Establishment of Switchgrass and Big Bluestem in Corn with Atrazine

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ABSTRACT

Switchgrass (*Panicum virgatum* L.) and big bluestem (*Andropogon gerardii* Vitman) provide abundant forage for livestock and wildlife during hot summer months when cool-season grass species may decline in production. Little biomass production for grazing may result during warm-season grass establishment because of weed competition. Chemical methods of weed control are now limited, because application of atrazine [6-chloro-*N*-ethyl-*N'*-(1-methylethyl)-1,3,5-triazine-2,4-diamine] to switchgrass and big bluestem is no longer allowed according to the label. Using corn (*Zea mays* L.) as a companion crop could provide potential for high biomass production during warm-season grass establishment, and allow the use of atrazine for weed control. This study investigated the ability of switchgrass and big bluestem to establish in a corn companion crop. The effects of corn hybrid (short- vs. long-season), population density, row spacing, and harvest date on switchgrass and big bluestem stands and on corn production were quantified. Establishment of switchgrass and big bluestem in corn was successful. Switchgrass mean stands were 26.3 plants m^{-2} in 1995 and 46.4 plants m^{-2} in 1996. Big bluestem stands were similar to switchgrass in 1995 (31.7 plants m^{-2}), but were much lower in 1996 (5.2 plants m^{-2}). Long-season corn hybrids and higher-density corn populations increased corn silage and grain yield without reducing warm-season grass stands. Within a season, no difference existed between corn grain yields when grown with either switchgrass (6.7 Mg ha^{-1} in 1995, 5.3 Mg ha^{-1} in 1996) or big bluestem (6.9 Mg ha^{-1} in 1995, 5.7 Mg ha^{-1} in 1996). Silage dry matter yield was not different between corn grown with switchgrass (12.6 Mg ha^{-1} in 1995, 16.1 Mg ha^{-1} in 1996) and corn grown with big bluestem (13.1 Mg ha^{-1} in 1995, and 16.6 Mg ha^{-1} in 1996) for a given year. Switchgrass and big bluestem grown in corn with atrazine reduced land production losses during the establishment year, yet allowed adequate establishment of these grasses for future forage production.

Switchgrass and big bluestem have the potential to provide abundant forage for grazing during the hot summer months when most cool-season forages phase into a period of low production. Dry matter (DM) yield of switchgrass and big bluestem has been shown to double from 4 Mg ha^{-1} to 8 Mg ha^{-1} with the application of 150 kg N ha^{-1} (Hall et al., 1982). However, establishment of these warm-season grasses is typically more difficult than establishment of cool-season grass pastures. Weed competition in young stands can inhibit warm-season grass seedling vigor and establishment, and warm-season grass yields may be as low as 1250 kg ha^{-1} or even undetectable during the establishment year without any form of weed control (Martin et al., 1982; Masters et al., 1990).

Atrazine [6-chloro-*N*-ethyl-*N'*-(1-methylethyl)-1,3,5-triazine-2,4-diamine] has been widely used for weed control during establishment of several warm-season grasses which are seeded into a clean-tilled seedbed. Martin et al. (1982) found that switchgrass and big bluestem were tolerant to preemergence applications of up to 3.4 kg active ingredient (a.i.) ha^{-1} atrazine on certain soils, and the yield of switchgrass (8420 kg ha^{-1}) and big bluestem (4300 kg ha^{-1}) in the seeding year was substantial when atrazine was used for weed control. Bahler et al. (1984, 1990) concluded that preplant applications of atrazine and atrazine applied 21 d following planting at a minimum rate of 2.2 kg a.i. ha^{-1} for proper weed control was acceptable for establishing switchgrass and big bluestem. Vogel (1987) was able to establish excellent stands (10–20 plants m^{-2}) of switchgrass and big bluestem at seeding rates as low as 107 pure live seeds (PLS) m^{-2} with either 2.2 or 3.0 kg a.i. ha^{-1} atrazine. Highly productive switchgrass stands with enough forage for harvest may be attained the establishment year with mid-April seeding, application of 120 kg N ha^{-1}, and the preemergence application of 2.3 kg a.i. ha^{-1} atrazine to suppress weeds (Vassey et al., 1985).

