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TECHNICAL NOTE

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Interseeded cover crops did not reduce silage corn performance in the sandy loam soils of South Carolina

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Abstract

A major concern with interseeding summer cover crops alongside cash crops is the possibility of cover crops competing with the main crop for water and nutrients and thus, reducing the main crop yields. We conducted on-farm trials in the sandy loam soils of the upstate of South Carolina in 2020 and 2021 to evaluate the effect of white clover (*Trifolium repens* L.), buckwheat (*Fagopyrum esculentum* Moench), and pigeon pea (*Cajanus cajan* (L.) Millsp.) and their mixture interseeded at V4, V7, and V10 corn growth stages on silage corn performance and soil moisture content. We found that none of the cover crops affected silage corn height and aboveground biomass production regardless of the interseeding time. Further, the volumetric water content in the upper 20-cm soil profile was not decreased by cover crops irrespective of their interseeding time. At physiological maturity, corn height, aboveground biomass, and volumetric water content ranged between 131 and 163 cm, 9 and 23 Mg ha^{-1}, and 10% and 22%, respectively, in season-1 and between 181 and 216 cm, 0.48 and 1.03 Mg ha^{-1}, and 10% and 17%, respectively, in season-2 when interseeded with cover crops. When cover crops were not interseeded, the average corn height, aboveground biomass, and volumetric water content values were 152 cm, 13 Mg ha^{-1}, and 13%, respectively, in season-1 and 204 cm, 0.7 Mg ha^{-1}, and 14%, respectively, in season-2. These results would encourage farmers who want to consider cover crop interseeding with corn in the regional production systems.

1 | INTRODUCTION

The long cash-crop seasons in the southern United States often limit the window for the establishment of fall cover crops (Chu et al., 2017; Dabney et al., 2001). An alternate approach for adding cover crops to southern production systems is to interseed cover crops into the main crop prior to harvest during the summer cropping season (CTIC, 2017). A major concern with interseeding is the possibility of cover crops acting as weeds and competing with the main crop for water and nutrients (Hall et al., 1992; Mohammed et al., 2020).

The effect of interseeded cover crops on soil moisture and nutrient contents is under active research. Nguyen et al. (2022) found that cover crop mixtures of oat (*Avena sativa* L.), pea (*Pisum sativum* L.), and radish (*Raphanus sativus* L.), or annual ryegrass (*Lolium multiflorum*), Dwarf Essex rapeseed (*Brassica napus*), and crimson clover (*Trifolium incarnatum* L.), when interseeded into corn (*Zea mays* L.) at the V5–V6 corn growth stage did not have an influence on soil moisture

Abbreviations: DAP, days after planting.

levels at the 0–10 cm depth when measured in the following spring in Michigan. Additionally, the same authors found an advantage of enhanced soil NO_3^- content with the interseeded mixtures of oat, pea, and radish. The lack of any negative effect of interseeded cover crops on soil moisture in corn production systems has also been reported by other studies (e.g., Mohammed et al., 2020 in Iowa, Minnesota, and North Dakota; Rusch et al., 2020 in Minnesota; and Martens et al., 2001 in Manitoba, Canada). In contrast, Noland et al. (2018) found that a rye cover crop interseeded into corn at the V7 corn growth stage reduced spring soil water content when sufficient rye biomass was present, and spring precipitation was less.

Contrasting results have also been reported on the effects of interseeded cover crops on corn yields. For example, multiple studies demonstrated successful cover crop establishment when interseeded after the V2 corn growth stage and no negative effects of interseeded cover crops on corn yield (Baributsa et al., 2008; Bich et al., 2014; Brooker, Renner, & Sprague, 2020; Brooker, Renner, & Basso, 2020; Curran et al., 2018; Mohammed et al., 2020; Noland et al., 2018). On the other hand, Curran et al. (2018) reported corn yield losses when cover crops were interseeded at the V2 corn growth stage. Corn yield losses in the interseeded system have been reported by other studies as well where cover crops were sown before or at the time of corn planting (Berti et al., 2017; Uchino et al., 2009). Time of interseeding is crucial to the success of the interseeding system as corn is not competitive with the intercrops/weeds that emerged before the V2 corn growth stage (Strahan et al., 2000). Successful establishment of interseeded cover crops will depend upon many factors such as cover crop species, interseeding method, soil tilth that affects seed-to-soil contact and cover crop stand establishment, precipitation during the interseeding period (1 week prior to through 1 month after interseeding), and light penetration through the corn canopy into the interseeded cover crops (Alonso-Ayuso et al., 2020; Brooker, Renner, & Basso, 2020; Caswell et al., 2019). Furthermore, the performance of both corn and cover crops in an interseeded system will depend upon soil type and topography (Brooker, Renner, & Basso, 2020). Taken together, previous research has demonstrated the necessity of regional testing of a corn-cover crop interseeded system.

