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NOVEL CORN HYBRIDS FOR SILAGE PRODUCTION

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ABSTRACT OF THESIS

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Four corn (*Zea mays*) hybrid types at three plant densities and two nitrogen rates were evaluated for forage yield, forage quality and ensilage quality. The four hybrid types over the first two year of the study included nutri-dense, waxy, leafy, and dual-purpose, the third year a second dual purpose hybrid was added; while the three target plant densities were 54 000, 68 000, and 81 000 plants per hectare; and the nitrogen rates were 134 and 224 kilograms per hectare. The dual-purpose hybrid consistently had high forage yields compared with the other types. When averaged over nitrogen rate and hybrid type, the two highest plant densities typically had higher yields. Across all hybrids nitrogen had no effect on forage yield when averaged across plant density. The leafy hybrid had a lower harvest index than other hybrid types indicating that leaves accounted for much of the harvested weight. Hybrids were examined both at harvest (green chop) and after ensiling for protein and digestibility. Higher nitrogen rates increased crude protein when averaged over all hybrids and plant densities. Dual purpose and waxy hybrid types typically had the lowest acid detergent fiber (ADF) and neutral detergent fiber (NDF) and the highest relative feed values (RFV); while the nutri-dense and leafy hybrids typically had the highest ADF and NDF values and lowest RFV.

KEYWORDS: Corn Silage, Forage Quality, Corn Hybrid Type, Plant Density, Nitrogen Rate

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NOVEL CORN HYBRIDS FOR SILAGE PRODUCTION

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May 2, 2007

RULES FOR THE USE OF THESES

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NOVEL CORN HYBRIDS FOR SILAGE PRODUCTION

THESIS

A Thesis submitted in partial fulfillment of the
requirements for the degree of Master of Science in the
College of Agriculture
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By

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Lexington, Kentucky

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In addition to the scholarly and technical assistance above I also receive a great deal of support from my family. My wife Misty Whitaker provided consistent support throughout the project. My daughter Isabella Whitaker was always able to help me relax and take my mind off of the project when the writing process became stressful. My parents were instrumental in introducing me to agriculture, and were supportive of my desire to pursue a Master's degree. Finally, I would like to thank Dr. Gary Janicke, my undergraduate advisor who guided me in the direction of graduate school and convinced me that it was truly an option for me.

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Chapter 1: Introduction

Many farmers in Kentucky are increasing the number of cattle (*Bos taurus*)in their operations to offset the decrease in tobacco (*Nicotiana tabacum*) production. A high quality forage for these cattle is corn silage. The United States is the world leader in the area of corn grown for forage (Lauer et al., 2001). In 2006, a total of 2,621,149 hectares of corn for forage was grown in the United States (USDA, NASS 2007). Much of the increase in forage yield in the past 70 years can be attributed to increases in grain yield by the corn hybrids (Lauer et al., 2001).

Traditionally, producers have used dual purpose hybrids (developed for both grain and silage productions) for both grain and silage production. Seed companies are developing hybrids that are targeted to silage producers (Ballard et al., 2001; Johnson et al., 1997; Kuehn et al., 1999). Leafy, waxy, and brown midrib hybrid types are being developed specifically for silage production, while a third type, nutri-dense, has been developed for silage and grain production. The leafy hybrid types have more leaves above the ear than dual purpose hybrids (Clark et al., 2002). The waxy types have starch that is 100% amylopectin (compared to typical corn starch which is 80% amylopectin and 20% amylose) which is believed to be more digestible (Akay et al. 2002). The brown midrib hybrid types have lower lignin content which also increases digestibility (Cox and Cherney, 2001a). Nutri-dense hybrid types have slightly higher oil and protein concentration in kernel than do dual purpose hybrids. For the purposes of our study the brown midrib hybrid types will be omitted from discussion because at the time of the study there were no brown midrib hybrids available that were of similar growing maturity to those included in the study.

The popularity of the silage specific hybrids is definitely growing; Dwyer et al. (1998) and Clark et al. (2002) indicate that approximately 16 to 17.5% of the silage corn produced in North America is from leafy hybrids. Akay et al. (2002) determined that, based upon feed value, nutri-dense and waxy were suitable replacements for dual purpose corn when feeding ruminants silage because they were of equal quality.

Darby and Lauer (2002) found in a study of four hybrids with similar maturities that hybrid did not affect dry matter (DM) yield. Bal et al. (2000), however, determined that leafy hybrids provided a DM yield advantage over dual-purpose hybrids when comparing one hybrid of each type. Widdicombe and Thelen (2002a) also found a yield advantage for full season leafy hybrids, with nutri-dense hybrids having the second highest yield, followed by dual-purpose and an early season leafy hybrid when comparing one hybrid of each of those types. While more dual-purpose hybrids are grown for silage than any other hybrid types, Coors et al. (1994) determined that hybrids with high grain yields may not necessarily be the highest yielding silage hybrids.

Forage quality is an important aspect of silage production, and can be defined as the potential for the forage to produce a desirable response from the animal consuming it (Ball et al. 2001). When discussing corn silage the parameters of forage quality most often discussed are crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF), and i*n vitro* dry matter disappearance (IVDMD). Crude protein is a measure of the protein available in the forage to ruminants, ADF is used to estimate the energy content in the forage for animals, NDF estimates the fiber content of the forage, and IVDMD gives an estimate of the digestibility of the forage in the rumen.

Lauer et al. (2001) found that little change occurred in forage quality of corn hybrids available in the Northern Corn Belt over the past 70 years. However, Johnson et al. (2002) found that hybrid affected corn silage quality. Waxy types had lower NDF, ADF and CP than the other hybrids, but nutri-dense hybrids had the highest levels of starch (Akay and Jackson, 2001). Akay et al. (2002) found the starch in waxy hybrids to be more digestible in the rumen that that of dual purpose hybrids. Clark et al. (2002) stated that leafy hybrids have a higher percentage of carbohydrates as sugars than starch which may enhance digestibility over a dual purpose hybrid. Bal et al. (2000), however, found the high starch digestibility for leafy hybrids to be offset by lower NDF digestibility. Kuehn et al. (1999) reported increased *in vitro* dry matter digestibility (IVDMD) for a leafy hybrid over dual purpose. Bal et al. (2000) found the NDF varied little among treatments (leafy and dual purpose hybrids at 59 000 plants ha^{-1} and 79 000 plants ha^{-1}).

Seed companies often recommend lower populations for silage specific leafy corn hybrids than dual purpose hybrids (Bal et al., 2000). It has been proven that plant density affects whole plant yield in corn, but not necessarily in the manor that the previously stated seed company recommendations would indicate. Cox (1997) determined that silage corn should, on average be planted at plant densities 7.5% higher than dual purpose hybrids grown for grain. Martin et al. (2005) determined that higher plant densities may increase plant to plant variability, but Andrade and Abbate (2005) reported less tillering in dominant plants, and since higher densities promote dominant plants they should also more effectively use resources which should increase yield. Optimum plant densities continue to increase harvest index (ear weight: whole plant weight) at physiological maturity. In older hybrids harvest index (HI) was generally reduced with an increase in density (Duncan, 1984), but that decrease is not seen in modern hybrids (Tollenaar, 1989). A harvest index that remains more constant over high plant densities will contribute to higher yields. In addition, as the harvest index remains high, the grain component contributes to digestibility of the forage.

Widdicombe and Thelen (2002a) found that as plant density increased whole plant yield increased, and simple linear regression indicated yields would increase beyond the maximum density tested (88,900 plants ha^{-1}). Cox and Cherney (2001b) also observed increased whole plant dm yield at higher densities in one study, while in a second study the increase in whole plant yield for increased plant densities was only seen in two out of three years (Cox and Cherney, 2001a). Cox and Cherney (2001a) observed no interaction between hybrid and plant density for whole plant dm yield.

