Cynodon dactylon* (L.) Pers.) mixed pasture. Despite differences in growth pattern and nutritive value, NWSG may serve as an acceptable alternative to introduced forage species in certain circumstances.

2.5.2 Animal Performance on NWSG

The broad adaptation of NWSGs allows them to support adequate animal gains across geographically disparate areas. In Tennessee, Brazil et al. (2020) reported that weaned steers grazing BB+LB+IG had an ADG of 0.98 kg d^{-1} when the stocking rate was left constant throughout the season and had a similar ADG of 0.89 kg d^{-1} when stocking rate was modified to align with the NWSG growth pattern. Krueger and Curtis (1979) report 0.7 kg d^{-1} on BB, 0.93 kg d^{-1} on upland SG, and 1.08 kg d^{-1} on IG for yearling steers continually grazing in South Dakota. In

Nebraska, Mitchell et al. (2005) reported that yearling steers had a mean ADG of 1.22 kg d^{-1} among four cultivars of BB. In North Carolina, Burns and Fisher (2013) reported that grade Angus steers had an ADG of .87 kg d^{-1} on EG, 1.08 kg d^{-1} on BB, and .91 kg d^{-1} on SG. In Tennessee, Lowe et al. (2015) found that weaned beef steers had an ADG of 1.23 kg d^{-1} on BB+IG, 1.14 kg d^{-1} on SG, and 0.84 kg d^{-1} on EG. In their dual-use Tennessee study, Backus et al. (2017) reported an ADG of 1.23 kg d^{-1} for BB+IG, 0.84 kg d^{-1} for EG, and 1.14 kg d^{-1} for SG when they were grazed early in the season before a late season biomass harvest.

2.5.3 Disparity Between Tested Nutritive Values and Actual Animal Performance

Animal gains on NWSG can seem to be higher than the nutritive value of the forage would predict. This could be due to the failure of nutritional tests to detect bypass proteins found in C_4 grasses (Mullahey et al., 1992), or due to the sampling of forage from lower in the canopy where livestock may be less likely to graze (Keyser et al., 2016b). Tilhou et al. (2018) found that leaf sub-samples of dormant BB+IG and SG had significantly greater CP and—in the case of SG—significantly lower NDF than whole plant samples; BB+IG leaf CP was 51 g kg^{-1} compared to a whole plant value of 31 g kg^{-1}, and BB+IG leaf NDF was 818 g kg^{-1} compared to a whole plant value of 824 g kg^{-1}. In this same study, the effect was more pronounced in SG, with a leaf CP of 65 g kg^{-1} compared to a whole plant value of 27 g kg^{-1}, and a leaf NDF of 824 g kg^{-1} compared to a whole plant NDF value of 860 g kg^{-1}. These findings suggest that selective grazing by livestock may account for animal performance that exceeds the expectations set by nutritive value measurements.

2.6 Interseeding Legumes into NWSG

2.6.1 Benefits of Interseeding

Though the potential benefits of interseeding are enticing, the available literature shows inconsistent results when legumes are incorporated into stands of NWSG. One potential benefit of interseeding legumes into NWSG is improvement of forage nutritional quality (Posler et al., 1993; Springer et al., 2001). In Iowa, Posler et al. (1993) found a SG and roundhead lespedeza (*Lespedeza capitata* Michx.) mixture to have a CP content of 71 g kg^{-1} compared to 31 g kg^{-1} for SG monoculture. In Arkansas, Springer et al. (2001) found that a mixture of IG and Illinois bundleflower [*Desmanthus illinoensis* (Michx.) MacMill., B. Robins. & Fern.] had a mean CP content of 84 g kg^{-1} over two years compared to 49 g kg^{-1} in IG monoculture. Interseeding cool-season legumes into grass stands has been explored as a possible method of extending the grazing season by expanding the seasonal distribution of forage production. In Iowa, Sleugh et al. (2000) found that all binary mixtures of three cool-season forage grasses with three legumes had greater forage mass than their respective grass monocultures in the latter half of the growing season. George et al. (1995) found similar results in their Iowa study, finding that a variety of legumes interseeded into SG pasture improved seasonal forage distribution by increasing the available forage in early June compared to SG monoculture. Research has suggested that pastures with greater species richness may produce greater forage yields and suppress weed species more effectively; a Virginia study by Bonin and Tracy (2012) found that mixed-species forage plots containing BB, IG, or SG had a strong positive complementarity effect, meaning that plots containing these grasses were more productive due to interaction between species and niche differentiation.

Legume-grass mixtures may yield more forage than a monoculture of each species (Sleugh et al., 2000). In Wisconsin, Jakubowski et al. (2017) reported that interseeding red clover in SG and BB resulted in forage and biomass yields equal to SG and BB monocultures fertilized with 112 kg N ha^{-1}. In Tennessee, Ashworth et al. (2015) found that SG interseeded with red clover, hairy vetch (*Vicia villosa* L.), ladino clover (*Trifolium repens* L.), and partridge pea (*Chamaecrista fasciculate* L.) generally produced biomass yields equivalent to SG monocultures fertilized with 33 to 67 kg N ha^{-1}. Contrasting these results, a Tennessee study conducted by Keyser et al. (2016b) reported that interseeding with red clover in SG and BB+IG had limited benefit on forage mass, ADG, CP, and NDF, likely due to inconsistent establishment. Similarly, in Alabama Mason et al. (2019) found no effect on EG seasonal herbage accumulation when overseeding EG with red clover and rye (*Secale cereale* L.), with the cool season species producing low levels of forage throughout the study. The inconsistency of results between these experiments reflects the complicated variety of factors that influence the success of interseeding legumes into NWSG. Improved yields in legume-grass mixtures may be caused by the direct or indirect provision of N from legume to grass, niche differentiation between species, and "nitrate sparing" arising from legume reliance on atmospheric N, leaving a greater proportion of soil N for grass exploitation (Temperton et al., 2006).

2.6.2 Difficulties Affecting Establishment

One factor that may limit the benefits of interseeding legumes into NWSG is the difficulty of establishment. Establishment of legume species are affected by a variety of factors. One such factor is the crown size of the NWSG species present in the sward. Larger crown sizes restrict the bare ground available for seed germination. Mason et al. (2019) found that red clover and rye interseeded into EG did not establish sufficiently well to influence forage yield, with the larger crown size of EG possibly influencing this failure by hindering good seed-soil contact. Another factor affecting establishment is the density of the NWSG stand in relation to the amount of forb seed planted. In their Kansas study, Dickson and Busby (2009) report that greater density of NWSG seed resulted in poorer establishment of forb species in restoration plantings, while greater quantity of forb seed improved forb cover and biomass; they recommend planting forbs into less dense grass stands for greater establishment success. This relationship between grass vigor and legume establishment is reflected in an experiment by Jung et al. (1985), in which overseeded legumes established well in NWSG stands with less than 75% grass ground cover, but established poorly in stands with greater grass ground cover. These factors are expanded on by Wilsey (2010), whose Iowa study suggests that light capture by taller grass and the covering of bare ground through tillering suppressed the establishment of other species; in their study, LB monocultures allowed far more subordinate species to establish than BB, IG, and SG, likely due to the short height of this species. This is consistent with the results Springer's (1997) Arkansas study, which found that a 5-cm increase in bermudagrass height resulted in a 2% reduction in crimson clover (*Trifolium incarnatum* L.) ground cover and a 10% reduction in white clover (*Trifolium repens* L.) ground cover. Because N-applications hinder legume establishment in mixed stands (Jakubowski et al. 2017), and because a lack of N-application and legume competition can cause a first-year shortfall in NWSG forage production, George et al. (1995) recommend that only a portion of NWSG stands be interseeded with legumes each year to minimize the yield loss caused by a lack of fertilizer and increase in competition. In Evers' (1985) Texas study, applying 112 kg N ha^{-1} to bermudagrass and bahiagrass (*Paspalum notatum* Flugge) stands interseeded with arrowleaf clover (*Trifolium vesiculosum* Savi) or subterranean clover (*Trifolium subterraneum* L.) did not improve total forage yield, but did reduce percentage clover in the stand 5% to 33% compared to unfertilized treatments.

2.6.3 *Excessive Competition*

A related factor that may negate benefits of interseeding legumes into NWSG is the potential for competition between species, especially early or late in the growing season when NWSG is not at its peak productivity. In their Kansas study, Posler et al. (1993) found that SG and IG stands interseeded with cicer milkvetch (*Astragalus cicer* L.) essentially became legume monocultures over the course of the experiment, due to this species' early initiation of spring growth that allowed it to develop a dense canopy before the grasses initiated growth. Keyser et al. (2016b) report that excessive red clover growth in the third year of their Tennessee study resulted in decreased sward height for BB+IG and SG, and decreased grass cover for BB+IG, and to a lesser extent, SG. George et al. (1995) managed competition between legumes and SG by employing early-June defoliation; this minimizes competition between legume species and NWSG as the grasses enter their most productive period. Similarly, Bow et al. (2008) harvested mixed forage plots when legume species reached 25% bloom, which occurred in April or May, opening the canopy for SG to enter its period of peak growth. Bow et al. (2008) also report that competition between species is reflected in nutritive data, as some legume species exhibited higher ADF values when grown in mixture with SG than when grown as a monoculture, potentially resulting from etiolation leading to lower leaf:stem ratios; the inclusion of arrowleaf clover resulted in greater SG ADF concentrations in April-May harvests but the effect dwindled in later harvests.

2.6.4 *Managing Competition with Fire*

Fire is one method of managing competition between species. This may be due to a germination response exhibited by some legumes when exposed to heat, allowing them to emerge without being hampered by residue (Rincker, 1954; Martin et al., 1975). Howe (2011) reported that over 21 years, burned NWSG prairie maintained higher forb species richness over time than unburned. Contradicting these results, Holcomb et al. (2014) report that yearly burnings did not stimulate forb populations in NWSG stands over a four-year period, and speculate that soil disturbance may be necessary to reduce NWSG cover and increase forb cover in dense NWSG stands. Bartholomew and Williams (2010) concur in their statement that the improvement of low productivity stands of NWSG with legume interseeding may require sustained management to maintain a productive legume population.

2.6.5 Effect of Seeding Method and Timing on Establishment

Seeding method and timing may have an effect on the success of interseeding with legumes. No-till drilling involves the planting of seed beneath the soil surface without tilling the soil; in their Kentucky study, Taylor et al. (1969) found that the seed coverage provided by this method protected seeds from temperature and moisture extremes, and resulted in improved legume stands when compared to seed placed on the soil surface in stands of Kentucky bluegrass. Broadcast seeding involves placing seed on the soil surface; frost seeding is a method of broadcast seeding involving broadcast seeding during winter to allow freeze and thaw action to improve seed-soil contact (Schlueter and Tracy, 2012). Seeding legumes in winter is an established practice that has been used by producers to improve both CSG (Taylor et al., 1972; Castillo et al., 2022) and WSG (Jung et al., 1985; Gettle et al., 1996) pasture in a cost-effective manner. In their North Carolina study, Mueller and Chamblee (1984) found that no-till drilling ladino clover and alfalfa into tall fescue resulted in initial stands with two to four times greater plant counts than achieved by broadcast seeding, producing up to 2000 kg ha^{-1} more legume yield. This early advantage declined over time, and Mueller and Chamblee (1984) reported that broadcast plots of ladino clover consistently had lower initial stand counts than drilled but eventually developed equally dense stands to drilled plots in 3 of 4 years; both seeding methods benefited from seeding in

February over March. In a Pennsylvania study, Byers and Templeton (1988) found that no-till drilling and broadcasting alfalfa into orchardgrass sod did not differ in DM yields in one experiment, while drilling produced significantly greater alfalfa DM in a second experiment, yielding 2055 kg ha^{-1} compared to 1358 kg ha^{-1} for broadcast in the production year; alfalfa DM yield differed between March and May seedings in both experiments. In South Centerbury, New Zealand, Moorehead et al. (1994) found drilled Caucasian clover (*Trifolium ambiguum*) treatments to have superior establishment in low fertility tussock grassland, with 38% of seed establishing compared to 9% for broadcast. Schlueter and Tracy (2012) found broadcast treatments to produce a mean clover seedling density of 118.2 m^{-2}, compared to a mean seedling density of 65.9 m^{-2} for drilled treatments, though this difference was not significant and did not result in a difference in clover biomass in any year, likely as a result of further clover emergence after the initial emergence count. Cuomo et al. (2001) found no difference in establishment success between the two planting methods for several legumes, and found that the primary determinant of interseeding success was suppressing the existing vegetation during establishment, accomplished in this experiment with 0.62 kg a.i. ha^{-1} glyphosate.

2.6.6 Effect of NWSG Suppression on Establishment

A commonality in interseeding studies is the value of suppressing the dominant species, and there are multiple methods that may be employed. This is due to the inverse relationship between grass height and biomass and legume seedling emergence (Springer, 1997; Schlueter and Tracy, 2012; Tracy et al., 2014). Cuomo et al. (2001) found that use of glyphosate to suppress sod resulted in legume stands of 38%; planting without suppressing resulted in stands of 3%. Taylor et al. (1969) found that minimal tillage and paraquat aided in legume establishment when grass stands were dense and vigorous; paraquat was more effective at suppressing grass than tillage, with a 1.11 kg a.i. ha^{-1} application in 10.2 cm bands achieving a 62% reduction in grass yield compared to a 31% reduction for the widest tilled strips at 5.7 cm. Mueller and Chamblee (1984) found that paraquat applications aided spring-planted ladino clover, but did not affect winter-planted ladino clover. Blanchet et al. (1995) and Gettle et al. (1996) employed early-June defoliation of SG to open the canopy for interseeded legumes; likewise, Schlueter and Tracy (2012) hypothesized that grass biomass removal or suppression, in their case accomplished by grazing, was very important in establishment of clover; this hypothesis was supported in further research by Tracy et al. (2014), who found that red and white clover produced twice as many seedlings when seeded into 2.5 cm stubble (226 seedlings m^{-2}) than when seeded into 27 cm swards (106 seedlings m^{-2}). Using fire to suppress NWSG prior to planting is a relatively unresearched. Regarding effects of fire on existing legume populations, Towne and Knapp (1996) found that annually burned BB+LB+IG prairie had greater legume density than unburned, while a 21-year experiment by Howe (2011) found a slight positive response burning NWSG stands in forb population richness.

2.7 Research Goal

The objective of this study was to investigate the effect of timing of legume interseeding, planting method of legume interseeding, and the efficacy of burning residue on legume establishment in NWSG. Specific goals within this objective include determining the germination rate of clover for each treatment, the botanical composition of each treatment throughout the growing season measured by mass and number, the forage yield of each treatment, and the forage nutritional value.

Chapter 3

Legume Establishment in Native Warm-Season Grass Pastures

3.1 Abstract

Interseeding legumes in native warm-season grasses (NWSG) may improve the nutritive value of the stand, result in more consistent forage availability throughout the growing season, and increase forage yield. These benefits are often not realized due to difficulties in establishing legumes in existing NWSG stands. This study evaluated the effect of planting method (no-till drill, broadcast, and unseeded control), burning of residue, and planting timing (fall planting, winter planting, and winter planting with residue burned) on the establishment of 'Alice' white clover (*Trifolium repens* L.) and 'Freedom HR' red clover (*Trifolium pratense* L.) in a mixed stand of 'Niagara' big bluestem (*Andropogon gerardi* Vitman), 'GA Ecotype' Indiangrass (*Sorghastrum nutans* Nash), and 'Camper' little bluestem (*Schizachyrium scoparium*) in 2022 and 2023 at the Southern Piedmont AREC in Blackstone, Virginia. Burned and drilled plots had the highest emergence (236 plants m^{-2}); next highest were winter drilled (146 plants m^{-2}) and burn broadcast (133 plants m^{-2}), which did not differ. Fall seeded plots and unseeded controls had a low clover emergence with a mean of 21 plants m^{-2}. Greater emergence in burned plots increased clover content from 5.9 % ground cover to 33.2% cover in the first year, while winter-seeded plots increased from 3% to 13.7%. Drilled plots increased from 5.6% to 28.6%, while broadcast plots increased from 2.1% to 14.8%. Clover dominated burned plots and winter seeded plots in the second year, averaging 91.5% of biomass in burned and drilled plots and 85.6% of biomass in winter drilled plots. The dominance of clover negatively impacted total forage yield for burned plots (5,757 kg ha^{-1}) compared to fall and winter-seeded plots (mean 7,429 kg ha^{-1}), while

improving crude protein content to a late-season value of 149 g kg^{-1} compared to a fall plot value of 99 g kg^{-1}. Results suggest that red clover may be incompatible with the NWSG which were evaluated, as early initiation of red clover growth and subsequent excessive competition limited NWSG growth and whole plots yields regardless of planting method. Further research is needed to evaluate forage legume species which complement NWSG in mixture rather than compete with them.

3.2 Introduction

Cool-season grasses (CSG) dominate forage production in the eastern US. These grasses produce ample forage in spring and early summer, but cannot maintain their productivity in the summer heat, leading to a decline in forage production and consequently pasture carrying capacity commonly known as the “summer slump” (Moore et al., 2004; Tracy et al., 2010). Native warm-season grasses, such as big bluestem, Indiangrass, little bluestem, switchgrass (*Panicum virgatum*), and eastern gamagrass (*Tripsacum dactyloides*) are most productive during the summer months and can therefore serve as an alternative forage source during this period (Hudson et al., 2010). This is because NWSG use the C_4 photosynthetic pathway, which is more water, nitrogen, and carbon efficient than the C_3 pathway used by CSG and operates efficiently at temperatures detrimental to cool-season species (Ehleringer and Björkman, 1977; Taylor et al., 2009). Favorable animal performance on NWSG can be achieved through multiple grazing strategies. In Tennessee, Backus et al. (2017) found that weaned beef steers gained 1.23 kg d^{-1} when grazing on mixed big bluestem and Indiangrass pasture early in the season and gained 0.84 kg d^{-1} when grazing for the full season. Similarly, Brazil et al. (2020) found that weaned steers continuously grazing on mixed big bluestem, Indiangrass, and little bluestem pasture gained 0.98 kg d^{-1} in Tennessee.

