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Full Length Research Paper

Effects of row spacing and plant density on silage yield of corn (*Zea mays* L.cv.sc704) in two plant pattern in North of Iran

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In order to investigate the effects of row spacing and plant density on silage yield corn in two plant pattern, an experimental design was a randomized complete block in a factorial, treatments arrangement with three replications in north of Iran in 2009. Row spacing was included 65, 75 and 85 cm that evaluated in plant density 70000 and 80000 plant in ha^{-1} and plant pattern were conventional row (linear) and new two rows (zigzag). The results indicated that row spacing and plant density did not significantly affect in biological yield and silage yield. New two rows had more biological yield (24%) than conventional row. New two rows pattern increased a plant fresh and dry weight, because plant height, stem diameter, ear length and ear diameter were high. There is negative between plant height and stem diameter. New two rows had increased silage yield of 29% related to conventional row. Difference was 3707 kg ha^{-1} between new two rows and conventional rows. High row spacing increased leaf fresh weight (10.4%) and stem fresh weight (4.7%), but decreased ear fresh weight (4.6%) relation to low row spacing. High plant density increased leaf fresh weight (1.3%) and stem fresh weight (7.1%) ear fresh weight (6.7%) relation to low plant density. We conclude that silage corn responds to plant pattern and new two rows is higher for biological yield than conventional rows. Finally, new two rows had greater biological yield (19.1 Mg ha^{-1}) and silage yield (53.3 Mg ha^{-1}) than conventional row, increasing the probability of corn silage harvest before a fall frost.

Key words: Forage, biological yield, conventional row, plant height.

INTRODUCTION

Corn (*Zea mays* L.) silage production is very important in winter in the north of Iran that producer need to forage, but deceasing temperature and solar energy in delay sowing date resulting in low silage yield because farmers used from common plant density, row spacing and plant pattern. So, seed row spacing is an agronomic management strategy used by producers to optimize the husbandry of the soil and plant ecosystem from sowing to harvest with the goal of bolstering the production of crops (Sharratt and McWilliams, 2005). Crop row spacing influences canopy architecture, which is a distinguishing characteristic that affects the utilization of light, water, and nutrients (Sharratt and McWilliams, 2005).

The effect of decreasing corn row spacing from a mean of 1.07 to 0.90 m was estimated to result in an overall mean yield increase of 175 kg ha^{-1} (Cardwell, 1982), while most farmers have reduced corn row spacing to 0.76 m or less. Corn yields may be further increased by reducing row spacing from 0.76 to 0.38 m (Nielsen, 1988; Widdicombe and Thelen, 2002), but there may be little advantage to further reduction (Porter et al., 1997). Porter et al. (1997), for example, reported a 7% increase in grain yield in Minnesota while Nielsen (1988) found about a 3% higher grain yield in Indiana for corn grown in narrow rows (spacing less than 0.76 m) vs. conventional rows (spacing of 0.76 m). Widdicombe and Thelen (2002) found that corn grown in narrow rows

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Table 1. Weather condition in experiment site in corn growth stages.

Variable	May	June	July	August	September	October	November	December
Minimum tem. (℃)	13.6	18.2	22	21.4	19.4	15.7	11.5	4.9
Maximum tem. (℃)	22	26.7	31.4	29.2	28.2	25.3	21.1	14.6
Evaporation (℃)	93.7	166.6	136.3	199.7	187.1	142.6	87.4	81.5
Precipitation (℃)	35.2	29.6	0.1	56.4	171.9	84.4	173.5	81.9

(spacing of 0.38 and 0.56 m) produced as much as 4% more grain compared with corn grown in conventional rows (spacing of 0.76 m) in Michigan. Nielsen (1988) and Widdicombe and Thelen (2002), however, found that higher yields were attained for corn grown in narrow rows vs. wide conventional rows irrespective of hybrids and plant populations tested in Indiana and Michigan.