Increases in plant density have been found to decrease silage quality. Cox and Cherney (2001b) observed that as plant density increases from 80,000 plants ha^{-1} to 116,000 plants ha^{-1} forage IVTD decreases by 7 g kg^{-1} and NDF increases by 13 g kg^{-1}. Widdicombe and Thelen (2002a) observed that as plant density increases from 64,200 plants ha^{-1} to 88,900 plants ha^{-1} dry matter digestibility (DMD) (11g kg^{-1} decrease), ADF (11 g kg^{-1} increase), NDF 15 g kg^{-1} increase), and CP (4 g kg^{-1} decrease) were adversely affected for both forage and dual-purpose hybrid types.

Widdicombe and Thelen (2002b) found that the highest plant density that they tested had the highest grain yield. Farnham (2001) found a 7% increases in grain yield as plant density was increased from 59,000 to 89,000 plants ha^{-1}. Cox and Cherney (2001a) observed no interaction between hybrid and plant density for whole plant DM yield.

Sheaffer et al. (2006) found that N-fertilization increased whole plant DM along with grain DM. Sheaffer et al. (2006) using N-rates of 0, 50, 100, and 200 kg ha^{-1}, found a response of both grain and whole plant DM to fertilizer N quadratic reaching maximum levels at 100 kg N ha^{-1} for whole plant yield at both locations. The stover response, however, was linear. Mehdi et al. (1999) found yield to not be related to corn leaf N concentration. In a three year study under irrigated conditions Al-Kaisi and Yin (2003) found that there was no difference in grain yield between treatments of 140 kg ha^{-1} and the area's typical 250 kg ha^{-1} recommendation in their location. Jokela and Randall (1989) found an increase in grain yield of 60% for two years at one location when comparing a treatment of 150 to 0 kg N ha^{-1} control, but an increase of only 3% when treatments of 225 and 150 kg ha^{-1} were compared. Stecker et al. (1995) found a quadratic increase of corn grain yield with the nitrogen rates (0, 67, 135, 202 and 269 kg ha^{-1}). Miao et al. (2006) found N-fertilization of as little as 50 kg ha^{-1} to significantly increase corn grain yield when averaged across site years while a plateau was seen between 150 kg ha^{-1} and 350 kg ha^{-1}.

Sheaffer et al. (2006) found that increased N fertilization increased forage CP concentration. N fertilization had minimal impact on other quality parameters. Sheaffer et al. (2006) also observed no interactions between N fertilization and corn hybrid for whole plant DM yield or any forage quality parameter. They suggested that producers can consistently select corn forage hybrids based on green chop quality analysis results without considering N fertility levels.

Widdicombe and Thelen (2002a) found that the optimum plant density for their early maturing leafy hybrid was less than the later maturing hybrids evaluated. This, however, was most likely a factor of maturity and not hybrid type.

An interaction between plant density and hybrid was observed in a group of dual purpose hybrids by Widdicombe and Thelen (2002b) for grain yield.

The recommendations for the state of Kentucky are a dual purpose hybrid planted at 59,000 to 74,000 seeds ha^{-1} for silage, with 140 to 179 kg N ha^{-1} (on well drained soils) (Lee et al. 2006).

Chapter 2: Yield

Introduction

Many farmers in Kentucky are increasing the number of cattle (*Bos taurus*)in their operations to offset the decrease in tobacco (*Nicotiana tabacum*) production. A high quality forage for these cattle is corn silage. The United States is the world leader in the area of corn grown for forage (Lauer et al., 2001). In 2006, a total of 2,621,149 hectares of corn for forage was grown in the United States (USDA, NASS 2007). Much of the increase in forage yield in the past 70 years can be attributed to increases in grain yield by the corn hybrids (Lauer et al., 2001).

Traditionally, producers have used dual purpose hybrids (developed for both grain and silage productions) for both grain and silage production. Seed companies are developing hybrids that are targeted to silage producers (Ballard et al., 2001; Johnson et al., 1997; Kuehn et al., 1999). Leafy, waxy, and brown midrib hybrid types are being developed specifically for silage production, while a third type, nutri-dense, has been developed for silage and grain production. The leafy hybrid types have more leaves above the ear than dual purpose hybrids (Clark et al., 2002). The waxy types have starch that is 100% amylopectin (compared to typical corn starch which is 80% amylopectin and 20% amylose) which is believed to be more digestible, and the brown midrib hybrid types have lower lignin content which also increases digestibility. Nutri-dense hybrid types have slightly higher oil and protein concentration in kernel than do dual purpose hybrids. For the purposes of our study the brown midrib hybrid types will be omitted from discussion because at the time of the study there were no brown midrib hybrids available that were of similar growing maturity to those included in the study.

While more dual purpose hybrids are grown for silage than any other hybrid types, Coors et al. (1994) determined that hybrids with high grain yields may not necessarily be the highest yielding silage hybrids. A leafy hybrid type yielded more DM than dual purpose type (Bal et al., 2000; Widdicombe and Thelen, 2002a) and a nutri-dense hybrid type (Widdicombe and Thelen, 2002a). The nutri-dense type yielded more DM than a dual purpose type (Widdicombe and Thelen, 2002a). Darby and Lauer (2002) found in a study of four hybrids with similar maturities that hybrid did not affect dry matter (DM) yield.

Seed companies often recommend lower populations for silage specific leafy corn hybrids than dual purpose hybrids (Bal et al., 2000). It has been proven that plant density affects whole plant yield in corn, but not necessarily in the manor that the previously stated seed company recommendations would indicate. Cox (1997) determined that silage corn should, on average be planted at plant densities 7.5% higher than dual purpose hybrids grown for grain. Martin et al. (2005) determined that higher plant densities may increase plant to plant variability, but Andrade and Abbate (2005) reported less tillering in dominant plants, and since higher densities promote dominant plants they should also more effectively use resources which should increase yield.

Widdicombe and Thelen (2002a) found that as plant density increased whole plant yield increased, and simple linear regression indicated that the maximum density tested (88,900 plants ha^{-1}) did not indicate maximum yield was achieved. Cox and Cherney (2001) also observed increased yield at higher densities in one study, but found no yield differences across densities in a second study. Cox and Cherney (2001) observed no interaction between hybrid and plant density in two studies.

Widdicombe and Thelen (2002b) found that the highest plant density that they tested had the highest grain yield. Farnham (2001) found a 7% increases in grain yield as plant density was increased from 59,000 to 89,000 plants ha^{-1}. Cox and Cherney (2001) observed no interaction between hybrid and plant density in two studies.

Sheaffer et al. (2006) found a quadratic relationship reaching maximum levels at 100 kg N ha^{-1} for whole plant DM at both locations. The stover response, however, was linear to the maximum rate of 200 kg N ha^{-1} tested. Mehdi et al. (1999) found yield to not be related to corn leaf N concentration.

In a three year study under irrigated conditions Al-Kaisi and Yin (2003) found that there was no difference in grain yield between treatments of 140 kg ha^{-1} and the area's typical 250 kg ha^{-1} recommendation in their location. Jokela and Randall (1989) found an increase in grain yield of 3% when treatments of 225 and 150 kg N ha^{-1} were compared. Stecker et al. (1995) found a quadratic increase of corn grain yield with the nitrogen rates (0, 67, 135, 202 and 269 kg ha^{-1}). Miao et al. (2006) found a plateau for grain yield between 150 and 350 kg N ha^{-1}.

The recommendations for the state of Kentucky are a dual purpose hybrid planted at 59,000 to 74,000 seeds ha^{-1} for silage, with 140 to 179 kg N ha^{-1} (on well drained soils) (Lee et al. 2006). The purpose of this study was to determine if hybrid type, plant density and/or N rate affected whole plant yield and grain yield.

Materials and Methods

Four hybrids (five in the third year) at three seeding rates and two nitrogen rates were analyzed with measurements taken to compare whole plant and grain yields. The experiment was conducted at University of Kentucky Spindletop research facility in Lexington, Kentucky. The soil type in 2003 was a Maury silt loam (fine, mixed, semiactive, mesic Typic Paleudalfs) with 2 to 6% slope. In 2004 the field used was split between Donerail silt loam (fine, mixed, active, mesic Oxyaquic Argiudolls) and a Maury silt loam (fine, mixed, semiactive, mesic Typic Paleudalfs), while in 2005 the experiment was on Armour silt loam (fine-silty, mixed, active, thermic Ultic Hapludalfs) with 0 to 2% slope. The study was conducted as a split-split plot design; the main plot was nitrogen rates (134 and 224 kg ha^{-1}), the split plot was hybrid types, and the split-split plot was seeding rates (54 300, 68 000, and 81 500 seeds ha^{-1}). The first two seeding rates are the lower and higher planting rates recommended in Kentucky, unlike the highest seeding rate that is beyond the range of current recommendations.