Despite the potential benefits of using multiple complementary forage species in grazing systems, improved animal performance can be difficult to achieve. In Iowa, Moore et al. (2004) found that growing cattle grazing mixed grass and legume cool-season pasture performed better than cattle which were rotated onto NWSG during the summer. In Michigan, Hudson et al. (2010) found that rotating cattle from cool-season pastures to big bluestem in the summer did not improve livestock gain or seasonal distribution of forage production. In both cases the inferior forage nutritive value of NWSG compared to CSG played a role in the reduction in animal performance. One strategy to alleviate these detriments is to interseed legumes in NWSG pasture.

Interseeding legumes in grass pasture can produce multiple benefits, including the improvement of forage nutritive value. In Arkansas, Springer et al. (2001) found that interseeding Illinois bundleflower [*Desmanthus illinoensis* (Michx.) MacMill., B. Robins. & Fern.] in Indiangrass pasture produced a forage mixture with a crude protein (CP) content of 84 g kg^{-1} compared to 49 g kg^{-1} in Indiangrass monoculture. It can also be employed to improve the availability of forage early in the season. In Iowa, George et al. (1995) found that interseeding legumes in switchgrass increased the available forage in early June, improving seasonal forage distribution. In addition to these benefits, grass pasture interseeded with legumes can yield more forage, either due to grass exploitation of nitrogen fixed by legumes, niche differentiation between species, or “nitrate sparing” allowed by legume acquisition of atmospheric N, leaving soil N for grass exploitation (Temperton et al., 2006). In Tennessee, Ashworth et al. (2015) found that switchgrass interseeded with red clover and other legumes generally produced biomass yields equivalent to switchgrass monocultures fertilized with 33 to 67 kg N ha^{-1}. Similarly, a Wisconsin study by Jakubowski et al. (2017) found that unfertilized big bluestem and switchgrass stands interseeded with red clover yielded forage mass equivalent to that of monocultures fertilized with 112 kg N ha^{-1}.

The benefits of interseeding grass pasture with legumes are not always realized, in part because of difficulties in establishing legumes in NWSG. This is reflected in a Tennessee study by Keyser et al. (2016b) where red clover interseeded in switchgrass monoculture and a big bluestem and Indiangrass mixture had a limited benefit on forage mass and nutritive value due to inconsistent establishment. In Alabama, Mason et al. (2019) found similar results when interseeding eastern gamagrass with red clover and rye (*Secale cereale* L.), finding no effect on seasonal herbage accumulation or CP. Several factors affect the outcome of interseeding legumes in grass stands. Planting method is one such factor. Mueller and Chamblee (1984) found that no-till drilling ladino white clover and alfalfa (*Medicago sativa* L.) into tall fescue (*Schedonerus arundinaceus* [Schreb.] Dumort) produced initial stands with two to four times greater plant counts than broadcast seeding and produced a legume yield 2000 kg ha^{-1} greater than broadcast seeding; in 3 to 4 years stand counts were equivalent for each planting method.

Another factor is the timing of planting. Reflecting this, Mueller and Chamblee (1984) found that both seeding methods produced greater establishment when seeding in February over March. “Frost seeding” is a method of broadcast seeding that takes advantage of freeze and thaw action on the soil surface to improve seed-soil contact and expose legume seed to cold temperatures that may stratify them; Gettle et al. (1996) used this method to successfully establish red clover and other legumes in switchgrass via broadcast seeding.

Often the most important determinant of success when interseeding legumes is the suppression of existing forage species and residue. When interseeding alfalfa, kura clover (*Trifolium ambiguum* Bieb.), and birdsfoot trefoil (*Lotus corniculatus* L.) into a smooth bromegrass (*Bromus inermis* Leyss.), quackgrass [*Elytrigia repens* (L.) Nevski.], and Kentucky bluegrass (*Poa pratensis* L.) mixture, Cuomo et al. (2001) found that suppressing existing grass with glyphosate resulted in legume stands of 38% compared to 3% in the control, while planting method did not affect the outcome.

There has been limited research on the effect of planting method, planting timing, and the suppression of existing forage on interseeding legumes in NWSG. The goal of this study was to evaluate the effect of planting method, planting timing, and the burning of residue on the establishment of legumes in mixed big bluestem, Indiangrass, and little bluestem pasture.

3.3 Methods and Materials

3.3.1 Site

The experiment was conducted during 2022 and 2023 at the Southern Piedmont Agricultural Research and Extension Center in Blackstone, Virginia (37°06’01” N, 77°56’37” W). The soil at the experimental site is classified as an Appling coarse sandy loam (fine, kaolinitic, thermic, Typic Kanhapludult). The study was conducted on a mixed stand of ‘Niagara’ big bluestem, ‘GA Ecotype’ Indiangrass, and ‘Camper’ little bluestem established in March 2020 and previously utilized as bovine pasture. Soil test results are summarized in Table 1. A combination fertilizer (6-12-18) was applied at 560.4 kg ha^{-1} (convert to kg/ha) on March 1, 2022 and February 9, 2023. Plot areas were sprayed with Remedy® Ultra [Triclopyr: 2-{(3,5,6-trichloro-2-pyridinyl)oxy} acetic acid, butoxyethyl ester] (Dow AgroSciences LLC, Indianapolis, IN) at 4.68 L ha^{-1} on October 22, 2021 and October 19, 2022 before the fall planting dates to control broadleaf weeds. Mean monthly air temperatures and precipitation totals were collected using a Dyacon weather station (Dyacon, Inc., Logan, UT), and are summarized in Table 2.

3.3.2 Experimental Design and Treatments

The experiment had a randomized complete block arrangement of a split-plot design with two factors, each factor having three treatment levels for a total of nine treatment combinations. The first factor is a combination of seeding timing with burn status and the second was the method of seeding. The seeding timing/burn status factor had three treatment levels: a fall seeding with no burning, a winter seeding with no burning, and winter seeding with burning. The seeding method factor had three treatment levels: broadcast seeding, drill seeding, and the control (control plots were left unseeded). Each plot measured 1.83 x 6.10 m and were grouped based on the seeding timing/burn status factor with 2.44 m alleys to avoid the risk of fire spreading from burn plots to non-burn plots. Replications were also separated by 2.44 m alleys. Figure 1. shows the plot map. Plots were delineated and seeded on late 2021 and early 2022. A second set of plots, with treatments arranged identically to the first set of plots, was delineated and seeded in late 2022 and early 2023. This allowed for replication of first-year establishment data and for a second year of data to be collected in the first set of plots.

3.3.3 Legume Establishment and Controlled Burning

To evaluate legume establishment in NWSG, a mixture of red and white clovers was planted into the big bluestem, Indiangrass, and little bluestem. Legume seeding rates were adjusted for pure live seed (PLS = % purity x % germination) and for seeding method. Drill treatments were seeded with ‘Freedom HR’ red clover at 4.48 kg ha^{-1} (4 lb ac^{-1}) and ‘Alice’ white clover at 1.12 kg ha^{-1} (1 lb ac^{-1}) with a Great Plains 3P605NT no-till drill (Great Plains Ag, Salina, KS) with 19.05 cm row spacing. Broadcast treatments were seeded with red clover at 6.73 kg^{-1}ha (6 lb ac^{-1}) and white clover at 1.68 kg ha^{-1} (1.5 lb ac^{-1}) by hand. Planting and burn dates are summarized in Table 3.

Before burning, alleys between plots and replications were disked to prevent the spread of fire to non-burned plots. Plots were burned by igniting the residue on the perimeter of the plot with a propane torch and allowing the flame to spread inward until the entire plot had been burned.

3.3.4 Harvest Management and Sample Collection

To measure the emergence rate of clovers, plant counts were made using five randomly placed 0.0929 m^2 (1 ft^2) quadrats in each plot; two of the quadrats were selected at random and their locations were marked with stakes so that plant counts and hand harvests could be made at those locations throughout the growing season. In the first plot set, plant emergence counts were taken on April 13th, 2022, and in the second plot set, plant emergence counts were taken on April 13th, 2023.

Botanical composition throughout the growing season was measured through two methods. Before and after each harvest, the occupancy grid method (Payne et al., 2020) was used to measure botanical composition. Using a 1 m^2 quadrat subdivided into 25 squares, percent ground cover of clover, grass, weeds, and bare ground was determined by counting the number of squares in which each component makes up over 50% of ground cover. This was done at three randomly selected central locations in each plot.

Before each harvest, plant separation counts for grasses, clovers, and weeds were obtained in the two marked 0.0929 m^2 areas in each plot. Afterward, plants were cut at 20.3 cm (8 in); harvested plant matter was hand separated to determine the number of stems per species and weight of each species at harvest. Each separation sample was then dried to obtain a dry matter content to determine yield.

Plots were harvested three times in 2022 and twice in 2023. Harvest dates are summarized in Table 4. Forage was harvested at 20.3 cm (8 in) using a Wintersteiger Cibus F forage plot harvester (Wintersteiger, Ried im Innkreis, Austria) and the whole plot forage mass was recorded using the onboard computer. Grab samples were obtained from the harvested forage from each plot, and then weighed before and after drying to determine dry matter content to determine the total dry matter forage yield.

Whole plot and separation samples were dried at 60 ℃ for at least 72 hours in a Grieve SC-400 forced-air oven (The Grieve Corporation, Round Lake, IL) until a constant weight was obtained. When dried, samples were weighed to determine the dry matter content and then inadvertently ground to pass a 1-mm screen in a Thomas-Wiley mill (Thomas Scientific, Swedesboro, NJ), rather than a 2-mm screen as was intended. Ground samples were ground a second time to pass a 1-mm screen in a Cyclone sample mill (Udy Corporation, Fort Collins, CO). The repeated grinding of samples to pass through a 1-mm screen could have affected sample fineness and therefore the results of lab analyses.

3.3.5 Lab Analysis

Samples were obtained from separated hand harvests and from whole plot harvests to determine CP, NDF, and ADF content. Both whole plot and separations samples were scanned using a Foss NIRS DS2500 (FOSS NIRS, Laurel, MD) spectrometer to obtain a reflectance spectrum used to predict nutritive values. Of the 252 whole plot samples, 88 were selected for wet chemistry analysis using the Win-ISI program to validate the values predicted with spectral data. An ANKOM^{200} Fiber Analyzer (ANKOM Technology, Macedon, NY) was used to determine NDF and ADF using the ANKOM filter bag system (Vogel et al., 1999). Nitrogen content was determined with an Elementar vario EL cube (Elementar Americas, Ronkonkoma, NY), using a modified version of the Dumas dry combustion method (Dubeux et al., 2017). Crude protein was determined by multiplying total N content by 6.25, based on the assumption that protein is 16% N.

3.3.6 Statistical Analysis

The data from this study was analyzed as a randomized complete block arrangement of a split-plot design with four replications using PROC GLIMMIX (Statistical Analysis Software, SAS Institute, Inc., Cary, NC), where timing/burn status was treated as the whole plot and planting method was the subplot. Plot Set 1 was established in 2022 and Plot Set 2 was established in 2023, and the establishment year data for each plot set were analyzed together as establishment year data. Plot Set 1 continued to be harvested in 2023, and the data collected was analyzed as a second year of production. Fixed effects included planting timing/burn status, planting method, and harvest. Year was treated as a random effect in all response variables measured other than stem separations (only performed in plot set one). Harvest was treated as a repeated measure. The statistical analysis was conducted on the following response variables: germination count, harvest plant counts, pre-harvest species composition, post-harvest species composition, total seasonal yield, harvest yield, harvest stem separation biomass, and whole plot nutritive value (crude protein, neutral detergent fiber, and acid detergent fiber). Least square difference was used for mean separation and difference were considered significant at $\alpha = 0.05$.

3.4 Results and Discussion

3.4.1 Clover Emergence

Year was treated as a random effect to evaluate the effect that timing and method had on emergence rather than yearly differences in weather conditions. There was a significant (P <

0.0001) interaction between planting method and planting timing on clover emergence (Table 5). Burned plots had greater clover emergence than winter plots; within burned and winter plots respectively, drilled plots had greater emergence (236 and 102 plants m^{-2}) than broadcast plots (133 and 95 plants m^{-2}), and broadcast had greater emergence than control plots (51 and 19 plants m^{-2}). Fall plots had lower clover emergence than burned or winter plots, and clover emergence did not differ within fall plots due to planting method (mean 12 plants m^{-2}).

Greater clover emergence in burned plots compared to winter plots can be attributed to the reduction in grass residue on the soil surface by burning. Improvement in legume germination and emergence through a reduction in ground cover, typically achieved through defoliation by clipping, has been commonly observed, and is generally explained as a result of improved light penetration to the soil surface and improved seed-soil contact (Springer, 1997; Guretzky et al., 2004; Tracy et al., 2014). Springer (1997) found that a 5-cm increase in bermudagrass [*Cynodon dactylon* (L.) Pers.] height at planting resulted in a 2% reduction in crimson clover ground cover and a 10% reduction in white clover ground cover; the greater reduction in white clover, a short-growing species, compared to crimson clover, a tall-growing species, supports the idea that reducing the initial competition for light can improve legume establishment.

Lesser emergence in fall-planted plots compared to burned and winter plots may be attributed to multiple factors. The quantity of residue present in fall-planted plots could negatively affect clover emergence. In North Carolina, Rogers et al. (1983) found that October-seeded white clover no-till drilled into tall fescue stubble clipped to four cm established and survived the winter well, though seedlings only had one trifoliate leaf on average by early December, with insect control and herbicide-based suppression of the grass stand improving establishment significantly. In contrast, we did not clip NWSG plots before seeding in the fall as Rogers et al. (1983) did, and residue on fall plots was not removed through burning as it was in burned plots. White clover seedlings in the study by Rogers et al. (1983) entered December with only one trifoliate leaf even with the grass clipped to 4 cm; clover seedlings in our study were seeded in unclipped, heavy fall residue and may have therefore fared worse if they emerged before winter, decreasing spring seedling counts, and explaining the difference in emergence counts between fall planted plots and burned plots. Winter planted plots, despite not having been burned or clipped to remove residue, may have still had less residue to constrain seedling development, as the residue in these plots was given more time to break down over winter. Two studies in North Dakota estimated native grass residue to decompose at a rate ranging from 0.99 g m^{-2} d^{-1} (Abouguendia and Whitman, 1979) to 0.57-0.86 g $[kg \times d]^{-1}$ (Joshi et al., 2019) over the winter. It is possible that decomposition of residue resulted in greater light penetration and seed-soil contact in winter plots than in fall plots, contributing to the difference in emergence. In addition to this factor, low temperatures during the winter planting may have prevented most clover seeds from germinating, allowing them to wait until temperatures warmed to emerge, improving their odds of survival over fall-seeded clover that emerged just before winter set in (Brar et al., 1991).

Greater clover emergence in drilled plots compared to broadcast plots may be a result of improved seed-soil contact resulting from the no-till drill seeding method. Research has generally found that drilling legumes results in greater emergence than broadcasting legumes, with other factors such as climatic conditions and the quantity of residue also affecting outcomes (Mueller and Chamblee, 1984; Campbell, 1985a; Campbell, 1985b; Schlueter and Tracy, 2012). Placing legume seed below the soil surface allows easier penetration of the soil by rootlets which can benefit seedling survival and accelerate root system development (Campbell, 1985a). Taylor et al. (1969) found that planting white clover seed 0.6 cm below the soil surface produced superior emergence to planting on the soil surface, and was the most important controllable factor in successful establishment when compared to tillage and herbicide use. They attributed the improved emergence to the higher stability of temperature and moisture conditions below the soil surface than on the soil surface. Mueller and Chamblee (1984) found that two to four times as many white clover and alfalfa seedlings emerged when drilled rather than broadcasted; likewise, Campbell (1985b) found that red clover drilled at 13 mm below the soil surface had greater emergence than red clover planted at 0, 26, or 39 mm below the soil surface. In contrast, Schlueter and Tracy (2012) found that red and white clover had 56% more seedlings two months after sowing when broadcast than when drilled, though this difference was not significant.

3.4.2 Stand Botanical Composition: Plant Counts

Though counts were done based on species groupings, with all grasses being counted together and all clovers being counted together, it was observed that the clover population was overwhelmingly composed of red clover, likely due to its greater height and therefore greater ability to compete in the sward. White clover, by comparison, is short in height and was therefore less able to compete with the tall-growing NWSG, and the white clover population dwindled over the course of the study. There was a significant (P = 0.0269) interaction of planting timing and planting method on clover count (Table 6). Burned broadcast plots had the greatest number of clover plants, with significantly greater clover counts than winter broadcast, winter control, fall broadcast, fall drill, and fall control, but did not differ from burn drill and winter drill. Plots with greater clover emergence (Table 6) generally had greater clover counts throughout the growing season in both years, though clover counts did differ by harvest.

There was a significant (P = 0.0012) effect of harvest on clover count (Table 7). Harvest 2 had significantly less clover plants (53.6 plants m^{-2}) than Harvest 1 (71.8 plants m^{-2}) and Harvest

3 (68.3 plants m^{-2}), which did not differ. The greater number of clover plants counted at the first and last harvests may be due to the cool-season growth pattern of red clover, where the bulk of plant growth occurs in the cooler temperatures of the early and late season, contrasting with NWSG which primarily grow in the hotter months of the year (Moore et al., 2004).