Weed control is now more difficult to attain, because switchgrass and big bluestem pastures for forage production have been removed from the atrazine label. Because of greater weed competition, there may be little biomass production for grazing or hay during the establishment year, forcing producers to leave their land idle. Growth of a companion crop for forage production and the use of herbicide for weed control could improve the feasibility of establishing switchgrass and big bluestem pastures. A common forage or grain crop compatible with warm-season grasses to allow grass establishment has not been widely researched or discovered.

Annual oat (*Avena sativa* L.) has been shown to be an acceptable companion crop for the establishment of perennial cool-season grasses (Buxton and Wedin, 1970); however, annual oat is likely to be competitive and incompatible with warm-season grass establishment because of differing seasons of growth. No-till seeding warm-season grasses into a dead or suppressed cool-season grass sod could serve as an alternative (Samson and Moser, 1982; Bryan et al., 1984).

Corn could provide abundant biomass in the form of silage or grain and would also enable using atrazine for weed control in the corn crop during warm-season grass establishment. This practice may adhere to the atrazine label if directions and restrictions for use on corn are followed.

Adequate light would be needed for sufficient warm-season grass establishment within the corn crop, and greater light interception by the corn crop would be needed for greater corn yield. Effects of corn height, population density, and row spacing could determine the survival of warm-season forage grasses and the corn crop yield.

Others have attempted to establish perennial cool-

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Abbreviations: DM, dry matter; GDD, growing degree days; PLS, pure live seed.

season forages in corn. Springfield and Thatcher (1951) determined that normal precipitation and corn row spacing (76 and 127 cm) had little effect on corn yield. When alfalfa (*Medicago sativa* L.) and ryegrass (*Lolium perenne* L.) were seeded in corn, hay yield increased as corn row width increased from 76 to 178 cm. Schaller and Larson (1955) showed that corn yields in 203-cm rows were 75 to 80% of yields grown in 76-cm rows. Weeds were more problematic in wide-spaced rows, but interseeded forage stands and growth were improved by wide-spaced rows.

Acceptable corn yields when grown with native warm-season grasses could pose a problem. Corn yield was reduced when grown in competition with two other warm-season grasses, johnsongrass [*Sorghum halepense* (L.) Pers.] and wild proso millet (*Panicum miliaceum* L.). Wild proso millet at 10 plants m^{-2} caused corn grain yield reduction of 13 to 22% in Nebraska and Colorado (Wilson and Westra, 1991). Mueller et al. (1993) concluded that corn grain yield increased as johnsongrass pressure decreased, but total johnsongrass and corn biomass could be similar to corn without johnsongrass. However, corn yield and dry matter production may suffer only slight or moderate reductions when grown with less competitive seedlings of switchgrass and big bluestem.

The objectives of this experiment were (i) to quantify the ability of switchgrass and big bluestem to establish stands when grown with or without corn and atrazine, (ii) to evaluate differing levels of corn maturity, population density, row width, and harvest date on switchgrass and big bluestem establishment, and (iii) to quantify biomass production from grain or forage of the corn companion crop.

MATERIALS AND METHODS

Field studies were conducted at the Iowa State University Research Farm near Boone, IA (41°59′ N, 93°55′ W), on Webster–Nicolett (fine-loamy, mixed, superactive, mesic Typic Endoaquolls–Aquic Hapludolls) soils during 1995 and 1996. The experimental design was a split-split plot with four replications and used warm-season grass species as the main plots. Factorial combinations of two corn hybrids differing in maturity (108 vs. 113 d relative maturity), two corn row spacings (76 and 114 cm), and three corn population densities (low, medium, and high) were the primary split. Corn harvest dates were the secondary split. Two control treatments (warm-season grass without corn, but with atrazine, and warm-season grass without either corn or atrazine) were used.