The four hybrids used all years in the study were a dual purpose (Exsegen ES112), a nutri-dense (Exsegen ES213ND), a leafy (Mycogen F2F797), and a waxy (Garst 8464wx). All of these hybrids fall in the 110 to 115 day maturity range, which would make them earlier maturing than those typically grown for silage in Kentucky. The maturities of the silage-specific hybrids used in this experiment were among the latest maturing silage-specific hybrids available. Since relative maturity can affect yield (Widdicombe and Thelen, 2002). A dual purpose hybrid (SS849CL) of 119 day maturity was added the final year of the study.

Fertilizer P and K were added according to soil test results and University of Kentucky recommendations. Seeds were planted with no tillage at a depth of 5 cm using a John Deere (Moline, IL) model 7200 corn planter with finger pick-up units spaced 76 cm apart into soybean residue. Plots were 3 m wide and 10 m wide. Plant populations were set by adjusting the driver and driven gear settings on the planter based upon the planter manual to give the desired seeding rates. At planting a banded application of tefluthrin (0.185 kg AI ha^{-1}) (Force) insecticide was applied in furrow. Glyphosate (1.064 kg AI ha^{-1} all years, with a second application of 1.736 kg AI ha^{-1} in 2003) (Roundup WeatherMax) and atrazine plus metolachlor (1.792 and 1.456 kg AI ha^{-1}) (Bicep II Magnum) were applied pre-plant to burn down vegetation and provide residual weed control. Post emergence herbicides were applied depending on weed species. The herbicides nicosulfuron (0.017 kg AI ha^{-1}) (Accent), and primisulfuron-methyl plus prosulfuron (0.02 and 0.02 kg AI ha^{-1}) (Exceed) were applied at V4-V5 (Ritchie et al., 1997) for weed control in 2003. In 2004, nicosulfuron (0.017 kg AI ha^{-1}) (Accent), prosulfuron plus primisulfuron-methyl (0.001 and 0.030 kg AI ha^{-1}) (Spirit), and diflufenzopyr plus dicamba (0.084 and 0.211 AI kg ha^{-1}) (Distinct) were applied at V3. In 2005, bentazon (1.12 kg AI ha^{-1}) (Basagran) was applied at growth stage V6 and nicosulfuron plus rimsulfuron (0.027 and 0.013 kg AI ha^{-1}) (Steadfast) and dicamba (0.28 kg AI ha^{-1}) (Clarity) were applied at growth stage V7 with drop nozzles.

In 2003 and 2004, fertilizer N was applied as ammonium nitrate at 67 kg ha^{-1} pre-emergence. The remaining fertilizer N was applied at V6 (Ritchie et al., 1997). In 2005 all fertilizer N was applied at the V6 growth stage as liquid urea ammonium nitrate (UAN 28%).

Corn stand counts were taken at growth stages ranging from V2 to about V6 and again at harvest each year. The counts were taken by counting the number of plants in a 3 m section of row from the center two rows of each plot.

Silage harvest was targeted for 0.5 to 0.75 milk line, with actual timing of harvest conducted at 0.75 milk line in 2003, full milk line in 2004, and 0.5 milk line in 2005 (Crookston and Kurle, 1988; Wiersma et al., 1993). Two 3 m sections of row from each plot were hand-harvested by cutting the plants, and the number of stalks was counted. Whole plant fresh weights were determined by weighing all plants (stover and grain) from both rows. Stalk numbers were taken from each of the two sections of row. All of the plant material harvested from one row was used to determine husked ear weights and harvest index. Ear numbers were taken in 2004 and 2005. All of the corn plants harvested from the second row were chopped with a wood chipper. A sub-sample was weighed and dried for a minimum of 72h for DM determination.

Two additional 3 m sections of row from each plot were harvest by hand, with ear numbers counted in each year, and stalk numbers counted for 2005 only. Fresh weights of all harvested and husked ears were taken. Five representative ears were then separated, weighed, dried for at least 72h at 60°C and weighed again. The dried ears were shelled, and grain from the 5 ears was weighed. The ratio of grain dry weight to ear dry weight was used with whole plot fresh ear weights to calculate grain yield for the plots (grain weight/ear weight *moisture*total plot ear weight).

The GLM procedure of the Statistical Analysis System (SAS) Version 9.1 (SAS Institute, 2002) was used for ANOVA. Means were separated with protected least significant difference (LSD) ($p<0.05$).

Results and Discussion

Main effects interacted with year ($p>0.05$) but not with any other main effects (Table 2-1). Over all, little whole plant yield difference was shown by hybrid, except, in 2003 and 2005 the waxy hybrid was the lowest yielding and in 2004 the nutri-dense hybrid yielded the most. (Table 2-2)

This study evaluated hybrid types that were not from the same genetic background, therefore, it is impossible to determine if the yield differences are due to hybrid or type. Other hybrid studies (Ballard et al., 2001; Widdicombe and Thelen, 2002a) made the assumption that hybrid type was the cause of yield difference, and we too will make this assumption. Nutri-dense was a high whole plant DM yielding hybrid, while the waxy hybrid had the lowest DM yields or a yield statistically the same as the lowest in all three years. Darby and Lauer (2002), found no significant differences in DM yield between two similar hybrids with differing maturities.

Leafy hybrid type was among the highest yielding forage hybrids in 2003 and 2005 (Table 2-2). Other studies found a yield advantage for leafy hybrids (Bal et al., 2000; Widdicombe and Thelen, 2002a). Both of those studies were further north. Perhaps the leafy hybrids intercepted more light and improved yield in northern latitudes.

The highest plant population resulted in the numerically highest whole plant yields and the lowest population resulted in the numerically lowest whole plant yields each year. In 2003 whole plant yield differences among plant density treatments were not significant. In 2004 and 2005, whole plant yields were 12% lower for the lowest seeding rate, while yields for the two higher seeding rates were not significantly different. (Table 2-2)

The lowest seeding rate always had the lowest whole plant DM yield, and the highest seeding rate always had the highest yield, but the yield differences were not always significant. The two highest populations always yielded similarly, with the lowest population having a 13% lower yield in two of the three years (Table 2-2). Widdicombe and Thelen (2002a) found that increased seeding rate significantly increased yield and were not able to establish a maximum yield with the populations tested. The findings of the study also agree with current Kentucky recommendations for silage seeding rates of between 59,000 to 74,000 seeds ha^{-1} (Lee et al. 2006).

Nitrogen rate did not affect silage yield in any of the three years of our study, which differs from the findings of Sheaffer et al. (2006) who determined that whole plant DM increased as N fertilization increased from 0 to 200 kg ha^{-1}. Nitrogen rate having no effect on silage yield is to be expected based upon Kentucky recommendations with the N rates used in the study because the lowest N rate was within the recommended range for the state while the highest N rate was much greater than recommended. Typically the recommendations are based upon yield benefit, and typically no significant yield benefit should be seen when greater than the recommended rates are used.

Grain yield was highest or similar to the highest grain yield for dual purpose each year. In 2003 dual purpose had the highest grain yields followed by nutri-dense and leafy with waxy having the lowest grain yield. In 2004, nutri-dense and dual purpose yields were similar and both were greater than waxy and leafy. Leafy was significantly less than waxy. In 2005 grain yields were similar among all hybrids. (Table 2-3)

Dual purpose was the highest yielding hybrid, or not statistically different than the highest yielding hybrid for grain in all three years. This is to be expected because the dual purpose hybrid is one that is promoted for both grain and silage production, not just as s silage hybrid. Waxy was the lowest yielding grain hybrid or not statistically different than the lowest yielding hybrid type in grain yield in two out of three years. The leafy hybrid type was inconsistent, yielding the lowest one year and similar to highest another year. The waxy and leafy hybrids novel traits focus primarily on the stover of the plants which may be the reason for their grain yields not being as high as the hybrid types wholes traits and breeding focused on grain.