There was a significant (P = 0.0006) effect of planting timing on grass count (Table 8). Fall planted plots had significantly more grass plants (59.3 plants m^{-2}) than winter planted plots (39.7 plants m^{-2}) and burned plots (39.7 plants m^{-2}), which did not differ. There was also a significant (P = 0.0256) effect of planting method on grass count (Table 9). Control plots had significantly more grass plants (54.6 plants m^{-2}) than broadcast plots (39.6 plants m^{-2}), while drill plots were similar (44.5 plants m^{-2}) to both control plots and broadcast plots.

There was a significant effect of harvest (P < 0.0001) on weed count (Table 10). Harvest 1 had significantly more weeds (70.7 plants m^{-2}) than Harvest 3 (25.5 plants m^{-2}), which had significantly more than Harvest 2 (15 plants m^{-2}). The most common weeds observed in this study, giant ragweed (*Ambrosia trifida*), common ragweed (*Ambrosia artemisifolia* L.), and horsenettle (*Solanum carolinense*), have the ability to emerge from seed or from belowground root systems at variable times throughout the growing season, explaining an increase in numbers at Harvest 3 (Nichols et al., 1991; Schutte et al., 2012; Onen et al., 2020).

3.4.3 Stand Botanical Composition: Pre-Harvest Ground Cover

Clover Content

Stand botanical composition data, measured as ground cover by species through the occupancy grid method, was recorded before each harvest. Data was separated based on the year of production for the plot sets and compared based on the season (spring or fall, or the first and last harvests respectively) in order to evaluate how the stand composition changed over the establishment year and in the second year of production.

In the establishment year, there was a significant (P = 0.0006) interaction of planting method and season of harvest on clover cover (Table 11). Drill-planted plots harvested in the fall had significantly greater clover content than any treatment combination (28.6%), while control plots (1.5%) and broadcast plots (2.1%) harvested in the spring had the lowest clover ground cover. Across seeding methods, all fall harvests had numerically greater clover content than all spring harvests. Within harvest seasons, drill-seeded plots had numerically greater clover content than broadcast seeded plots, which in turn had numerically greater clover content than control plots. The differences in establishment year clover content by seeding method may be attributed to the differences in emergence rate while the greater clover content in fall harvested plots over spring harvested plots may reflect an increase in clover content over the course of the season as the interseeded forage established itself in the stand.

There was also a significant interaction (P < 0.0001) of planting timing and season of harvest on clover content in the establishment year (Table 12). Burned plots harvested in the fall had a greater clover content than any treatment combination (33.2%), followed by winter plots harvested in the fall (13.7%). This followed the trend of burned and winter planted plots producing more clover than fall planted plots, and the trend of fall harvests having a greater clover content in the establishment year than spring harvests.

In the second year of production, there was a significant (P = 0.0433) interaction of planting timing, planting method, and season of harvest on clover content (Table 13). Broadcast-seeded, burned plots harvested in the spring (92.7%) and drill-seeded burned plots harvested in the fall (92.3%) had greater clover content than all non-burned plots. Clover was so dominant in burn plots that it maintained about 90% ground cover regardless of season in drilled and broadcasted plots. Winter-seeded plots that were drill-seeded or broadcast-seeded had a clover content intermediate burned and fall-seeded plots, ranging from 43% in broadcast-seeded spring harvests to 68% in drill-seeded fall harvests. Winter control plots and all fall-planted plots did not differ from one another and had low clover content (<8%) at spring and fall harvests. In contrast, burned control plots, which were unseeded, had a clover content of 64.7% at spring harvest and 80.7% at fall harvest. This suggests that burning NWSG stands with a red clover seedbank may allow large quantities of the legume to emerge in the stand. This effect has been observed before. In Kansas, Towne and Knapp (1996) found that burning tallgrass prairie composed of BB, IG, and LB increased legume density to 8 stems m^{-2}, compared to 3 stems m^{-2} in the unburned control, though legume biomass did not change.

Grass Content

In the establishment year, there was a significant (P = 0.0003) interaction of planting timing and season of harvest on grass content (Table 14). Burned plots harvested in the spring had a grass content of 74.8%, and fell to 51.5% by the end of the season due to an increasing clover fraction of the stand. Winter-planted plots saw a less dramatic fall from 76.2% in the spring to 68.6% in the fall, and fall-planted plots did not change significantly from spring (80.2%) to fall (78.3%).

In the establishment year there was also a significant interaction (P = 0.0089) of planting method and season of harvest on grass content (Table 15). Drill-seeded plots harvested in the spring had a grass cover of 75.6% which fell to 56.8% by the fall, while broadcast-seeded plots only fell from 79.6% in the spring to 67.8% in the fall; the change was due to an increasing proportion of clover in the stand. Control plots did not change significantly between spring (76.1%) and fall (73.8%).

In the second year of production there was a significant (P = 0.0227) interaction of planting timing, planting method, and harvest on grass content (Table 16). Fall-seeded plots generally had a high grass content ranging from 79.3 to 87.7%, while burned plots generally had much lower grass content, with burned control plots having the highest value at 33.7% grass in the spring; drill-seeded, burned plots harvested in the fall had a grass content of 1%. Winter-seeded plots were more variable and more influenced by seeding method and season of harvest; winter-seeded control plots had a grass content of 88% in the fall, while drill-seeded plots had a grass content of 23.3% in the fall.

3.4.4 Stand Botanical Composition: Post-Harvest Ground Cover

Clover Content

Stand botanical composition data, measured as cover by species through the occupancy grid method, was also recorded after each harvest. Data was again separated based on the year of production for each plot and for the season of harvest to track changes in stand composition over the course of the study. In the establishment year, there was a significant (P = 0.0003) interaction of planting timing and planting method on clover content (Table 17). Following the same trend as the pre-harvest botanical composition data, drill-seeded burned plots had the greatest clover content (31.2%), followed by broadcast-seeded burned plots (19.2%) and drill-seeded winter plots (18.4%), which did not differ. Fall-seeded plots and control plots had the lowest clover content. In the establishment year, there was also a significant (P < 0.0001) interaction of planting timing and season of harvest on clover content (Table 18). Fall harvests had greater clover content than spring harvests and burned plots had greater clover content than all others in a given season, continuing the trend observed in pre-harvest data.

In the second year of production there was a significant (*P* = 0.0050) interaction of planting timing and planting method on clover content (Table 19). Burned plots had greater clover content than winter plots, which generally had greater clover content than fall plots. Winter control plots and fall control plots did not differ. Drill-seeded and broadcast-seeded plots had similar clover content within any given timing of planting, suggesting that differences in initial emergence and establishment year stand counts between drilled clover and broadcasted clover may disappear over time. Mueller and Chamblee (1984) found that no-till drilling ladino clover and alfalfa into tall fescue produced two to four times greater initial plant counts compared to broadcast seeding, but that equally dense stands developed over time.

In the second year of production there was also a significant (*P* = 0.0359) interaction of planting timing and season of harvest on clover content (Table 20). Reflecting trends observed in pre-harvest plant composition data, burned plots had greater clover content than winter plots regardless of harvest, and winter plots had greater clover content than fall plots. Fall harvests for burned and winter plots had lower clover content than spring harvests, while clover content did not differ by harvest for fall plots.

Grass Content

In the establishment year, there was a significant (*P* < 0.0001) interaction of planting timing and season of harvest on grass content (Table 18). Burned plots saw their grass content fall from 48.7% in the spring to 37.0% in the fall, a change which may be attributed to an increase in clover content from 11.3% in the spring to 28.1% in the fall (Table 18). Winter plots did not see a change in grass from spring (40.3%) to fall (42.6%), while clover content still managed to rise from 6.2% to 12.9%. Fall plots did not change in terms of grass content or clover content between spring and fall.

In the establishment year, there was also a significant (*P* = 0.0003) interaction of planting method and season of harvest on grass content (Table 22). Broadcast and control grass content did not differ between spring and fall harvests, while drill-seeded plots declined in grass content from 46.1% in the spring to 36.0% in the fall, reflecting the greater emergence of clover in drilled plots than broadcast or control plots.

Weed Content

In the second year of production of Plot Set 1, there was a significant (*P* = 0.0009) interaction of planting timing and harvest season on weed content (Table 23). Weed content increased in winter plots from 1.4% in the spring to 4.4% in the fall, while weed content increased in fall plots from 0.4% in the spring to 7.3% in the fall. Burned plots did not change in weed content from spring (0.3%) to fall (0.6%). The greater clover content in burned plots may have contributed to a weed suppression effect, as the early growth and canopy closure of red clover would allow clover-dominated plots to shade out weeds earlier in the year than NWSG-dominated plots, reducing weed content later in the season.

Bare Ground

In the second year of production of Plot Set 1, there was a significant (*P* = 0.0001) interaction of planting timing and harvest season on the proportion of bare ground (Table 23). Fall plots had a consistently greater proportion of bare ground in post-harvest measurements, staying similar from spring (43.6%) to fall (40.0%). Contrasting fall plots, burned plots started the season with the lowest proportion of bare ground of all treatments at 10.1% in the spring, which increased to 29.0% by the fall. The higher proportion of bare ground in fall plots compared to burn plots may be attributable to a lack of clover to contribute ground cover between grass crowns, causing the stand to have more exposed ground following harvest. Winter plots began the season with a lower proportion of bare ground than fall plots at 29.8% in the spring, but by the fall they did not differ from fall plots at 42.7%.

3.4.5 Stand Botanical Composition: Biomass

There was a significant ($P = 0.0026$) interaction of planting timing and planting method on the grass proportion of stand biomass (Table 24). Burned and winter-seeded plots that were drilled or broadcasted had the lowest grass biomass (31.1-38.7%) and did not differ. Fall seeded plots had higher grass biomass; fall-seeded drilled plots had 86% grass biomass and fall control plots had 82.3% grass biomass. In comparison, fall-seeded broadcast plots only had 62.7% grass biomass due to a greater clover content (Table 26) than other fall plots. Broadcast seeding produced more clover in fall plots than drill seeding. There was a significant ($P < 0.0001$) interaction of year and harvest season on the grass portion of stand biomass (Table 25). Grass content declined from 86.7% of biomass in spring of the first year to 68.9% in the fall, as clover content increased. In the second year, grass content rose from 31.2% in the spring to 40.7% in the fall.

There was also a significant ($P < 0.0001$) interaction of year, planting timing, and planting method on the clover portion of stand biomass (Table 26). Burned plots and winter-seeded plots had a significant increase in clover biomass from the first to the second year. Burned control plots, despite not being seeded, increased in clover percentage of biomass from 13.2% in the first year to 75.9% in the second year. Fall-seeded drill and control plots did not increase in clover biomass, but fall-seeded broadcast plots did increase from 4.1% in the first year to 38.9% in the second. There was also a significant ($P = 0.0006$) interaction of year and harvest season on the clover portion of stand biomass (Table 25). Clover biomass increased significantly in the first year from

4.4% in the spring to 21.1% in the fall. In the second year, clover biomass did not differ by season, with a value of 53.9% in the spring and 56.6% in the fall.

There was a significant (P = 0.0472) interaction of year, planting timing, and planting method on the weed portion of stand biomass (Table 27). Burned treatments had numerical declines in weed biomass from the already low establishment year weed biomass. Winter-seeded drill plots had a significant decline in weed percentage of biomass, from 18.0% in the first year to 5.8% in the second year. Winter-seeded broadcast plots had a large numerical decline from 17.6% to 6.3%. Fall seeded plots did not change in weed biomass, and winter control and fall control plots had significant increases in weed biomass. Winter-seeded plots likely had the greatest decline in weed biomass from the first to the second year because clover did not establish as quickly in the first year in winter plots as it did in burned plots; therefore, the dominance of clover in the second year placed greater competitive pressure on weed populations, causing a decline in weeds as a proportion of biomass. There was also a significant (P = 0.0008) interaction of year and harvest season on the weed proportion of stand biomass (Table 25). Weed biomass remained constant in the first year between spring and fall. In the second year weed biomass declined from 15% in the spring to 2.7% in the fall.

3.4.6 Whole Plot Nutritive Value

In the establishment year, there was a significant (P = 0.0002) interaction of planting timing and season of harvest on whole plot CP content (Table 28). In the spring, winter and fall planted plots had similar whole plot CP contents of 122 g kg^{-1} and 123 g kg^{-1} respectively. By the fall, winter and fall planted plots had declined in CP content to the similar values of 101 g kg^{-1} and 93 g kg^{-1} respectively. In contrast, burned plots started the year with a lower CP content than winter and fall plots, at 115 g kg^{-1}, and maintained it through the fall harvest with a value of 114 g kg^{-1}.

The decline in nutritive value among winter and fall plots may be explained by the greater proportion of NWSG in these plots in the establishment year. Native warm-season grasses decline in CP content and increases in NDF and ADF content as it matures, decreasing the nutritive value of the forage (McIntosh et al., 2016). The increase in clover content over the course of the establishment year in burned plots (Table 18) may have offset the decline in CP content in NWSG, allowing these plots to maintain a consistent CP content throughout the season.

In the establishment year, there was also a significant ($P = 0.0005$) interaction of planting timing and season of harvest on whole plot NDF content (Table 28). Winter plots had a numerical increase in NDF content from 603 g kg^{-1} in the spring to 616 g kg^{-1} in the fall, though these values did not differ. Fall plots also had a numerical increase in NDF content, from 617 g kg^{-1} in the spring to 636 g kg^{-1} in the fall. In contrast, burned plots had a decline in NDF content from 609 g kg^{-1} in the spring to 576 g kg^{-1} in the fall. This may be attributed to an increase in clover content over the course of the establishment year (Table 18).

In the establishment year, there was a significant effect ($P < 0.0001$) of season of harvest on whole plot ADF content (Table 29). Plots had greater ADF content in the spring (329 g kg^{-1}) than in the fall (365 g kg^{-1}), as would be expected in a maturing stand of NWSG.

In the second year of production there was a significant ($P = 0.0286$) interaction of planting method and season of harvest on whole plot CP content (Table 30). Plots were similar in CP content in spring across seeding methods. Drill-seeded plots had a relatively modest drop in CP content over the course of the season, from 145 g kg^{-1} in the spring to 132 g kg^{-1} in the fall. In contrast, broadcast plots declined from 147 g kg^{-1} in the spring to 117 g kg^{-1} in the fall, and control plots declined from 148 g kg^{-1} in the spring to 114 g kg^{-1} in the fall. As a result, drill-seeded plots had greater CP content than broadcast-seeded or control plots in the fall. This may be attributed to greater clover content in drill-seeded plots maintaining a higher CP content over the course of the season (Table 13).

In the second year of production there was a significant (P = 0.0001) interaction of planting timing and season of harvest on whole plot CP content (Table 31). Burned plots retained a similar CP content over the course of the season, changing from 152 g kg^{-1} in the spring to 149 g kg^{-1} in the fall. In contrast, winter-seeded plots declined from 148 g kg^{-1} in the spring to 115 g kg^{-1} in the fall, and fall-seeded plots declined from 139 g kg^{-1} to 99 g kg^{-1}. This reflects the trend of plots with greater clover content to retain a higher CP content in comparison to plots with greater NWSG content.

In the second year of production there was a significant (P = 0.0357) interaction of planting timing and season of harvest on whole plot NDF content (Table 31). Burned plots had a lower NDF content than winter and fall plots for the entire season, increasing from 440 g kg^{-1} in the spring to 468 g kg^{-1} in the fall. Winter plots increased from 509 g kg^{-1} to 582 g kg^{-1} and fall plots increased from 561 g kg^{-1} to 636 g kg^{-1}, the highest of any treatment combination.

In the second year of production there was a significant effect (P < 0.0001) of season of harvest on whole plot ADF content (Table 32). Plots had a lower ADF content when harvested in the spring (340 g kg^{-1}) than in the fall (366 g kg^{-1}).

Treatments that had greater CP content and lower NDF content generally had the greatest clover emergence and subsequently the greatest clover content throughout the experiment (Table 5 and Table 26). It has been observed that the addition of legumes to NWSG stands may improve forage nutritive value, and this is often a key motivating factor when interseeding legumes (Posler et al., 1993; Springer et al., 2001; Biligetu et al., 2014). Posler et al. (1993) found that July harvested IG had a mean CP content of 32 g kg^{-1} over two years; in comparison, a mixture of roundhead lespedeza (*Lespedeza capitata* Michx.) and IG had a CP content of 68 g kg^{-1}, and a mixture of Illinois bundleflower (*Desmanthus illinoensis* [Michx.] Macmill., B. Robbins. & Fern.) and IG had a CP content of 77 g kg^{-1}, with the legumes comprising 56 and 77% of the stand, respectively. Similarly, Springer et al. (2001) found that BB alone had a mean CP content of 58 g kg^{-1} over two years while a mixture of BB with Illinois bundleflower had a CP content of 74.5 g kg^{-1}. Biligetu et al. (2014) found that a BB monoculture had an NDF content of 574 g kg^{-1} compared to a BB-alfalfa (*Medicago sativa* L.) mixture NDF content of 478 g kg^{-1}; additionally, the BB monoculture CP content of 69 g kg^{-1} rose to 107 g kg^{-1} in mixture with alfalfa.

3.4.7 Total Seasonal Yield

Total seasonal yield did not differ among treatments in 2022 for Plot Set 1, and did not differ in 2023 for Plot Set 2; for each plot set this was the establishment year. There was a significant effect of both planting timing (P = 0.0068) and of planting method (P = 0.0122) on total seasonal yield in 2023 for Plot Set 1, the second growing season for that plot set (Table 33 and Table 34, respectively). Burn plots yielded less (5,757 kg ha^{-1}) than both winter (7,259 kg ha^{-1}) and fall (7,599 kg ha^{-1}) plots, which did not differ. Control plots yielded more (7,619 kg ha^{-1}) than both drill (6,574 kg ha^{-1}) and broadcast (6,422 kg ha^{-1}) plots, which did not differ.