Though cover crop interseeding with corn has been tested in the midwestern and northern production regions of the United States, little information is available from the southern state of South Carolina to date. The objective of this study was to evaluate the effect of three cover crop species (white clover [*Trifolium repens* L.], buckwheat [*Fagopyrum esculentum* Moench], and pigeon pea [*Cajanus cajan* (L.) Millsp.]) and their mixture interseeded at V4, V7, and V10 corn growth stages on silage corn performance and soil moisture content in the upstate of South Carolina. It has been reported in literature that white clover demonstrates shade tolerance, establishes a rapid ground cover, and can be used as a companion crop with corn to reduce soil erosion, enhance soil fertility, and suppress weeds and pests (Hartwig & Ammon, 2002; National Resources Conservation Service [NRCS], 2011; Clark, 2012; Sanders et al., 2017). It fixes nitrogen and encourages the association between mycorrhizal fungi and corn plants to assist in nutrient supply from soils with high phosphorous fixation capabilities (Deguchi et al., 2007). Buckwheat is another cover crop that has been shown to work well as an interseeded cover crop with corn (L. Steinlage, Personal. Communication, 28 October 2019). Buckwheat can produce a quick ground cover, scavenge phosphorus, rejuvenate low-fertility soils, attract beneficial insects, and suppress weeds (Clark, 2012). It produces abundant fine roots, which makes soil friable (Clark, 2012), which in turn makes this species a good choice for compacted soils in the southeastern United States. Pigeon pea has a bio-tilling potential due to its deep root system with a strong taproot (Snapp et al., 2003; Valenzuela, 2011). It is moderately shade tolerant (Aniela, 2018) and well suited for intercropping as it draws water from deeper soil profiles than most legumes, without interfering with the water uptake of other crops (Sheahan, 2012). In the present study, the previous cover crops were tested in on-farm trials in a silage corn farm characterized by a sandy loam soil.

Core Ideas

- Interseeded white clover, buckwheat, and pigeon pea did not affect silage corn height and biomass yield.
- Interseeded cover crops did not decrease water content in the upper 20-cm soil profile.
- Interseeding between V4 and V10 corn stages does not negatively impact silage corn production in South Carolina.

2 | MATERIALS AND METHODS

2.1 | Study site and management

This study involved on-farm trials under rain-fed conditions at the Mull Meadow farm in Pendleton, SC, USA (34˚68′38.44″N, −82˚67′27.20″W, 266 m above sea level). The trials were conducted for two consecutive years in 2020 (season-1) and 2021 (season-2). The study site is characterized with a humid subtropical climate (Köppen classification; Griffin & Mogil, 2021) with long, hot, and humid summers, and short and mild winters. The soil series at the study site

TABLE 1 Soil nutrient status at the time of corn planting in season-1 and -2

Soil parameters/nutrients	Season-1 (2020)	Season-2 (2021)
Soil pH	5.9	6
Phosphorus (kg ha^{-1})	6.72 (low)	11.21 (low)
Potassium (kg ha^{-1})	135.62 (medium)	116.57 (medium)
Calcium (kg ha^{-1})	608.62 (medium)	483.09 (medium)
Magnesium (kg ha^{-1})	124.41 (medium)	132.26 (sufficient)
Zinc (kg ha^{-1})	1.79 (low)	2.24 (medium)
Manganese (kg ha^{-1})	24.66 (medium)	12.33 (medium)
Boron (kg ha^{-1})	0.11 (medium)	0.56 (medium)
Copper (kg ha^{-1})	0.78	0.56
Sodium (kg ha^{-1})	4.48	15.69
Nitrate nitrogen (ppm)	1	2
Organic matter (%)	3.9	3.53

Note: The remarks: low, medium, and sufficient were provided in the soil test report.

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The study site, which had been under native clover and used as a pastureland for cattle, had not been used for any crop production in the past 30 years. In season-1, land preparation consisted of primary tillage with a chisel plow (Model 131, Ford tractor company, Minneapolis, MN, USA) 1 day before corn planting. On the day of the corn planting, a secondary tillage was performed with a Leinbach Line disk harrow (Model 300-S 3-point hitch, Leinbach Company, East Bend, NC, USA) to which a 4′ × 4′ homemade field leveling drag harrow was attached. In season-2, no tillage operations were conducted.

