Effect of Within-Row Spacing on Agronomic and Morphological Characteristics of the Flue-Cured Tobacco Cultivars

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Summary

In flue-cured tobacco (*Nicotiana tabacum* L.) production the aim is improvement of yield and quality (usability) of cured leaf. This has been achieved through development of new cultivars and adjustment of cultural practices. In Croatia, most of the flue-cured tobacco is grown at plant spacing of 45 cm within and 100 cm between rows, i.e. at planting density of about 22,000 plants per ha. In order to evaluate the effect of decreased planting density on agronomic and morphological characteristics of flue-cured tobacco, field experiments with six flue-cured tobacco cultivars and two within row plant spacings (45 and 55 cm) were conducted at two locations in the main Croatian flue-cured tobacco growing regions, over four years (2005 to 2008). Wider spacing within rows resulted in 396.12 kg ha^{-1} higher yield and 861.01 \$ ha^{-1} higher value than the closer spacing. Change in price was not significant. Length, width, and leaf area of the 9th leaf also increased significantly at 55 cm within row spacing, while plant height and leaf number were unchanged. Cultivar x plant spacing and environment x plant spacing interactions were not significant for the studied traits.

Results indicate that higher yield, higher value and good quality of cured tobacco leaf could be produced at 55 cm within row spacing (about 18,000 plants per ha).

Key words

flue-cured tobacco, morphological and agronomic traits, plant spacing

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Introduction

Flue-cured tobacco leaf can be classified according to its physical and chemical characteristics, and smoking quality (aroma and flavour) as filler (thin, lemon colour, less nicotine, neutral smoking quality, good filling capacity), or aromatic tobacco (full body, orange colour, more nicotine, expressed smoking quality). The former is sold on the world market at a lower price than the latter one. Body and smoking quality can be modified by cultivar and growing practices (Akehurst, 1968). Among growing practices, plant spacing can affect agronomic and chemical traits of tobacco (Collins and Hawks, 1993). Plant spacing in tobacco production usually refers to distances between tobacco plants within rows and between rows in the field, but it can also be interpreted as total number of plants and leaves produced within a defined area (Tso, 1990). In Northern Italy, the recommended number of flue-cured tobacco plants per ha is 24,000 (Cristanini, 2006). It is obtained by 115 to 120 cm between rows and approximately 35 cm within row spacing. Such spacing enhances leaf growth towards the row and eases mechanical harvesting. It gives high leaf yield of a quality appreciated by the cigarette manufacturers. In the USA, plant populations in conventional flue-cured tobacco production average 14,700 plants ha^{-1}. Row spacing is 122 cm with approximately 56 cm between plants (Campbell et al., 1980). In Croatia flue-cured tobacco is commonly grown at plant spacing of 100 cm between and 45 cm within rows (planting density of about 22,000 plants per ha). Plants are usually topped at about 20 leaves per plant and, about 400,000 leaves per ha are harvested. This is about 100,000 leaves more than commonly harvested in the USA (Collins and Hawks, 1993). Closer spacing of plants generally results in a reduction of size, body, thickness, and weight per unit area of the leaf (Tso, 1990). At higher planting densities an increase of yield has been reported by several authors (Chaplin et al., 1968; Collins et al., 1969; Campbell et al., 1982; Collins and Hawks, 1993). However, quality of such leaves was usually lower due to decreased nicotine content (Chaplin et al., 1968; Campbell et al., 1982; Collins and Hawks, 1993). Price of tobacco grown at higher plant densities was also lower, resulting in lower income from such production (Chaplin et al., 1968; Collins et al., 1969; Collins and Hawks, 1993). Collins et al. (1969) and Wu et al. (1971) observed a decrease in total leaf area per plant with increased plant population. The objective of this study was to compare the agronomic and morphological traits of Croatian flue-cured tobacco cultivars grown at two within-row spacings.