Both experiment years followed soybean [*Glycine max* (L.) Merr.] on sites previously in corn–soybean rotations. A credit of 45 kg N ha^{-1} was given to the previous soybean crop, and 67 kg N ha^{-1} was applied and incorporated by disking twice. Following seedbed preparation, 6.2 kg PLS ha^{-1} of 'Cave-in-Rock' switchgrass and 9.0 kg PLS ha^{-1} of 'Rountree' big bluestem were seeded with a Brillion Sure-Stand seeder (a broadcast packer-wheel drill). Corn was planted perpendicular to warm-season grass seeding by no-tilling with a four-row (76-cm spacings) John Deere 71 Flexi-Unit planter equipped with 38-cm skip-row units. Plots were four rows for narrow-row (76 cm) treatments and three rows for wide-row (114 cm) treatments. Corn was planted at 74 000 seeds ha^{-1} and later thinned to lower-density populations. Atrazine was applied preemergence immediately following grass and corn planting, at 2.8 kg a.i. ha^{-1} with 30 psi (≈0.2 MPa) tank pressure, 118 L ha^{-1} water carrier, and TeeJet 8002 nozzles. All ground preparation, fertilization, seeding, planting, and chemical application occurred on 18 May 1995 and 1996.

Table 1. Stands of switchgrass and big bluestem grown in atrazine-treated corn differing in maturity, population density, row spacing, and harvest date.

	Plant stand			
	Switchgrass		Big bluestem	
Corn trait	1995	1996	1995	1996
	plants m^{-2}			
Corn + atrazine	26.3b†	46.4a	31.7b	5.2c
Maturity				
108 d	24.8a	45.2a	31.2a	5.4a
113 d	28.0a	47.4a	32.3a	5.4a
Population				
Low	28.0a	42.0a	31.2a	4.3b
Medium	27.0a	50.6a	29.1a	6.5a
High	23.7a	50.4a	34.4a	4.7ab
Spacing‡				
76 cm	25.7a	44.8a	34.0a	5.8a
114 cm	28.7a	47.2a	29.9a	5.4a
Harvest				
Early silage	23.7a	48.4a	34.4a	6.5a
Late silage	23.7a	43.1a	27.0a	4.3b
Grain	28.0a	48.4a	25.8a	5.4ab
Controls				
Atrazine	21.5a	53.8a	16.1b	7.5a
No atrazine	14.0b	45.2a	10.8b	4.3a
Corn + atrazine	26.3a	46.4a	31.7a	5.2a

† Means followed by different letters are significantly different at the 0.01 probability level. For the corn with atrazine trait, comparisons were made for the row, across species and across years; comparisons for each other trait were made in a column, within a species and within a year.
‡ Row spacing data are based on equal corn plant populations.

Final corn population goals of 44 500, 54 400, and 64 200 plants ha^{-1} in each row spacing and hybrid combination were not achieved because of ground squirrel (primarily *Spermophilus tridecemlineatus*) feeding on emerging corn seedlings in 1995. Final corn populations in 1995 were adjusted to 12 400, 24 700, and 37 000 plants ha^{-1} for 114-cm row spacings and 24 700, 37 000, and 49 400 plants ha^{-1} for 76-cm row spacings. Since the final corn populations differed for the two row spacings, only data at equal populations were used for row spacing comparisons. For other statistical comparisons, populations were adjusted in 1996 to attain the same final populations used in 1995.

Corn was harvested on three dates each year. The first date (9 Aug. 1995 and 13 Aug. 1996) was representative of an early, high-moisture silage harvest. The second date (15 Sept. 1995 and 16 Sept. 1996) was a normal silage harvest, and the third date (28 Sept. 1995 and 23 Sept. 1996) was for grain harvest after black layer. Silage harvest plants were hand cut at 20- to 25-cm stalk height in 3-m lengths from a nonborder row during each harvest and weighed. Samples were also dried to determine percentage dry matter and yield, and then were ground and prepared for future forage quality analysis. Grain yield was investigated by picking ears within a 3-m section of nonborder row from each split plot and drying ears in a forced-air dryer until dry. Ears were then weighed and converted from ear weight to grain weight at 12% (w/w) moisture for grain yield determination.