To determine the soil nutrient status, composite soil samples were collected at the time of corn planting on 17 April 2020 in season-1 and 5 March 2021 in season-2. Soil samples were tested at the Clemson University Agricultural Service Laboratory, Clemson, SC. The results of the soil testing are presented in Table 1. A 19-19-19 N-P-K fertilizer was applied at the rate of 181 kg ha^{-1} at 45 days after corn planting (DAP) in season-1, using a centrifugal Countyline Fertilizer Spreader (Model P-PL, Tarter Farm and Ranch Equipment, Dunnville, KY, USA). The first fertilizer application was delayed in season-1 due to fertilizer unavailability that was related to the COVID-19-associated supply chain disruptions. In the same season, 91 kg ha^{-1} of the same fertilizer was applied using a Sta-Green 32-lb broadcast spreader (Model 75260, Parker fertilizer company, Sylacauga, AL, USA) at 64 DAP. In season-2, the same fertilizer was applied at the rate of 181 kg ha^{-1} on the day of corn planting using the centrifugal Countyline Fertilizer Spreader. The same fertilizer was again applied at the rate of 91 kg ha^{-1} using the Sta-Green 32-lb broadcast spreader at 59 DAP. The nutrient addition recommendations by the soil testing laboratory were 202 kg ha^{-1} of N, 112 kg ha^{-1} of P_2O_5, and 135 kg ha^{-1} of K_2O. We could not apply the recommended amounts of nutrients in season-1 due to COVID-19-associated fertilizer unavailability. In season-2, we repeated the nutrient application rate of season-1. As the soil pH indicated acidity, 2,242 kg ha^{-1} of lime was broadcasted using the centrifugal Countyline Fertilizer Spreader at 45 DAP in season-1 following the recommendations of the soil testing laboratory.

2.2 | Corn and cover crop management

Corn hybrid P2089VYHR was planted on 17 April 2020 in season-1, and P2088YXR was planted on 16 April 2021 in season-2. Both were glyphosate (*N*-(phosphonomethyl)glycine)-resistant silage corn hybrids. A different hybrid was used in season-2 as the one that was used in season-1 was not available to purchase at the beginning of season-2. As per the seed company (Corteva Agriscience), both P2089VYHR and P2088YXR are from the same hybrid family and have the same silage scores. Though the targeted population was 80,000 plants ha^{-1}, because of a calibration issue with the planting equipment (Model Van brunt T412M, John Deere, Moline, IL, USA), corn was planted at a population of about 109,000 plants ha^{-1} in season-1. In season-2, corn was planted at the expected population of 80,000 plants ha^{-1} using a no-till planter (Model 7000, John Deere, Moline, IL, USA). In season-1, each plot had four rows of corn with a row spacing of 0.9 m. In season-2, each plot had six rows of corn with a row spacing of 0.76 m. The changes in the number of rows per plot and row spacing from season-1 to season-2 resulted from the use of different planters and from the effort to avoid the calibration issues and overseeding that occurred in season-1. The plot size was 5.5 m × 2.7 m in 2020 and 5.5 m × 3.8 m in 2021. The individual plots were separated by allies which were at least 0.61-m wide.

Three cover crop species: white clover, buckwheat, and pigeon pea were interseeded as single species or the three-species mixture at the V4, V7, and V10 growth stages of corn. The dates of interseeding of cover crops in season-1 and -2 are presented in Table 2. The corn growth stages were determined using the leaf-collar method by counting the leaves with visible collars and using the lowermost round-tipped leaf as leaf no. 1 (Abendroth et al., 2011; Nielsen, 2014). Cover crops were broadcast interseeded manually using a precision garden seeder (Model-1001B, Earthway products Inc., Bristol, IN, USA) in both seasons. Between two adjacent corn rows, three cover crop rows were interseeded with 0.19-m row spacing (Curran et al., 2018). The seeding rates were 3.4 kg ha^{-1} for white clover, 53.8 kg ha^{-1} for buckwheat, and 11.2 kg ha^{-1} for pigeon pea as single species (Clark, 2012)

TABLE 2 Cover crop interseeding dates at the Mull Meadow Farm in Pendleton, SC, USA

Time of interseeding[a]	Interseeding date	
	Season-1 (2020)	**Season-2 (2021)**
V4	3 June (47 DAP)	21 May (35 DAP)
V7	16 June (60 DAP)	28 May (42 DAP)
V10	27 June (71 DAP)	8 June (53 DAP)

Abbreviation: DAP, days after corn planting.

[a]Cover crops were interseeded at the V4, V7, or V10 growth stages of corn.

and 1.1, 17.9, and 3.7 kg ha^{-1} for white clover, buckwheat, and pigeon pea, respectively, in the mixture. The seeding rate of individual species in the mixtures was calculated as the seeding rate of the species when used as a monoculture divided by the number of species in the mixture (Wortman et al., 2012). The 'control' plots were not interseeded with any cover crops and just had corn rows. Each plot received the same cover crop or control treatment in both seasons. The experiment was laid out in a split-plot design with the time of interseeding (corn growth stage) as the main plot factor and cover crop treatment (white clover, buckwheat, pigeon pea, mixture, or the control treatment) as the subplot factor. There were four replications for each cover crop treatment under each interseeding time.

To control weeds, the broad-spectrum herbicide Roundup (glyphosate, *N*-(phosphonomethyl)glycine) (Monsanto, St. Louis, MO, USA) was applied at the rate of 1.1 kg ai ha^{-1} at 45 DAP in season-1. In the same season, the control plots, where no cover crops were interseeded, were again sprayed with Roundup at the rate of 1.1 kg ai ha^{-1} at 64 DAP when corn was at the V10 growth stage. In season-2, Roundup was applied at the rate of 1.1 kg ai ha^{-1} at 5 days before corn planting. In the same season, the control plots were again sprayed with Roundup at the rate of 1.1 kg ai ha^{-1} at 60 DAP when corn was at the V10 growth stage.