Corn grain yield typically exhibits a quadratic response to plant density, with a near-linear increase across a range of low densities, a gradually decreasing rate of yield increase relative to density increase, and finally a yield plateau at some relatively high plant density (Duncan, 1984; Ottman and Welch, 1989; Thomison and Jordan, 1995). Higher plant density combined with narrower row spacing results in a more equidistant planting pattern that is expected to delay initiation of intraspecific competition (Duncan, 1984) while early crop growth is increased (Bullock et al., 1988). Although the optimum row spacing varies among plant genus, yields will generally be maximized by sowing in rows that result in an equidistant spacing among plants (Sharratt and McWilliams, 2005). Narrow-row corn has been advocated in recent years as a technique to enhance grain yield (Orchard, 1998). These differences in yield associated with row spacing appear to be accentuated for corn grown at more northerly locations within the U.S. Corn Belt (Sharratt and McWilliams, 2005). Paszkiewicz (1997), for example, found that corn grown in narrow rows to the north of Interstate 90 (44_ N latitude) resulted in an 8% higher grain yield while that grown in narrow rows to the south of Interstate 90 resulted in a 4% higher grain yield compared with corn grown in wide conventional rows.

However, Ottman and Welch, (1989) have reported a positive response in yield to growing corn in narrower rows (Westgate et al., 1997). In fact, Pedersen and Lauer (2003) found an 11% lower yield for corn grown in 0.19-m rows vs. 0.38- and 0.76-m rows in Wisconsin while Farnham (2001) found a 2% lower yield for corn grown in 0.38-m rows vs. 0.76-m rows in Iowa. Farnham (2001) observed significant hybrid row spacing interaction among six hybrids grown in narrow and wide conventional rows in Iowa. Westgate et al. (1997), however, reported that light interception was not affected by corn row spacing; they found no yield advantage to growing corn in narrow (spacing of 0.38 m) rows vs. conventional (spacing of 0.76 m) rows over two growing seasons in Minnesota. Crop row spacing can also influence soil water utilization (Sharratt and McWilliams, 2005). Objectives in this studies was the effects of row spacing and plant density on silage yield corn in two plant pattern in north of Iran.

MATERIALS AND METHODS

The study was conducted at the Research Center of Agricultural and Resource Mazandaran, Gharakhil, Ghemshar, Iran (36°27' N, 52°51' E) in 2009. The weather in this zone has an average annual temperature of 23℃ and receives annual rainfall of 600 to 700 mm from May through December. Weather condition in the experiment site are summarized (Table 1). The soil type was classified as clay loam. Some of its properties are as fallows: 43, 32 and 25 g kg^{-1} clay, silt and sand, respectively; organic matter, 1.18 g kg^{-1}; pH, 7.4; 0.28, 35.8 and 250 available N, P and K, respectively. Before seeding, soil available N, P, and K were determined for depths (0 to 30 cm). The experimental design was a randomized complete block in a factorial, treatments arrangement with three replications. There are three row spacing included 65 (low), 75 (medium) and 85 cm (high) that evaluated in plant density 70000 and 80000 plant in ha^{-1} and plant pattern were conventional row (linear) and new two rows (zigzag). Individual plots were 9 rows (65 cm), 8 rows (75 cm) and 7 rows (85 cm) wide by 7 m long. The plot size (experimental unit) was 6 by 7 m. Cultivar corn was a single cross hybrid (*Z. mays* L. cv. singel cross 704) that was popular among growers in the north Mazandaran during the period of this study. Plots were overplanted and hand-thinned to achieve the desired target plant densities. Plots were seeded 23rd August. In site, and seeding rates were adjusted for based on germination of the cultivar. The land was prepared for planting by disk followed by cultivator tillage. Immediately after tillage, plots were seeded 15 to 20 mm deep using a hand with row spacing. The site was irrigated with 25.4 mm of water using a sprinkler irrigation system when soil water was, 60% of field capacity.