Initial warm-season grass stand counts were taken 8 to 10 wk after seeding on 10 July 1995 and 22 July 1996, before corn canopy closure (data not shown). Final stand counts were taken on 5 Oct. 1995 and 8 Nov. 1996. Counts (plants m^{-2}) were made by placing a square 0.37-m^{2} frame on the ground

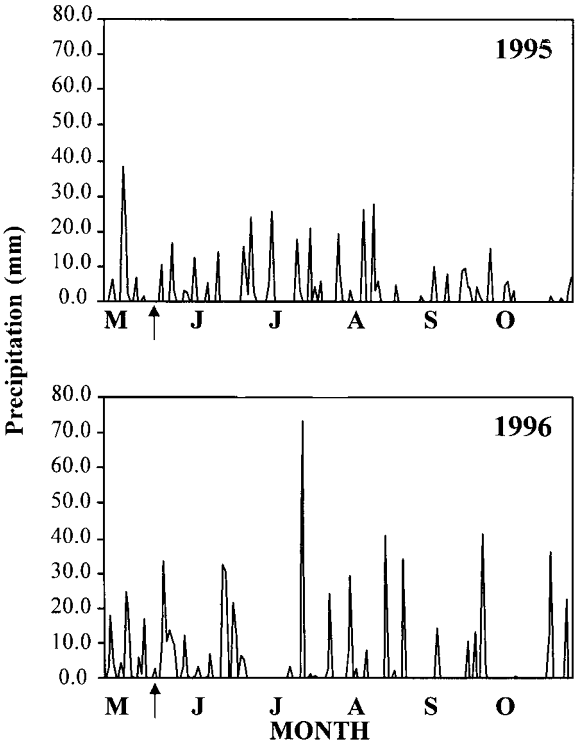

Fig. 1. Daily precipitation in 1995 and 1996 during warm-season grass establishment, May to October (M to O) (Boone, IA). Arrow indicates time of seeding.

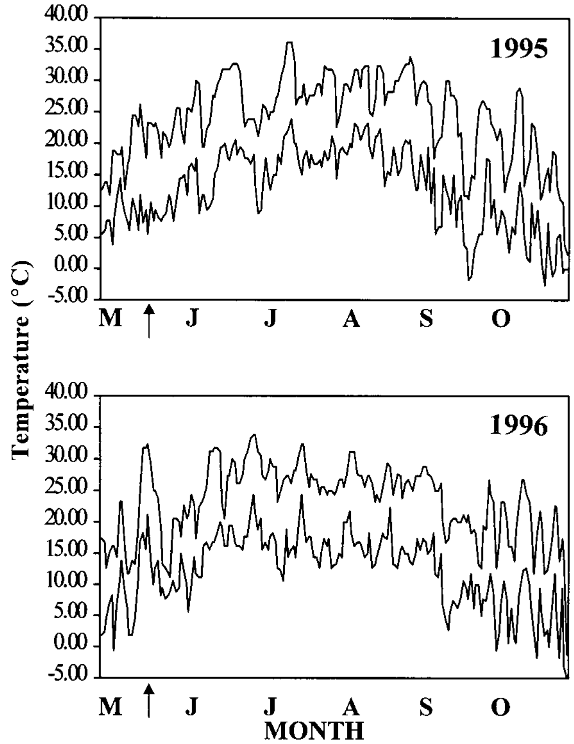

Fig. 2. Maximum and minimum daily temperatures in 1995 and 1996 during warm-season grass establishmen, May to October (M to O)t (Boone, IA). Arrow indicates time of seeding.

within each split-split plot and counting live plants within the frame.

Statistical analysis was performed by the general linear model procedure of Statistical Analysis Systems (1985). Significant differences were based on a $P < 0.01$ level. Fisher's protected least significant differences were used for means comparisons between corn trait parameters, and single degree of freedom linear contrasts were used to test values from treatments with corn and atrazine against values from control treatments.

RESULTS AND DISCUSSION

Switchgrass and Big Bluestem Stand Counts

Establishment of switchgrass and big bluestem in corn was successful. Based on values set by the Great Plains Agricultural Council (1966), switchgrass stands were rated excellent in 1995 (26.3 plants m^{-2}) and 1996 (46.4 plants m^{-2}); and big bluestem stands were excellent in 1995 (31.7 plants m^{-2}), and significantly lower (fair rating; 5.2 plants m^{-2}) in 1996 (Table 1). Big bluestem stands in 1995 and switchgrass stand counts in 1995 and 1996 were exceptional, and well above the suggested density of 10.8 to 21.6 plants m^{-2} for productive stands (Launchbaugh and Owensby, 1970).