2.3 | Environmental conditions during the study period

Total rainfall was 68.8 cm in season-1 and 63 cm in season-2. Total rainfall in season-1 and -2 exceeded the 30-year average by 22.4 and 17.4 cm, respectively. Season-2 began as a drier year compared to season-1. However, toward the end of the study (that was marked by the silage corn harvest), season-2 received higher rainfall than season-1 (Figure 1A). For example, in the last 14 days, rainfall was 6 cm in season-1 and 11 cm in season-2. Monthly average air temperatures were approximately similar to the 30-year average temperatures throughout the seasons except in April and May, when it was slightly cooler than the average temperature normals for this region (Figure 1B).

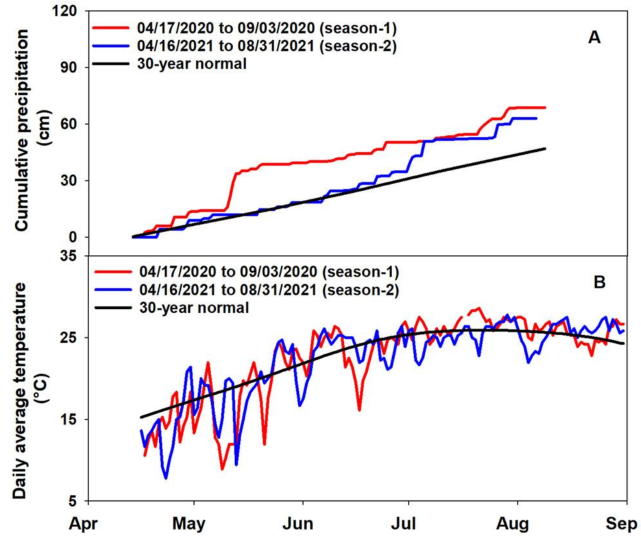

FIGURE 1 Cumulative precipitation (A) and daily average temperatures (B) during the study period (from planting through the harvest of corn) in comparison with the 30-year normal data. Cumulative precipitation normal for a 139-day period in season-1 and 137-day period in season-2 were calculated from the daily precipitation normal for a period of 30 years from 1991 to 2020. Precipitation and temperature data were acquired from the National Centers for Environmental Information, Data, and Information Service, a division within the National Oceanic and Atmospheric Administration (NOAA).

2.4 | Data collection

In both seasons, two corn plants were tagged midway in the second row of each plot to facilitate the data collection on plant height and volumetric soil water content. Plant height was measured as the distance between the soil surface and the arch of the uppermost leaf pointing down (Gadédjisso-Tossou et al., 2020). Plant height was measured when the corn crop was at V10 and R6 (physiological maturity) growth stages in both seasons, which occurred at 71 DAP (V10) and 136 DAP (R6) in season-1 and at 60 DAP (V10) and 131 DAP (R6) in season-2. An additional measurement was taken at the R4 growth stage (dough stage) at 103 DAP in season-2.

To measure corn aboveground biomass, all corn plants from a 1-m length on the second row of each plot were hand-harvested in both seasons. Aboveground biomass was harvested at 139 DAP in season-1 and at 137 DAP in season-2 when the corn crop reached physiological maturity (R6). Aboveground biomass samples were weighed to get the fresh weight. The fresh weights of aboveground biomass samples were converted to dry weights by multiplying the fresh weight with the dry matter percentage (Rajcan & Tollenaar, 1999; Pordesimo et al., 2002; Vacek & Rooney, 2018). To estimate the dry matter percentage, a subsample was taken from the aboveground biomass sample harvested from each plot, weighed to get the fresh weight, and oven-dried at 70°C till

TABLE 3 Analysis of variance results on the effect of interseeded cover crops and the time of interseeding on various traits measured in the study

Trait	Season-1 (2020) *p* values DAP	Interseeded cover crops (CC)	Time of interseeding[a] (CS)	CC × CS	Season-2 (2021) *p* values DAP	CC	CS	CC × CS
Corn plant height	71	0.9023	0.5491	0.5394	60	0.2814	0.4258	0.1576
	136	0.3720	0.9390	0.2177				
	–	–	–	–	103	0.3797	0.7858	0.9144
	–	–	–	–	131	0.9003	0.1085	0.4807
Corn aboveground biomass[b]	139	0.6659	0.0003	0.3867	137	0.9575	0.0008	0.6916
Volumetric soil water content	136	0.0929	0.0002	0.1604	146	0.0768	0.0472	0.7301

Abbreviation: DAP, days after corn planting.
[a]Cover crops were interseeded at V4, V7, or V10 growth stages of corn.
[b]Data were log-transformed for analyses.

constant weight to get the dry weight. The dry matter percentage was calculated by multiplying the ratio between the subsample dry weight and fresh weight by 100. The rest of the corn aboveground biomass in the field was raked by a wheel rake (Model 720, John Deere) and picked and baled using a New Holland forage harvester (BR7060) to make haylage.