Lower seasonal yields in burned plots and in drilled and broadcasted plots may be explained by the greater proportion of clover that emerged and remained in those plots for the duration of the study, resulting in domination by red clover (Table 5 and Table 26). Cool-season legumes have the potential to outcompete warm-season grasses when planted in mixture due to their earlier initiation of growth in the spring. In Kansas, Posler et al. (1993) found that cicer milkvetch (*Astragalus cicer* L.) was capable of completely closing a canopy over IG and forming a milkvetch monoculture, producing over 90% of the forage in the stand. In Tennessee, Keyser et al. (2016b) observed interseeded red clover grow taller than a BB+IG blend by early May; this competition led to an earlier cessation of grazing than in previous years due to a drop in sward height, and to reduced grass cover after grazing had stopped. In an earlier study, George et al. (1995) managed this risk by defoliating plots in early June to open the red clover canopy and allow SG to remain competitive in the stand. Despite harvesting in early June in 2023, red clover continued to dominate the burned, drilled, and broadcast plots of Plot Set 1, possibly because BB, LB, and IG do not grow as tall as SG. Lending credence to this explanation, Keyser et al. (2016b) did not observe red clover achieve dominance in SG stands but did observe red clover achieve dominance in BB+IG stands, suggesting that these grasses may be more vulnerable to competition with red clover.

There are possible methods for mitigating red clover dominance when interseeding in NWSG swards. Given the dominance of red clover in burned plots in this study, allowing residue to remain on the soil surface would likely slow clover establishment, permitting NWSG to initiate growth unimpeded. Decreasing the seeding rate of red clover would naturally limit the amount of red clover that can establish, decreasing the likelihood of red clover dominance. As mentioned previously, George et al. (1995) managed red clover in NWSG through defoliation, which failed to control red clover in this study. Though the method of defoliation may play a role in shaping the relative dominance of species in a forage mixture, the study by Keyser et al. (2016b) makes it apparent that either mechanical clipping or grazing may result in NWSG pasture dominated by red clover. Keyser et al. (2016b) interseeded red clover into a BB+IG mixture and stocked the pasture with bred heifers; despite the ability of cattle to selectively graze the palatable and nutritious legumes in the forage mixture, competition from red clover still resulted in an earlier cessation of grazing than normal and reduced NWSG cover.

3.4.8 Harvest Yield

In the establishment year of each plot set, harvest yield did not differ by any treatment, though they did differ by harvest season ($P < 0.0001$) (Table 35). Harvest yields in spring (3,478 kg ha^{-1}) were greater than harvest yields in fall (2,872 kg ha^{-1}), perhaps influenced by ample rain in May and a shortfall of precipitation in June and July in 2022 (Table 2) and consequently an insufficiently long rest period following the first harvest in 2022.

In the second year of production for Plot Set 1, there was a significant ($P < 0.0001$) interaction of planting timing and season of harvest (Table 36). Fall-seeded plots harvested in the fall had greater yields than all other treatments at 4,666 kg ha^{-1}, while fall-seeded plots harvested in the spring yielded only 2,933 kg ha^{-1}, suggesting that the bulk of forage production in these grass-dominated plots occurred after the spring harvest due to their warm-season nature. In contrast, burned plots harvested in the fall yielded only 2,312 kg ha^{-1}, a significant decline from a spring harvest of 3,446 kg ha^{-1}, suggesting that the bulk of forage production in these red clover-dominated plots occurred before the spring harvest due to their cool-season nature. Winter-seeded plots did not differ significantly between spring (3,395 kg ha^{-1}) and fall (3,864 kg ha^{-1}) harvests, suggesting that the intermediate clover content of these plots resulted in a more balanced distribution of forage production throughout the season, which is one of the key benefits that interseeding legumes in NWSG is intended to provide. This benefit is further underlined by the lack of difference between grass-dominated fall plots and mixed species winter plots in terms of total seasonal yield (Table 33).

In the second year of production for Plot Set 1, there was also a significant (*P* = 0.0207) interaction of planting method and season of harvest (Table 37). Control plots harvested in the fall had greater yields (4,396 kg ha^{-1}) than all other treatments, which did not differ (mean 3,244 kg ha^{-1}). This is attributable to the greater productivity of NWSG-dominated plots in the latter half of the season in comparison to plots with a greater proportion of clover.

In the second year of production for Plot Set 1, there was a significant (*P* = 0.0470) interaction of planting timing and planting method (Table 38). Burned plots had numerically lower yields than all other treatments regardless of planting method, ranging from 2,730 to 3,046 kg ha^{-1}, and significantly lower yields than winter control, fall control, and fall-drilled plots which ranged from 3994 to 4389 kg ha^{-1}. This difference follows the trend of legume dominated plots yielding less than plots with a greater proportion of NWSG.

Conclusion

In conclusion, the timing of planting, the method of planting, and the burning of residue have a significant effect on the establishment of legumes in NWSG. No-till drilling consistently produced greater initial stands of clover than broadcast seeding, but both methods produced dense stands of clover in the second year when planted in the winter. Burning residue aided in the establishment of clovers, and permitted volunteer clover to emerge in significant quantities when no seed was planted. The dominance of clover in the second year resulted in a reduced total seasonal yield for burned, drilled, and broadcasted plots, through excessive competition with NWSG. Though interseeding legumes may be done in order to improve the seasonal distribution of forage production, excessive clover populations in burned plots simply skewed forage production toward the beginning of the season rather than the end. Winter-planted plots that were not burned were often intermediate to burned and fall-planted plots in clover content, resulting in a more balanced forage distribution than in the other treatments. Plots with large quantities of clover sustained a higher CP content and a lower NDF, avoiding the significant drop in nutritive value that maturing NWSG undergo. The results suggest that red clover has the potential to outcompete big bluestem, Indiangrass, and little bluestem when interseeded, with the negative impact on forage yield and late-season forage production outweighing the positive impact on forage nutritive value.

Continued research should focus on the further optimization of establishment and the evaluation of legumes that will compliment rather than dominate NWSG stands. Legumes should be evaluated for beneficial traits, such as their ability to improve the nutritive value of the stand, their ability to improve the distribution of forage availability throughout the season, their ability to suppress weeds, and their availability to improve forage yields. Compatible legumes should be able to provide important benefits such as these or others to a stand of NWSG without harming the health of the stand through excessive competition, as red clover did, or failing to persist when grown in mixture with NWSG, as white clover did. Producers intending on interseeding legumes in NWSG should consider the compatibility of the species involved, which may be influenced by factors such as plant height and the timing of the initiation of growth. Taller legumes may compete more aggressively in the stand, and the earlier initiation of spring growth characteristic of cool-season legumes may allow them to outcompete still-dormant NWSG. The potential for legumes to outcompete NWSG may be mitigated by leaving plant residue on the soil surface before seeding, reducing legume seeding rates, and allowing heavy defoliation of legumes early in the season to maintain the competitiveness of NWSG.

Tables

Table 1. Soil chemical attributes of plot set areas at the Southern Piedmont Agricultural Research and Education Center in Blackstone, VA.

Year	Plot Set	pH		OM	P[3]	K	Ca	Mg
		water[1]	buffer[2]	g kg^{-1}	-----------------------	kg ha^{-1}	----------------------	
2021	1	6.49	6.32	39	52	300	1984	296
2022	2	6.28	6.28	34	34	234	1888	284

[1]Soil pH determined in 3 M KCl solution
[2]Buffer pH determined with Melich buffer
[3]P, K, Ca, and Mg extracted with Melich 1 solution.

Table 2. Summary of monthly total precipitation (cm), maximum and minimum daily temperatures (°C), and average daily temperature (°C) in 2021, 2022, and 2023 at the Southern Piedmont Agricultural Research and Education Center in Blackstone, VA.

Month	Total Precipitation				Temperature (Min./Max.)			Temperature (Average)			
	2021	2022	2023	30-yr mean	2021	2022	2023	2021	2022	2023	30-yr mean
	----------------	cm	----------------		---------------------------			°C	-----------------------------		
January	8.4	8.4	9.4	9.3	-1/8	-3/8	3/13	3	2	7	4
February	11.7	5.7	5.8	7.9	0/8	1/14	4/16	4	7	11	6
March	9.6	13.2	4.9	10.6	5/17	5/18	4/16	11	11	10	9
April	4.3	5.8	16.6	9.8	8/22	8/21	10/22	15	15	16	15
May	6.3	17.3	8.1	11	12/25	14/25	12/23	18	20	17	19
June	14.2	2.3	15.5	10.8	19/29	18/30	16/28	23	24	21	23
July	19.5	5.7	19.7	12.1	20/31	21/33	21/31	25	26	26	25
August	17.7	24.7	12.1	10.6	21/31	20/30	20/30	25	24	24	25
September	11.2	6.8	16.9	12.5	16/27	16/28	16/26	23	21	21	21
October	8.4	5.9	3.6	10	13/24	8/20	10/23	17	14	16	15
November	0.6	9.9	-	7.6	3/15	6/17	-	9	11	-	10
December	3.2	12.4	-	9.6	5/16	0/9	-	10	4	-	6
Total	115.1	118.1	112.6	121.8							

Table 3. Fall planting, burning, and winter planting dates for each plot set in Blackstone, VA.

Plot set	Fall Plant	Burn	Winter Plant
1	25 October, 2021	13 January, 2022	2 March, 2022
2	20 October, 2022	7 February, 2023	28 February, 2023

Table 4. Harvest dates for each plot set in 2022 and 2023 in Blackstone, VA.

Year	Plot set	Harvest 1 date	Harvest 2 data	Harvest 3 date
2022	1	20 May	30 June	6 Sept.
2023	1	1 June	2 Aug.	-
2023	2	5 June	7 Aug.	-

Table 5. Effect of planting timing x planting method interaction (*P* < 0.0001) on clover emergence (plants m^{-2}) within NWSG averaged over 2022 and 2023 in Blackstone, VA.

Timing	Clover Emergence (plants m^{-2})					
	Method					
	Drill	SE	Broadcast	SE	Control	SE
Burn	235.5 a[1]	16.4	133.2 bc	16.4	51.1 de	16.4
Winter	145.9 b	16.4	95.3 cd	16.4	19.1 e	16.4
Fall	18.0 e	16.4	10.5 e	16.4	7.0 e	16.4

[1]Data with the same letter are not significantly different at the *P* < 0.05 level

Table 6. Effect of planting timing x planting method interaction (*P* = 0.0269) on clover count (plants m^{-2}) within NWSG averaged over 2022 and 2023 in Blackstone, VA.

Timing	Clover Count (plants m^{-2})					
	Method					
	Drill	SE	Broadcast	SE	Control	SE
Burn	120.3 ab[1]	14.3	133.1 a	14.3	87.4 bc	14.3
Winter	102.4 abc	14.3	83.6 c	14.3	13.0 d	14.3
Fall	10.4 d	14.3	25.5 d	14.3	5.5 d	14.3

[1]Data with the same letter are not significantly different at the *P* < 0.05 level

Table 7. Effect of harvest (*P* = 0.0012) on clover count (plants m^{-2}) within NWSG averaged over 2022 and 2023 in Blackstone, VA.

Harvest	Grass Count	
	plants m^{-2}	SE
1	71.8 a[1]	8.17
2	53.6 b	7.05
3	68.3 a	9.63

[1]Data with the same letter are not significantly different at the *P* < 0.05 level

Table 8. Effect of planting timing (P = 0.0006) on grass count (plants m^{-2}) within NWSG averaged over 2022 and 2023 in Blackstone, VA.

Timing	Grass Count	
	plants m^{-2}	SE
Burn	39.7 b[1]	11.2
Winter	39.7 b	11.2
Fall	59.3 a	11.2

[1]Data with the same letter are not significantly different at the P < 0.05 level

Table 9. Effect of planting method (P = 0.0256) on grass count (plants m^{-2}) within NWSG averaged over 2022 and 2023 in Blackstone, VA.

Method	Grass Count	
	plants m^{-2}	SE
Drill	44.5 ab[1]	11.2
Broadcast	39.6 b	11.2
Control	54.6 a	11.2

[1]Data with the same letter are not significantly different at the P < 0.05 level

Table 10. Effect of harvest (P < 0.0001) on weed count (plants m^{-2}) within NWSG averaged over 2022 and 2023 in Blackstone, VA.

Harvest	Grass Count	
	plants m^{-2}	SE
1	70.7 a[1]	15.2
2	15.0 c	6.9
3	25.5 b	7.8

[1]Data with the same letter are not significantly different at the P < 0.05 level

Table 11. Effect of planting method x harvest season interaction (P = 0.0006) on pre-harvest clover ground cover (%) within NWSG in the establishment year of Plot Set 1 (2022) and Plot Set 2 (2023) in Blackstone, VA.

Harvest Season	Clover Cover (%)					
	Method					
	Drill	SE	Broadcast	SE	Control	SE
Spring	5.6 c[1]	1.1	2.1 d	1.1	1.5 d	1.1
Fall	28.6 a	3.1	14.8 b	3.1	8.6 bc	3.1

[1]Data with the same letter are not significantly different at the P < 0.05 level

Table 12. Effect of planting timing x harvest season interaction ($P < 0.0001$) on pre-harvest clover ground cover (%) within NWSG in the establishment year of Plot Set 1 (2022) and Plot Set 2 (2023) in Blackstone, VA.

Harvest Season	Clover Cover (%)					
	Timing					
	Burn	SE	Winter	SE	Fall	SE
Spring	5.9 c[1]	1.1	3.0 d	1.1	0.2 d	1.1
Fall	33.2 a	3.1	13.7 b	3.1	5.1 cd	3.1

[1]Data with the same letter are not significantly different at the $P < 0.05$ level

Table 13. Effect of planting timing x planting method x harvest season interaction ($P = 0.0433$) on pre-harvest clover ground cover (%) within NWSG in the second year of production of Plot Set 1 (2023) in Blackstone, VA.

Timing	Harvest Season	Clover Cover (%)					
		Method					
		Drill	SE	Broadcast	SE	Control	SE
Burn	Spring	90.3 ab[1]	8.4	92.7 a	8.4	64.7 cde	8.4
	Fall	92.3 a	8.2	88.7 ab	8.2	80.7 abc	8.2
Winter	Spring	62.3 cde	8.4	43.0 e	8.4	6.3 f	8.4
	Fall	68.0 bcd	8.2	56.0 de	8.2	2.7 f	8.2
Fall	Spring	7.3 f	8.4	4.7 f	8.4	4.3 f	8.4
	Fall	3.7 f	8.2	6.7 f	8.2	1.0 f	8.2

[1]Data with the same letter are not significantly different at the $P < 0.05$ level

Table 14. Effect of planting timing x harvest season interaction ($P = 0.0003$) on pre-harvest grass ground cover (%) within NWSG in the establishment year of Plot Set 1 (2022) and Plot Set 2 (2023) in Blackstone, VA.

Harvest Season	Grass Cover (%)					
	Timing					
	Burn	SE	Winter	SE	Fall	SE
Spring	74.8 ab[1]	3.0	76.2 a	3.0	80.2 a	3.0
Fall	51.5 c	3.1	68.6 b	3.1	78.3 a	3.1

[1]Data with the same letter are not significantly different at the $P < 0.05$ level

Table 15. Effect of planting method x harvest season interaction (P = 0.0089) on pre-harvest grass ground cover (%) within NWSG in the establishment year of Plot Set 1 (2022) and Plot Set 2 (2023) in Blackstone, VA.

Harvest Season	Grass Cover (%)					
	Method					
	Drill	SE	Broadcast	SE	Control	SE
Spring	75.6 ab[1]	3.0	79.6 a	3.0	76.1 a	3.0
Fall	56.8 c	3.1	67.8 b	3.1	73.8 ab	3.1

[1]Data with the same letter are not significantly different at the P < 0.05 level

Table 16. Effect of planting timing x planting method x harvest season interaction (P = 0.0227) on pre-harvest grass ground cover (%) within NWSG in the second year of production of Plot Set 1 (2023) in Blackstone, VA.

Timing	Harvest Season	Grass Cover (%)					
		Method					
		Drill	SE	Broadcast	SE	Control	SE
Burn	Spring	7.7 de[1]	7.7	6.0 de	7.7	33.7 bc	7.7
	Fall	1.0 e	7.6	3.3 de	7.6	14.0 cde	7.6
Winter	Spring	33.7 bc	7.7	52.3 b	7.7	84.3 a	7.7
	Fall	23.3 cd	7.6	33.3 c	7.6	88.0 a	7.6
Fall	Spring	81.7 a	7.7	87.7 a	7.7	84.7 a	7.7
	Fall	86.7 a	7.6	79.3 a	7.6	84.7 a	7.6

[1]Data with the same letter are not significantly different at the P < 0.05 level

Table 17. Effect of planting timing x planting method interaction (P = 0.0003) on post-harvest clover ground cover (%) within NWSG in the establishment year of Plot Set 1 (2022) and Plot Set 2 (2023) in Blackstone, VA.

Timing	Clover Cover (%)					
	Method					
	Drill	SE	Broadcast	SE	Control	SE
Burn	31.2 a[1]	2.4	19.2 b	2.4	8.3 c	2.4
Winter	18.4 b	2.4	7.8 cd	2.4	2.3 cd	2.4
Fall	1.1 d	2.4	1.8 cd	2.4	1.0 d	2.4

[1]Data with the same letter are not significantly different at the P < 0.05 level

Table 18. Effect of planting timing x harvest season interaction on post-harvest clover ground cover (%) ($P < 0.0001$) and on post-harvest grass ground cover (%) ($P < 0.0001$) within NWSG in the establishment year of Plot Set 1 (2022) and Plot Set 2 (2023) in Blackstone, VA.

