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Plant Spacing and Variety of Field Corn (*Zea mays* L.) Affecting Yield, Yield Components and Silage Quality

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Abstract

The recent increase in dairy and cattle production in Thailand has increased demand for high-quality roughage, particularly corn silage. Although there has been a great deal of research on field corn, far fewer studies have focused on corn intended as silage. This study involved a field experiment that analyzed crop management methods, focusing on plant spacing and 8 of the field corn varieties most commonly used in Thailand. The objectives were to determine which plant spacing and variety produced the best forage yield and silage qualities of corn silage. The plantings were arranged in a split-plot Randomized Complete Block Design (RCBD) with four replications. The main plot contained two spacing (75×20 and 75×25 cm^2), each with subplots of 8 field corn varieties (SW5, NS2, NS3, NSX982013, TE1719, WS6437, WS6440, WS6442). All plants received the same crop management care regarding soil conditions, water, fertilization, and weeding. The results showed plant spacing did not significantly affect plant height (cm) and ears per plant, but the narrower 75×20 cm^2 spacing produced the highest fresh leaf yield (13 t ha^{-1}) and dry stalk yield (4.5 t ha^{-1}) ($p < 0.05$). At 75×20 cm^2 spacing, the TE1719 varietal had more ears per plant than SW5 (the check variety). TE1719 had the best fresh ear, stalk, and total biomass yield at both spacing of all the varieties. With regard to silage quality, the plant spacing did not significantly affect the CP, ADF, ADL, ash, and pH of the corn silage. The study revealed planting TE1719 varieties at 75×20 cm^2 spacing is more economical for farmers because it increases forage yields without negatively affecting the nutritional value of corn silage.

Keywords: Plant spacing, Field corn, Yield component, Nutritional value, Corn silage

Introduction

Corn (*Zea mays* L.) is a critical forage crop widely cultivated around the world [1-3] but historically occupied limited acreage in Thailand. Recently, however, the rapid expansion of the cattle and dairy industries in Thailand has caused a growing demand for high-quality roughage, and corn silage production has increased to meet that demand. Corn silage has valuable characteristics compared to other roughages, most notably because of its high content of starch and water-soluble carbohydrate (WSC) and its ease of ruminant and digestion [4]. Moreover, the utilization of silage corn as the main roughage can reduce dairy and beef production costs by decreasing the cost of concentrates [5].

Corn silage yield and quality depend significantly on the corn hybrid planted and crop management practices. In-depth knowledge of field corn varieties grown in Thailand that are most suitable for producing corn silage is relatively low. Due to the growing demand for corn, governmental and private research entities have dramatically increased their focus on field corn breeding, which is continuing.

Several elite inbred lines have been developed and released; the cornfield hybrids most respected and reported on for their high yield include CP888, S7328, S6248, PAC559, NS3, and SW4452.

This study analyzed eight field corn varieties: SW5, NS2, NS3, NSX982013, TE1719, WS6437, WS6440, WS6442. SW5 is widely used in Thailand and served as the check variety. NS2 has long been a variety recommended by the Department of Agriculture (DOA), and NS3 is a drought-tolerant hybrid improved by the Nakhon Sawan Field Crops Research Center (NSFCRC) and released in 2009 and promoted across many provinces in the central part of Thailand. The other five varieties selected for the study were varieties recently released, intended for silage corn hybrids.

The agronomic traits most desired for a silage corn hybrid are not the same as the traits most valued for grain corn. The most suitable corn varieties for silage production have a high grain:stalk ratio, more leaf, and high dry matter. When combined with appropriate crop management (specifically plant density, use of fertilizers, and harvesting time), breeding that promotes these traits can provide the highest corn silage yield and best nutritional qualities.

It is well-known that crop management practices play important roles in promoting crop fodder yield and quality. Plant density management has been shown to be one of the most important agricultural crop management practices that determines forage yield and affects other important agronomic traits of corn [6]. Previously, researchers have reported that corn dry matter yield and quality characteristics are affected by plant spacing and the variety of the hybrid selected and planted [7,8]. In Thailand, the conventional plant spacing for most corn hybrids has been 75×25 cm^2 plant spacing, which results in a plant density of 53,331 plant ha^{-1}. However, to increase the above ground biomass yield of corn silage production, the plant spacing should be less than 75×25 cm^2. Indeed, many farmers have adopted narrow spacing to achieve greater plant densities of corn used in corn silage As a result, the crops have successfully yielded more dry matter per hectare [9]. For instance, [9] found that 75×22.7 cm^2 plant spacing (40,000 plant ha^{-1}) resulted in higher dry matter of corn silage compared to 75×9.6 cm^2 plant spacing (140,000 plant ha^{-1}). This is because high plant density increases competition between individual plants, which enhances the amount of available light, water and nutrients.