Volumetric soil water content to a depth of 20 cm was measured using a Hydrosense II CS658 soil moisture probe (Campbell Scientific Devices). Measurements were taken at the base of each of the two tagged plants in each plot to obtain an average volumetric water content per plot. Data were collected at corn harvest at 136 DAP in season-1 and at 146 DAP in season-2.

2.5 | Statistical analysis

Analysis of variance (ANOVA) for all data was conducted with the GLIMMIX procedure in SAS 9.4 (SAS Institute, Cary, NC, USA). The statistical model for the ANOVA was based on a split-plot design and included the fixed effects of interseeding (whole plot treatment), cover crops (split-plot treatment), and their interaction. Replication and the interaction between replication and interseeding time were considered random effects in the analysis. Separation of least squares means was performed using Fisher's least significant difference (LSD) test using the LSMEANS option in the GLIMMIX procedure. Any *p*-values less than 0.05 were considered evidence of statistical significance. Normality and homogeneity of variance assumptions required for ANOVA were checked for all traits by examining the model residuals. Normality was evaluated with the Shapiro–Wilk test, and homogeneity of variance was evaluated with Levene's test. Evidence of the normality assumption being violated was found for corn aboveground biomass. The lognormal distribution in GLIMMIX was used to redo the ANOVA and LSD for corn aboveground biomass. The lognormal results for corn aboveground biomass were consistent with the original normal distribution results; suggesting that the normality assumption violation was not significantly impacting the original ANOVA and LSD results. Therefore, the figure presenting the corn aboveground biomass data is based on the original scale data for ease of interpretation.

3 | RESULTS AND DISCUSSION

3.1 | Effects of interseeded cover crops on corn performance

The present study evaluated the effect of interseeded cover crops on silage corn performance based on two traits: corn plant height and aboveground biomass production. The main