Timing	Harvest Season	Component Cover (%)			
		Species			
		Grass	SE	Clover	SE
Burn	Spring	48.7 a[1]	1.6	11.3 b	0.9
	Fall	37.0 c	2.2	28.1 a	2.4
Winter	Spring	40.3 c	1.6	6.2 c	0.9
	Fall	42.6 bc	2.2	12.9 b	2.4
Fall	Spring	44.8 b	1.6	0.7 d	0.9
	Fall	47.0 ab	2.2	1.9 cd	2.4

[1]Data with the same letter within the same column are not significantly different at the $P < 0.05$ level

Table 19. Effect of planting timing x planting method interaction ($P = 0.0050$) on post-harvest clover ground cover (%) within NWSG in the second year of production of Plot Set 1 (2023) in Blackstone, VA.

Timing	Clover Cover (%)					
	Method					
	Drill	SE	Broadcast	SE	Control	SE
Burn	84.5 a	6.2	76.7 a	6.2	40.0 b	6.2
Winter	49.2 b	6.2	34.3 b	6.2	2.7 c	6.2
Fall	2.5 c	6.2	2.3 c	6.2	1.8 c	6.2

[1]Data with the same letter are not significantly different at the $P < 0.05$ level

Table 20. Effect of planting timing x harvest season interaction ($P = 0.0359$) on post-harvest clover ground cover (%) within NWSG in the second year of production of Plot Set 1 (2023) in Blackstone, VA.

Harvest Season	Clover Cover (%)					
	Timing					
	Burn	SE	Winter	SE	Fall	SE
Spring	72.3 a	4.8	35.6 c	4.8	2.0 e	4.8
Fall	61.8 b	3.3	21.9 d	3.3	2.4 e	3.3

[1]Data with the same letter are not significantly different at the $P < 0.05$ level

Table 21. Effect of planting timing x harvest season interaction ($P < 0.0001$) on post-harvest grass ground cover (%) within NWSG in the establishment year of Plot Set 1 (2022) and Plot Set 2 (2023) in Blackstone, VA.

Harvest Season	Grass Cover (%)					
	Timing					
	Burn	SE	Winter	SE	Fall	SE
Spring	48.7 a	1.6	40.3 c	1.6	44.8 b	1.6
Fall	37.0 c	2.2	42.6 bc	2.2	47.0 ab	2.2

[1]Data with the same letter are not significantly different at the $P < 0.05$ level

Table 22. Effect of planting method x harvest season interaction ($P = 0.0003$) on post-harvest grass ground cover (%) within NWSG in the establishment year of Plot Set 1 (2022) and Plot Set 2 (2023) in Blackstone, VA.

Harvest Season	Grass Cover (%)					
	Method					
	Drill	SE	Broadcast	SE	Control	SE
Spring	46.1 a	1.6	43.6 a	1.6	44.1 a	1.6
Fall	36.0 b	2.2	43.6 a	2.2	47.1 a	2.2

[1]Data with the same letter are not significantly different at the $P < 0.05$ level

Table 23. Effect of planting timing x harvest season interaction on post-harvest clover ground cover (%) ($P = 0.0359$), on post-harvest grass ground cover (%) ($P = 0.4305$), on post-harvest weed ground cover (%) ($P = 0.0009$), and on post-harvest bare ground (%) ($P = 0.0001$) in the second year of production of Plot Set 1 (2023) in Blackstone, VA.

Timing	Harvest Season	Component Cover (%)							
		Species							
		Grass	SE	Clover	SE	Weeds	SE	Bare Ground	SE
Burn	Spring	17.2 c[1]	3.2	72.3 a	4.8	0.3 b	0.8	10.1 c	2.3
	Fall	8.7 d	3.3	61.8 b	3.3	0.6 b	1.2	29.0 b	2.2
Winter	Spring	33.2 b	3.2	35.6 c	4.8	1.4 b	0.8	29.8 b	2.2
	Fall	31.0 b	3.3	21.9 d	3.3	4.4 a	1.2	42.7 a	2.2
Fall	Spring	54.0 a	3.2	2.0 e	4.8	0.4 b	0.8	43.6 a	2.2
	Fall	50.2 a	3.3	2.4 e	3.3	7.3 a	1.2	40.0 a	2.2

[1]Data with the same letter within the same column are not significantly different at the $P < 0.05$ level

Table 24. Effect of planting timing x planting method interaction (P = 0.0026) on the grass proportion of biomass (%) within NWSG in Blackstone, VA.

Timing	Biomass Proportion (%)					
	Method					
	Drill	SE	Broadcast	SE	Control	SE
Burn	37.4 cd	6.5	38.7 cd	6.5	52.0 bc	6.5
Winter	31.1 d	6.5	38.2 cd	6.5	83.0 a	6.5
Fall	86.4 a	6.5	62.7 b	6.5	82.3 a	6.5

[1]Data with the same letter are not significantly different at the P < 0.05 level

Table 25. Effect of year x harvest season interaction on the grass proportion of biomass (%) (P < 0.0001), on the clover proportion of biomass (%) (P = 0.0006), and on the weed proportion of biomass (%) (P = 0.0008) within NWSG in Blackstone, VA.

Year	Harvest Season	Biomass Proportion (%)					
		Species					
		Grass	SE	Clover	SE	Weeds	SE
1	Spring	86.7 a[1]	2.8	4.4 c	2.5	9.0 b	2.7
	Fall	68.9 b	2.8	21.1 b	2.5	9.9 ab	2.7
2	Spring	31.2 d	2.8	53.9 a	2.5	15.0 a	2.7
	Fall	40.7 c	2.8	56.6 a	2.5	2.7 c	2.7

[1]Data with the same letter within a column are not significantly different at the P < 0.05 level

Table 26. Effect of year x planting timing x planting method interaction (P < 0.0001) on the clover proportion of biomass (%) within NWSG in Blackstone, VA.

Timing	Year	Clover Biomass Proportion (%)					
		Method					
		Drill	SE	Broadcast	SE	Control	SE
Burn	1	25.0 bcd[1]	6.2	26.6 bcd	6.2	13.2 cde	6.2
	2	91.5 a	6.2	89.8 a	6.2	75.9 a	6.2
Winter	1	28.4 bc	6.2	16.4 cde	6.2	1.0 e	6.2
	2	85.6 a	6.2	83.4 a	6.2	12.0 cde	6.2
Fall	1	0.02 e	6.2	4.1 e	6.2	0.3 e	6.2
	2	9.9 de	6.2	38.9 b	6.2	10.0 de	6.2

[1]Data with the same letter are not significantly different at the P < 0.05 level

Table 27. Effect of year x planting timing x planting method interaction (*P* = 0.0472) on the weed proportion of biomass (%) within NWSG in Blackstone, VA.

Timing	Year	Weeds Biomass Proportion (%)					
		Method					
		Drill	SE	Broadcast	SE	Control	SE
Burn	1	8.0 bcdefg[1]	4.6	4.7 fg	4.6	6.4 cdefg	4.6
	2	0.7 g	4.6	1.5 g	4.6	0.6 g	4.6
Winter	1	18.0 abc	4.6	17.6 abcd	4.6	2.0 g	4.6
	2	5.8 efg	4.6	6.3 cdefg	4.6	18.9 ab	4.6
Fall	1	6.2 defg	4.6	17.3 abcde	4.6	4.7 fg	4.6
	2	11.1 abcdefg	4.6	14.3 abcdef	4.6	20.5 a	4.6

[1]Data with the same letter are not significantly different at the $P < 0.05$ level

Table 28. Effect of planting timing x harvest season interaction on whole plot crude protein content (g kg^{-1}) (*P* = 0.0002) and on whole plot neutral detergent fiber content (g kg^{-1}) (*P* = 0.0005) within NWSG in the establishment year of Plot Set 1 (2022) and Plot Set 2 (20230 in Blackstone, VA.

Timing	Harvest Season	Nutritive Value (g kg^{-1})			
		Component			
		Crude Protein	SE	Neutral Detergent Fiber	SE
Burn	Spring	115 b[1]	4.11	609 b	5.20
	Fall	114 b	4.96	576 c	8.50
Winter	Spring	122 a	4.11	603 b	5.20
	Fall	101 c	4.96	616 ab	8.50
Fall	Spring	123 a	4.11	617 ab	5.20
	Fall	93 c	4.96	636 a	8.50

[1]Data with the same letter within the same column are not significantly different at the $P < 0.05$ level

Table 29. Effect of harvest season (*P* < 0.0001) on whole plot acid detergent fiber content (g kg^{-1}) within NWSG in the establishment year of Plot Set 1 (2022) and Plot Set 2 (2023) in Blackstone, VA.

Harvest Season	Acid Detergent Fiber	
	g kg^{-1}	SE
Spring	329 b	5.30
Fall	365 a	5.30

[1]Data with the same letter are not significantly different at the $P < 0.05$ level

Table 30. Effect of planting method x harvest season interaction (*P* = 0.0286) on whole plot crude protein content (g kg^{-1}) within NWSG in the second year of production of Plot Set 1 (2023) in Blackstone, VA.

Harvest Season	Crude Protein (g kg^{-1})					
	Method					
	Drill	SE	Broadcast	SE	Control	SE
Spring	145 a[1]	4.05	147 a	4.05	148 a	4.05
Fall	132 b	4.11	117 c	4.11	114 c	4.11

[1]Data with the same letter are not significantly different at the *P* < 0.05 level

Table 31. Effect of planting timing x harvest season interaction on whole plot crude protein content (g kg^{-1}) (*P* = 0.0001) and on whole plot neutral detergent fiber content (g kg^{-1}) (*P* = 0.0357) within NWSG in the second year of production of Plot Set 1 (2023) in Blackstone, VA.

Timing	Harvest Season	Nutritive Value (g kg^{-1})			
		Component			
		Crude Protein	SE	Neutral Detergent Fiber	SE
Burn	Spring	152 a[1]	4.05	440 e	11.89
	Fall	149 ab	4.11	468 d	13.28
Winter	Spring	148 ab	4.05	509 c	11.89
	Fall	115 c	4.11	582 b	13.28
Fall	Spring	139 b	4.05	561 b	11.89
	Fall	99 d	4.11	636 a	13.28

[1]Data with the same letter within the same column are not significantly different at the *P* < 0.05 level

Table 32. Effect of harvest season (*P* < 0.0001) on whole plot acid detergent fiber content (g kg^{-1}) within NWSG in the second year of production of Plot Set 1 (2023) in Blackstone, VA.

Harvest Season	Acid Detergent Fiber	
	g kg^{-1}	SE
Spring	340 b[1]	2.36
Fall	366 a	2.77

[1]Data with the same letter are not significantly different at the *P* < 0.05 level

Table 33. Effect of planting timing (*P* = 0.0068) on total seasonal yield (kg ha^{-1}) within NWSG in the second year of production of Plot Set 1 (2023) in Blackstone, VA.

Timing	Total Seasonal Yield	
	kg ha^{-1}	SE
Burn	5,757 b[1]	301
Winter	7,259 a	301
Fall	7,599 a	301

[1]Data with the same letter are not significantly different at the *P* < 0.05 level

Table 34. Effect of planting method (P = 0.0122) on total seasonal yield (kg ha^{-1}) within NWSG in the second year of production of Plot Set 1 (2023) in Blackstone, VA.

Method	Total Seasonal Yield	
	kg ha^{-1}	SE
Drill	6,574 b[1]	301
Broadcast	6,422 b	301
Control	7,619 a	301

[1]Data with the same letter are not significantly different at the P < 0.05 level

Table 35. Effect of harvest season (P < 0.0001) on harvest yield (kg ha^{-1}) within NWSG in the establishment year of Plot Set 1 (2022) and Plot Set 2 (2023) in Blackstone, VA.

Harvest Season	Harvest Yield	
	kg ha^{-1}	SE
Spring	3,478 a[1]	1,447
Fall	2,872 b	1,447

[1]Data with the same letter are not significantly different at the P < 0.05 level

Table 36. Effect of planting timing x harvest season interaction (P < 0.0001) on harvest yield (kg ha^{-1}) within NWSG in the second year of production of Plot Set 1 (2023) in Blackstone, VA.

Harvest Season	Harvest Yield (kg ha^{-1})					
	Timing					
	Burn	SE	Winter	SE	Fall	SE
Spring	3,446 bc[1]	194	3,395 bc	194	2,933 cd	194
Fall	2,312 d	264	3,864 b	264	4,666 a	264

[1]Data with the same letter are not significantly different at the P < 0.05 level

Table 37. Effect of planting method x harvest season interaction (P = 0.0207) on harvest yield (kg ha^{-1}) within NWSG in the second year of production of Plot Set 1 (2023) in Blackstone, VA.

Harvest Season	Harvest Yield (kg ha^{-1})					
	Method					
	Drill	SE	Broadcast	SE	Control	SE
Spring	3,370 b[1]	194	3,181 b	194	3,223 a	194
Fall	3,204 b	264	3,242 b	264	4,396 b	264

[1]Data with the same letter are not significantly different at the P < 0.05 level

Table 38. Effect of planting timing x planting method interaction (P = 0.0470) on harvest yield (kg ha^{-1}) within NWSG in the second year of production of Plot Set 1 (2023) in Blackstone, VA.

Timing	Harvest Yield (kg ha^{-1})					
	Method					
	Drill	SE	Broadcast	SE	Control	SE
Burn	2,730 c[1]	248	2,861 c	248	3,046 c	248
Winter	3,095 c	248	3,404 bc	248	4,389 a	248
Fall	4,036 ab	248	3,369 bc	248	3,994 ab	248

[1]Data with the same letter are not significantly different at the P < 0.05 level

Figures

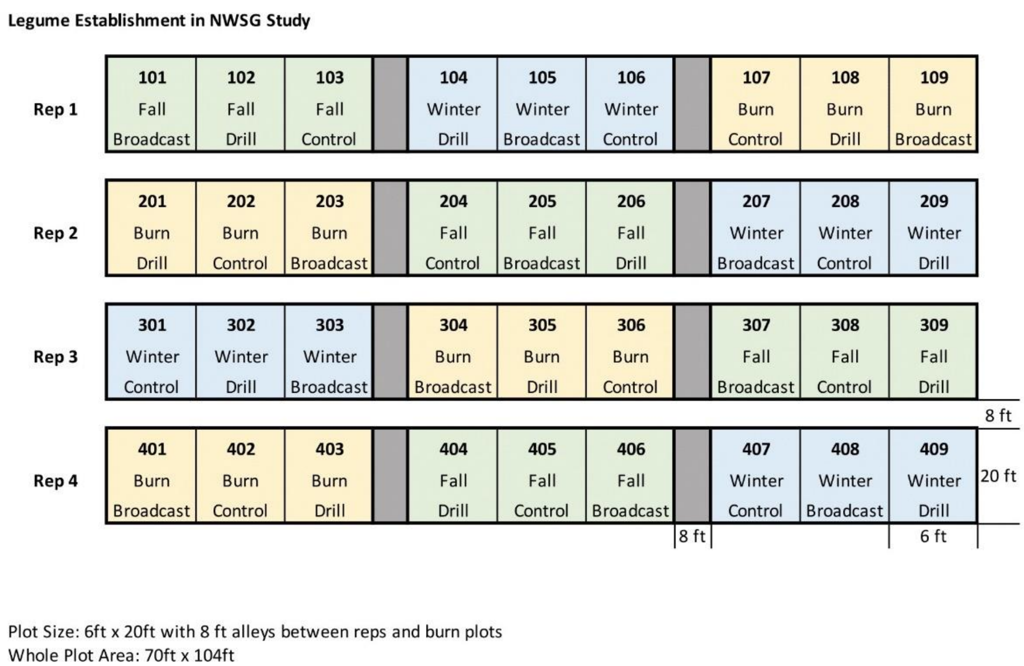

Figure 1. Plot map delineated at the Southern Piedmont AREC in Blackstone, VA.

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Appendix

Table 1. Effect of planting timing (*P* < 0.0001) on clover emergence (plants m^{-2}) within NWSG averaged over 2022 and 2023 in Blackstone, VA.

Timing	Clover Emergence	
	plants m^{-2}	SE
Burn	139.9 a[1]	11.7
Winter	86.7 b	11.7
Fall	11.8 c	11.7

[1]Data with the same letter are not significantly different at the *P* < 0.05 level

Table 2. Effect of planting method (*P* < 0.0001) on clover emergence (plants m^{-2}) within NWSG averaged over 2022 and 2023 in Blackstone, VA.

Method	Clover Emergence	
	plants m^{-2}	SE
Drill	133.1 a[1]	9.5
Broadcast	79.7 b	9.5
Control	25.7 c	9.5

[1]Data with the same letter are not significantly different at the *P* < 0.05 level

Table 3 (Table 5). Effect of planting timing x planting method interaction (*P* < 0.0001) on clover emergence (plants m^{-2}) within NWSG averaged over 2022 and 2023 in Blackstone, VA.

Timing	Clover Emergence (plants m^{-2})					
	Method					
	Drill	SE	Broadcast	SE	Control	SE
Burn	235.5 a[1]	16.4	133.2 bc	16.4	51.1 de	16.4
Winter	145.9 b	16.4	95.3 cd	16.4	19.1 e	16.4
Fall	18.0 e	16.4	10.5 e	16.4	7.0 e	16.4

[1]Data with the same letter are not significantly different at the *P* < 0.05 level

Table 4. Effect of planting timing (*P* < 0.0001) on clover count (plants m^{-2}) within NWSG averaged over 2022 and 2023 in Blackstone, VA.