Narrow spacing can increase plant height, but taller plants may have more lodging and a slightly slower rate of plant maturation [10]. Greater plant density also tends to reduce the number of kernels per row per corn ear, which is essential in that the number of kernels is a determinant of forage yield and quality. Fewer kernels per ear indicate low concentrations of starch and higher fiber concentrations (low energy concentration) [11,12]. Silage fiber content increased in relation to an increase in plant density, whereas digestible fiber and whole plant digestibility decreased. However, various studies have shown that increasing plant density has minimum effects on the nutritional value and corn silage digestibility [13].

Prior research has also shown that optimum plant spacing depends on environmental factors and controlled factors; soil fertility, hybrid selection, planting date, planting pattern, and harvest time are among the most critical controlled factors [6,14]. Moreover, the seeding rate is an essential factor that farmers often consider to achieve an increase in yield.

The selection of specified hybrids and plant spacing recommendations should be based on local data [15]. Optimal plant densities for silage corn production vary widely from 45,000 to 125,000 plants ha^{-1}, depending on corn varieties, which typically translates into greater yield, development of desirable yield components, and improvement of corn's nutritional value silage [16]. Considering these fundamental considerations, this study's objectives were to evaluate the effects of plant spacing and field corn varieties on the growth, forage yields, yield components, and quality of corn silage, with the primary focus on corn silage production.

Materials and methods

Experimental site and design

The field experiment was conducted at the National Corn and Sorghum Research Center, Pak Chong, Nakhon Ratchasima province, Thailand (14°38'N, 101°18'E, elevation of 388 m above sea level) under rain-fed conditions. Soil samples were collected from a depth of 0 - 30 cm. The soil analysis was a clay soil that was slightly alkaline (pH 7.7), medium in organic matter (2.14 %), very high in phosphorus (133 mg kg^{-1}), very high in potassium (152 mg kg^{-1}), high in calcium (2,587 mg kg^{-1}) and high in magnesium (204 mg kg^{-1}). Throughout the study period (May - August 2017), the total rainfall was 555.0 mm, the mean temperature was 27.3 °C, and the mean relative humidity was 79.9 %.

The experiment plantings were arranged in a split plot RCBD design with 4 replications. The mainplot consisted of 2 plant spacing, which were 75×20 (density of 66,663 plant ha^{-1}) and 75×25 cm^2 (53,331 plant ha^{-1}). Eight varieties were managed in sub plots: NS2, NS3, NSX982013, TE1719, WS6437, WS6440, WS6442 and SW5 (the check variety). SW5 was used as the check variety because it has consistently produced high levels of fresh and dry weight yield. Moreover, Thai farmers first began to plant SW5in the 1990s and it is now one of the most widely planted field corn varieties in Thailand.

Establishment and management

The experiment field was ploughed to produce a good seedbed before sowing, then basal fertilizer NPK (15-15-15) was applied at a rate 156.25 kg ha^{-1}. Seeds were planted on May 2017. Row spacing was 75 cm and the distance between plants in the rows was 20 and 25 cm for 7 and 5 plant/m^2 sowing densities. Plot size was 5×3 m^2 with 4 rows/plot. Two weeks after planting, the seedlings were thinned according to the experimental treatment. Then, Urea (46-0-0) was applied at the rate 187.5 kg ha^{-1} as a side dressing at 4 weeks after planting. Pre-emergence herbicide was applied and hand weeding was used to control weeds. The experiment plot was irrigated using a sprinkler irrigation system during the first 5 weeks and after that furrow irrigation provided water once each week (June - July 2017).

Plant measurements

Ten plants of each variety were selected randomly from each plot's two central rows, and data was collected on the critical important agronomic traits: plant height, ear height, and ears per plant were measured 60 days after planting. During harvesting, the number of ears per plant was measured, and the 1^{st}, 2^{nd}, and 3^{rd} fully expanded leaves (counting from the bottom of the plant) were measured and analyzed by SPAD for leaf greenness. The percentage of root lodging was measured at a 45° angle in the plots and calculated based on the total number of plant stalks lodged per plot divided by the total number of plants per plot.

Each plot's two center rows were harvested at 75 % of kernel milk-line (78 days after planting). All sample plants were separated and categorized according to leaf, stalk, and ear fractions, and the fresh weight of every plant part was recorded at harvest by using an electronic balance. Ear diameter and ear length were measured by using a vernier caliper. Ears were also categorized according to their husk, ear, and kernel components and then oven-dried to measure percentages of ear components. Three plants per plot were randomly selected and then separately dried at 75 °C for 72 h in order to measure for percentage of dry matter. Specifically, the ear's ratios: stover and kernel: stover (stover included leaves, leaf sheaths, stalks, and tassels) were determined, and then the dry matter yield of each plot was calculated.