In 2003, the lowest seeding rate resulted in the lowest grain yield and the two higher seeding rates resulted in yields not significantly different from each other. In 2004, grain yield of the two highest seeding rates were similar. The lowest seeding rate was similar in grain yield to the middle seeding rate, but lower than the highest seeding rate. Seeding rate had no effect on grain yield in 2005. (Table 2-3)

The two higher seeding rates resulted in similar yields, which were higher than the lowest seeding rate in two out of three years. These results differ from data in more northern latitudes (Widdicombe and Thelen, 2002a) where they found yield to always increase significantly as plant density increased. These differing results may be a result of differences in management or climate between the two areas.

In 2003 and 2005 N-rate did not affect grain yield. In 2004 the lower N-rate resulted in greater grain yield. (Table 2-3)

Nitrogen rate did not affect grain yield. Miao et al. (2006) reported higher grain yields for N rates up to 125 kg ha^{-1} after which there was a plateau between 125 kg ha^{-1} and 350 kg ha^{-1}. Both N-rates from this study would fall within this plateau.

Whole plant yields were plotted against grain yield across all variables to determine if there was a correlation. Whole plant yield correlated positively and linearly to grain yield (R2=0.7562) indicating that selecting a high yielding grain hybrid may be the best option for choosing a hybrid that will have a high silage yield. The current silage production recommendations for Kentucky are that generally speaking selecting a good yielding grain hybrid will be selecting a high yielding silage hybrid (Lee et al. 2006). These data agree with this statement and recommendation. Higher forage yields for the higher yielding grain hybrids may also indicate why the dual purpose and nutri-dense hybrid types were among the top yielding forage hybrids, the dual purpose can also be used as a grain hybrid and the nutri-dense's novel traits relates to the grain of the hybrid.

Dual purpose seeded at the middle seeding rate of 68 000 seeds ha^{-1} with 134 kg ha^{-1} of N applied in Kentucky resulted in the best outcome of both grain and forage yield, and forage quality.

Conclusion

Novel corn hybrid types do not appear to provide a benefit over dual purpose hybrid types in Kentucky. While the dual purpose and other hybrid types often yielded similarly no hybrid type consistently had higher whole plant or grain yields than the dual purpose hybrid type.

By the findings of this study the overall recommendation for corn silage and grain production in Kentucky should be DP seeded at 68,000 seeds ha^{-1} with 134 kg ha^{-1} of N applied. Based on these finding for optimum yield no changes should be made to the current silage production recommendations for Kentucky.

Table 2-1. Analysis of Variance for whole plant and grain yield for all three years of the study. (***p≤0.001, **p≤0.05, *p≤0.10)

2003

Source of Variation	df	Whole Plant Yield Mean Squares	
Nitrogen (N)	1	8.20	
NxReplication (R)(error A)	2	3.80	
Hybrid (H)	3	85.54	***
HxN	3	1.64	
HxNxR (error B)	6	3.48	
Seeding Rate (SR)	2	4.42	
SRxN	2	0.01	
SRxH	6	3.60	
SRxNxH	6	6.63	
SRxNxHxR (error C)	16	4.21	

2004

Source of Variation	df	Whole Plant Yield Mean Squares	
Nitrogen (N)	1	17.21	
NxReplication (R)(error A)	2	0.99	
Hybrid (H)	3	47.54	**
HxN	3	2.05	
HxNxR (error B)	6	3.05	
Seeding Rate (SR)	2	60.89	
SRxN	2	9.59	
SRxH	6	2.25	
SRxNxH	6	8.04	
SRxNxHxR (error C)	16	5.98	

2005

Source of Variation	df	Whole Plant Yield Mean Squares	
Nitrogen (N)	1	0.69	
NxReplication (R)(error A)	2	8.02	*
Hybrid (H)	4	17.98	***
HxN	4	3.18	
HxNxR (error B)	8	1.17	
Seeding Rate (SR)	2	12.76	**
SRxN	2	1.46	
SRxH	8	1.39	
SRxNxH	8	2.12	
SRxNxHxR (error C)	20	1.61	

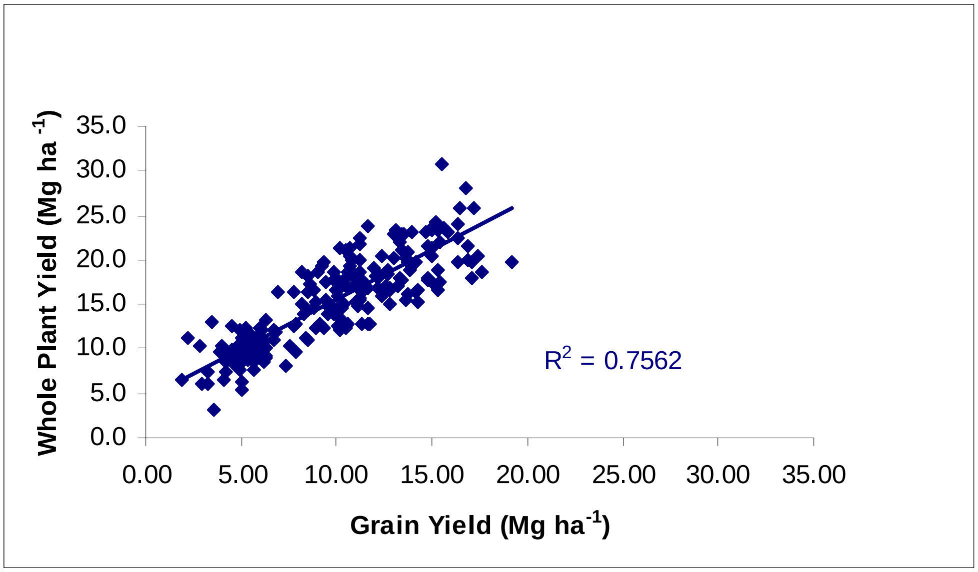
Table 2-2. Whole plant yields by hybrid type, plant density, and N-rate for 2003, 2004, and 2005.

		Year 2003	2004	2005
		Silage DM Yield (Mg ha^{-1})		
Hybrid	Nutri-dense	16.6	22.3	9.7
	Dual purpose 1	17.6	19.2	10.3
	Leafy	16.5	18.7	10.3
	Waxy	12.7	19.8	7.9
	Dual purpose 2			9.9
	LSD(0.05)	1.4	1.7	0.9
Plant Density	54 300 ha^{-1}	15.5	18.3	8.9
	68 000 ha^{-1}	16.3	20.2	9.9
	81 500 ha^{-1}	15.7	21.5	10.2
	LSD(0.05)	NS	1.5	0.7
N-Rate	134 kg ha^{-1}	15.5	20.5	9.7
	224 kg ha^{-1}	16.2	19.5	9.6
	LSD(0.05)	NS	NS	NS

Table 2-3. Grain yields by hybrid type, plant density, and N-rate for 2003, 2004, and 2005.

		Year 2003	2004	2005
		Grain Yield (Mg ha^{-1}) at 15.5% moisture		
Hybrid	Nutri-dense	10.6	15.1	5.4
	Dual purpose 1	12.2	15.6	5.6
	Leafy	9.8	10.5	4.8
	Waxy	8.8	13.0	4.7
	Dual purpose 2			5.2
	LSD(0.05)	1.0	1.1	NS
Plant Density	54 300 ha^{-1}	9.7	12.7	5.2
	68 000 ha^{-1}	10.8	13.7	5.1
	81 500 ha^{-1}	10.5	14.3	5.0
	LSD(0.05)	0.8	1.0	NS
N-Rate	134 kg ha^{-1}	10.2	14.0	5.2
	224 kg ha^{-1}	10.5	13.1	5.0
	LSD(0.05)	NS	0.8	NS

Figure 2-1. Whole plant yield by grain yield across all variables.