Timing	Clover Count	
	plants m^{-2}	SE
Burn	113.6 a[1]	9.6
Winter	66.3 b	9.6
Fall	13.8 c	9.6

[1]Data with the same letter are not significantly different at the *P* < 0.05 level

Table 5. Effect of planting method (P < 0.0001) on clover count (plants m^{-2}) within NWSG averaged over 2022 and 2023 in Blackstone, VA.

Method	Clover Count	
	plants m^{-2}	SE
Drill	77.7 a[1]	9.6
Broadcast	80.7 a	9.6
Control	35.3 b	9.6

[1]Data with the same letter are not significantly different at the P < 0.05 level

Table 6 (Table 6). Effect of planting timing x planting method interaction (P = 0.0269) on clover count (plants m^{-2}) within NWSG averaged over 2022 and 2023 in Blackstone, VA.

Timing	Clover Count (plants m^{-2})					
	Method					
	Drill	SE	Broadcast	SE	Control	SE
Burn	120.3 ab[1]	14.3	133.1 a	14.3	87.4 bc	14.3
Winter	102.4 abc	14.3	83.6 c	14.3	13.0 d	14.3
Fall	10.4 d	14.3	25.5 d	14.3	5.5 d	14.3

[1]Data with the same letter are not significantly different at the P < 0.05 level

Table 7 (Table 7). Effect of harvest (P = 0.0012) on clover count (plants m^{-2}) within NWSG averaged over 2022 and 2023 in Blackstone, VA.

Harvest	Grass Count	
	plants m^{-2}	SE
1	71.8 a[1]	8.17
2	53.6 b	7.05
3	68.3 a	9.63

[1]Data with the same letter are not significantly different at the P < 0.05 level

Table 8 (Table 8). Effect of planting timing (P = 0.0006) on grass count (plants m^{-2}) within NWSG averaged over 2022 and 2023 in Blackstone, VA.

Timing	Grass Count	
	plants m^{-2}	SE
Burn	39.7 b[1]	11.2
Winter	39.7 b	11.2
Fall	59.3 a	11.2

[1]Data with the same letter are not significantly different at the P < 0.05 level

Table 9 (Table 9). Effect of planting method (P = 0.0256) on grass count (plants m^{-2}) within NWSG averaged over 2022 and 2023 in Blackstone, VA.

Method	Grass Count	
	plants m^{-2}	SE
Drill	44.5 ab[1]	11.2
Broadcast	39.6 b	11.2
Control	54.6 a	11.2

[1]Data with the same letter are not significantly different at the P < 0.05 level

Table 10 (Table 10). Effect of harvest (P < 0.0001) on weed count (plants m^{-2}) within NWSG averaged over 2022 and 2023 in Blackstone, VA.

Harvest	Grass Count	
	plants m^{-2}	SE
1	70.7 a[1]	15.2
2	15.0 c	6.9
3	25.5 b	7.8

[1]Data with the same letter are not significantly different at the P < 0.05 level

Table 11. Effect of planting timing (P < 0.0001) on pre-harvest clover ground cover (%) within NWSG in the establishment year of Plot Set 1 (2022) and Plot Set 2 (2023) in Blackstone, VA.

Timing	Clover Cover	
	%	SE
Burn	19.5 a[1]	1.9
Winter	8.4 b	1.9
Fall	2.7 c	1.9

[1]Data with the same letter are not significantly different at the P < 0.05 level

Table 12. Effect of planting method (P < 0.0001) on pre-harvest clover ground cover (%) within NWSG in the establishment year of Plot Set 1 (2022) and Plot Set 2 (2023) in Blackstone, VA.

Method	Clover Cover	
	%	SE
Drill	17.1 a[1]	1.9
Broadcast	8.4 b	1.9
Control	5.1 b	1.9

[1]Data with the same letter are not significantly different at the P < 0.05 level

Table 13. Effect of harvest season ($P < 0.0001$) on pre-harvest clover ground cover (%) within NWSG in the establishment year of Plot Set 1 (2022) and Plot Set 2 (2023) in Blackstone, VA.

Harvest Season	Clover Cover	
	%	SE
Spring	3.0 b[1]	0.8
Fall	17.3 a	1.9

[1]Data with the same letter are not significantly different at the $P < 0.05$ level

Table 14 (Table 12). Effect of planting timing x harvest season interaction ($P < 0.0001$) on pre-harvest clover ground cover (%) within NWSG in the establishment year of Plot Set 1 (2022) and Plot Set 2 (2023) in Blackstone, VA.

Harvest Season	Clover Cover (%)					
	Timing					
	Burn	SE	Winter	SE	Fall	SE
Spring	5.9 c[1]	1.1	3.0 d	1.1	0.2 d	1.1
Fall	33.2 a	3.1	13.7 b	3.1	5.1 cd	3.1

[1]Data with the same letter are not significantly different at the $P < 0.05$ level

Table 15 (Table 11). Effect of planting method x harvest season interaction ($P = 0.0006$) on pre-harvest clover ground cover (%) within NWSG in the establishment year of Plot Set 1 (2022) and Plot Set 2 (2023) in Blackstone, VA.

Harvest Season	Clover Cover (%)					
	Method					
	Drill	SE	Broadcast	SE	Control	SE
Spring	5.6 c[1]	1.1	2.1 d	1.1	1.5 d	1.1
Fall	28.6 a	3.1	14.8 b	3.1	8.6 bc	3.1

[1]Data with the same letter are not significantly different at the $P < 0.05$ level

Table 16. Effect of planting timing ($P < 0.0001$) on pre-harvest clover ground cover (%) within NWSG in the second year of production of Plot Set 1 (2023) in Blackstone, VA.

Timing	Clover Cover	
	%	SE
Burn	84.9 a[1]	4.9
Winter	39.7 b	4.9
Fall	4.6 c	4.9

[1]Data with the same letter are not significantly different at the $P < 0.05$ level

Table 17. Effect of planting method (P = 0.0004) on pre-harvest clover ground cover (%) within NWSG in the second year of production of Plot Set 1 (2023) in Blackstone, VA.

Method	Clover Cover	
	%	SE
Drill	54.0 a[1]	4.9
Broadcast	48.6 a	4.9
Control	26.6 b	4.9

[1]Data with the same letter are not significantly different at the P < 0.05 level

Table 18. Effect of planting timing x planting method interaction (P = 0.0097) on pre-harvest clover ground cover (%) within NWSG in the second year of production of Plot Set 1 (2023) in Blackstone, VA.

Timing	Clover Cover (%)					
	Method					
	Drill	SE	Broadcast	SE	Control	SE
Burn	91.3 a[1]	7.8	90.7 a	7.8	72.7 ab	7.8
Winter	65.2 bc	7.8	49.5 c	7.8	4.5 d	7.8
Fall	5.5 d	7.8	5.7 d	7.8	2.7 d	7.8

[1]Data with the same letter are not significantly different at the P < 0.05 level

Table 19 (Table 13). Effect of planting timing x planting method x harvest season interaction (P = 0.0433) on pre-harvest clover ground cover (%) within NWSG in the second year of production of Plot Set 1 (2023) in Blackstone, VA.

Timing	Harvest Season	Clover Cover (%)					
		Method					
		Drill	SE	Broadcast	SE	Control	SE
Burn	Spring	90.3 ab[1]	8.4	92.7 a	8.4	64.7 cde	8.4
	Fall	92.3 a	8.2	88.7 ab	8.2	80.7 abc	8.2
Winter	Spring	62.3 cde	8.4	43.0 e	8.4	6.3 f	8.4
	Fall	68.0 bcd	8.2	56.0 de	8.2	2.7 f	8.2
Fall	Spring	7.3 f	8.4	4.7 f	8.4	4.3 f	8.4
	Fall	3.7 f	8.2	6.7 f	8.2	1.0 f	8.2

[1]Data with the same letter are not significantly different at the P < 0.05 level

Table 20. Effect of planting timing (P < 0.0001) on pre-harvest grass ground cover (%) within NWSG in the establishment year of Plot Set 1 (2022) and Plot Set 2 (2023) in Blackstone, VA.

Timing	Grass Cover	
	%	SE
Burn	63.1 c[1]	2.5
Winter	72.4 b	2.5
Fall	79.3 a	2.5

[1]Data with the same letter are not significantly different at the P < 0.05 level

Table 21. Effect of planting method ($P = 0.0142$) on pre-harvest grass ground cover (%) within NWSG in the establishment year of Plot Set 1 (2022) and Plot Set 2 (2023) in Blackstone, VA.

Method	Grass Cover	
	%	SE
Drill	66.2 b[1]	2.5
Broadcast	73.7 a	2.5
Control	74.9 a	2.5

[1]Data with the same letter are not significantly different at the $P < 0.05$ level

Table 22. Effect of harvest season ($P < 0.0001$) on pre-harvest grass ground cover (%) within NWSG in the establishment year of Plot Set 1 (2022) and Plot Set 2 (2023) in Blackstone, VA.

Harvest Season	Grass Cover	
	%	SE
Spring	77.1 a[1]	2.0
Fall	66.1 b	2.0

[1]Data with the same letter are not significantly different at the $P < 0.05$ level

Table 23 (Table 14). Effect of planting timing x harvest season interaction ($P = 0.0003$) on pre-harvest grass ground cover (%) within NWSG in the establishment year of Plot Set 1 (2022) and Plot Set 2 (2023) in Blackstone, VA.

Harvest Season	Grass Cover (%)					
	Timing					
	Burn	SE	Winter	SE	Fall	SE
Spring	74.8 ab[1]	3.0	76.2 a	3.0	80.2 a	3.0
Fall	51.5 c	3.1	68.6 b	3.1	78.3 a	3.1

[1]Data with the same letter are not significantly different at the $P < 0.05$ level

Table 24 (Table 15). Effect of planting method x harvest season interaction ($P = 0.0089$) on pre-harvest grass ground cover (%) within NWSG in the establishment year of Plot Set 1 (2022) and Plot Set 2 (2023) in Blackstone, VA.

Harvest Season	Grass Cover (%)					
	Method					
	Drill	SE	Broadcast	SE	Control	SE
Spring	75.6 ab[1]	3.0	79.6 a	3.0	76.1 a	3.0
Fall	56.8 c	3.1	67.8 b	3.1	73.8 ab	3.1

[1]Data with the same letter are not significantly different at the $P < 0.05$ level

Table 25. Effect of planting timing ($P < 0.0001$) on pre-harvest grass ground cover (%) within NWSG in the second year of production of Plot Set 1 (2023) in Blackstone, VA.

Timing	Grass Cover	
	%	SE
Burn	10.9 c[1]	4.1
Winter	52.5 b	4.1
Fall	84.1 a	4.1

[1]Data with the same letter are not significantly different at the $P < 0.05$ level

Table 26. Effect of planting method ($P = 0.0003$) on pre-harvest grass ground cover (%) within NWSG in the second year of production of Plot Set 1 (2023) in Blackstone, VA.

Method	Grass Cover	
	%	SE
Drill	39.0 b[1]	4.1
Broadcast	43.7 b	4.1
Control	64.9 a	4.1

[1]Data with the same letter are not significantly different at the $P < 0.05$ level

Table 27. Effect of harvest season ($P = 0.0024$) on pre-harvest grass ground cover (%) within NWSG in the second year of production of Plot Set 1 (2023) in Blackstone, VA.

Harvest Season	Grass Cover	
	%	SE
Spring	52.4 a[1]	2.6
Fall	46.0 b	2.6

[1]Data with the same letter are not significantly different at the $P < 0.05$ level

Table 28. Effect of planting timing x planting method interaction ($P = 0.0072$) on pre-harvest grass ground cover (%) within NWSG in the second year of production of Plot Set 1 (2023) in Blackstone, VA.

Timing	Grass Cover (%)					
	Method					
	Drill	SE	Broadcast	SE	Control	SE
Burn	4.3 c	7.1	4.7 c	7.1	23.8 bc	7.1
Winter	28.5 b	7.1	42.8 b	7.1	86.2 a	7.1
Fall	84.2 a	7.1	83.5 a	7.1	84.7 a	7.1

[1]Data with the same letter are not significantly different at the $P < 0.05$ level

Table 29 (Table 16). Effect of planting timing x planting method x harvest season interaction (P = 0.0227) on pre-harvest grass ground cover (%) within NWSG in the second year of production of Plot Set 1 (2023) in Blackstone, VA.

Timing	Harvest Season	Grass Cover (%) Method: Drill	SE	Broadcast	SE	Control	SE
Burn	Spring	7.7 de[1]	7.7	6.0 de	7.7	33.7 bc	7.7
	Fall	1.0 e	7.6	3.3 de	7.6	14.0 cde	7.6
Winter	Spring	33.7 bc	7.7	52.3 b	7.7	84.3 a	7.7
	Fall	23.3 cd	7.6	33.3 c	7.6	88.0 a	7.6
Fall	Spring	81.7 a	7.7	87.7 a	7.7	84.7 a	7.7
	Fall	86.7 a	7.6	79.3 a	7.6	84.7 a	7.6

[1]Data with the same letter are not significantly different at the $P < 0.05$ level

Table 30. Effect of harvest season (P = 0.0013) on pre-harvest weeds ground cover (%) within NWSG in the establishment year of Plot Set 1 (2022) and Plot Set 2 (2023) in Blackstone, VA.

Harvest Season	Weeds Cover %	SE
Spring	15.5 a[1]	2.5
Fall	11.8 b	2.3

[1]Data with the same letter are not significantly different at the $P < 0.05$ level

Table 31. Effect of planting timing (P = 0.0009) on pre-harvest weeds ground cover (%) within NWSG in the second year of production of Plot Set 1 (2023) in Blackstone, VA.

Timing	Weeds Cover %	SE
Burn	1.9 b[1]	1.1
Winter	5.3 a	1.1
Fall	5.2 a	1.1

[1]Data with the same letter are not significantly different at the $P < 0.05$ level

Table 32. Effect of harvest season (P < 0.0001) on pre-harvest weeds ground cover (%) within NWSG in the second year of production of Plot Set 1 (2023) in Blackstone, VA.

Harvest Season	Weeds Cover %	SE
Spring	2.2 b[1]	1.0
Fall	6.1 a	1.1

[1]Data with the same letter are not significantly different at the $P < 0.05$ level

Table 33. Effect of planting timing ($P < 0.0001$) on pre-harvest bare ground (% of surface) within NWSG in the second year of production of Plot Set 1 (2023) in Blackstone, VA.

Timing	Bare Ground	
	%	SE
Burn	2.2 b[1]	0.4
Winter	2.5 b	0.4
Fall	6.0 a	0.4

[1]Data with the same letter are not significantly different at the $P < 0.05$ level

Table 34. Effect of planting timing x harvest season interaction ($P = 0.0157$) on pre-harvest bare ground (% of surface) within NWSG in the second year of production of Plot Set 1 (2023) in Blackstone, VA.

Harvest Season	Bare Ground (%)					
	Timing					
	Burn	SE	Winter	SE	Fall	SE
Spring	1.0 d[1]	0.7	2.9 cd	0.7	7.0 a	0.7
Fall	3.3 bc	0.6	2.1 cd	0.6	5.0 ab	0.6

[1]Data with the same letter are not significantly different at the $P < 0.05$ level

Table 35. Effect of planting timing ($P < 0.0001$) on post-harvest clover ground cover (%) within NWSG in the establishment year of Plot Set 1 (2022) and Plot Set 2 (2023) in Blackstone, VA.

Timing	Clover Cover	
	%	SE
Burn	19.7 a[1]	1.4
Winter	9.5 b	1.4
Fall	1.3 c	1.4

[1]Data with the same letter are not significantly different at the $P < 0.05$ level

Table 36. Effect of planting method ($P < 0.0001$) on post-harvest clover ground cover (%) within NWSG in the establishment year of Plot Set 1 (2022) and Plot Set 2 (2023) in Blackstone, VA.

Method	Clover Cover	
	%	SE
Drill	17.1 a[1]	1.4
Broadcast	9.6 b	1.4
Control	3.9 c	1.4

[1]Data with the same letter are not significantly different at the $P < 0.05$ level

Table 37. Effect of harvest season (*P* < 0.0001) on post-harvest clover ground cover (%) within NWSG in the establishment year of Plot Set 1 (2022) and Plot Set 2 (2023) in Blackstone, VA.

Harvest Season	Clover Cover	
	%	SE
Spring	6.0 b[1]	0.5
Fall	14.3 a	1.4

[1]Data with the same letter are not significantly different at the *P* < 0.05 level

Table 38 (Table 17). Effect of planting timing x planting method interaction (*P* = 0.0003) on post-harvest clover ground cover (%) within NWSG in the establishment year of Plot Set 1 (2022) and Plot Set 2 (2023) in Blackstone, VA.

Timing	Clover Cover (%)					
	Method					
	Drill	SE	Broadcast	SE	Control	SE
Burn	31.7 a[1]	2.4	19.2 b	2.4	8.3 c	2.4
Winter	18.4 b	2.4	7.8 cd	2.4	2.3 cd	2.4
Fall	1.1 d	2.4	1.8 cd	2.4	1.0 d	2.4

[1]Data with the same letter are not significantly different at the *P* < 0.05 level

Table 39 (Table 18). Effect of planting timing x harvest season interaction (*P* < 0.0001) on post-harvest clover ground cover (%) within NWSG in the establishment year of Plot Set 1 (2022) and Plot Set 2 (2023) in Blackstone, VA.

Harvest Season	Clover Cover (%)					
	Timing					
	Burn	SE	Winter	SE	Fall	SE
Spring	11.3 b[1]	0.9	6.2 c	0.9	0.7 d	0.9
Fall	28.1 a	2.4	12.9 b	2.4	1.9 cd	2.4

[1]Data with the same letter are not significantly different at the *P* < 0.05 level

Table 40. Effect of planting timing (*P* < 0.0001) on post-harvest clover ground cover (%) within NWSG in the second year of production of Plot Set 1 (2023) in Blackstone, VA.