Materials and methods

A field experiment including six flue-cured tobacco cultivars and two within row plant spacings was conducted at two locations in Croatia: at Kutjevo (silt loam soil), and at Virovitica (sand loam soil), for four years, 2005 to 2008. At Virovitica in 2005 and 2008, the experiment was heavily damaged by hail, and was not analysed. Plant spacings were 100 cm between rows, and 45 cm and 55 cm within rows, i.e. plant densities of about 22,000 and 18,000 plants per ha, respectively. Five of the cultivars were Croatian F_1 hybrids (DH12, DH17, DH33, DH27, and DH36), and one was the USA flue-cured tobacco cultivar (NC55). Fertilization at the rate of 40 kg N, 25 kg P_2O_5 and 180 kg K_2O per ha was applied, as recommended for flue-cured tobacco production in Croatia (Budimir et al., 2008). All other cultivation practices were performed as usual in flue-cured tobacco production. Each year the experimental design was a randomized complete block design (RCBD), with four replications and three 22 plant rows per experimental plot. Twenty plants of the middle plot row were analyzed for morphological traits (plant height, leaf number per plant, and 9th leaf length, width, and area) and harvested. Harvesting was done manually. Curing was in bulk curing barns with heated air. After curing, yield (kg ha^{-1}) of each experimental plot was determined. Average price (\$ kg^{-1}) was ascribed by a tobacco cooperative agronomist to the cured tobacco of each plot. Total value (\$ ha^{-1}) for each experimental plot was calculated by multiplying its yield and respective average price. Chemical analyses on the 9th leaf samples were done in 2006 only. Agronomic and morphological traits of two experimental years from Virovitica and four from Kutjevo (i.e. six environments) were modelled as General Linear Model (GLM) with cultivars, spacings, and environments as fixed explanatory variables. Pearson's correlation coefficients were calculated among all the traits for each plant spacing separately. All statistical analyses were performed using SAS Release 8.2 (SAS Institute 1999 – 2001) computer program.

Results and discussion

Within row spacing had a significant effect on yield, value, and length, width, and area of the 9th leaf (Table 1). Differences between the two spacings in price, plant height and number of leaves were not significant. Environments differed significantly in all the studied traits.

Variation in temperature and precipitation (Table 2), as well as in the soil type within environments might have influenced the obtained trait values.

Kutjevo 2005, environment with the highest amount of precipitation, gave the lowest yield, price and value of cured leaf, while plant height, 9th leaf length, width and area were the highest (data not shown).

Cultivars differed significantly in all the studied traits except yield (Table 1). Cultivar x environment interactions were highly significant for yield, price, value, 9th leaf length, and area. Cultivar x spacing, environment x spacing and cultivar x spacing x environment interactions were not significant for any of the studied traits.

In our study, properties of the 9th leaf significantly increased at 100 x 55 cm compared to 100 x 45 cm spacing (Table 3). At the wider spacing, the 9th leaf was 1.29 cm longer, 1.41 cm wider and 67.11 cm^2 larger than at the closer spacing. Similarly, Collins et al. (1969) and Wu et al. (1971) reported increased tobacco leaf area at wider plant spacings. In cigar tobacco Kozumplik and Lamarre (1979) obtained a significant increase in leaf length and width at 117 x 41 cm plant spacing compared to 117 x 31 cm spacing in one of the three experimental years. Farah (1975) studied the effect of six plant spacings (60 x 60 cm, 80 x 60 cm, 100 x 60 cm, 80 x 80 cm, 100 x 80 cm and 100 x 100 cm) and fertilization on yield and quality of flue-cured tobacco in Sudan. At the plant spacings 60 x 60 cm and 80 x 60 cm leaf area index and number of leaves increased significantly compared to other studied spacings.

Table 1. GLM results for yield (kg ha^{-1}), price (\$ kg^{-1}), value (\$ ha^{-1}), plant height (cm), number of leaves, 9th leaf length (cm), 9th leaf width (cm), and 9th leaf area (cm^2)

Source of Variation	n–1	Pr > F							
		Yield	Price	Value	Plant height	No of leaves	9th leaf length	9th leaf width	9th leaf area
Environment, (E)	5	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Spacing, (S)	1	<0.0001	0.7718	<0.0001	0.0985	0.1418	<0.0001	<0.0001	<0.0001
Cultivar, (C)	5	0.1922	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
CxE	25	0.0013	0.0003	<0.0001	0.1449	0.1760	0.0008	0.0103	0.0001
CxS	5	0.8011	0.7154	0.8324	0.9489	0.9768	0.7378	0.2652	0.4524
SxE	5	0.9601	0.6155	0.4686	0.1585	0.2158	0.5353	0.7688	0.4484
CxSxE	25	0.9950	0.9885	0.9993	0.9316	0.7157	0.0686	0.4470	0.1631

Table 2. Average air temperature (°C), and precipitation (mm) at Kutjevo and Virovitica from 2005 till 2008 during the tobacco vegetation period