Chapter 3: Forage Quality

Introduction

Many farmers in Kentucky are increasing the number of cattle (*Bos taurus*) in their operations to offset the decrease in tobacco (*Nicotiana tabacum*) production. A high quality forage for these cattle is corn silage. The United States is the world leader in the area of corn grown for forage (Lauer et al., 2001). In 2006, a total of 2,621,149 hectares of corn for forage was grown in the United States (USDA, NASS 2007). Much of the increase in forage yield in the past 70 years can be attributed to increases in grain yield by the corn hybrids (Lauer et al., 2001).

Forage quality is an important aspect of silage production, and can be defined as the potential for the forage to produce a desirable response from the animal consuming it (Ball et al. 2001). When discussing corn silage the parameters of forage quality most often discussed are crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF), and i*n vitro* dry matter disappearance (IVDMD). Crude protein is a measure of the protein available in the forage to ruminants, ADF is used to estimate the energy content in the forage for animals, NDF estimates the fiber content of the forage, and IVDMD gives an estimate of the digestibility of the forage in the rumen.

Traditionally, producers have used dual purpose hybrids (developed for both grain and silage productions) for both grain and silage production. Seed companies are developing hybrids that are targeted to silage producers (Ballard et al., 2001; Johnson et al., 1997; Kuehn et al., 1999). Leafy, waxy, and brown midrib hybrid types are being developed specifically for silage production, while a third type, nutri-dense, has been developed for silage and grain production. The leafy hybrid types have more leaves above the ear than dual purpose hybrids (Clark et al., 2002). The waxy types have starch that is 100% amylopectin (compared to typical corn starch which is 80% amylopectin and 20% amylose) which is believed to be more digestible (Akay et al. 2002). The brown midrib hybrid types have lower lignin content which also increases digestibility (Cox and Cherney, 2001a). Nutri-dense hybrid types have slightly higher oil and protein concentration in kernel than do dual purpose hybrids. For the purposes of our study the brown midrib hybrid types will be omitted from discussion because at the time of the study there were no brown midrib hybrids available that were of similar growing maturity to those included in the study.

Lauer et al. (2001) found that little change occurred in forage quality of corn hybrids available in the Northern Corn Belt over the past 70 years. However, Johnson et al. (2002) found that hybrid affected corn silage quality. Waxy types had lower NDF, ADF and CP than the other hybrids, but nutri-dense hybrids had the highest levels of starch (Akay and Jackson, 2001). Akay et al. (2002) found the starch in waxy hybrids to be more digestible in the rumen that that of dual purpose hybrids. Clark et al. (2002) stated that leafy hybrids have a higher percentage of carbohydrates as sugars than starch which may enhance digestibility over a dual purpose hybrid. Bal et al. (2000), however, found the high starch digestibility for leafy hybrids to be offset by lower NDF digestibility. Kuehn et al. (1999) reported increased *in vitro* dry matter digestibility (IVDMD) for a leafy hybrid over dual purpose. Bal et al. (2000) found the NDF varied little among treatments (leafy and dual purpose hybrids at 59 000 plants ha^{-1} and 79 000 plants ha^{-1}).

Seed companies often recommend lower populations for silage specific leafy corn hybrids than dual purpose hybrids (Bal et al., 2000). It has been proven that plant density affects whole plant yield in corn, but not necessarily in the manor that the previously stated seed company recommendations would indicate. Cox (1997) determined that silage corn should, on average be planted at plant densities 7.5% higher than dual purpose hybrids grown for grain. Martin et al. (2005) determined that higher plant densities may increase plant to plant variability, but Andrade and Abbate (2005) reported less tillering in dominant plants, and since higher densities promote dominant plants they should also more effectively use resources which should increase yield. Optimum plant densities continue to increase harvest index (ear weight: whole plant weight) at physiological maturity. In older hybrids harvest index (HI) was generally reduced with an increase in density (Duncan, 1984), but that decrease is not seen in modern hybrids (Tollenaar, 1989). A harvest index that remains more constant over high plant densities will contribute to higher yields. In addition, as the harvest index remains high, the grain component contributes to digestibility of the forage.

Increases in plant density have been found to decrease silage quality. Cox and Cherney (2001b) observed that as plant density increases from 80,000 plants ha^{-1} to 116,000 plants ha^{-1} forage IVTD decreases by 7 g kg^{-1} and NDF increases by 13 g kg^{-1}. Widdicombe and Thelen (2002a) observed that as plant density increases from 64,200 plants ha^{-1} to 88,900 plants ha^{-1} dry matter digestibility (DMD) (11g kg^{-1} decrease), ADF (11 g kg^{-1} increase), NDF 15 g kg^{-1} increase), and CP (4 g kg^{-1} decrease) were adversely affected for both forage and dual-purpose hybrid types.

Sheaffer et al. (2006) found that increased N fertilization increased forage CP concentration. N fertilization had minimal impact on other quality parameters. Sheaffer et al. (2006) also observed no interactions between N fertilization and corn hybrid for whole plant DM yield or any forage quality parameter. They suggested that producers can consistently select corn forage hybrids based on green chop quality analysis results without considering N fertility levels.

The recommendations for the state of Kentucky are a dual purpose hybrid planted at 59,000 to 74,000 seeds ha^{-1} for silage, with 140 to 179 kg N ha^{-1} (on well drained soils) (Lee et al. 2006). The purpose of this study was to determine if hybrid type, plant density and/or N rate affected whole plant yield and grain yield.

Materials and Methods

Field procedures were the same as stated in Chapter 2 until after silage harvest weights were measured.

Silage harvest was conducted at 0.75 milk line in 2003, full milk line in 2004, and 0.5 milk line in 2005 (Crookston and Kurle, 1988; Wiersma et al., 1993). Whole corn plants were harvested from by hand-harvesting two 3-m sections of row from each plot. For one of those two rows, whole plant fresh weight was taken, ears pulled, schucked and weighed to calculate harvest index (HI) (ear weight/whole plant weight). Whole plants harvested from the second row were chopped with a Fitchburg (Fitchburg, MA) wood chipper. A sub-sample was weighed and dried for a minimum of 72h for DM determination and forage quality analysis. Approximately 1.36 kg of chopped forage was packed in miniature silos (38-cm tall sections of 10-cm diameter poly vinyl chloride (PVC) pipe with caps on both ends and a one way valve inserted into the top cap). Samples were ensiled for a minimum of 30 days in a well-ventilated building, removed, and split into two approximately equal portions. One portion was frozen and used for pH determination, and the second was dried for DM determination and forage quality analysis.

Sample pH and the forage quality parameters NDF, ADF, IVDMD, and total N (to determine Crude Protein (CP)) were determined on both the green chop forage (not ensiled) and ensiled samples. Green chop and ensiled samples were analyzed in duplicate for each field plot. Sample pH was determined by mixing approximately equal portions of water and frozen silage by volume into a beaker. All ensiled samples were found to be within the appropriate pH range (3.5 to 4) for ensiling (data not shown). ADF and NDF were determined using the ANKOM fiber analyzer (Model No. ANKOM 200; Ankom Technology, Fairport, NY). *In vitro* dry matter disappearance (IVDMD) was determined using a modified version of the method described by Tilley and Terry (1963) and modified by Marten and Barnes (1980). For IVDMD determination 0.250g +/- 0.001g from each sample was weighed into an ANKOM fiber digestion bag (Ankom Technology, Fairport, NY). One hundred of the sample bags are placed into a container with the appropriate buffer solutions and rumen fluid for digestion. Samples were rinsed with deionized water using an ANKOM fiber analyzer (Model No. ANKOM 200; Ankom Technology, Fairport, NY). After the water rinse samples were rinsed in acetone air dried, and dried in an oven at 100˚C overnight.

Total N was determined using a micro kjeldahl procedure in which all forms of nitrogen were converted to ammonium (Bradstreet, 1965), and measurements were taken using a modification of the Berthelot reaction developed by Chaney and Marbach (1962).

Crude protein, ADF and NDF were used to calculate relative feed value (RFV) and value (dollars per 45 kg) using the University of Wisconsin's FeedVal calculator (Howard and Shaver, 1997). The value was combined with dry matter whole plant yields to determine the crop value in dollars per hectare.