The final stage involved ensiling. The 15 random plants/plots were harvested to ensile in a plastic bag. After 21 days of ensiling, the nutritional value of corn silage samples was analyzed for NDF, ADF, and ADL content using a sequential detergent analysis method [17]. CP content was calculated by multiplying total N by 6.25 (N content was analyzed using a CHN elemental analyzer), the ash content was determined according to the method of AOAC [18], and the pH of corn silage samples were analyzed using a pH meter.

Statistical analysis

The data sets were analyzed using analysis of variance (ANOVA) calculated using R-program. The least significant difference (LSD) at the 0.05 level was used to conduct mean comparisons and to determine any significant statistical differences.

Results and discussion

Growth, yield and yield components

The results showed that plant spacing did not affect plant height, leaf greenness, root lodging, ear height, ears per plant, ear diameter, and ear length (**Table 1**). Similar results were found in [1,6,19], who reported different plant spacing conditions and corn variety, but the result of these earlier studies demonstrated that plant height, ear diameter, and ear length relate positively to plant spacing [6]. The interaction of spacing and corn varieties significantly affected the plant height, ear height, ear per plant, leaf greenness, root lodging, and ear length, but not on-ear diameter. At both spacing, plant height, leaf greenness, and ear diameter of TE1719 were not significantly different compared to the check variety (SW5). However, NS2 planted in a wide spacing (75×25 cm^2 compared to the narrower 75×20 cm^2) matured to a corresponding decrease in plant height. TE1719 had higher ear height than SW5 (check variety) in both 75×20 and 75×25 cm^2 spacing. It also showed more ears per plant than NS2, NS3, and SW5, especially in a narrow spacing (75×20 cm^2) (**Table 1**). However, the prolific trait was expressed more often with wider plant spacing due to less interplant competition [20]. These findings are consistent with [21] and [14], who reported that the number of cobs per plants was not significantly affected by field corn hybrids.

Greater plant densities (due to narrower spacing) during the vegetative growth stage improves dry matter and N accumulation because of the larger plant canopy [22]. A large plant canopy during the reproductive growth stage may accelerate the leaf senescence rate [23] and lower the percent of greenness in the bottom leaves.

However, environmental and management also play important roles in determining the leaf greenness of the corn. In this study, there was no significant difference in leaf greenness between the plant spacing at harvest. TE1719 showed more leaf greenness within the varieties studied than WS6440 at 75×25 cm^2 spacing ($p < 0.01$). However, TE1719 showed significantly less leaf greenness than the other corn varieties, which conflicts with the report by [24], who reported that leaf greenness positively related to CP content (**Table 1**). The higher CRP concentration observed in these corn hybrids is consistent with observations previously made regarding higher leaf N concentrations in stay-green sorghum hybrids [24]. This is probably due to greater retention of chloroplast proteins and greater N uptake capacity in stay-green hybrids [24].

There was an interaction between plant spacing and corn varieties on plant height, ear height, and ears per plant, leaf greenness, lodging, and ear length (**Table 1**). It has been noted that plant height can cause root lodging [25]. In this study, NS2 did not show root lodging in the narrow spacing compared to TE1719. TE1719 had the highest root lodging percentage than any other varieties. Indeed, root lodging in TE1719 was two times greater when plant spacing was increased to 75×25 cm^2 (6.5 vs12.8 %). In the wider plant spacing, there were no significant differences in plant height and ears per plant in TE1719. Notably, TE1719 had excessive ear height (greater than 150 cm), which may have been a factor contributing to the higher rate of root lodging (153 cm height at 75×20 cm^2 spacing, 158 cm^2 height at 75×25 cm^2 spacing) (**Table 1**). Elevated ear height lifts the plant's center of gravity, making the corn plant more susceptible to wind lodging [26]. TE1719 had more ears per plant than other varieties at 75×20 cm^2 plant spacing but not different at 75×25 cm^2 plant spacing. TE1719 had more ears per plant, which may have contributed to a higher root lodging percentage. In the present study, the results indicated a relationship between ear height and ears per plant of corn, causing higher root lodging percentage (**Table 1**). These findings align with a study reported by [25], where the plant height and ear height of corn cv. LD981 was much higher than that of cv. ZD958, which resulted in higher percentage of lodging. In this study, ear height and ears per plant played an important role in the root lodging of prolific corn (**Table 1**). However, there was no evidence that root lodging affected the yield components and biomass yield of TE1719 in both plant spacing. In contrast, [27] found that corn yield declined when plant density was increased beyond the optimum plant density and concluded that this was primarily because of a decline in the harvest index and increased lodging.

There was no difference in ear diameter in both plant spacing, so there was no interaction between plant spacing and corn varieties regarding ear diameter. However, [6] reported that corn varieties and narrower plant spacing significantly affected ear diameter and ear length. Similarly, [28] observed that wider plant spacing increased ear length and ear diameter. This study noted that corn variety significantly affected ear length; SW5 showed longer ear length (19.9 cm) than WS6440 (14.0 cm) in 75×20 cm^2 spacing but at 75×25 cm^2 plant spacing. In other words, there was insignificant differences for all corn varieties. However, there was an interaction between plant spacing and corn varieties on ear length (**Table 1**).