Adequate precipitation (68.8 mm) (Fig. 1) in the first 5 wk after seeding resulted in similar excellent stands for both switchgrass and big bluestem in 1995. Switchgrass establishment in 1996 was greater than in 1995 (Table 1). Big bluestem establishment in 1996 was much lower than for switchgrass in 1995 and 1996 and big bluestem in 1995. In 1996, precipitation (221.7 mm) was threefold greater than 1995 for the first 5 wk following seeding. This may have led to excessive soil moisture conditions for big bluestem in 1996. Temperatures (Fig. 2) and growing degree days (GDD) (data not shown) were also greatly reduced in the second and third weeks following seeding in 1996 (117.5 GDD) relative to 1995 (214.0 GDD). Although the effect of cold temperature delays warm-season grass seedling development, the interaction with excessive moisture is not well defined for warm-season grasses. The combination of excessive soil moisture and low temperatures may have stressed big bluestem seedlings and caused low seedling vigor, making them susceptible to cold injury, fungal infestation, or damping, and may have resulted in greater seedling death and lower stand counts in 1996. We speculate that seedling development was delayed and that big bluestem was more susceptible than switchgrass to injury from environmental stresses in 1996. This Year × Grass effect on stands, and the resulting Year × Grass × Corn Trait interactions (data not shown), were due to differences between establishment of big bluestem in 1995 and 1996. Because this significant interaction can be explained by the difference in establishment of big bluestem in 1995 and 1996, stand comparisons at differing levels of corn traits were made within a given grass species and year.

Little difference was detected for warm-season grass stands when evaluated at the various levels of corn traits. The long-season corn hybrid generally had greater warm-season grass stands than the short-season hybrid, but differences were insignificant. Corn population had no significant effect on stands of switchgrass in either year and on big bluestem in 1995 (Table 1). In 1996, big bluestem stands (6.5 plants m^{-2}) were greater grown in medium-density corn populations than big bluestem stands (4.3 plants m^{-2}) grown in low-density corn populations. The difference between these two grass stands (2.2 plants m^{-2}) is relatively small compared with the greater difference that was found for big bluestem stands between years (26.5 plants m^{-2}). Apparently, warm-season grass stands are more dependent on year, or environmental conditions such as precipitation or temperature of a particular season, than on corn population. Corn plant spacing also had no effect on grass stands.

Corn harvest date had no significant effect on warm-season grass stands, except for big bluestem in 1996. Big bluestem stands (6.5 plants m^{-2}) in 1996 for the early silage harvest tended to be greater than stands (4.3 plants m^{-2}) for the late silage harvest. Once again, the difference (2.2 plants m^{-2}) between the two bluestem stands for harvest date in 1996 is relatively small compared with the main difference between years (26.5 plants m^{-2}), which indicates that corn harvest date is probably less important than environmental conditions of a particular year for warm-season grass establishment success.

Stands of warm-season grasses grown in corn with atrazine and stands of grasses grown in control plots with atrazine only were not different for either grass in 1996 (Table 1). Stands were greater for big bluestem in 1995 in corn with atrazine than for the atrazine-only control. Switchgrass and big bluestem stands in 1995 without corn and without atrazine were significantly lower than stands in corn with atrazine (Table 1). Although weed stands were not quantified, general observations of the without-corn and without-atrazine control plots tended to show that foxtail (*Setaria* sp.) was dominant and probably competing with switchgrass and big bluestem. Foxtail was also present in the atrazine-only control plots late in the season, but did not appear to dominate the stand. Atrazine probably helped control early-season weed competition, resulting in consistently greater stands with atrazine (Martin et al., 1982; Masters et al., 1990), and the corn canopy probably helped to control late-emerging weeds by shading the area between corn rows. Therefore, warm-season grass stands were not lessened by the growth of corn, and the corn probably increased grass stands by shading late emerging weeds. Corn could also produce biomass during warm-season grass establishment, a benefit which would not be realized by establishing warm-season grasses without corn but with atrazine, or with neither corn nor atrazine.