Fertilizer N was applied following recommended practices for placement of fertilizer and seed to minimize seedling damage. N, P, and K fertilizers were applied according to yield potentials and soil test levels (P and K) for site. Fertilizer use as N, P and K (200–100–100, N–P–K) from urea, triple super phosphate and potassium sulfate. N, P and K was incorporated mid-row banded into soil 38 to 40 mm deep using a shallow rotary tillage before seeding. The tillage operation oriented the length of the plots to minimize possible interplot movement of fertilizer. The experimental site received 92 kg N ha^{-1} broadcast after plowing, before planting, and a further 46 kg N ha^{-1} split in half and sidedressed 35 and 40 d after planting (at the fifth leaf stage). Weeds were controlled using preplant herbicides and hand weeding was done where necessary. The previous crop at site was wheat. Plants were cut at the surface from the central of the three middle rows in the plots.

All plots were harvested using hand in growth stage soft dough, on 6th December, 2009. Ears were separated, weighed and the

Table 2. Mean square effects of row space, plant density and planting pattern on plant height, stem diameter, ear length, ear diameter, plant fresh weight and plant dry weight of forage corn

S.O.V.	df	Plant height	Stem diameter	Ear length	Ear diameter	Plant fresh weight	Plant dry weight
Rep.	3	2497.3**	5.1**	14.1**	2.2 ns	21712.0 ns	706.1 ns
Row space (A)	2	724.4**	1.0 ns	4.7 ns	2.9 ns	5560.1 ns	995.6 ns
Plant density (B)	1	5.8 ns	2.9 ns	0.9 ns	11.7 ns	5547.0 ns	3168.8 ns
A×B	2	12.6 ns	2.2 ns	4.3	6.3 ns	7817.3 ns	1154.3 ns
Planting pattern (C)	1	7059.2**	120.0**	367.4**	260.9**	407745.3**	33602.1**
A×C	2	22.9 ns	0.8 ns	1.8 ns	0.6 ns	3488.6 ns	761.6 ns
B×C	1	40.9 ns	0.5 ns	1.1 ns	2.7 ns	690.1 ns	690.1 ns
A×B×C	2	11.8 ns	1.5 ns	0.8 ns	2.5 ns	871.6 ns	871.6 ns
Error	33	67.0 ns	0.9 ns	2.1 ns	3.1 ns	1044.5 ns	1044.5 ns
C.V.%	-	3.77	4.29	7.44	3.46	8.86	14

ns, *, **; non significant, significant at 0.05 and 0.01 level probability, respectively.

Table 3. Mean comparison effects of row space, plant density and planting pattern on plant height, stem diameter, ear length, ear diameter, plant fresh weight and plant dry weight of forage corn.

Treatments Rows space	Plant height (cm)	Stem diameter (mm)	Ear length (cm)	Ear diameter (mm)	Plant fresh weight (g. plant^{-1})	Plant dry weight (g. plant^{-1})
65	209.5[b]	22.12[a]	18.91[b]	51.34[a]	1021[a]	224.1[a]
75	218.1[a]	21.64[a]	19.52[ab]	50.62[a]	1049[a]	239.5[a]
85	222.8[a]	21.77[a]	20.01[a]	51.37[a]	1014[a]	228.8[a]
Plant density						
70000	216.4[a]	22.08[a]	19.62[a]	51.60[a]	1039[a]	238.9[a]
80000	217.1[a]	21.60[a]	19.35[a]	50.62[a]	1017[a]	222.6[a]
Planting pattern						
Conventional	204.7[b]	20.26[b]	16.72[b]	48.78[b]	936[b]	204.3[b]
New two row	228.9[a]	23.42[a]	22.25[a]	53.44[a]	1120[a]	257.3[a]

*; means with similar letters in each column are not significant difference at the 5% level of probability according to DMRT.

moisture content was measured. Aboveground plant biological was determined by harvesting one 4 m^2 area of each plot at harvest. Biological yield was calculated from stover and ear weights, which were adjusted to oven-dry weights after subsamples of ear and stover, were dried at 65 to 70-℃ for 72 h, and weighed. The plant samples were oven dried. Total weight of ears and stover were measured in the field. All ears were then dried in a forced-air oven at 80℃ for 1 week. Moisture content of stover was determined from a three-plant subsample in each plot. Five plants were randomly selected at harvest from each plot to estimate leaf, stem and ear fresh weight. Data were analyzed using the SAS procedure to develop the ANOVA for a factorial design (SAS 2001). The DMRT procedure was used to make tests of simple and interaction effects by MSTAT-C, all differences reported are significant at $P \leq 0.05$ unless otherwise stated.