Plant spacing did not affect the fresh ear, stalk, and total biomass yield and ear: stover and kernel: stover ratios, but it did affect fresh leaf yield. There was a corresponding decrease in fresh leaf yield with the increase in plant spacing (75×20 to 75×25 cm^2). Similar results were found by [28], who reported that plant spacing did not affect corn's biomass yield under different plant densities (70,000 and 80,000 plants ha^{-1}).

The variety of the corn plant had a significant effect on the fresh weight yield and yield components. Fresh leaf yield was affected by varieties ($p < 0.01$) (**Table 2**). Leafy varieties increased the leaf yield. The new leaf yield data showed insignificant differences in all varieties, except WS6437, which was lower than the other varieties. These results are identical with [29], who reported the corn varieties to affect leaves per plant at ($p < 0.01$). When considering the two factors of plant spacing and corn varieties, the results showed an interaction between plant spacing and corn varieties on fresh weight yield of the leaf, ear, stalk, and total biomass, ear: stover and kernel: stover ratio (**Table 2**).

TE1719 produced more ears per plant. TE1719 had a higher fresh ear yield than WS6437 in the 75×20 cm^2 spacing and a higher fresh ear yield than SW5 in the 75×25 cm^2 spacing, and TE1719 had a higher fresh ear yield than NS3 in both plant spacing. SW5 produced a higher fresh ear yield in the wider spacing, but WS6437 and WS6440 showed a higher fresh ear yield in the wider spacing.
TE1719 also had higher fresh stalk yield and total biomass than NS3, NSX982013, and WS6437 in both plant spacing, particularly in the narrower 75×20 cm^2 spacing. In the 75×25 cm^2 spacing, SW5 produced lower fresh stalk yield than TE1719, but not in the 75×20 cm^2 spacing.

With regard to the economic realities, a narrow plant spacing (75×20 cm^2) necessitates higher planting seed cost than low plant density spacing (75×25 cm^2), but the benefits of narrow plant spacing decreased the percentage of root lodging and increased total biomass of corn, especially in TE1719 varieties. This increase in cost is an important consideration. Farmers have higher seed costs if they use higher density plantings (**Table 2**). However, because the yield is proportionately higher, the seed price increases when farmers use a lower density planting (75×25 cm^2). The improved yield provides the farmers with an overall economic benefit.

The yield per corn plant was more significant in plants with wider plant spacing; however, the yield per area was higher with narrower plant spacing. Plant spacing affected the control variety: SW5 had the less fresh ear and stalk yield in the wider plant spacing (from 75×20 to 75×25 cm^2) comparing with TE1719. Moreover, SW5 showed decreased total fresh biomass (approximately 10.2 t ha^{-1}) in the wider plant spacing. TE1719 performed better in the narrower plant spacing (75×20 cm^2) than the other varieties (**Table 2**).

The results of this study indicated that a narrower plant spacing with a density rate of approximately 66,663 plants ha^{-1} (75×20 cm^2 spacing) produces higher corn yields than the wider plant spacing, which has a density of approximately 53,331 plants ha^{-1} (75×25 cm^2 spacing). These findings provide benefits to the farmers in Thailand who commonly plant with a density of 53,331 plants ha^{-1}. These results are consistent with those reported by [10], who recommended planting corn at a density of 60,000 plants ha^{-1}. That study determined that a plant-to-plant distance of 22.7 produced the highest corn yields. However, it is essential to be aware that density and resulting yields depend on many other factors related to the crop's region.

Therefore, based on this study's finding, the recommended plant spacing for corn silage production in Thailand is 75×20 cm^2 because of the additional 2.2 t ha^{-1} of fresh biomass yield produced. Although the initial seed costs will be higher at the time the crop is planted, farmers' total profit will potentially increase by 4,400 Baht ha^{-1} (estimated prices at 2,000 Baht t^{-1} of corn silage) comparing with75×25 cm^2 spacing. Other research has reported other significant positive correlations, including plant height and stover yield, plant height, and dry matter yield of corn [30]. WS6437, a short plant height variety, was low in total biomass yield but had a high ear: stover ratio.

Improving the digestibility of forage corn can be achieved to some extent by increasing the fraction of the ear in the total dry matter yield [31]. Although SW5 grown at the narrower (75×20 cm^2) and wider (75×25 cm^2) plant spacing had longer ear length, it showed a higher husk and cob percentage that resulted in low kernel percentage. Because of a high dry stalk yield and low kernel percentage, SW5 showed a low kernel: stover ratio in both plant spacing (**Table 2**).