The study was conducted as a split-split plot design; the main plot was nitrogen rates (134 and 224 kg ha^{-1}), the split plot was hybrid types, and the split-split plot was seeding rates (54 300, 68 000, and 81 500 seeds ha^{-1}). The GLM procedure of the Statistical Analysis System (SAS) Version 9.1 (SAS Institute, 2002) was used for ANOVA and means were separated by LSD values ($p<0.05$).

Results

Main effects interacted with year, but not with each other ($p<0.05$) (Tables 3-1, 3-2 and 3-3).

Nitrogen had no effect on any quality parameters except green chop crude protein (CPg) and ensiled crude protein (CPs) (Tables 3-4, 3-5, and 3-6). The dual purpose hybrid type had the numerically highest HI which was statistically higher than all other hybrids in two out of three years. The leafy hybrid always had the statistically lowest HI. (Tables 3-4, 3-5, and 3-6)

In two out of three years plant density did not affect HI (Tables 3-4 and 3-5). In the third year the lowest and highest populations had similar HI values, while HI for the middle population was less than the lowest population and similar to the highest population (Table 3-6).

The hybrid effect on CPg varied across the three years. Nutri-dense and leafy hybrids had the highest CPg values one year (Table 3-5), while eafy and dual purpose 2 had the highest CPg values in another year (Table 3-6).

Plant density did not significantly affect CPg for two years of the study (Tables 3-4 and 3-6). The third year the lowest seeding rate had the highest CPg (75 g kg^{-1}) and the highest seeding rate had the lowest CPg (71 g kg^{-1}) (Table 3-5).

Hybrid type did not significantly affect ensiled crude protein (CPs) in two out of three years(Tables 3-4 and 3-5). In the third year of the study, CPs was greater for leafy and dual purpose 2 similar to CPg (Table 3-6).

Ensiled crude protein was numerically highest for the lowest seeding rate all three years but was significant only in 2004, similar to CPg (Table 3-5).

Nutri-dense had the numerically highest green chop acid detergent fiber (ADFg) in each year. Nutri-dense and leafy hybrid types had statistically higher ADFg values than the other hybrids in two years (Tables 3-4 and 3-5), while ADFg was not affected by hybrid type in the third year (Table 3-6).

For the 2003 season, the two highest seeding rates had similar ADFg values with the lowest seeding rate being significantly lower than the highest seeding rate (Table 3-4). In the other two years of the study seeding rate did not affect ADFg (Tables 3-5 and 3-6).

Ensiled acid detergent fiber (ADFs) was consistently lowest, numerically, for the dual purpose hybrid type, but the statistical ranking of the other hybrid types was not consistent.

The lowest seeding rate had the numerically lowest ADFs in all three years of the study, which was statistically lower two year out of the three years (Tables 3-5 and 3-6).

Hybrid effect on green chop neutral detergent fiber (NDFg) was significant in 2003 and 2004, with a range in value of 32 and 83 g kg^{-1} in 2003 and 2004 respectively (Tables 3-4 and 3-5). Nutri-dense and leafy hybrids had greater NDFg than the other hybrids ini 2003 and 2004 (Tables 3-4 and 3-5). Waxy had the lowest NDFg both years.

In 2003 NDFg increased as seeding rate increased (Table 3-4). Seeding rate did not affect NDFg in the other two years.

Ensiled neutral detergent fiber (NDFs) values were inconsistent across hybrid types each year, with no significant differences in 2004 (Table 3-4). While NDFs ws significantly different among hybrid types in 2003 and 2004, the range in values was 69 and 56 g kg^{-1} respectively.

The lowest seeding rate always had the numerically lowest NDFs values, while the highest seeding rate always had the numerically highest NDFs values. However, differences were not significant in 2003 and 2004 (Tables 3-4 and 3-5), and were significant in 2005

In 2003 and 2005, hybrid type did not significantly affect green chop *in vitro* dry matter disappearance (IVDMDg) (Tables 3-4 and 3-6). In 2004, IVDMDg was greatest for the waxy hybrid type (Table 3-5).

Numerically the lowest seeding rate always had the highest IVDMDg value and the highest seeding rate always has the lowest IVDMDg values. Differences in IVDMDg among the lowest and highest seeding rate were significant in 2003 (Table 3-4).

In 2003, ensiled in vitro dry matter disappearance (IVDMDs) was lowest for nutri-dense (Table 3-4). In 2004 and 2005, no significant differences were observed (Tables 3-5 and 3-6).

In 2003 and 2005, plant density did not significantly affect IVDMDs (Tables 3-4 and 3-6). For 2004 the lowest seeding rate had higher IVDMDs than did the highest seeding rate, with the middle seeding rate being similar to both (Table 3-5).

Relative feed value (RFV) is a calculation that combines many aspects of forage quality to give producers one number to determine which forage has the highest quality. In 2003 the dual purpose and waxy hybrid types a 13% higher green chop relative feed value (RFVg) than did the other hybrids (Table 3-7). In 2004 the waxy hybrid type had a 17% higher RFVg than the dual purpose hybrid type, and a 32% higher RFVg than the nutri-dense and leafy hybrid types (Table 3-7). There were no differences in RFVg in 2005 (Table 3-7).

In 2003 the lowest seeding rate had a 10% higher RFVg than did the highest seeding rate, but both rates were similar to the middle seeding rate (Table 3-7). No differences were found in RFVg by seeding rate in 2004 and 2005.

Ensiled relative feed value (RFVs) was 17% and 21% higher for dual purpose and waxy hybrid types than for nutri-dense and leafy hybrid types in 2003 and 2004 respectfully (Table 3-8). In 2005, however, the waxy hybrid type had a 16% lower RFVs than did the top ranking hybrids (which included the dual purpose hybrid) (Table 3-8).

Seeding rate did not affect RFVs in 2003, however in 2004 and 2005 RFVs decreased as seeding rate increased, with the lowest seeding rate having a 10% higher RFVs than the highest seeding rate(Table 3-8).

The value of the corn forage crop (dollars per hectare) was calculated from the quality and yield data. That value takes into account both the silage quality parameters measured, and the whole plant yield for each hybrid type, seeding rate, and N rate.

In 2003 and 2005 the green chop value of the waxy hybrid type was 31 and 28% less than the value of all other hybrid types (Table 3-9). In 2004 the green chop value of the nutri-dense was 14% higher than the value of all other hybrid types (Table 3-9).

For the 2003 growing season green chop value was not affected by seeding rate. In 2004 and 2005 the highest seeding rate had 15% and 14% greater value than did the lowest seeding rate (Table 3-9).

In 2003 and 2005 the ensiled value of the waxy hybrid type was 31% and 32% less than the value of all other hybrid (Table 3-10). In 2004 the ensiled value of the nutri-dense is 14% higher than the value of all other hybrid types (Table 3-10).

For the 2003 growing season ensiled value was not affected by seeding rate. In 2004 and 2005 the highest seeding rate had 13% and 12% greater value than did the lowest seeding rate (Table 3-10).

Discussion

In this study, hybrid type affected quality variables of whole plant forage, similar to other studies (Johnson, 2002; Clark, 2002). CP typically was similar among hybrids, but NDF and ADF were lower for WX than ND or DP. Akay and Jackson (2001) reported similar results. DP was greater than or equal to LF for digestibility, which differs with other reports on LF (Clark, 2002; Kuehn et al., 1999).

Relative feed value provides a composite estimate of forage quality. The RFVs for this study indicate that the highest quality hybrid typically were the waxy and dual purpose hybrids. This was true for both green chop and ensiled samples. This disagrees with studies that have shown that novel hybrids provide higher quality forage than dual purpose hybrids (Akay and Jackson, 2001; Clark, 2002; Kuehn et al., 1999).

The relative feed values also indicate that as seeding rate increases forage quality decreases. These findings are in agreement with Cox and Cherney (2001), but not with Widdicombe and Thelen (2002). In our studies, the lower seeding rate typically had the highest digestibility, lowest fiber, and highest CP concentration; however in most cases the two higher populations were not significantly different. If there was any difference in quality among populations then the lowest seeding rate had the highest quality.

Our data agrees with Sheaffer et al. (2006) that N-rate only seems to affect CP. As N-rate increases CP typically increases.