Location	Year	Month					Average
		May	June	July	August	September	
				Temperature, °C			
Kutjevo	2005	18.7	20.2	22.2	19.5	17.3	19.6
	2006	15.2	19.5	23.6	20.0	17.6	19.2
	2007	18.6	19.7	23.3	21.7	14.7	19.6
	2008	17.6	21.8	22.2	19.4	15.1	19.2
Virovitica	2006	15.8	18.6	22.6	18.9	16.8	18.5
	2007	17.7	21.0	23.4	22.0	14.5	19.7
				Precipitation, mm			Total
Kutjevo	2005	61.5	143.5	173.0	232.5	61.0	671.5
	2006	58.5	96.0	26.0	173.0	23.0	376.5
	2007	101.8	42.6	27.4	99.9	83.2	354.9
	2008	44.4	91.3	126.2	42.2	77.5	381.6
Virovitica	2006	75.7	65.8	18.1	150.4	12.0	322.0
	2007	87.5	60.1	19.8	82.3	80.4	330.1

Table 3. Average values of the studied agronomic and morphological traits; Virovitica, 2006-2007; Kutjevo, 2005-2008

Trait	Spacing, cm	
	100 x 45	100 x 55
Yield, (kg ha^{-1})	2824.81	3220.93
Price, (\$ kg^{-1})	2.21	2.20
Value, (\$ ha^{-1})	6215.50	7076.47
Plant height, (cm)	100.91	102.37
Number of leaves	20.40	20.66
9th leaf length, (cm)	50.41	51.70
9th leaf width, (cm)	25.69	27.10
9th leaf area, (cm^2)	836.69	903.86

The plant spacing 100 x 55 cm in our study resulted in an average increase of 396.12 kg ha^{-1} in yield and 860.97 \$ ha^{-1} in value, compared to the 100 x 45 cm spacing. Average price decreased slightly. Chaplin et al. (1968) reported higher yield and lower price of tobacco planted at closer plant spacing. Farah (1975) obtained a significant increase of yield at 60 x 60 cm and 80 x 60 cm plant spacings compared to 100 x 60 cm, 80 x 80 cm, 100 x 80 cm and 100 x 100 cm spacings. The highest planting density resulted also in the highest leaf quality due to significantly increased number of upper grade leaves per unit area. Farah (1980) obtained a higher yield as well as better quality of flue-cured tobacco at a plant density higher than 33,332 plants ha^{-1} compared to a density of 27,778 plants ha^{-1}. The same author associated the high yields with the number of leaves per unit area, and quality with the quantity of fertilizer, particularly nitrogen, applied to each plant.

Campbell et al. (1982) studied the response of tobacco to three planting spacings: 120 x 30.5 cm, 120 x 45 cm, and 120 x 60.1 cm. The spacing 120 x 30.5 cm resulted in significantly highest yield. The difference between the two larger spacings was not significant. Kozumplik et al. (1983) found no significant differences in yield and price between the spacing 120 x 35 cm and 120 x 45 cm when flue-cured tobacco was planted without ridges. When planting was on ridges, closer planting gave significantly higher yield and there was a significant difference in average price. The authors explained that the difference was due to drought at the time of the experiment. In the present study different cultivars and cultural practices were used than in the earlier studies. Also, all the tobacco was cured under the regime adjusted for tobacco from the 100 x 45 cm spacing, which might have affected the cured leaf quality expressed as price.

Chemical analysis in our study revealed slightly increased nicotine and reducing sugar content of cured leaf from the wider plant spacing (data not shown). Chaplin et al. (1968) also reported higher nicotine content of tobacco grown at wider within row plant spacing. Campbell et al. (1982) similarly reported that increased plant spacing from 120 x 45.7 to 120 x 61.0 cm resulted in higher nicotine percentage. Collins and Hawks (1993) also reported a reduction of alkaloid content as plant population increased. These authors explained that the reduction of alkaloids

Table 4. Pearson's correlation coefficients among agronomical and morphological traits at 100 x 45 plant spacing