Corn grain yield was closely associated with the number of kernels set per unit of the land surface area [35], which depended on the plant density, the number of ears per plant, and the number of kernels per ear [36]. However, dry leaf, ear, total biomass, and ear components did not significantly differ among the different plant spacing, but dry stalk yield decreased within the wider 75×25 cm^2 spacing (**Table 3**). Similar results were reported by [32]; however, [16] reported that the percentage of cob decreased as plant spacing decreased.

Varieties had a significant effect on the dry weight yield and ear components. NS2 had a high dry leaf in the 75×20 cm^2 spacing, which did not significantly differ from most other varieties (the exception was NSX982013 in the 75×25 cm^2 spacing). At 75×25 cm^2 spacing, NSX982013 showed higher dry ear yield than NS3 and SW5. TE1719 and SW5 exhibited higher dry stalk and total biomass yield than NS3 (75×20 cm^2 spacing) and WS6437 (both plant spacing). SW5 also had less dry stalk and total biomass yield in the wider 75×25 cm^2 spacing (**Table 3**). Low plant height of WS6437 in both plant spacing resulted in low fresh and dry stalk yield. There was an interaction between plant spacing and corn varieties on dry weight yield of the leaf, ear, stalk, and total biomass and ear components (**Table 3**).

Because of the long ear length and greater ear diameter, SW5 showed a higher husk and cob percentage in the narrower 75×20 cm^2 spacing (**Table 1**). In the narrower 75×20 cm^2 plant spacing, SW5 had higher husk and cob percentages, but the kernel percentage was lower than the other varieties. In the wider 75×25 cm^2 plant spacing, NSX982013 has the highest husk percentage, but TE1719 and WS6442 had the greatest kernel percentages (**Table 3**).

As the ratio of corn kernel charged, there was a difference in the quality of the corn silage. Long ear length of SW5 resulted in a higher husk and cob percentage. Although WS6440 had a shorter ear length than SW5, it had a higher kernel percentage in the 75×20 cm^2 spacing (**Table 3**). This is important because kernel provides higher nutrient values than husk and cob due to its high starch and low NDF content [33]. A narrow plant spacing typically reduces the number of kernel rows per ear and the number of kernels per row within an ear, which decreases the kernel percentage. The total number of kernels produced by a single plant decreased because of the higher narrow plant spacing, which was already noted by [12,34]. SW5 had a high husk percentage, but its ears had a lower kernel percentage in the narrower 75×20 cm^2 spacing than in the 75×25 cm^2 spacing. TE1719 and WS6440 had a higher kernel percentage than SW5 (check variety) (**Table 3**). Better kernel percentage means a better overall quality of corn silage.

Nutritional value and pH of corn silage

The crude protein (CP), ADF, ADL, ash, and pH were not significantly different between the different plant spacing (**Table 4**). This result is identical with the findings by [35], who reported that plant spacing (75×18 and 75×24 cm^2) did not have any significant impact on the nutritive value (NDF, ADF, and CP) of corn silage.

The crude protein (CP) content did not significantly differ between the two plant spacing (**Table 4**). However, [8] observed that the CP content of corn silage decreased in a wider plant spacing. In this study, the highest CP content was found in the WS6437 variety, but it did not significantly differ from SW5 (check variety). The TE1719 variety showed the lowest CP in in both plant spacing.

Leaves are rich in CP content, which is advantageous because high leaf yield improves the CP content of corn silage [33]. Although WS6437 had high CP content in both plant spacing (7.34 in 75×25 and 7.54 % in 75×20), it was not a high leaf yield variety (**Table 4**). Similar results were found by [36], which reported differences in nutritional value and milk yield between corn hybrids. This firmly indicates that some corn hybrids produce more milk yield than others. In [37], in all of the corn varieties studied, the CP content was below minimum dietary levels needed by milking cows to achieve maximum milk production. Although corn silage is not a high-protein roughage, it has commonly been used as a carbohydrate source of feed for dairy cows [38].

There was an interaction between plant spacing and corn varieties on CP, NDF, ADF, ash, and pH of corn silage (**Table 4**). The NDF content increased when plant spacing decreased from 75×25 to 75×20 cm^2 (52 vs 54 %) (**Table 4**). A similar trend was observed by [39], where NDF concentrations increased an average of 2.6 % as plant spacing decreased, potentially reducing feed value, and NDF increased 1.3 % with the decrease in plant spacing [40]. NDF concentration increased linearly as the plant spacing decreased [16], while ADF percentage increased 3.0 % with increased plant spacing [41].

Stover, made up of stalk, leaf, husk, and cob, is of lower quality feed than the kernel. Stover contains no starch, has limited water-soluble carbohydrates (WSC), low protein, and is high in NDF [33]. However, in this study, the result indicated that the ear: stover and kernel: stover ratio was not related to NDF, ADF, and ADL content (**Table 3**). Although SW5 showed a low kernel: stover ratio and kernel percentage, its content of NDF and ADF were did not significantly differ from the other varieties.