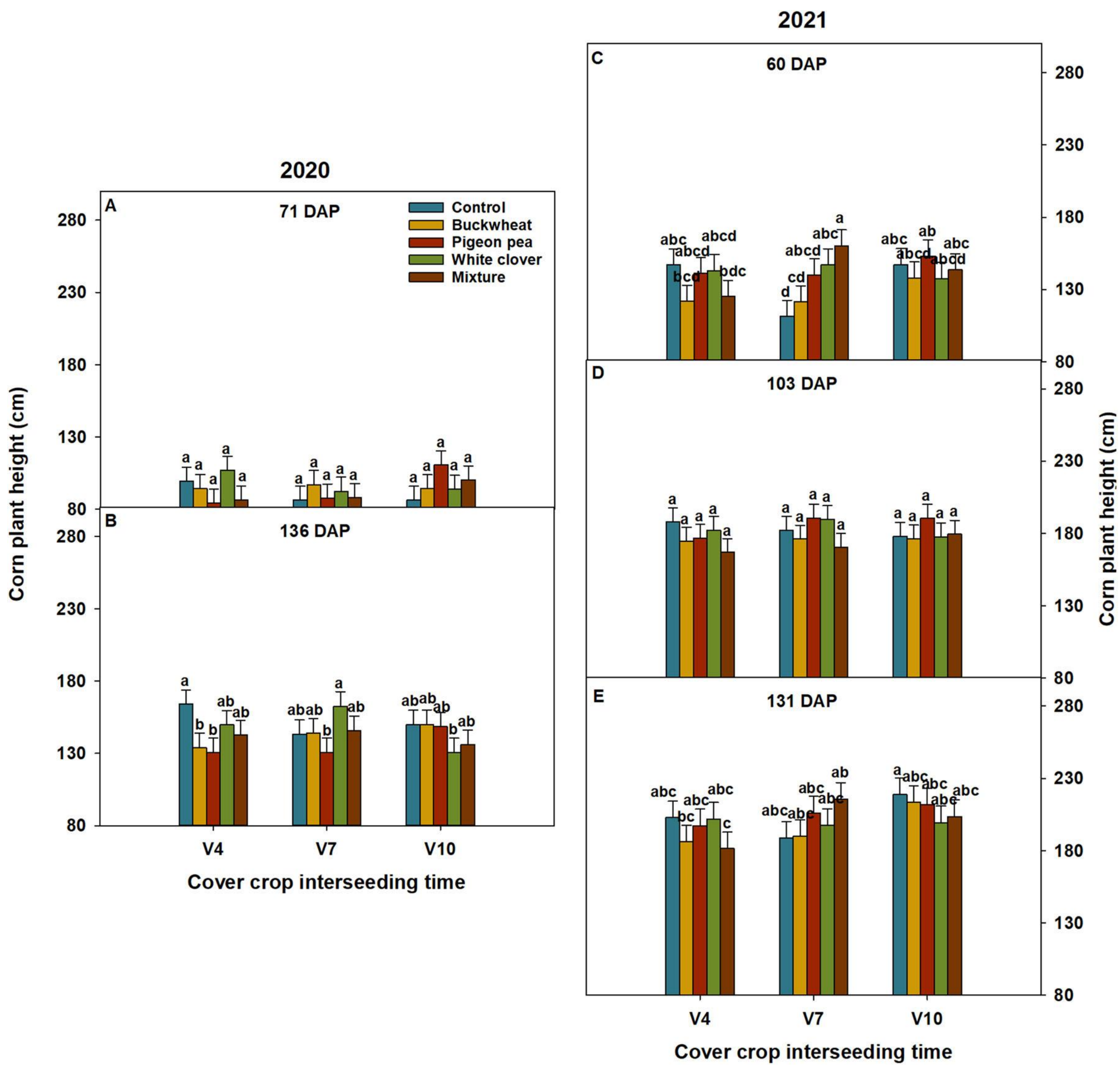

FIGURE 2 Plant height of silage corn in 2020 (A and B) and 2021 (C–E). In 2020, plant height was measured at 71 and 136 days after planting (DAP) when the corn crop was at V10 or R6 (physiological maturity) growth stages, respectively. In 2021, plant height was measured at 60, 103, and 131 DAP when the corn crop was at V10, R4 (dough stage), or R6 growth stages, respectively. The final measurement time in both years correspond with final harvest of silage corn. Labels V4, V7, and V10 represent the corn growth stages when cover crops were interseeded. Cover crops were not interseeded in the 'control' plots. Bars represent the least squares means ± standard error. Bars with the same letters are not significantly different from each other.

effects of cover crop species and cover crop interseeding time and their interaction effects were not significant on corn plant height in both years (Table 3). Overall, corn plant height for the control treatment was not different from that for the other treatments (interseeded cover crop treatments) (Figure 2). The only exception was that corn plant height measured at 136 DAP in season-1 was lower in plots interseeded with buckwheat or pigeon pea at the V4 corn stage, compared to control. As this trend was absent in any other comparisons between cover crop and control treatments across interseeding time and measurement time in both seasons, the previous anomaly may not have a biological significance. Thus, our results do not support a negative effect of interseeding on corn plant height. Abdin et al. (1998) found that adequate rainfall and soil moisture can minimize any effect of cover crops on corn plant height. In our study, season-1 was a wet year compared to the 30-year precipitation normal (Figure 1). Season-2 received normal amounts of precipitation in the first half of the growing season and above normal precipitation in the second half (Figure 1). Thus, the high rainfall may be part of the reason for no effect of interseeded cover crops on corn plant height in our study.

2013The main effect of cover crop species and the interaction effect of cover crop species and interseeding time were not significant, and the main effect of interseeding time was significant on corn aboveground biomass production in both

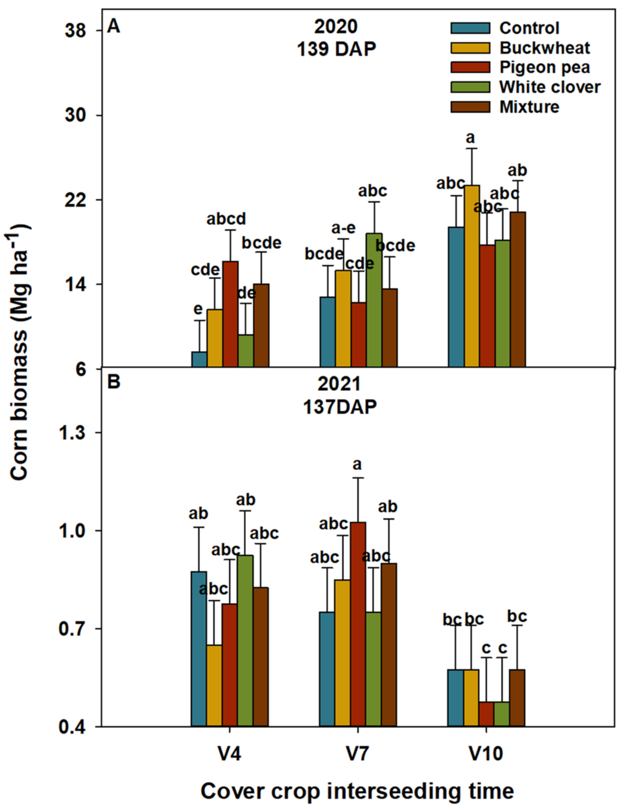

FIGURE 3 Silage corn aboveground biomass production at the end of the season in 2020 (A) and 2021 (B). The labels, V4, V7, and V10 represent the corn growth stages when cover crops were interseeded. Bars represent the least squares means ± standard error. Bars with the same letters are not significantly different from each other. DAP, days after corn planting.