RESULTS AND DISCUSSION

Plant height and ear length ($P \leq 0.01$) were affected by the row spacing and planting pattern, but stem diameter was not significant (Table 2). Plant height increased with high row spacing and resulting in stem diameter had deceased although stem diameter was not consistent, as stem diameter reached from 22.12 to 21.64 cm at the 75 cm while ear length increased with higher row spacing (Table 3). Between plant height and stem diameter was negative correlation. Narrow-row corn has been advocated for enhancing grain production in corn due to less weed competition and better resource (soil water, solar radiation and nutrients) utilization (Sharratt and McWilliams, 2005). Also, Hybrid and plant population may influence the yield response of corn to row spacing (Tollenaar, 1989).

High plant density had increased plant height, but stem diameter had decreased. Low plant density increased ear length and ear diameter. Plant height, stem diameter, ear length, ear diameter and plant fresh and dry weight were also affected by the planting pattern, but unaffected by plant density (Table 2). Plant height was less with conventional than with new pattern (two rows zigzag). Low plant density was higher fresh weight of one plant than high plant density. Conventional pattern was lower plant height and stem diameter than new pattern. The new

Table 4. Mean square effect of row space, plant density and planting pattern on leaf, stem, ear fresh weight and silage yield of forage corn.

S.O.V.	df	Leaf fresh weight	Stem fresh weight	Ear fresh weight	Silage yield
Rep.	3	968722.2 ^{ns}	49194955.6 ^{ns}	12670008.3 ^{ns}	115847096.7**
Row space (A)	2	4455900.0 ^{ns}	14962033.3 ^{ns}	9822308.3 ^{ns}	64710086.0 ^{ns}
Plant density (B)	1	192533.3 ^{ns}	72619200.0 ^{ns}	49735408.3 ^{ns}	7612150.5 ^{ns}
A×B	2	3626233.3 ^{ns}	33670000.0 ^{ns}	461608.3 ^{ns}	21712049.5 ^{ns}
Planting pattern (C)	1	1196033.3 **	329491200.0**	375312675**	1712614400.5**
A×C	2	5084633.3 ^{ns}	3510700.0 ^{ns}	12577575.0 ^{ns}	52041950.3*
B×C	1	2116800.0 ^{ns}	8806533.3 ^{ns}	8585208.3 ^{ns}	176206856.0**
A×B×C	2	820300.0 ^{ns}	1576033.3 ^{ns}	36772608.3 ^{ns}	8207667.0 ^{ns}
Error	33	36847643646	21509785.9	20414444.7	19533814.0
C.V.%	-	19.46	12.94	14.55	9.35

ns, *, **; non significant, significant at 0.05 and 0.01 level probability, respectively.

Table 5. Mean comparison effect of row space, plant density and planting pattern on leaf, stem, ear fresh weight and silage yield of forage corn.

Treatments Rows space	Leaf fresh weight (kg ha^{-1})	Stem fresh weight (kg ha^{-1})	Ear fresh weight (kg ha^{-1})	Silage yield (kg ha^{-1})
65	9165^{a}	34730^{a}	31540^{a}	49220^{a}
75	10040^{a}	36440^{a}	31480^{a}	47420^{ab}
85	10120^{a}	36370^{a}	30150^{a}	45200^{b}
Plant density				
70000	9709^{a}	34618^{a}	30038^{a}	46883^{a}
80000	9836^{a}	37078^{a}	32037^{a}	47680^{a}
Planting pattern				
Conventional	9273^{b}	33228^{b}	28259^{b}	41308^{b}
New two row	10272^{a}	38468^{a}	33852^{a}	53255^{a}

*;Means with similar letters in each column are not significant difference at the 5% level of probability according to DMRT.