Overall, the ADF content did not significantly differ in all varieties studied at both plant spacing (**Table 4**). In contrast, [41] reported that ADF content increased by 4.5 % in plantings with higher-density, and [1] reported that the various corn hybrids showed significant ADF variations. Indeed, the below ear portion of the stalk was more heavily lignified (indigestible fiber) to support the plant stalk. Ideally, ear height should be at a lower position on a corn plant to increase the proportion of digestible fiber above the ear.

Although TE1719 and WS6440 proved to have a high ear height variety, their ADL content did not differ from the other varieties (**Table 4**). [31] reported that increasing the ear's fraction in the total dry matter yield promotes greater forage corn digestibility. WS6437 showed a higher ear: stover ratio, but ADL content did not differ from other varieties. NSX982013 showed the high husk (32 %) and low kernel (49 %) percentages (SW5 had low husk percentage and high kernel percentage) (**Table 3**), but NSX982013 has low ADL content (2.51 %) (compared to SW5 at 3.05 %). Therefore, NSX982013 produced one of the high-quality corn silage in the wider plant spacing.

ADL content of the varieties studied here showed lower values than reported by [42], which found 9 - 11% of ADL content in corn silage. Ash content ranged from 5.71 - 6.90 % in the 2plant spacing and across the varieties; SW5 had higher ash content than NS3 in the 75×20 cm^2 spacing (**Table 4**). In general, corn silage has less ash than legume-grass forages; the normal ash content of corn silage is approximately 5.0 % of DM. WS6437 had lower pH than SW5 in the 75×20 cm^2 spacing (**Table 4**). This important because a low pH is needed to promote stable and high-quality silage. Good quality silage usually has a pH level of 3.5 - 4.2 [44]. Corn silage pH in this study varied from 3.53 - 3.66 with significant differences between varieties at ($p < 0.01$) (**Table 4**).

Table 1 Plant height (cm), ear height (cm), ears per plant, leaf greenness, lodging (%), ear width (cm) and ear length (cm) of field corn at different plant spacings and varieties.

Spacing (A)	Varieties (B)	Plant height	Ear height	Ear/plant	Leaf greenness	Lodging (%)	Ear diameter	Ear length
75×20 cm^2	NS2	299 a	146 bcde	1.2 b	43.4 ab	0.0 b	3.7	17.0 ab
	NS3	230 bcd	134 ef	1.3 b	42.7 ab	0.0 b	3.7	17.6 ab
	NSX982013	245 abcd	145 bcde	1.4 ab	43.6 ab	0.3 b	3.5	17.2 ab
	SW5	243 abcd	137 de	1.3 b	47.8 ab	0.0 b	3.9	19.9 a
	TE1719	268 abc	153 abc	1.9 a	53.3 a	6.5 ab	3.5	16.4 ab
	WS6437	211 cd	122 g	1.4 ab	49.4 ab	0.0 b	3.6	16.9 ab
	WS6440	249 abcd	148 abcd	1.6 ab	49.6 ab	0.0 b	3.9	14.0 b
	WS6442	239 bcd	145 bcde	1.6 ab	48.5 ab	0.0 b	3.5	16.7 ab
75×25 cm^2	NS2	241 bcd	138 de	1.3 ab	45.6 ab	0.0 b	3.7	18.6 ab
	NS3	230 bcd	137 de	1.6 ab	44.5 ab	0.0 b	3.3	17.3 ab
	NSX982013	251 abcd	143 cde	1.8 ab	44.1 ab	0.0 b	3.4	15.9 ab
	SW5	236 bcd	138 de	1.3 b	47.3 ab	0.0 b	3.5	19.6 a
	TE1719	275 ab	158 a	1.8 ab	52.6 a	12.8 a	3.8	16.7 ab
	WS6437	205 d	122 fg	1.6 ab	48.5 ab	0.0 b	3.5	16.5 ab
	WS6440	253 abcd	156 ab	1.4 ab	38.2 b	0.3 b	3.7	18.6 ab
	WS6442	237 bcd	143 cde	1.5 ab	49.3 ab	0.0 b	3.4	17.2 ab
Mean	75×20 cm^2	248	141	1.5	47.3	0.9	3.7	17.0
	75×25 cm^2	241	142	1.5	46.3	1.6	3.5	17.6
Mean	total	245	142	1.5	46.8	1.3	3.6	17.3
C.V. (%)	A×B	12.42	4.46	27.85	14.45	381.53	14.91	15.68
LSD	A×B	57.90	12.05	0.59	12.90	8.98	0.76	5.16
				ANOVA				
A		ns	ns	ns	ns	ns	ns	ns
B		**	**	**	**	**	ns	*
A×B		**	**	**	**	**	ns	**

Remarks: Mean values in the same column followed by the same lowercase letter are not different at $p < 0.05$.Note *, **: significantly different at the 0.05 and 0.01 probability levels, respectively; ns: non-significant difference.