Corn Silage and Corn Grain Production

Corn biomass production during grass establishment was harvested as either silage or grain. No significant difference was found between corn silage DM yield grown with switchgrass or big bluestem, but silage yields differed, depending on the year: 3.5 Mg ha^{-1} greater for switchgrass and big bluestem in 1996 than in 1995 (Table 2). This indicates that corn silage DM yield was more dependent on the environment than on the warm-season grass species in which the corn was grown. Rainfall for the entire 1996 growing season (469.9 cm) was much greater than for 1995 (318.3 cm) (Fig. 1). Temperatures also were cooler for the 1996 season (Fig. 2), resulting in lower GDD through 15 Sept. for 1996 (2295.5 GDD) than for 1995 (2484.0 GDD). Cool temperatures and abundant moisture were probably responsible for the increased silage yield of 1996. Conditions were optimal for vegetative growth, and lower temperatures probably delayed corn development and enabled a greater time period for the corn companion crop to continue vegetative growth. Therefore, greater amounts of photosynthetic products were probably used for the formation of vegetative components and fewer products used toward reproductive or grain components. All resulting comparisons for corn silage DM yield were made specifically within grass species and within a given year for each corn trait (Table 2).

Table 2. Corn silage dry matter yield for corn grown in switchgrass and big bluestem.

Corn trait	Corn silage yield			
	Switchgrass		Big bluestem	
	1995	1996	1995	1996
	Mg ha^{-1}			
Corn + atrazine	12.6b†	16.1a	13.1b	16.6a
Maturity				
108 d	13.1a	15.8a	13.1a	15.6b
113 d	12.3a	16.6a	13.1a	17.6a
Population				
Low	10.3b	13.3c	10.0b	13.3c
Medium	13.1a	16.6b	13.8a	16.8b
High	14.8a	18.6a	15.1a	19.3a
Spacing‡				
76 cm	11.7a	14.9a	12.1a	15.3a
114 cm	11.2a	14.5a	11.8a	14.7a
Harvest				
Early silage	9.8b	13.3b	10.0b	13.1b
Late silage	15.6a	19.1a	16.1a	20.1a

† Means followed by different letters are significantly different at the 0.01 probability level. For the corn with atrazine trait, comparisons were made for the row, across species and across years; comparisons for each other trait were made in a column, within a species and within a year.
‡ Row spacing data are based on equal corn plant populations.

No significant difference was found in corn silage yield between short- and long-season corn hybrids, except in big bluestem during 1996 (Table 2). The long-season hybrid produced 2.0 Mg ha^{-1} more silage dry matter than did the short-season hybrid. This is consistent with the general trend found by others that long-season hybrids will generally produce greater dry matter than short-season hybrids when planted and harvested on the same dates (Alessi and Power, 1974; Stivers et al., 1971). This trend was especially noticeable if the hybrids came from within the same seed company (Graybill et al., 1991; Roth, 1994), as was the case in this experiment. Long-season hybrids, therefore, show greater potential for producing more biomass than short-season hybrids when grown to establish warm-season grasses.

Corn silage yields were consistently greater for higher-density corn plant populations grown in both grass species each year (Table 2). Silage yield from low-density corn populations was 2.8 to 3.8 Mg ha^{-1} less

Table 3. Corn grain yield for corn grown in switchgrass and big bluestem.

	Corn grain yield			
	Switchgrass		Big bluestem	
Corn trait	1995	1996	1995	1996
	Mg ha^{-1}			
Corn + atrazine	6.7a†	5.3b	6.9a	5.7b
Maturity				
108 d	7.0a	5.0b	6.8a	5.3b
113 d	6.5a	5.7a	7.0a	6.1a
Population				
Low	5.5b	4.0c	5.8b	4.2b
Medium	7.1a	5.4b	7.1a	6.2a
High	7.7a	6.6a	7.7a	6.6a
Spacing‡				
76 cm	7.1a	5.7a	7.0a	6.1a
114 cm	6.8a	5.4a	6.8a	5.9a

† Means followed by different letters are significantly different at the 0.01 probability level. For the corn with atrazine trait, comparisons were made for the row, across species and across years; comparisons for each other trait were made in a column, within a species and within a year.
‡ Row spacing data are based on equal corn plant populations.