pattern had higher ear length and ear diameter than conventional pattern. Plant fresh and dry weight had increased in new pattern (Table 3). High row spacing increased leaf fresh weight (10.4%) and stem fresh weight (4.7%), but decreased ear fresh weight (4.6%) relation to low row spacing. High plant density increased leaf fresh weight (1.3%) and stem fresh weight (7.1%) ear fresh weight (6.7%) relation to low plant density (Table 3). Demand for N increases with biological yield, which may be enhanced by reduced row spacing and greater plant density (Jordan et al., 1950). Earlier canopy closure of corn grown in narrower rows has been found to enhance light interception (Ottman and Welch, 1989; Andrade et al., 2002) as well as suppress weed growth (Forcella et al., 1992).

Silage yield

Row spacing had no effect on silage yield (Table 4). Corn silage yield decreased with high row spacing, but give me d pampers money the difference was not significant (Table 5). Mean silage yield were 4.92, 4.74, and 4.52 Mg ha^{-1} in 65, 75, and 85 rows spacing, respectively. Paszkiewicz (1997), who found that corn grown in narrower rows resulted in an 8% higher grain yield at locations north of Interstate 90 in the USA. Andrade et al. (2002) found that yield response to decreased row spacing was negatively correlated to radiation interception at pollination time with the wider spacing. Silage yield response to row spacing and plant density might have been different for other hybrids. Porter et al. (1997), however, found in a study with six adapted, high-yielding hybrids, that corn hybrids were similarly affected by plant density and row spacing. Silage yield was lower with conventional row vs. new row spacing. Mean silage yield were 4.13 and 5.33 Mg ha^{-1} in conventional row and new rows, respectively. Silage yield was increased as much as 1.19 Mg ha^{-1}.

The row spacing × plant pattern interaction and plant

Table 6. Mean square effect of row space, plant density and planting pattern on leaf, stem, ear dry weight and biological yield of forage corn

S.O.V.	df	Leaf dry weight	Stem dry weight	Ear dry weight	Biological yield
Rep.	3	285611.1 ns	4308719.4 ns	9813075.0 ns	4291688.9 ns
Row space (A)	2	44233.3 ns	183108.3 ns	1725733.3 ns	4567858.3 ns
Plant density (B)	1	353633.3 ns	1074008.3 ns	639408.3 ns	997633.3 ns
A×B	2	187633.3 ns	3262058.3 ns	69233.3 ns	5315158.3 ns
Planting pattern (C)	1	1104133.3**	25491675.0**	47720408.3**	164872533.3**
A×C	2	47633.3 ns	123025.0 ns	1963233.3 ns	1835508.3 ns
B×C	1	16133.3 ns	122008.3 ns	2058408.3 ns	8830700.0 ns
A×B×C	2	12933.3 ns	1855808.3 ns	5628033.3 ns	5280075.0 ns
Error	33	123168.7	1716313.4	3887196.2	4818010.1
C.V. (%)	-	13.77	17.05	28.57	12.34

ns, *, **; non significant, significant at 0.05 and 0.01 level probability, respectively.

density × plant pattern interaction for silage yield was due to differing responses at 5% and 1% levels were significant, respectively (Table 4). High silage yield can be achieved from ear, stem and leaf fresh weight, however, as was significant in ear, stem and leaf fresh weight, but interaction effects of silage yield was higher than in previous traits and was significant. The effect of plant density was not significant for silage yield (Table 4). The silage yield was highest at the low plant density because it was low at the leaf, stem, and ear fresh weight of corn (Table 5). These results differ with findings in Maryland where grain yield increased as plant density was increased from 56000 to 128000 plants ha^{-1} (Teasdale, 1998), but intra row competition was an important factor in this study, as Karlen and Camp (1985) hypothesized that corn spaced more uniformly would reduce intra row competition for water and thereby bolster yield. Cox and Cherney (2001) reported increased corn silage yield by changing plant density from 80000 to 116000 plants ha^{-1}. There was no plant density × row spacing interaction effect; although theory based on plant crowding alone suggests that such an interaction should occur with a greater advantage with narrower row spacing at high plant density than at lower plant density (Duncan, 1984). The row spacing × plant density interaction did not significantly affect yield (Porter et al. 1997). Silage yield increased less with increased row spacing relative to accumulated ear fresh weight, resulting in decreased silage yield values at higher row. Silage yield in the aboveground crop ranged from 0.91 to 1.01, 3.47 to 3.64, and 3.15 and 3.02 kg ha^{-1} accumulated fresh weight applied row spacing at the leaf, stem, and ear of corn.