Table 2 Fresh weight yield (t ha^{-1}) and yield components of field corn at different plant spacings and varieties.

Spacing (A)	Varieties (B)	Leaf	Ear	Stalk	Total	E:S	K:S
75×20 cm^2	NS2	13.8 ab	20.8 ab	26.9 abcd	61.5 abcd	0.52 bc	0.16 abc
	NS3	14.2 a	18.0 bc	22.9 defgh	55.1 cdefgh	0.49 bc	0.19 a
	NSX982013	11.7 abc	19.7 abc	22.6 edgh	54.0 defgh	0.58 abc	0.17 abc
	SW5	14.0 ab	20.8 ab	28.0 ab	62.8 abc	0.50 bc	0.14 c
	TE1719	13.5 abc	22.2 a	28.7 a	64.3 a	0.53 bc	0.16 abc
	WS6437	11.0 bc	17.8 bc	21.4 fgh	50.2 fgh	0.55 abc	0.16 abc
	WS6440	13.1 abc	18.8 abc	26.0 abcde	58.0 abcdef	0.48 bc	0.18 abc
	WS6442	12.8 abc	19.8 abc	25.9 abcde	58.4 abcde	0.51 bc	0.18 abc
75×25 cm^2	NS2	11.5 abc	20.9 abc	25.4 abcdef	57.8 abcdefg	0.57 abc	0.16 abc
	NS3	11.6 abc	17.3 bc	19.7 gh	48.6 h	0.56 abc	0.17 abc
	NSX982013	11.2 abc	21.0 ab	23.5 cdefgh	55.6 bcdefgh	0.61 ab	0.16 abc
	SW5	12.5 abc	16.2 c	23.8 bcdefg	52.6 efgh	0.46 c	0.15 bc
	TE1719	13.8 ab	21.2 ab	28.2 a	63.2 ab	0.51 bc	0.17 abc
	WS6437	10.5 c	20.0 abc	19.5 h	49.9 gh	0.68 a	0.18 ab
	WS6440	12.9 abc	21.1ab	27.6 abc	61.6 abcd	0.52 bc	0.18 ab
	WS6442	11.9 abc	19.9 abc	25.1 abcdef	56.9 abcdefg	0.54 bc	0.18 ab
Mean	75×20 cm^2	13.0	19.7	25.3	58.0	0.52	0.17
	75×25 cm^2	12.0	19.7	24.1	55.8	0.56	0.19
Mean	total	13.0	19.7	24.7	56.9	0.54	0.18
C.V. (%)	A×B	13.28	10.32	9.06	7.27	12.33	11.02
LSD	A×B	3.16	3.88	4.27	7.90	0.13	0.04
ANOVA							
A		*	ns	ns	ns	ns	ns
B		**	**	**	**	**	**
A×B		**	**	**	**	**	**

Remarks: Mean values in the same column followed by the same lowercase letter are not different at $p < 0.05$. Note *, **: significantly different at the 0.05 and 0.01 probability levels, respectively, ns: non-significant difference, E:S : ears per stover, K:S : kernels per stovert ha^{-1}: Tonnes per hectare.

Table 3 Dry weight yield (t ha^{-1}) and ear components of field corn at different plant spacings and varieties.

Spacing (A)	Varieties (B)	Leaf	Ear	Stalk	Total	Ear components (%)		
						Husk	Cob	Kernel
75×20 cm^2	NS2	3.6 a	6.6 ab	4.4 abcd	14.5 ab	29 abcd	17 ab	54 abcde
	NS3	3.5 ab	5.9 abc	4.1 cdef	13.5 abcd	24 bcd	17 ab	59 abc
	NSX982013	3.1 ab	6.5 abc	4.5 abcd	14.0 abcd	27 abcd	20 ab	53 bcde
	SW5	3.4 ab	6.6 ab	5.2 a	15.1 a	33 a	21 a	46 e
	TE1719	3.2 ab	6.6 ab	5.1 a	14.9 a	27 abcd	17 ab	56 abcd
	WS6437	2.9 ab	5.6 bc	3.9 def	12.5 cd	27 abcd	18 ab	55 abcd
	WS6440	3.3 ab	6.1 abc	4.4 abcd	13.7 abcd	23 d	17 ab	60 ab
	WS6442	3.2 ab	6.5 abc	4.6 abcd	14.2 abc	23 d	19 ab	58 cde
75×25 cm^2	NS2	3.2 ab	6.3 abc	4.2 bcde	13.6 abcd	30 ab	18 ab	52 cde
	NS3	3.4 ab	5.4 c	3.4 f	12.2 d	29 abcd	18 ab	53 bcde
	NSX982013	2.8 b	6.8 a	4.6 abcd	14.2 abc	32 a	19 ab	49 de
	SW5	2.9 ab	5.5 bc	4.0 def	12.4 cd	24 bcd	19 ab	57 abcd
	TE1719	3.2 ab	6.3 abc	4.8 abc	14.3 abc	24 bcd	15 b	61 a
	WS6437	3.2 ab	6.2 abc	3.5 ef	12.9 bcd	30 abc	17 ab	53 bcde
	WS6440	3.3 ab	6.4 abc	5.0 ab	14.6 ab	23 cd	16 b	61 a
	WS6442	2.9 ab	6.5 abc	4.5 abcd	13.8 abcd	25 bcd	19 ab	56 abcd
Mean	75×20 cm^2	3.3	6.3	4.5	14.0	27	18	55
	75×25 cm^2	3.1	6.2	4.2	13.5	27	18	55
Mean	total	3.2	6.2	4.4	13.8	27	18	55
C.V. (%)	A×B	11.63	9.56	9.14	7.48	13.40	11.80	7.26
LSD	A×B	0.70	1.13	0.76	1.96	6.86	4.07	7.67
ANOVA								
A		ns	ns	*	ns	ns	ns	ns
B		**	**	**	**	**	**	**
A×B		**	**	**	**	**	**	**