Timing	Clover Cover	
	%	SE
Burn	67.1 a[1]	3.6
Winter	28.7 b	3.6
Fall	2.2 c	3.6

[1]Data with the same letter are not significantly different at the *P* < 0.05 level

Table 41. Effect of planting method ($P < 0.0001$) on post-harvest clover ground cover (%) within NWSG in the second year of production of Plot Set 1 (2023) in Blackstone, VA.

Method	Clover Cover	
	%	SE
Drill	45.4 a[1]	3.6
Broadcast	37.8 a	3.6
Control	14.8 b	3.6

[1]Data with the same letter are not significantly different at the $P < 0.05$ level

Table 42. Effect of harvest season ($P = 0.0013$) on post-harvest clover ground cover (%) within NWSG in the second year of production of Plot Set 1 (2023) in Blackstone, VA.

Harvest Season	Clover Cover	
	%	SE
Spring	36.6 a[1]	2.8
Fall	28.7 b	2.0

[1]Data with the same letter are not significantly different at the $P < 0.05$ level

Table 43 (Table 19). Effect of planting timing x planting method interaction ($P = 0.0050$) on post-harvest clover ground cover (%) within NWSG in the second year of production of Plot Set 1 (2023) in Blackstone, VA.

Timing	Clover Cover (%)					
	Method					
	Drill	SE	Broadcast	SE	Control	SE
Burn	84.5 a[1]	6.2	76.7 a	6.2	40.0 b	6.2
Winter	49.2 b	6.2	34.3 b	6.2	2.7 c	6.2
Fall	2.5 c	6.2	2.3 c	6.2	1.8 c	6.2

[1]Data with the same letter are not significantly different at the $P < 0.05$ level

Table 44 (Table 20). Effect of planting timing x harvest season interaction ($P = 0.0359$) on post-harvest clover ground cover (%) within NWSG in the second year of production of Plot Set 1 (2023) in Blackstone, VA.

Harvest Season	Clover Cover (%)					
	Timing					
	Burn	SE	Winter	SE	Fall	SE
Spring	72.3 a[1]	4.8	35.6 c	4.8	2.0 e	4.8
Fall	61.8 b	3.3	21.9 d	3.3	2.4 e	3.3

[1]Data with the same letter are not significantly different at the $P < 0.05$ level

Table 45. Effect of planting timing (P = 0.0379) on post-harvest grass ground cover (%) within NWSG in the establishment year of Plot Set 1 (2022) and Plot Set 2 (2023) in Blackstone, VA.

Timing	Grass Cover	
	%	SE
Burn	42.9 ab[1]	1.6
Winter	41.4 b	1.6
Fall	45.9 a	1.6

[1]Data with the same letter are not significantly different at the $P < 0.05$ level

Table 46. Effect of planting method (P = 0.0394) on post-harvest grass ground cover (%) within NWSG in the establishment year of Plot Set 1 (2022) and Plot Set 2 (2023) in Blackstone, VA.

Method	Grass Cover	
	%	SE
Drill	41.1 b[1]	1.6
Broadcast	43.6 ab	1.6
Control	45.6 a	1.6

[1]Data with the same letter are not significantly different at the $P < 0.05$ level

Table 47 (Table 18). Effect of planting timing x harvest season interaction ($P < 0.0001$) on post-harvest grass ground cover (%) within NWSG in the establishment year of Plot Set 1 (2022) and Plot Set 2 (2023) in Blackstone, VA.

Harvest Season	Grass Cover (%)					
	Timing					
	Burn	SE	Winter	SE	Fall	SE
Spring	48.7 a[1]	1.6	40.3 c	1.6	44.8 b	1.6
Fall	37.0 c	2.2	42.6 bc	2.2	47.0 ab	2.2

[1]Data with the same letter are not significantly different at the $P < 0.05$ level

Table 48 (Table 22). Effect of planting method x harvest season interaction (P = 0.0003) on post-harvest grass ground cover (%) within NWSG in the establishment year of Plot Set 1 (2022) and Plot Set 2 (2023) in Blackstone, VA.

Harvest Season	Grass Cover (%)					
	Method					
	Drill	SE	Broadcast	SE	Control	SE
Spring	46.1 a[1]	1.6	43.6 a	1.6	44.1 a	1.6
Fall	36.0 b	2.2	43.6 a	2.2	47.1 a	2.2

[1]Data with the same letter are not significantly different at the $P < 0.05$ level

Table 49. Effect of planting timing (P < 0.0001) on post-harvest grass ground cover (%) within NWSG in the second year of production of Plot Set 1 (2023) in Blackstone, VA.

Timing	Grass Cover	
	%	SE
Burn	12.9 c[1]	2.7
Winter	32.1 b	2.7
Fall	52.1 a	2.7

[1]Data with the same letter are not significantly different at the P < 0.05 level

Table 50. Effect of planting method (P < 0.0001) on post-harvest grass ground cover (%) within NWSG in the second year of production of Plot Set 1 (2023) in Blackstone, VA.

Method	Grass Cover	
	%	SE
Drill	24.1 b[1]	2.7
Broadcast	29.2 b	2.7
Control	43.8 a	2.7

[1]Data with the same letter are not significantly different at the P < 0.05 level

Table 51. Effect of harvest season (P = 0.0249) on post-harvest grass ground cover (%) within NWSG in the second year of production of Plot Set 1 (2023) in Blackstone, VA.

Harvest Season	Grass Cover	
	%	SE
Spring	34.8 a[1]	1.8
Fall	30.0 b	1.9

[1]Data with the same letter are not significantly different at the P < 0.05 level

Table 52. Effect of planting timing x planting method interaction (P = 0.0242) on post-harvest grass ground cover (%) within NWSG in the second year of production of Plot Set 1 (2023) in Blackstone, VA.

Timing	Grass Cover (%)					
	Method					
	Drill	SE	Broadcast	SE	Control	SE
Burn	3.8 d[1]	4.7	5.7 cd	4.7	29.3 b	4.7
Winter	17.5 bc	4.7	29.5 b	4.7	49.3 a	4.7
Fall	51.0 a	4.7	52.5 a	4.7	52.8 a	4.7

[1]Data with the same letter are not significantly different at the P < 0.05 level

Table 53. Effect of planting timing ($P = 0.0010$) on post-harvest weeds ground cover (%) within NWSG in the second year of production of Plot Set 1 (2023) in Blackstone, VA.

Timing	Weeds Cover	
	%	SE
Burn	0.4 b[1]	0.9
Winter	2.9 a	0.9
Fall	3.9 a	0.9

[1]Data with the same letter are not significantly different at the $P < 0.05$ level

Table 54. Effect of harvest season ($P < 0.0001$) on post-harvest weeds ground cover (%) within NWSG in the second year of production of Plot Set 1 (2023) in Blackstone, VA.

Harvest Season	Weeds Cover	
	%	SE
Spring	0.7 b[1]	0.7
Fall	4.1 a	0.9

[1]Data with the same letter are not significantly different at the $P < 0.05$ level

Table 55 (Table 23). Effect of planting timing x harvest season interaction ($P = 0.0009$) on post-harvest weeds ground cover (%) within NWSG in the second year of production of Plot Set 1 (2023) in Blackstone, VA.

Harvest Season	Weeds Cover (%)					
	Timing					
	Burn	SE	Winter	SE	Fall	SE
Spring	0.3 b[1]	0.8	1.4 b	0.8	0.4 b	0.8
Fall	0.6 b	1.2	4.4 a	1.2	7.3 a	1.2

[1]Data with the same letter are not significantly different at the $P < 0.05$ level

Table 56. Effect of planting timing ($P < 0.0001$) on post-harvest bare ground (% of surface) within NWSG in the establishment year of Plot Set 1 (2022) and Plot Set 2 (2023) in Blackstone, VA.

Timing	Bare Ground	
	%	SE
Burn	30.6 b[1]	1.5
Winter	40.7 a	1.5
Fall	44.4 a	1.5

[1]Data with the same letter are not significantly different at the $P < 0.05$ level

Table 57. Effect of planting method ($P = 0.0073$) on post-harvest bare ground (% of surface) within NWSG in the establishment year of Plot Set 1 (2022) and Plot Set 2 (2023) in Blackstone, VA.

Method	Bare Ground	
	%	SE
Drill	35.0 b[1]	1.5
Broadcast	38.9 ab	1.5
Control	41.7 a	1.5

[1]Data with the same letter are not significantly different at the $P < 0.05$ level

Table 58. Effect of harvest season ($P = 0.0075$) on post-harvest bare ground (% of surface) within NWSG in the establishment year of Plot Set 1 (2022) and Plot Set 2 (2023) in Blackstone, VA.

Harvest Season	Bare Ground	
	%	SE
Spring	41.0 a[1]	1.0
Fall	36.1 b	1.4

[1]Data with the same letter are not significantly different at the $P < 0.05$ level

Table 59. Effect of planting timing ($P < 0.0001$) on post-harvest bare ground (% of surface) within NWSG in the second year of production of Plot Set 1 (2023) in Blackstone, VA.

Timing	Bare Ground	
	%	SE
Burn	19.6 c[1]	1.5
Winter	36.2 b	1.5
Fall	41.8 a	1.5

[1]Data with the same letter are not significantly different at the $P < 0.05$ level

Table 60. Effect of planting method ($P < 0.0001$) on post-harvest bare ground (% of surface) within NWSG in the second year of production of Plot Set 1 (2023) in Blackstone, VA.

Method	Bare Ground	
	%	SE
Drill	27.8 b[1]	1.5
Broadcast	30.5 b	1.5
Control	39.2 a	1.5

[1]Data with the same letter are not significantly different at the $P < 0.05$ level

Table 61. Effect of harvest season ($P < 0.0001$) on post-harvest bare ground (% of surface) within NWSG in the second year of production of Plot Set 1 (2023) in Blackstone, VA

Harvest Season	Bare Ground	
	%	SE
Spring	27.8 b[1]	1.3
Fall	37.2 a	1.2

[1]Data with the same letter are not significantly different at the $P < 0.05$ level

Table 62. Effect of planting timing x planting method interaction ($P = 0.0169$) on post-harvest bare ground (% of surface) within NWSG in the second year of production of Plot Set 1 (2023) in Blackstone, VA.

Timing	Bare Ground (%)					
	Method					
	Drill	SE	Broadcast	SE	Control	SE
Burn	11.5 d[1]	2.6	17.0 d	2.6	30.2 c	2.6
Winter	30.0 c	2.6	33.7 bc	2.6	45.0 a	2.6
Fall	42.0 a	2.6	40.8 ab	2.6	42.5 a	2.6

[1]Data with the same letter are not significantly different at the $P < 0.05$ level

Table 63 (Table 23). Effect of planting timing x harvest season interaction ($P = 0.0001$) on post-harvest bare ground (% of surface) within NWSG in the second year of production of Plot Set 1 (2023) in Blackstone, VA.

Harvest Season	Bare Ground (%)					
	Timing					
	Burn	SE	Winter	SE	Fall	SE
Spring	10.1 c[1]	2.2	29.8 b	2.2	43.6 a	2.2
Fall	29.0 b	2.2	42.7 a	2.2	40.0 a	2.2

[1]Data with the same letter are not significantly different at the $P < 0.05$ level

Table 64. Effect of planting timing ($P < 0.0001$) on the clover proportion of biomass (%) within NWSG in Blackstone, VA.

Timing	Clover Biomass Proportion	
	%	SE
Burn	53.6 a[1]	3.2
Winter	37.8 b	3.2
Fall	10.5 c	3.2

[1]Data with the same letter are not significantly different at the $P < 0.05$ level

Table 65. Effect of planting method ($P < 0.0001$) on the clover proportion of biomass (%) within NWSG in Blackstone, VA.

Method	Clover Biomass Proportion	
	%	SE
Drill	40.1 a[1]	3.2
Broadcast	43.1 a	3.2
Control	18.7 b	3.2

[1]Data with the same letter are not significantly different at the $P < 0.05$ level

Table 66. Effect of planting timing x planting method interaction ($P = 0.0013$) on the clover proportion of biomass (%) within NWSG in Blackstone, VA.

Timing	Clover Biomass Proportion (%)					
	Method					
	Drill	SE	Broadcast	SE	Control	SE
Burn	58.2 a[1]	5.5	58.2 a	5.5	44.5 a	5.5
Winter	57.0 a	5.5	49.9 a	5.5	6.5 bc	5.5
Fall	5.0 c	5.5	21.5 b	5.5	5.1 c	5.5

[1]Data with the same letter are not significantly different at the $P < 0.05$ level

Table 67. Effect of harvest season ($P < 0.0001$) on the clover proportion of biomass (%) within NWSG in Blackstone, VA.

Harvest Season	Clover Biomass Proportion	
	%	SE
Spring	29.1 b[1]	2.1
Fall	38.8 a	2.1

[1]Data with the same letter are not significantly different at the $P < 0.05$ level

Table 68. Effect of planting timing x harvest season interaction ($P = 0.0035$) on the clover proportion of biomass (%) within NWSG in Blackstone, VA.

Harvest Season	Clover Biomass Proportion (%)					
	Timing					
	Burn	SE	Winter	SE	Fall	SE
Spring	45.3 b[1]	3.6	31.8 c	3.6	10.3 d	3.6
Fall	62.0 a	3.6	43.8 b	3.6	10.7 d	3.6

[1]Data with the same letter are not significantly different at the $P < 0.05$ level

Table 69. Effect of planting method x harvest season interaction ($P = 0.0472$) on the clover proportion of biomass (%) within NWSG in Blackstone, VA.

Harvest Season	Clover Biomass Proportion (%)					
	Method					
	Drill	SE	Broadcast	SE	Control	SE
Spring	31.9 b[1]	3.6	38.9 ab	3.6	16.6 c	3.6
Fall	48.2 a	3.6	47.5 a	3.6	20.8 c	3.6

[1]Data with the same letter are not significantly different at the $P < 0.05$ level

Table 70. Effect of year ($P < 0.0001$) on the clover proportion of biomass (%) within NWSG in Blackstone, VA.

Year	Clover Biomass Proportion	
	%	SE
1	12.8 b[1]	2.1
2	55.2 a	2.1

[1]Data with the same letter are not significantly different at the $P < 0.05$ level

Table 71. Effect of year x planting timing interaction ($P < 0.0001$) on the clover proportion of biomass (%) within NWSG in Blackstone, VA.

Year	Clover Biomass Proportion (%)					
	Timing					
	Burn	SE	Winter	SE	Fall	SE
1	21.6 c[1]	3.6	15.3 c	3.6	1.5 d	3.6
2	85.7 a	3.6	60.3 b	3.6	19.6 c	3.6

[1]Data with the same letter are not significantly different at the $P < 0.05$ level

Table 72. Effect of year x planting method interaction ($P < 0.0001$) on the clover proportion of biomass (%) within NWSG in Blackstone, VA.

Year	Clover Biomass Proportion (%)					
	Method					
	Drill	SE	Broadcast	SE	Control	SE
1	17.8 c[1]	3.6	15.7 c	3.6	4.8 d	3.6
2	62.3 a	3.6	70.7 a	3.6	32.6 b	3.6

[1]Data with the same letter are not significantly different at the $P < 0.05$ level

Table 73 (Table 26). Effect of year x planting timing x planting method interaction (*P* < 0.0001) on the clover proportion of biomass (%) within NWSG in Blackstone, VA.

Timing	Year	Clover Biomass Proportion (%)					
		Method					
		Drill	SE	Broadcast	SE	Control	SE
Burn	1	25.0 bcd[1]	6.2	26.6 bcd	6.2	13.2 cde	6.2
	2	91.5 a	6.2	89.8 a	6.2	75.9 a	6.2
Winter	1	28.4 bc	6.2	16.4 cde	6.2	1.0 e	6.2
	2	85.6 a	6.2	83.4 a	6.2	12.0 cde	6.2
Fall	1	0.02 e	6.2	4.1 e	6.2	0.3 e	6.2
	2	9.9 de	6.2	38.9 b	6.2	10.0 de	6.2

[1]Data with the same letter are not significantly different at the *P* < 0.05 level

Table 74. Effect of year x harvest season interaction (*P* = 0.0006) on the clover proportion of biomass (%) within NWSG in Blackstone, VA.

Year	Clover Biomass Proportion (%)			
	Harvest			
	Spring	SE	Fall	SE
1	4.4 c[1]	2.5	21.1 b	2.5
2	53.9 a	2.5	56.6 a	2.5

[1]Data with the same letter are not significantly different at the *P* < 0.05 level

Table 75. Effect of planting timing (*P* < 0.0001) on the grass proportion of biomass (%) within NWSG in Blackstone, VA.

Timing	Grass Biomass Proportion	
	%	SE
Burn	42.3 b[1]	3.8
Winter	50.8 b	3.8
Fall	77.1 a	3.8

[1]Data with the same letter are not significantly different at the *P* < 0.05 level

Table 76. Effect of planting method (*P* < 0.0001) on the grass proportion of biomass (%) within NWSG in Blackstone, VA.

Method	Grass Biomass Proportion	
	%	SE
Drill	51.6 b[1]	3.8
Broadcast	46.5 b	3.8
Control	72.4 a	3.8

[1]Data with the same letter are not significantly different at the *P* < 0.05 level

Table 77 (Table 24). Effect of planting timing x planting method interaction (P = 0.0026) on the grass proportion of biomass (%) within NWSG in Blackstone, VA.