than the medium-density corn populations in both years. In 1995, silage yields of medium-density corn populations were also consistently less in both switchgrass ($P <$ 0.05) and big bluestem ($P < 0.10$) than for the high-density corn populations grown in switchgrass and big bluestem. In 1996, corn silage DM yield was significantly (2.0 Mg ha^{-1}) greater for high-density corn populations than medium-density corn populations grown in switchgrass, and 2.5 Mg ha^{-1} greater for high-density corn populations than medium-density corn populations grown in big bluestem. This same trend, in which greater corn plant populations (from 30 000 to 88 000 plants ha^{-1}) produced greater DM yields, has been observed by others (Cummins and Dobson, 1973; Graybill et al., 1991; Stivers et al., 1971). However, this DM yield increase has also been shown to cease for some hybrids at populations from 68 000 to 125 000 plants ha^{-1} (Cummins and Dobson, 1973; Rutger and Crowder, 1967). Higher-density corn populations also consistently produced greater silage yields in this study, and would help increase biomass production during the year of warm-season grass establishment.

Corn silage DM yield was not different for narrow rows than for wide rows with equal corn plant populations when grown with both grass species for both years (Table 2). Silage yields have earlier been shown to increase as rows were narrowed from 102 to 51 cm (Cummins and Dobson, 1973). Furthermore, 76-cm rows have been shown to increase DM yield over 102-cm rows for both early and late maturing varieties of corn (Stivers et al., 1971). However, corn planted in more narrow rows in this study did not help to increase silage biomass production during the year of warm-season grass establishment.

Yields for the late silage harvest of corn grown with switchgrass and big bluestem during 1995 and 1996 were consistently 5.8 to 7.0 Mg ha^{-1} greater than silage yields from the early silage harvest.

Within a year, grain yield of corn grown with switchgrass or big bluestem was not significantly different (Table 3). Combined grain yields were greater in 1995 than 1996, in contrast to silage dry matter yields. In 1995, higher temperatures probably sped the development of the corn companion crop (Fig. 2). Shorter period of vegetative growth probably resulted in less photosynthetic product partitioning toward vegetative components, and may have allowed more photosynthetic partitioning toward reproductive components and grain fill. Grain yield comparisons for corn traits were made within a grass species and within a given year. Corn grain yield with respect to the various corn traits followed the same trends as for silage production.

Corn hybrid had no effect on grain yield in 1995. In 1996, however, the long-season hybrid had greater yields than the short-season hybrid (Table 3). Long-season hybrid corn yield in switchgrass in 1996 reached 5.7 Mg ha^{-1}, while the short-season hybrid achieved a lower yield of 5.0 Mg ha^{-1}. In big bluestem, the long-season hybrid had an average yield of 6.1 Mg ha^{-1}, while the short-season hybrid yield was only 5.3 Mg ha^{-1}. This follows the general trend for long-season hybrids to produce greater grain yield than short-season hybrids if maturity is reached before the onset of a killing frost (Duncan, 1954; Stivers et al., 1971). Growing long-season corn hybrids with switchgrass and big bluestem could provide the potential for greater corn grain yield during the establishment year.

Lower-density corn plant populations consistently resulted in lower grain yield, ranging from 4.0 to 5.8 Mg ha^{-1}. Medium-density corn populations also consistently had lower grain yields than the high-density corn populations, but the difference was significant only for switchgrass in 1996, when the high-density corn population attained an average yield of 6.6 Mg ha^{-1}, and the medium-density corn population achieved an average yield of only 5.4 Mg ha^{-1}. High-density corn populations provided average yields of 7.7 Mg ha^{-1} when grown with both switchgrass and big bluestem in 1995. Grain yield increased with greater corn populations when grown with both switchgrass and big bluestem. Narrow row spacings did not result in greater grain yields than wide rows when planted at equal populations.

Conclusions

Establishment of switchgrass and big bluestem grown with corn and atrazine was successful at equal or greater levels than without corn or atrazine, and is a viable option for establishing warm-season grass pastures for second-year forage production. Establishment of warm-season grasses appears to be more dependent on precipitation and environmental conditions than on corn hybrid, population density, row spacing, or harvest date. The improvement of warm-season grass stands when grown with corn may be attributed to two possible sources. It is likely that atrazine helped control early cool-season weed species, and that the corn canopy suppressed whatever late-emerging weed species escaped the atrazine treatment. Long-season corn hybrids and higher-density corn populations showed the potential to increase corn companion crop biomass production for either silage or grain harvest when grown with seedings of switchgrass and big bluestem. This greater biomass potential of the corn companion crop could help reduce the risk of land production losses and provide the crop producer with an income source during the year of warm-season grass establishment without reducing warm-season grass stands.