Remarks: Mean values in the same column followed by the same lowercase letter are not different at $p < 0.05$. Note *, **: significantly different at the 0.05 and 0.01 probability levels, respectively; ns: non-significant differencet ha^{-1}: Tonnes per hectare.

Table 4 Crude protein, NDF, ADF, ADL, ash and pH of corn silage at different plant spacings and field corn varieties.

Spacing (A)	Varieties (B)	CP (%)	NDF (%)	ADF (%)	ADL (%)	Ash (%)	pH
75×20 cm^2	NS2	6.12 de	57 a	30 ab	3.42	5.74 ab	3.60 abc
	NS3	6.95 abcd	52 abc	28 ab	3.03	5.56 b	3.66 a
	NSX982013	6.35 cde	52 abc	28 ab	3.08	6.09 ab	3.63 abc
	SW5	6.70 abcde	55 ab	30 ab	3.60	6.90 a	3.54 bc
	TE1719	6.38 cde	55 ab	31 a	3.23	6.71 ab	3.62 abc
	WS6437	7.34 ab	52 abc	28 ab	2.92	6.09 ab	3.65 a
	WS6440	6.85 abcde	53 abc	29 ab	3.60	5.84 ab	3.62 abc
	WS6442	6.46 cde	53 abc	29 ab	3.27	5.91ab	3.61 abc
75×25 cm^2	NS2	6.69 bcde	54 abc	29 ab	3.41	5.71 ab	3.63 abc
	NS3	6.91 abcd	53 abc	29 ab	3.05	5.94 ab	3.61 abc
	NSX982013	6.47 cde	51 bc	27 b	2.51	6.13 ab	3.65 a
	SW5	6.90 abcd	52 abc	28 ab	3.05	6.64 ab	3.60 abc
	TE1719	6.01 e	52 abc	28 ab	3.25	6.54 ab	3.61 abc
	WS6437	7.54 a	50 c	28 ab	3.67	6.01 ab	3.64 ab
	WS6440	6.85 abcde	51 bc	29 ab	3.15	6.26 ab	3.53 c
	WS6442	7.01 abc	54 abc	30 ab	3.15	6.46 ab	3.65 a
Mean	75×20 cm^2	6.64	54	29	3.27	6.10	3.61
	75×25 cm^2	6.80	52	29	3.25	6.21	3.61
Mean	total	6.72	53	29	3.26	6.16	3.61
C.V. (%)	A×B	6.65	6.69	9.49	17.35	10.43	1.58
LSD	A×B	0.85	5.03	3.89	1.26	1.22	0.11
ANOVA							
A		ns	*	ns	ns	ns	ns
B		**	*	ns	ns	**	**
A×B		**	*	*	ns	**	**

Remarks: Mean values in the same column followed by the same lowercase letter are not different at $p < 0.05$. Note *, **: significantly different at the 0.05 and 0.01 probability levels, respectively; ns: non-significant difference.

Conclusions

Using 75×20 cm^2 plant spacing (66,663 plants ha^{-1}) produces the highest fresh leaf content, stalk, and total biomass yields of field corn. Moreover, this plant spacing improves forage yields without negatively affecting the nutritional value and corn silage's pH. The corn varieties had a significant effect on CP, NDF, ash, pH of the silage, and yield and yield components. TE1719 showed high leaf greenness and had more ears per plant than SW5 (check variety), resulting in greater fresh ear yield in both plant spacing. Therefore, the study revealed that cultivating TE1719 variety at 75×20 cm^2 plant spacing, which is more economical for farmers, could increase forage yields without negatively affecting corn silage's nutritional value.

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