Timing	Grass Biomass Proportion (%)					
	Method					
	Drill	SE	Broadcast	SE	Control	SE
Burn	37.4 cd[1]	6.5	38.7 cd	6.5	52.0 bc	6.5
Winter	31.1 d	6.5	38.2 cd	6.5	83.0 a	6.5
Fall	86.4 a	6.5	62.7 b	6.5	82.3 a	6.5

[1]Data with the same letter are not significantly different at the $P < 0.05$ level

Table 78. Effect of planting timing x harvest season interaction (P = 0.0001) on the grass proportion of biomass (%) within NWSG in Blackstone, VA.

Harvest Season	Grass Biomass Proportion (%)					
	Timing					
	Burn	SE	Winter	SE	Fall	SE
Spring	50.5 c[1]	4.2	52.9 c	4.2	73.3 b	4.2
Fall	34.9 d	4.2	48.6 c	4.2	81.0 a	4.2

[1]Data with the same letter are not significantly different at the $P < 0.05$ level

Table 79. Effect of planting method x harvest season interaction (P = 0.0012) on the grass proportion of biomass (%) within NWSG in Blackstone, VA.

Harvest Season	Grass Biomass Proportion (%)					
	Method					
	Drill	SE	Broadcast	SE	Control	SE
Spring	58.6 bc[1]	4.2	48.7 cd	4.2	69.5 ab	4.2
Fall	44.7 d	4.2	44.4 d	4.2	75.4 a	4.2

[1]Data with the same letter are not significantly different at the $P < 0.05$ level

Table 80. Effect of year ($P < 0.0001$) on the grass proportion of biomass (%) within NWSG in Blackstone, VA.

Year	Grass Biomass Proportion	
	%	SE
1	77.8 a[1]	2.4
2	35.9 b	2.4

[1]Data with the same letter are not significantly different at the $P < 0.05$ level

Table 81. Effect of year x planting timing interaction ($P < 0.0001$) on the grass proportion of biomass (%) within NWSG in Blackstone, VA.

Year	Grass Biomass Proportion (%)					
	Timing					
	Burn	SE	Winter	SE	Fall	SE
1	72.0 b[1]	4.2	72.2 b	4.2	89.1 a	4.2
2	13.3 d	4.2	29.3 c	4.2	65.1 b	4.2

[1]Data with the same letter are not significantly different at the $P < 0.05$ level

Table 82. Effect of year x planting method interaction ($P = 0.0484$) on the grass proportion of biomass (%) within NWSG in Blackstone, VA.

Year	Grass Biomass Proportion (%)					
	Method					
	Drill	SE	Broadcast	SE	Control	SE
1	71.5 b[1]	4.2	71.1 b	4.2	90.8 a	4.2
2	31.8 d	4.2	21.9 d	4.2	54.0 c	4.2

[1]Data with the same letter are not significantly different at the $P < 0.05$ level

Table 83 (Table 25). Effect of year x harvest season interaction ($P < 0.0001$) on the grass proportion of biomass (%) within NWSG in Blackstone, VA.

Year	Grass Biomass Proportion (%)			
	Harvest			
	Spring	SE	Fall	SE
1	86.7 a[1]	2.8	68.9 b	2.8
2	31.2 d	2.8	40.7 c	2.8

[1]Data with the same letter are not significantly different at the $P < 0.05$ level

Table 84. Effect of planting timing ($P = 0.0035$) on the weeds proportion of biomass (%) within NWSG in Blackstone, VA.

Timing	Weeds Biomass Proportion	
	%	SE
Burn	3.7 b[1]	2.6
Winter	11.4 a	2.6
Fall	12.3 a	2.6

[1]Data with the same letter are not significantly different at the $P < 0.05$ level

Table 85. Effect of harvest season (P = 0.0038) on the weeds proportion of biomass (%) within NWSG in Blackstone, VA.

Harvest Season	Weeds Biomass Proportion	
	%	SE
Spring	12.0 a[1]	2.4
Fall	6.3 b	2.4

[1]Data with the same letter are not significantly different at the $P < 0.05$ level

Table 86. Effect of year x planting timing interaction (P = 0.0464) on the weeds proportion of biomass (%) within NWSG in Blackstone, VA.

Year	Weeds Biomass Proportion (%)					
	Timing					
	Burn	SE	Winter	SE	Fall	SE
1	6.4 bc[1]	3.1	12.5 ab	3.1	9.4 ab	3.1
2	1.0 c	3.1	10.3 ab	3.1	15.3 a	3.1

[1]Data with the same letter are not significantly different at the $P < 0.05$ level

Table 87. Effect of year x planting method interaction (P = 0.0026) on the weeds proportion of biomass (%) within NWSG in Blackstone, VA.

Year	Weeds Biomass Proportion (%)					
	Method					
	Drill	SE	Broadcast	SE	Control	SE
1	10.7 ab	3.1	13.2 a	3.1	4.4 b	3.1
2	5.9 b	3.1	7.4 ab	3.1	13.3 a	3.1

[1]Data with the same letter are not significantly different at the $P < 0.05$ level

Table 88 (Table 27). Effect of year x planting timing x planting method interaction (P = 0.0472) on the weed proportion of biomass (%) within NWSG in Blackstone, VA.

Timing	Year	Weeds Biomass Proportion (%)					
		Method					
		Drill	SE	Broadcast	SE	Control	SE
Burn	1	8.0 bcdefg[1]	4.6	4.7 fg	4.6	6.4 cdefg	4.6
	2	0.7 g	4.6	1.5 g	4.6	0.6 g	4.6
Winter	1	18.0 abc	4.6	17.6 abcd	4.6	2.0 g	4.6
	2	5.8 efg	4.6	6.3 cdefg	4.6	18.9 ab	4.6
Fall	1	6.2 defg	4.6	17.3 abcde	4.6	4.7 fg	4.6
	2	11.1 abcdefg	4.6	14.3 abcdef	4.6	20.5 a	4.6

[1]Data with the same letter are not significantly different at the $P < 0.05$ level

Table 89 (Table 25). Effect of year x harvest season interaction (*P* = 0.0008) on the weeds proportion of biomass (%) within NWSG in Blackstone, VA.

Year	Weeds Biomass Proportion (%)			
	Harvest			
	Spring	SE	Fall	SE
1	9.0	2.7	9.9	2.7
2	15.0	2.7	2.7	2.7

[1]Data with the same letter are not significantly different at the *P* < 0.05 level

Table 90. Effect of year x planting timing x harvest season interaction (*P* = 0.0117) on the weed proportion of biomass (%) within NWSG in Blackstone, VA.

Timing	Year	Weeds Biomass Proportion (%)			
		Harvest Season			
		Spring	SE	Fall	SE
Burn	1	7.3 cde[1]	3.9	5.4 cde	3.9
	2	1.1 e	3.9	0.8 e	3.9
Winter	1	12.8 bc	3.9	12.3 bc	3.9
	2	17.8 ab	3.9	2.9 de	3.9
Fall	1	6.8 cde	3.9	12.0 bcd	3.9
	2	26.0 a	3.9	4.6 cde	3.9

[1]Data with the same letter are not significantly different at the *P* < 0.05 level

Table 91. Effect of planting timing (*P* = 0.0194) on whole plot crude protein content (g kg^{-1}) within NWSG in the establishment year of Plot Set 1 (2022) and Plot Set 2 (2023) in Blackstone, VA.

Timing	Crude Protein	
	g kg^{-1}	SE
Burn	114 a[1]	3.89
Winter	111 ab	3.89
Fall	108 b	3.89

[1]Data with the same letter are not significantly different at the *P* < 0.05 level

Table 92. Effect of harvest season (*P* < 0.0001) on whole plot crude protein content (g kg^{-1}) within NWSG in the establishment year of Plot Set 1 (2022) and Plot Set 2 (2023) in Blackstone, VA.

Harvest Season	Crude Protein	
	g kg^{-1}	SE
Spring	120 a[1]	3.74
Fall	102 b	4.07

[1]Data with the same letter are not significantly different at the *P* < 0.05 level

Table 93 (Table 28). Effect of planting timing x harvest season interaction (*P* = 0.0002) on whole plot crude protein content (g kg^{-1}) within NWSG in the establishment year of Plot Set 1 (2022) and Plot Set 2 (2023) in Blackstone, VA.

Harvest Season	Crude Protein (g kg^{-1})					
	Timing					
	Burn	SE	Winter	SE	Fall	SE
Spring	115 b[1]	4.11	122 a	4.11	123 a	4.11
Fall	114 b	4.96	101 c	4.96	93 c	4.96

[1]Data with the same letter are not significantly different at the *P* < 0.05 level

Table 94. Effect of planting timing (*P* < 0.0001) on whole plot crude protein content (g kg^{-1}) within NWSG in the second year of production of Plot Set 1 (2023) in Blackstone, VA.

Timing	Crude Protein	
	g kg^{-1}	SE
Burn	150 a[1]	3.06
Winter	132 b	3.06
Fall	119 c	3.06

[1]Data with the same letter are not significantly different at the *P* < 0.05 level

Table 95. Effect of harvest season (*P* < 0.0001) on whole plot crude protein content (g kg^{-1}) within NWSG in the second year of production of Plot Set 1 (2023) in Blackstone, VA.

Harvest Season	Crude Protein	
	g kg^{-1}	SE
Spring	147 a[1]	2.34
Fall	121 b	2.37

[1]Data with the same letter are not significantly different at the *P* < 0.05 level

Table 96 (Table 31). Effect of planting timing x harvest season interaction (*P* = 0.0001) on whole plot crude protein content (g kg^{-1}) within NWSG in the second year of production of Plot Set 1 (2023) in Blackstone, VA.

Harvest Season	Crude Protein (g kg^{-1})					
	Timing					
	Burn	SE	Winter	SE	Fall	SE
Spring	152 a[1]	4.05	148 ab	4.05	139 b	4.05
Fall	149 ab	4.11	115 c	4.11	99 d	4.11

[1]Data with the same letter are not significantly different at the *P* < 0.05 level

Table 97. Effect of planting method x harvest season interaction ($P = 0.0286$) on whole plot crude protein content (g kg^{-1}) within NWSG in the second year of production of Plot Set 1 (2023) in Blackstone, VA.

Harvest Season	Crude Protein (g kg^{-1})					
	Method					
	Drill	SE	Broadcast	SE	Control	SE
Spring	145 a[1]	4.05	147 a	4.05	148 a	4.05
Fall	132 b	4.11	117 c	4.11	114 c	4.11

[1]Data with the same letter are not significantly different at the $P < 0.05$ level

Table 98. Effect of planting timing ($P < 0.0001$) on whole plot neutral detergent fiber content (g kg^{-1}) within NWSG in the establishment year of Plot Set 1 (2022) and Plot Set 2 (2023) in Blackstone, VA.

Timing	Neutral Detergent Fiber	
	g kg^{-1}	SE
Burn	593 c[1]	5.05
Winter	610 b	5.05
Fall	626 a	5.05

[1]Data with the same letter are not significantly different at the $P < 0.05$ level

Table 99 (Table 28). Effect of planting timing x harvest season interaction ($P = 0.0005$) on whole plot neutral detergent fiber content (g kg^{-1}) within NWSG in the establishment year of Plot Set 1 (2022) and Plot Set 2 (2023) in Blackstone, VA.

Harvest Season	Neutral Detergent Fiber (g kg^{-1})					
	Timing					
	Burn	SE	Winter	SE	Fall	SE
Spring	609 b[1]	5.20	603 b	5.20	617 ab	5.20
Fall	576 c	8.50	616 ab	8.50	636 a	8.50

[1]Data with the same letter are not significantly different at the $P < 0.05$ level

Table 100. Effect of planting timing ($P < 0.0001$) on whole plot neutral detergent fiber content (g kg^{-1}) within NWSG in the second year of production of Plot Set 1 (2023) in Blackstone, VA.

Timing	Neutral Detergent Fiber	
	g kg^{-1}	SE
Burn	454 c[1]	10.6
Winter	546 b	10.6
Fall	598 a	10.6

[1]Data with the same letter are not significantly different at the $P < 0.05$ level

Table 101. Effect of harvest season (P < 0.0001) on whole plot neutral detergent fiber content (g kg^{-1}) within NWSG in the second year of production of Plot Set 1 (2023) in Blackstone, VA.

Harvest Season	Neutral Detergent Fiber	
	g kg^{-1}	SE
Spring	503 b[1]	6.90
Fall	562 a	7.70

[1]Data with the same letter are not significantly different at the P < 0.05 level

Table 102 (Table 31). Effect of planting timing x harvest season interaction (P = 0.0357) on whole plot neutral detergent fiber content (g kg^{-1}) within NWSG in the second year of production of Plot Set 1 (2023) in Blackstone, VA.

Harvest Season	Neutral Detergent Fiber (g kg^{-1})					
	Timing					
	Burn	SE	Winter	SE	Fall	SE
Spring	440 e[1]	11.90	509 c	11.90	561 b	11.90
Fall	468 d	13.28	582 b	13.28	636 a	13.28

[1]Data with the same letter are not significantly different at the P < 0.05 level

Table 103 (Table 29). Effect of harvest season (P < 0.0001) on whole plot acid detergent fiber content (g kg^{-1}) within NWSG in the establishment year of Plot Set 1 (2022) and Plot Set 2 (2023) in Blackstone, VA.

Harvest Season	Acid Detergent Fiber	
	g kg^{-1}	SE
Spring	329 b	5.30
Fall	365 a	5.30

[1]Data with the same letter are not significantly different at the P < 0.05 level

Table 104 (Table 32). Effect of harvest season (P < 0.0001) on whole plot acid detergent fiber content (g kg^{-1}) within NWSG in the second year of production of Plot Set 1 (2023) in Blackstone, VA.

Harvest Season	Acid Detergent Fiber	
	g kg^{-1}	SE
Spring	340 b[1]	2.36
Fall	366 a	2.77

[1]Data with the same letter are not significantly different at the P < 0.05 level

Table 105 (Table 33). Effect of planting timing ($P = 0.0068$) on total seasonal yield (kg ha^{-1}) within NWSG in the second year of production of Plot Set 1 (2023) in Blackstone, VA.

Timing	Total Seasonal Yield	
	kg ha^{-1}	SE
Burn	5,757 b[1]	301
Winter	7,259 a	301
Fall	7,599 a	301

[1]Data with the same letter are not significantly different at the $P < 0.05$ level

Table 106 (Table 34). Effect of planting method ($P = 0.0122$) on total seasonal yield (kg ha^{-1}) within NWSG in the second year of production of Plot Set 1 (2023) in Blackstone, VA.

Method	Total Seasonal Yield	
	kg ha^{-1}	SE
Drill	6,574 b[1]	301
Broadcast	6,422 b	301
Control	7,619 a	301

[1]Data with the same letter are not significantly different at the $P < 0.05$ level

Table 107 (Table 35). Effect of harvest season ($P < 0.0001$) on harvest yield (kg ha^{-1}) within NWSG in the establishment year of Plot Set 1 (2022) and Plot Set 2 (2023) in Blackstone, VA.

Harvest Season	Harvest Yield	
	kg ha^{-1}	SE
Spring	3,478 a[1]	1,447
Fall	2,872 b	1,447

[1]Data with the same letter are not significantly different at the $P < 0.05$ level

Table 108. Effect of planting timing ($P < 0.0001$) on harvest yield (kg ha^{-1}) within NWSG in the second year of production of Plot Set 1 (2023) in Blackstone, VA.

Timing	Harvest Yield	
	kg ha^{-1}	SE
Burn	2,879 b	152
Winter	3,629 a	152
Fall	3,799 a	152

[1]Data with the same letter are not significantly different at the $P < 0.05$ level

Table 109. Effect of planting method ($P = 0.0073$) on harvest yield (kg ha^{-1}) within NWSG in the second year of production of Plot Set 1 (2023) in Blackstone, VA.

Method	Harvest Yield	
	kg ha^{-1}	SE
Drill	3,287 b	152
Broadcast	3,211 b	152
Control	3,809 a	152

[1]Data with the same letter are not significantly different at the $P < 0.05$ level

Table 110 (Table 38). Effect of planting timing x planting method interaction (*P* = 0.0470) on harvest yield (kg ha^{-1}) within NWSG in the second year of production of Plot Set 1 (2023) in Blackstone, VA.

Timing	Harvest Yield (kg ha^{-1})					
	Method					
	Drill	SE	Broadcast	SE	Control	SE
Burn	2,730 c[1]	248	2,861 c	248	3,046 c	248
Winter	3,095 c	248	3,404 bc	248	4,389 a	248
Fall	4,036 ab	248	3,369 bc	248	3,994 ab	248

[1]Data with the same letter are not significantly different at the *P* < 0.05 level

Table 111 (Table 36). Effect of planting timing x harvest season interaction (*P* < 0.0001) on harvest yield (kg ha^{-1}) within NWSG in the second year of production of Plot Set 1 (2023) in Blackstone, VA.

Harvest Season	Harvest Yield (kg ha^{-1})					
	Timing					
	Burn	SE	Winter	SE	Fall	SE
Spring	3,446 bc[1]	194	3,395 bc	194	2,933 cd	194
Fall	2,312 d	264	3,864 b	264	4,666 a	264

[1]Data with the same letter are not significantly different at the *P* < 0.05 level

Table 112 (Table 37). Effect of planting method x harvest season interaction (*P* = 0.0207) on harvest yield (kg ha^{-1}) within NWSG in the second year of production of Plot Set 1 (2023) in Blackstone, VA.

Harvest Season	Harvest Yield (kg ha^{-1})					
	Method					
	Drill	SE	Broadcast	SE	Control	SE
Spring	3,370 b[1]	194	3,181 b	194	3,223 a	194
Fall	3,204 b	264	3,242 b	264	4,396 b	264

[1]Data with the same letter are not significantly different at the *P* < 0.05 level