seasons (Table 3). Corn aboveground biomass production was not negatively affected by cover crops interseeded at V4, V7, or V10 corn growth stages in both seasons (Figure 3). Furthermore, a numerical or statistically significant increase in corn aboveground biomass production due to interseeding was observed in most cases (Figure 3). The absence of any negative effect of interseeded cover crops on corn aboveground biomass may be because the cover crops were interseeded only at or after the V4 corn growth stage by which corn already passes the critical period of weed/plant competition (Strahan et al., 2000). Further, any increase in corn aboveground biomass production due to interseeding may be because of the increased level of complementarity between cover crops and corn. In an intercropped system, complementarity occurs when intercropped plants with complementary traits interact positively to increase productivity more than expected from their corresponding monocultures. Some mechanisms that might have increased complementarity in the present study could be improved soil physical and chemical properties that in turn increase the phytoavailability of water and nutrients, attraction of beneficial organisms, deterrence of pests and pathogens, and the suppression of weeds (Brooker et al., 2015; Li et al., 2014; Shen et al., 2013; White, George, Dupuy, et al., 2013 ; White, George, Gregory, et al., 2013; Zhang et al., 2010), which need to be tested in future research. Our results are supported by previous research in the upper Midwest that reported no negative effect of cover crops (winter rye [*Secale cereale* L.], red clover [*Trifolium pretense* L. 'Medium'], hairy vetch [*Vicia villosa* Roth], field pennycress [*Thlaspi arvense* L.], and a mixture of oat, pea, and tillage radish) on corn biomass production when interseeded during corn crop's mid vegetative growth (V7 growth stage) (Noland et al., 2018). Similar results have been reported for grain corn as well (Antosh et al., 2022; Baributsa et al., 2008; Brooker, Renner, & Sprague, 2020; Exner & Cruse, 1993; Schmitt et al., 2021).

Corn aboveground biomass production was lower in season-2 than in season-1 (Figure 3). A major reason for this difference might be the lower seeding rate in season-2 than in season-1 (80,000 plants ha^{-1} in season-2 and 109,000 plants ha^{-1} in season-1). Along with that, the drier conditions at the beginning of season-2 might have contributed to lower plant population in season-2 (3.8 plants m^{-1}) than in season-1 (17.4 plants m^{-1}), which might also have reduced aboveground biomass in season-2. Furthermore, there was an accidental mixing of sunflower seeds with corn seeds when we planted the V10 section in season-2, which decreased corn aboveground biomass in the V10 section in season-2.

At the end of the season, corn aboveground biomass values corresponding with interseeding at V4, V7, and V10 corn growth stages (main effect of interseeding time) were 12, 15, and 20 Mg ha^{-1}, respectively in season-1 and 0.79, 0.88, and 0.53 Mg ha^{-1}, respectively, in season-2. Though corn aboveground biomass production was greater when cover crops were interseeded at V10 than at V4 or V7 or compared to that under 'no-cover crop' control condition in season-1, that trend was absent in season-2, likely due to the reason explained earlier (sunflower seeds mixed and planted with corn in the V10 section in season-2). Thus, we are unable to make any conclusions at this point regarding any possible advantage of V10 corn growth stage over V4 or V7 as an effective time for cover crop interseeding. Curran et al. (2018) investigated the influence of interseeding time (V2–V6 corn growth stage) on corn grain yield in Pennsylvania. The tested cover crops were annual ryegrass, a legume mixture of red clover, crimson clover, and hairy vetch, and the same legume mixture along with annual ryegrass. Based on cover crop fall and spring biomass and the effect of interseeded cover crops on corn yield, the authors recommended interseeding at or after V4 to prevent competition with corn. In Michigan, Brooker, Renner, and Sprague (2020) found that annual ryegrass and oilseed radish (*R. sativus* L.) interseeded between V2 and V7 corn growth stages did not reduce corn grain yield. They found the highest cover crop density at the V4–V7 interseeding times.