Differences in silage yield were related stem and leaf fresh weight response to plant pattern. Ear fresh weight as well as silage yield decrease, was lower in 85 than in the other rows. So, the increased yield with two rows spacing is supported by the findings of others who have reported yield increases of up to 10% with reduced row spacing (Hodges and Evans, 1990; Porter et al., 1997; Widdicombe and Thelen, 2002). The absence of a row spacing effect on yield may be due to the great plant growth, resulting in canopy interception of a very large proportion of the incident incoming photosynthetically active radiation at both row spacings (Ottman and Welch, 1989).

Yao and Shaw (1964), for example, reported corn grown in 0.53-m rows used less water more efficiently than that grown in 0.81 or 1.07 m rows. Finally, the response of silage yield to changed plant pattern was positive, agreeing with the results of others (Cox and Cherney, 2001).

Biological yield

Corn biological yield increased with high row spacing, but the difference was not significant (Table 6). Biological yield was not affected by increasing plant density from 70000 to 80000 plant ha^{-1} did not result in a significant increase in biological yield. Corn biological production was less with the one row linear than the two row spacing (Table 7), but was significant. Biological yield was lower with one row vs. new two rows. Mean biological yield were 1.54 and 1.91 Mg ha^{-1} in one row linear and two rows, respectively. Biological yield was increased as much as 37.07 Mg ha^{-1} with two row spacing changed but did not respond to plant density (Table 7). Biological yield at the low row was 16700 Kg ha^{-1} and increased to 17770 Kg ha^{-1} at the medium and 17200 Kg ha^{-1} at the high row.

Conclusions

Findings from this study suggest that silage production of new row corn may even exceed, that of conventional-row corn. In corn grown, in new row may have higher root densities, occasionally suppressed soil evaporation, and

Table 7. Mean comparison effect of row space, plant density and planting pattern on leaf, stem, ear dry weight and biological yield of forage corn.

Treatments Rows space	**Leaf dry weight (kg ha.$^{-1}$)**	**Stem dry weight (kg ha.$^{-1}$)**	**Ear dry weight (kg ha.$^{-1}$)**	**Biological yield (kg ha.$^{-1}$)**
65	2475[a]	7690[a]	6589[a]	16700[a]
75	2580[a]	7575[a]	7244[a]	17770[a]
85	2533[a]	7789[a]	6874[a]	17200[a]
Plant density				
70000	2443[a]	7535[a]	7018[a]	17079[a]
80000	2615[a]	7834[a]	6787[a]	17367[a]
Planting pattern				
Conventional	2377[b]	6956[b]	5905[b]	15370[b]
New two row	2681[a]	8413[a]	7899[a]	19077[a]

*; Means with similar letters in each column are not significant difference at the 5% level of probability according to DMRT.

abated daytime soil temperatures. The results suggest that corn grown in narrow rows will establish a more uniform root and leaf distribution that may promote more effective utilization of light and water resources. Also, equidistant spacing among plants optimizes the utilization of nutrients, water, and solar radiation (Shubeck and Young, 1970; Bullock et al*.,* 1988). Then differences in soil temperature can affect root and shoot growth as optimum growth is achieved at soil temperatures between 25 and 35°C (Shaw, 1988). So, we conclude that silage corn responds to plant pattern especially new two rows is higher for biological yield than conventional rows. Finally, new two rows had greater biological yield (19.1 Mg ha^{-1}) and silage yield (53.3 Mg ha^{-1}) than conventional row, increasing the probability of corn silage harvest before a fall frost.

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