When looking at the crop value in dollars per hectare of the corn forage, the results of both whole plant yield and forage quality are accounted for. The value rankings are the same for green chop and ensiled samples, and show that waxy is typically the least valuable corn forage hybrid while the other three hybrids are often very similar. The value calculations also show that as seeding rate increases the value of the corn silage crop also increases.

Conclusion

Novel hybrid types over all do not appear to provide benefits over dual purpose hybrid types in forage quality. While the waxy hybrid type is equal to the dual purpose in forage quality with the waxy type yield is sacrificed (as shown in Chapter 2). For optimum forage quality a novel corn hybrid does not appear to be beneficial in the state of Kentucky.

The findings of this study indicate that the overall recommendation for the highest quality corn silage in Kentucky should be a waxy hybrid, or dual purpose hybrid seeded at 68,000 seeds ha^{-1} with 134 kg ha^{-1} of N applied. The dual purpose hybrid is similar to the waxy in quality, but much higher yielding as shown in Chapter 2 so the over all recommendation should be of a dual purpose hybrid at 68 000 seeds ha^{-1} with 134 kg ha^{-1} of N applied as indicated by the forage crop value calculations. Based on this study no changes should be made to the current silage production recommendations.

Table 3-1. Analysis of Variance for HI, and the quality factors of DM, CP, ADF, NDF, and IVDMD for both green chop (DMg, CPg, etc.) and ensiled samples (DMs, CPs, etc.) for the 2003 growing season. (***p≤0.001, **p≤0.05, *p≤0.10)

2003

		Mean Squares					
Source of Variation	df	HI	DMg	CPg	ADFg	NDFg	IVDMDg
N	1	0.0001	0.28	2.76*	1.54	9.76	33.96
NxRep (error A)	2	0.0020	3.93	0.97	0.93	5.57	8.90
Hyb	3	0.0561***	120.79***	0.19	38.92**	82.44**	88.78*
HybxN	3	0.0030	0.37	0.34	2.75	8.24	32.68
HybxNxRep (err B)	6	0.0032	10.75	0.21	4.87	12.79	19.98
Seeding Rate (SR)	2	0.0020	7.55	0.09	21.56*	48.96*	79.65*
SRxN	2	0.0008	0.44	0.04	1.36	2.04	23.38
SRxHyb	6	0.0030	2.46	0.67	4.40	11.28	13.99
SRxNxHyb	6	0.0050	2.95	0.18	0.86	2.40	4.42
SRxNxHybxRep (err C)	16	0.0026	4.88	0.36	4.12	9.98	18.50

Source of Variation	df	DMs	CPs	ADFs	NDFs	IVDMDs
N	1	1.16	3.80**	14.50	48.69	37.86
NxRep (error A)	2	1.71	0.20	2.14	11.37	23.95
Hyb	3	95.66***	0.28	67.39***	143.29**	68.44**
HybxN	3	0.55	0.20	1.16	4.75	16.25
HybxNxRep (err B)	6	3.28	0.17	3.82	12.08	7.61
Seeding Rate (SR)	2	0.47	0.24	1.98	3.18	27.57
SRxN	2	0.33	0.09	1.22	3.19	7.27
SRxHyb	6	1.54	0.56	4.67	13.36	14.01
SRxNxHyb	6	1.11	0.13	2.61	7.93	1.01
SRxNxHybxRep (err C)	16	1.87	0.38	6.37	16.35	10.43

Table 3-2. Analysis of Variance for HI, and the quality factors of DM, CP, ADF, NDF, and IVDMD for both green chop (DMg, CPg, etc.) and ensiled samples (DMs, CPs, etc.) for the 2004 growing season. (***p≤0.001, **p≤0.05, *p≤0.10)

2004

		Mean Squares					
Source of Variation	df	HI	DMg	CPg	ADFg	NDFg	IVDMDg
N	1	0.0010	2.30	3.87***	2.82	7.11	7.55
NxRep (error A)	2	0.0075*	17.01	0.41	3.38	6.01	21.50
Hyb	3	0.0809***	215.85***	2.08***	90.12***	238.17**	173.16***
HybxN	3	0.0102*	10.72	0.31	5.77	12.54	5.43
HybxNxRep (err B)	6	0.0080*	26.04	0.31	1.50	2.28	6.92
Seeding Rate (SR)	2	0.0034	3.06	.89*	10.65	10.61	8.70
SRxN	2	0.0002	27.26	0.40	16.85	34.94	51.18
SRxHyb	6	0.0039	5.46	0.10	3.12	5.01	14.67
SRxNxHyb	6	0.0063*	31.17	0.11	11.94	26.60	18.27
SRxNxHybxRep (err C)	16	0.0020	18.11	0.17	7.48	19.32	18.09
Source of Variation	df		DMs	CPs	ADFs	NDFs	IVDMDs
N	1		1.28	3.59***	3.61	10.87	0.88
NxRep (error A)	2		0.65	0.47	3.36	5.82	5.08
Hyb	3		291.02***	1.46***	101.98***	234.99***	191.62***
HybxN	3		1.15	0.31	5.82	8.46	19.36
HybxNxRep (err B)	6		24.74	0.53*	23.51*	50.88*	70.35**
Seeding Rate (SR)	2		10.92	1.02**	35.87*	53.65	105.87**
SRxN	2		10.30	0.11	0.46	1.44	8.97
SRxHyb	6		20.89	0.28	12.89	27.25	29.41
SRxNxHyb	6		32.70	0.19	9.45	20.87	12.48
SRxNxHybxRep (err C)	16		11.96	0.15	6.87	16.14	15.26

Table 3-3. Analysis of Variance for HI, and the quality factors of DM, CP, ADF, NDF, and IVDMD for both green chop (DMg, CPg, etc.) and ensiled samples (DMs, CPs, etc.) for the 2005 growing season. (***p≤0.001, **p≤0.05, *p≤0.10)

2005

		Mean Squares					
Source of Variation	df	HI	DMg	CPg	ADFg	NDFg	IVDMDg
N	1	0.0147	7.96	12.65***	16.33	47.95	73.03
NxRep (error A)	2	0.0438**	131.74***	1.39	0.88	1.04	8.71
Hyb	4	0.0753***	444.62***	4.23***	5.19	14.75	57.71*
HybxN	4	0.0018	3.76	0.10	8.44	16.62	32.45
HybxNxRep (err B)	8	0.0034	12.00	0.44	9.82	26.48	37.45
Seeding Rate (SR)	2	0.0164*	16.18	0.10	0.89	6.23	32.92
SRxN	2	0.0105	7.60	0.34	5.89	16.65	5.33
SRxHyb	8	0.0072	11.94	0.36	11.25	27.34	11.82
SRxNxHyb	8	0.0037	13.77	0.59	8.39	20.24	27.56
SRxNxHybxRep (err C)	20	0.0035	5.17	0.40	9.13	24.59	16.88

Source of Variation	df	DMs	CPs	ADFs	NDFs	IVTDs
N	1	3.22	4.97***	0.00	2.89	2.85
NxRep (error A)	2	70.47**	0.65	31.91*	80.35*	68.87*
Hyb	4	389.61***	2.67***	36.61**	89.90**	48.29*
HybxN	4	7.36	0.54	3.19	7.88	27.35
HybxNxRep (err B)	8	7.27	0.22	8.67	19.44	16.15
Seeding Rate (SR)	2	2.62	0.18	26.81*	64.57*	17.89
SRxN	2	3.35	0.21	2.62	4.49	2.91
SRxHyb	8	8.46	0.32	14.50	41.98*	18.91
SRxNxHyb	8	2.21	0.22	8.12	19.85	42.84*
SRxNxHybxRep (err C)	20	8.46	0.27	6.16	16.80	14.57

Table 3-4. HI, green chop DM, ADF, NDF, IVDMD, and CP and ensiled DM, ADF, NDF, IVDMD, and CP for each hybrid, plant density, and N-rate for the 2003 growing season.