	Price ($ kg^{-1})		Value ($ ha^{-1})		Plant height, (cm)		Number of leaves		9th leaf length, (cm)		9th leaf width, (cm)		9th leaf area, (cm^2)	
Yield, (kg ha^{-1})	−0.093	n.s.	0.613	**	0.040	n.s.	0.194	*	−0.149	n.s.	−0.241	**	−0.214	*
Price, ($ kg^{-1})			0.711	**	−0.416	**	−0.106	n.s.	−0.645	**	−0.508	**	−0.599	**
Value, ($ ha^{-1})					−0.271	**	0.043	n.s.	−0.615	**	−0.583	**	−0.628	**
Plant height, (cm)							0.247	**	0.516	**	0.487	**	0.516	**
Number of leaves									0.311	**	0.148	n.s.	0.211	*
9th leaf length, (cm)											0.819	**	0.933	**
9th leaf width, (cm)													0.965	**

* – significant at p<0.05; ** – significant at p<0.01; n.s. – not significant

Table 5. Pearson's correlation coefficients among agronomical and morphological traits at 100 x 55 plant spacing

	Price ($ kg^{-1})		Value ($ ha^{-1})		Plant height, (cm)		Number of leaves		9th leaf length, (cm)		9th leaf width, (cm)		9th leaf area, (cm^2)	
Yield, (kg ha^{-1})	−0.081	n.s.	0.560	**	0.103	n.s.	0.257	**	−0.139	n.s.	−0.274	**	−0.241	**
Price, ($ kg^{-1})			0.762	**	−0.308	**	−0.061	n.s.	−0.721	**	−0.523	**	−0.659	**
Value, ($ ha^{-1})					−0.141	n.s.	0.117	n.s.	−0.682	**	−0.628	**	−0.706	**
Plant height, (cm)							0.148	n.s.	0.283	**	0.283	**	0.321	**
Number of leaves									0.174	*	−0.054	n.s.	0.032	n.s.
9th leaf length, (cm)											0.740	**	0.909	**
9th leaf width, (cm)													0.947	**

* – significant at p<0.05; ** – significant at p<0.01; n.s. – not significant

was related to greater degree of root competition where alkaloids are synthesized.

Correlations among the analyzed traits of the two spacings followed the same pattern (Table 4 and 5), except for number of leaves and leaf width, which at both spacings was not significant. At both spacings significant positive correlations were found between yield and value, yield and number of leaves, price and value, plant height and 9th leaf length, plant height and 9th leaf width, plant height and 9th leaf area, number of leaves and 9th leaf length, 9th leaf length and 9th leaf width, 9th leaf length and 9th leaf area, and 9th leaf width and 9th leaf area. Significant negative correlations were found between yield and 9th leaf width, yield and 9th leaf area, price and plant height, price and 9th leaf length, price and 9th leaf width, price and 9th leaf area, value and 9th leaf length, value and 9th leaf width and value and 9th leaf area. Significant positive correlation between plant height and number of leaves, and between number of leaves and 9th leaf area, as well as significant negative correlation between value and plant height were found at the 100 x 45 cm spacing only. All other correlations were not significant. Positive correlations between yield and value and between price and value of the flue-cured tobacco were found earlier by Bukan et al. (2006). Šmalcelj and Kozumplik (1980) found negative correlation between yield and value, but for different flue-cured tobacco cultivars and cultural practices than used in the present study.

Collins et al. (1969) and Collins and Hawks (1993) reported that within reasonable limits, the row spacing, plant spacing within the row or height of topping is not as important as the combination of all three, or the leaf number per acre. According to these authors, about 300,000 leaves per ha is the most practical leaf number, especially when leaf quality and cost of production are considered. According to Tso (1990) that number can vary from about 300,000 to 370,000. With plant spacing of 100 cm between and 55 cm within rows instead of 100 x 45 cm, plant population decreases from about 22,000 to about 18,000 plants per ha. In leaf number this means 80,000 leaves less for harvesting and curing. Such reduction could improve farmer's income especially because labor is getting scarce and more expensive. Harvesting and curing operations require more labor than any other part of tobacco production (Collins and Hawks 1993), and are major costs in tobacco production (Kozumplik and Lamarre 1979).

Conclusions

Wider plant spacing, 100 x 55 cm, resulted in 396.12 kg ha^{-1} higher yield, 860.97 $ ha^{-1} higher value, and increase of the 9th leaf length, width and area, than the closer spacing 100 x 45 cm. Chemical analysis of the cured leaf from the two spacings revealed similar nicotine and reducing sugar content. Correlations among the analyzed traits of the two spacings generally followed the same pattern.

Results of this study indicate that under Croatian pedo-climatic conditions with presently grown flue-cured tobacco cultivars, reduction of planting density from about 22,000 to about 18,000 plants ha^{-1} could give a significantly higher yield and total income without affecting cured leaf quality.

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