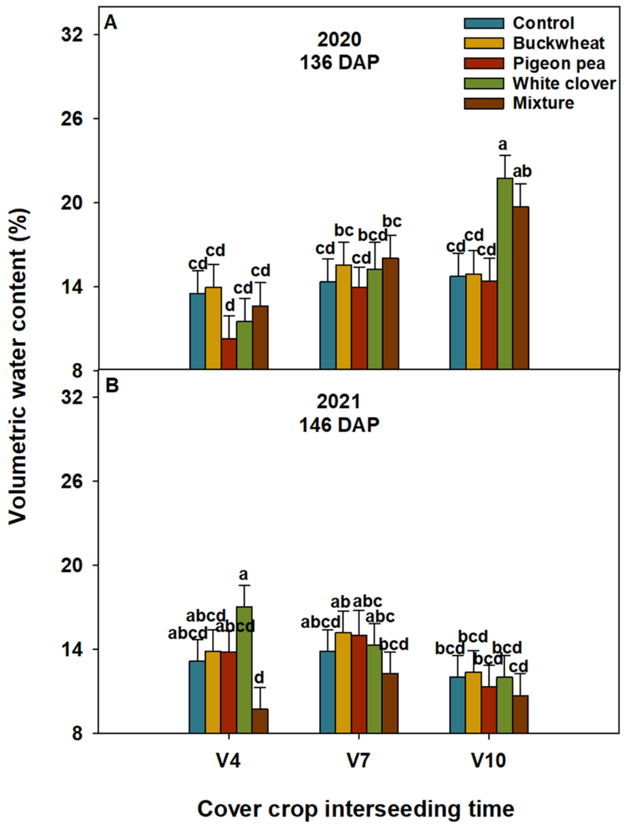

FIGURE 4 Volumetric soil water content in 0–20-cm soil profile at the end of the season (at silage corn harvest) in 2020 (A) and 2021 (B). The labels, V4, V7, and V10 represent the corn growth stages when cover crops were interseeded. Bars represent the least squares means ± standard error. Bars with the same letters are not significantly different from each other. DAP, days after corn planting.

3.2 | Effects of interseeded cover crops on soil water content

One of the major concerns of farmers regarding cover crop interseeding is whether cover crops may act as weeds and compete with the main crop for soil water content. To address this concern, we measured volumetric soil water content in the upper 20-cm soil profile in the interseeded and control plots at the end of the season (i.e., at silage corn harvest). We found that the main effect of cover crop species and the interaction effect of cover crop species and interseeding time were not significant, and the main effect of interseeding time was significant on the volumetric soil water content in both seasons (Table 3). The volumetric water content in the upper 20-cm soil profile was not decreased by cover crops irrespective of their interseeding time at V4, V7, or V10 corn growth stages (Figure 4). Furthermore, volumetric soil water content was statistically or numerically greater in the interseeded plots than in the 'control' plots in most cases (Figure 4). As soil water content was measured only at the end of the season (at silage corn harvest) in the present study, future studies are warranted to confirm the results during the corn-growing season. Our finding of the lack of any negative effects of interseeded cover crops on soil water content is supported by the previous research. Mohammed et al. (2020) investigated the effect of winter camelina (*Camelina sativa* L.), field pennycress, and winter rye interseeded at R4, R5, and R6 growth stages for corn, and R6, R7, and R8 for soybean on soil moisture content in the upper Midwest. They found that the effect of interseeding time and cover crops was not significant on soil water content at 0–30- and 30–60-cm soil depths at corn and soybean harvest and early in the following spring. The previous results do not support the concern that interseeded cover crops may deplete soil water and cause water stress to the main crop. It should also be noted that both season-1 and -2 were wetter than normal considering the historic precipitation data from the study site (Figure 1). Good amount of rainfall was recorded in both years toward the end of the season when the soil water content was measured (4.6 and 1.7 cm of rainfall in the last 10 days of measurement in season-1 and -2, respectively). It has been established in the literature that cover crops not only use soil water but increase soil water infiltration and water-holding capacity (Dabney et al., 2001; Reicosky & Forcella, 1998), which might have contributed to the lack of differences in soil water content between interseeded and control conditions, particularly in periods of greater-than-normal rainfall.

4 | CONCLUSIONS

In this research, we found that three cover crop species: white clover, buckwheat, and pigeon pea, and their mixture interseeded at V4, V7, and V10 corn growth stages did not affect silage corn height and aboveground biomass production in the sandy loam soils in the upstate of South Carolina. Further, the volumetric water content in the upper 20-cm soil profile was not decreased by cover crops irrespective of their interseeding time. These results would encourage farmers who want to consider cover crop interseeding with corn in the regional production systems. Future research should investigate whether interseeding with more adapted cover crop species could result in better cover crop establishment which in turn could improve corn aboveground biomass production, soil moisture retention, and soil health. However, the present study provides valuable baseline information to design follow-up studies that can optimize the management practices of cover crop interseeding (e.g., land preparation; method, rate, and time of interseeding; and cover crop selection) in South Carolina. The present study was conducted on a farmer's land that had been used as pastureland in previous years. Thus, it would be interesting to confirm the present results on land which has regularly been under crop production. The present results are produced under conventional corn production conditions where weeds were controlled through herbicide application. For effective cover crop establishment in organic production systems, cover crop may need to be interseeded at an earlier corn growth stage than V4 (but ≥V2) or after an inter-cultivation in order to offer cover crops a competitive advantage over weeds, which needs to be tested in future studies.

AUTHOR CONTRIBUTIONS

Ricardo St. Aime: Data curation; Formal analysis; Investigation; Methodology; Validation; Visualization; Writing-original draft; Writing-review & editing. **William C. Bridges, Jr**: Formal analysis; Methodology; Validation; Writing-review & editing. **Sruthi Narayanan**: Conceptualization; Data curation; Formal analysis; Funding acquisition; Methodology; Project administration; Resources; Supervision; Validation; Visualization; Writing-review & editing.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

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