REFERENCES

Alessi, J., and J.F. Power. 1974. Effects of plant population, row spacing, and relative maturity on dryland corn in the Northern Plains: I. Corn forage and grain yield. Agron. J. 66:316–319.

Bahler, C.C., L.E. Moser, T.S. Griffin, and K.P. Vogel. 1990. Warm-season grass establishment as affected by post-planting atrazine application. J. Range Manage. 43:421–424.

Bahler, C.C., K.P. Vogel, and L.E. Moser. 1984. Atrazine tolerance in warm-season grass seedlings. Agron. J. 76:891–895.

Bryan, W.B., T.A. Mills, and J.A. Cronauer. 1984. Sod-seeding switchgrass and tall fescue into hill land pasture. J. Soil Water Conserv. 39:70–72.

Buxton, D.R., and W.F. Wedin. 1970. Establishment of perennial forages: I. Subsequent yields. Agron J. 62:93–97.

Cummins, D.G., and J.W Dobson, Jr. 1973. Corn silage as influenced by hybrid maturity, row spacing, plant population, and climate. Agron. J. 65:240–243.

Duncan, E.R. 1954. Influences of varying plant population, soil fertility and hybrid on corn yields. Soil Sci. Soc. Am. Proc. 18:437–440.

Graybill, J.S., W.J. Cox, and D.J. Otis. 1991. Yield and quality of forage maize as influenced by hybrid, planting date, and plant density. Agron. J. 83:559–564.

Great Plains Agricultural Council. 1966. A stand establishment survey of grass plantings in the Great Plains. Neb. Agric. Exp. Stn., Great Plains Agric. Council Rep. 23.

Hall, K.E., J.R. George, and R.R. Riedl. 1982. Herbage dry matter yields of switchgrass, big bluestem, and indiangrass with N fertilization. Agron. J. 74:47–51.

Launchbaugh, J.L., and C.E. Owensby. 1970. Seeding rate and first-year stand relationships for six native grasses. J. Range Manage. 23:414–417.

Martin, A.R., R.S. Moomow, and K.P. Vogel. 1982. Warm-season grass establishment with atrazine. Agron. J. 74:916–920.

Masters, R.A., K.P. Vogel, P.E. Reece, and D. Bauer. 1990. Sand bluestem and prairie sandreed establishment. J. Range Manage. 43:540–544.

Mueller, J.P., W.M. Lewis, J.T. Green, and J.C. Burns. 1993. Yield and quality of silage corn as altered by johnsongrass infestation. Agron. J. 85:49–52.

Roth, G.W. 1994. Hybrid quality and yield differences for corn silage in Pennsylvania. J. Prod. Agric. 7:50–54.

Rutger, J.N., and L.V. Crowder. 1967. Effect of population and row width on corn silage yields. Agron. J. 59:475–476.

Samson, J.F., and L.E. Moser. 1982. Sod-seeding perennial grasses into eastern Nebraska pastures. Agron. J. 74:1055–1060.

SAS Institute. 1985. SAS procedures guide for personal computers. Version 6 ed. SAS Inst., Cary, NC.

Schaller, F.W., and W.E. Larson. 1955. Effect of wide spaced corn rows on corn yields and forage establishment. Agron. J. 47:271–276.

Springfield, G.H., and L.E. Thatcher. 1951. Corn row spaces and crop sequences. Agron. J. 43:276–281.

Stivers, R.K., D.R. Griffith, and E.P. Christmas. 1971. Corn performance in relation to row spacings, populations, and hybrids on five soils in Indiana. Agron. J. 63:580–582.

Vassey, T.L., J.R. George, and R.E. Mullen. 1985. Early-, mid-, and late-spring establishment of switchgrass at several seeding rates. Agron. J. 77:253–257.

Vogel, K.P. 1987. Seeding rates for establishing big bluestem and switchgrass with preemergence atrazine applications. Agron. J. 79:509–512.

Wilson, R.G., and P. Westra. 1991. Wild proso millet (*Panicum miliaceum*) interference in corn (*Zea mays*). Weed Sci. 39:217–220.