	Harvest Index	Green Chop			
		CP	ADF	NDF	IVDMD
Hybrid	Ear:Whole Plant	g kg^{-1}	g kg^{-1}	g kg^{-1}	g kg^{-1}
Nutri-dense	0.36	78	201	417	665
Dual purpose	0.40	76	177	383	690
Leafy	0.28	75	200	414	709
Waxy	0.40	76	174	375	710
LSD(0.05)	0.04	NS	14	22	NS
Plant Density					
54 300 ha-1	0.35	77	179	383	710
68 000 ha-1	0.36	76	188	396	696
81 500 ha-1	0.37	76	197	412	674
LSD(0.05)	NS	NS	12	19	26
N-Rate					
134 kg ha-1	0.36	74	190	401	687
224 kg ha-1	0.36	78	187	393	700
LSD(0.05)	NS	NS	NS	NS	NS
		Silage			
		CP	ADF	NDF	IVDMD
Hybrid		g kg^{-1}	g kg^{-1}	g kg^{-1}	g kg^{-1}
Nutri-dense		81	221	412	621
Dual purpose		78	188	361	659
Leafy		78	229	420	664
Waxy		80	197	377	655
LSD(0.05)		NS	18	29	23
Plant Density					
54 300 ha-1		81	205	388	662
68 000 ha-1		79	210	394	648
81 500 ha-1		79	210	395	641
LSD(0.05)		NS	NS	NS	NS
N-Rate					
134 kg ha-1		77	213	401	643
224 kg ha-1		82	204	384	657
LSD(0.05)		3	NS	NS	NS

Table 3-5. HI, green chop DM, ADF, NDF, IVDMD, and CP and ensiled DM, ADF, NDF, IVDMD, and CP for each hybrid, plant density, and N-rate for the 2004 growing season.

	Harvest Index	Green Chop			
		CP	ADF	NDF	IVDMD
Hybrid	Ear:Whole Plant	g kg^{-1}	g kg^{-1}	g kg^{-1}	g kg^{-1}
Nutri-dense	0.41	75	210	383	617
Dual purpose	0.51	70	185	353	645
Leafy	0.36	77	208	400	614
Waxy	0.49	71	163	317	681
LSD(0.05)	0.03	3	19	31	30
Plant Density					
54 300 ha-1	0.45	75	186	359	645
68 000 ha-1	0.43	73	189	360	640
81 500 ha-1	0.45	71	199	371	633
LSD(0.05)	NS	3	NS	NS	NS
N-Rate					
134 kg ha-1	0.44	71	194	367	636
224 kg ha-1	0.44	76	190	360	642
LSD(0.05)	NS	2	NS	NS	NS
		Silage			
		CP	ADF	NDF	IVDMD
Hybrid		g kg^{-1}	g kg^{-1}	g kg^{-1}	g kg^{-1}
Nutri-dense		71	224	388	505
Dual purpose		68	187	347	641
Leafy		74	227	417	585
Waxy		69	182	341	650
LSD(0.05)		NS	NS	NS	NS
Plant Density					
54 300 ha-1		73	192	358	639
68 000 ha-1		70	205	375	618
81 500 ha-1		69	217	387	597
LSD(0.05)		2	16	NS	24
N-Rate					
134 kg ha-1		69	203	369	617
224 kg ha-1		73	207	377	619
LSD(0.05)		2	NS	NS	NS

Table 3-6. HI, green chop DM, ADF, NDF, IVDMD, and CP and ensiled DM, ADF, NDF, IVDMD, and CP for each hybrid, plant density, and N-rate for the 2005 growing season.

	Harvest Index	Green Chop			
		CP	ADF	NDF	IVDMD
Hybrid	Ear:Whole Plant	g kg^{-1}	g kg^{-1}	g kg^{-1}	g kg^{-1}
Nutri-dense	0.39	78	245	464	606
Dual purpose	0.45	76	236	459	630
Leafy	0.27	84	231	448	655
Waxy	0.39	75	239	455	620
Dual purpose 2	0.33	87	242	472	628
LSD(0.05)	0.04	4	NS	NS	NS
Plant Density					
54 300 ha-1	0.39	79	239	463	629
68 000 ha-1	0.34	79	237	455	617
81 500 ha-1	0.36	80	240	461	638
LSD(0.05)	0.03	NS	NS	NS	NS
N-Rate					
134 kg ha-1	0.38	76	243	467	619
224 kg ha-1	0.35	83	234	452	637
LSD(0.05)	NS	3	NS	NS	NS
		Silage			
		CP	ADF	NDF	IVDMD
Hybrid		g kg^{-1}	g kg^{-1}	g kg^{-1}	g kg^{-1}
Nutri-dense		70	232	427	625
Dual purpose		70	220	419	619
Leafy		75	235	433	647
Waxy		69	259	475	602
Dual purpose 2		78	238	451	621
LSD(0.05)		4	17	28	NS
Plant Density					
54 300 ha-1		73	226	424	628
68 000 ha-1		72	242	449	626
81 500 ha-1		73	243	450	614
LSD(0.05)		NS	13	22	NS
N-Rate					
134 kg ha-1		70	237	443	621
224 kg ha-1		75	237	439	624
LSD(0.05)		2	NS	NS	NS

Table 3-7. Green chop relative feed value (RFV) for each hybrid plant density and N rate for all growing seasons.

		Year		
		2003	2004	2005
		Green Chop RFV		
Hybrid	Nutri-dense	165	181	142
	Dual purpose	184	198	145
	Leafy	166	171	148
	Waxy	189	232	145
	Dual purpose 2			140
	LSD(0.05)	13	23	NS
Plant Density	54 300 ha^{-1}	184	200	143
	68 000 ha^{-1}	176	197	146
	81 500 ha^{-1}	168	190	143
	LSD(0.05)	11	NS	NS
N-Rate	134 kg ha^{-1}	174	193	141
	224 kg ha^{-1}	178	197	147
	LSD(0.05)	NS	NS	NS

Table 3-8. Ensiled relative feed value (RFV) for each hybrid plant density and N rate for all growing seasons.

		Year		
		2003	2004	2005
		Ensiled RFV		
Hybrid	Nutri-dense	164	177	156
	Dual purpose	193	203	163
	Leafy	159	162	153
	Waxy	184	208	136
	Dual purpose 2			147
	LSD(0.05)	15	16	12
Plant Density	54 300 ha^{-1}	177	196	159
	68 000 ha^{-1}	174	186	147
	81 500 ha^{-1}	173	179	146
	LSD(0.05)	NS	14	10
N-Rate	134 kg ha^{-1}	170	189	150
	224 kg ha^{-1}	179	186	152
	LSD(0.05)	NS	NS	NS

Table 3-9. Green chop forage crop value ($ ha^{-1}) for each hybrid plant density and N rate for all growing seasons.

		Year		
		2003	2004	2005
		Green Chop Value($ ha^{-1})		
Hybrid	Nutri-dense	2631	3519	1484
	Dual purpose	2860	3062	1580
	Leafy	2616	2950	1608
	Waxy	2058	3245	1208
	Dual purpose 2			1531
	LSD(0.05)	236	299	135
Plant Density	54 300 ha^{-1}	2504	2946	1369
	68 000 ha^{-1}	2615	3235	1519
	81 500 ha^{-1}	2504	3401	1559
	LSD(0.05)	NS	259	104
N-Rate	134 kg ha^{-1}	2479	3258	1483
	224 kg ha^{-1}	2604	3130	1482
	LSD(0.05)	NS	NS	NS

Table 3-10. Ensiled forage crop value ($ ha^{-1}) for each hybrid plant density and N rate for all growing seasons.

		Year		
		2003	2004	2005
		Ensiled Value($ ha^{-1})		
Hybrid	Nutri-dense	2593	3451	1491
	Dual purpose	2840	2993	1596
	Leafy	2556	2894	1588
	Waxy	2026	3178	1177
	Dual purpose 2			1521
	LSD(0.05)	244	244	143
Plant Density	54 300 ha^{-1}	2454	2921	1380
	68 000 ha^{-1}	2574	3181	1501
	81 500 ha^{-1}	2483	3298	1543
	LSD(0.05)	NS	212	111
N-Rate	134 kg ha^{-1}	2433	3197	1482
	224 kg ha^{-1}	2574	3067	1467
	LSD(0.05)	NS	NS	NS

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