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Research Article

The impact of seeding rate and inter-row spacing on Italian ryegrass for seed in the first harvest year

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Abstract: Italian ryegrass (*Lolium multiflorum* Lam.) cv. Tetraflorum sown with different inter-row spacings and seeding rates was grown under the agroecological conditions of Western Serbia. Field experiments were carried out between 2002 and 2006, and biometric characteristics—generative tillers, seed yield, and shoot dry mass—were measured during the first production year. Italian ryegrass was grown with 3 row spacings (20, 40, and 60 cm), using 4 seeding rates (5, 10, 15, and 20 kg ha^{-1}). Tiller length was affected by stand density, while 2 other tiller parameters were affected considerably less by the treatments applied. The influence of tiller characteristics on yield components was insignificant. The highest seed yield in the first production year varied with treatment, depending on seasonal conditions. Plant parameters and seed yield were impacted by inter-row spacing, marked, however, by an opposite impact in arid and humid weather conditions. Inter-row spacing of 40 cm was the least risky for seed production. While the increase in seed rates (15-20 kg ha^{-1}) in stand establishment provided higher seed yields in years with unfavorable weather conditions, the seed rate had either no impact on seed yield, or decreased the seed yield as a result of ryegrass lodging, following seed shedding in the years with favorable weather conditions. Abundant shoot dry mass was obtained with some treatment variants, but there was no linear correlation between seed yield and yield components.

Key words: Harvest index, Italian ryegrass, inter-row spacing, seeding rate, seed yield

Introduction

Italian ryegrass is one of the best forage grasses in Serbia, producing high-quality forage from early spring to late summer. Italian ryegrass is valuable in row crop rotations for maintaining soil structure and health (Kunelius et al., 2004). Ryegrasses are defined as cool season grasses because of their preferential adaptation to cool and moist environments (Romani et al., 2002). Italian ryegrass is well adapted to high rainfall, but can be grown where a minimum of about 500 mm of rainfall occurs during the growing season (Evers et al., 1997). Chastain (2000) suggested that rainfall events and short-term rainfall patterns have much greater influence on seed yield than do temperature events or patterns. According to Vučković et al. (2003), excellent ryegrass seed yield achieved in Serbia in the first year is partially the result of a high rate of seedling growth—the highest among cultivated cool season grasses—the feature that produces an effective competitive edge in crop

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establishment (Griffith and Chastain, 1997). Local production covers only 50% (Simić, 2008) of forage production needs in Serbia for this seed, partially due to low seed yield. The optimum stand density for maximum seed yield in annual ryegrass has not been determined (Young et al., 1996). A very dense crop stand and/or inadequate environmental conditions can play an important role in maximizing seed productivity. The spatial arrangement of plants at seeding was reported to have a strong influence on the yield and longevity of seed stands of Italian ryegrass (Young et al., 1996; Choi et al., 2002; Vučković et al., 2003, Kunelius et al., 2004; Venuto et al., 2004), but such differences tend to disappear during the later stages of development. The fate of tillers is the major determinant of productivity in ryegrass crops. Tillering in Italian ryegrass is under significant influence of the quality of light (Deregibus et al., 1983), i.e. plants develop more tillers when illuminated with higher red/far-red ratios. As canopy density increases over time, the red/far-red ratio at plant bases decreases, enhancing tiller extension growth. There is a reduction in the investment of resources in new tillers, but a larger investment in elongation of the tillers already formed (Casal et al., 1987). Shoot angle responses to ryegrass plant density place leaf laminae at different heights within the canopy, affecting their ability to compete for light and, consequently, the effectiveness of photosynthesis, and affecting their susceptibility to wind impact and possibly lodging (Gibson et al., 1992).

Initial establishment conditions have more of a direct impact on crop management in the first production year than in subsequent years due to changes in plant morphology and undersowing (Young et al., 1996; Fairey and Lefkovitch, 1999). High seed shattering in the first year results in a very dense stand and low seed yields in subsequent years. The present field study was conducted to determine the methods for managing the seed crop of Italian ryegrass during the first production year. The following working hypothesis was made: the application of different sowing rates and row spacing will affect the development of morphological and biological characteristics of the plants that define the level of productivity when used for seed.

Materials and methods

The study was conducted for 4 consecutive years, between 2002 and 2006, near Šabac, Serbia (44°47′N, 19°35′E, 80 m a.s.l.), which is located in a semi-humid region (with very variable years). Seeds from the primary growth of tetraploid Italian ryegrass cv. Tetraflorum were harvested in the first production year after establishment. Italian ryegrass was planted (20, 40, and 60 cm row spacing) each autumn (first to third decade of October) prior to the preceding summer seed harvest. The seeding rate was equivalent to 5, 10, 15, and 20 kg ha^{-1}, providing 12 plant spatial treatments in combination with inter-row spacing. The plot for harvest was 10 m^2 (2.5 × 4 m) and was replicated 4 times in a randomized complete block design. Phosphorus, potassium, and a portion of nitrogen were applied in the autumn before each seed production year (250 kg ha^{-1} of 8-16-24 fertilizer NPK), with an additional application of 100 kg of N ha^{-1} in the spring.

Prior to the seed harvest, biometric measurements were made: generative tiller length, spike length, and the number of spikelets per spike, based on 10 randomly sampled tillers from each plot. Italian ryegrass was harvested by sickle in the third decade of June or in the first decade of July. The harvest always began when gentle hand rubbing of spikes resulted in evident seed shattering. Tillers were placed in wisps and dried outdoors on a well-ventilated rack. After air-drying, the seeds were threshed, cleaned, and weighed with seed moisture of 140-150 g kg^{-1}. After seed threshing, the straw was collected and weighed as dry shoot mass. This measurement was needed for calculating the harvest index, using the formula HI = [SY/(SY + SDM)] × 100, where HI is the harvest index (%), SY is seed yield (kg ha^{-1}), and SDM is shoot dry mass (straw yield) (kg ha^{-1}).

Data were analyzed using appropriate statistical analyses (e.g. ANOVA and regression) and Statistica v.8.0 software. The level of significance ($P \geq 0.05$) was determined by LSD testing.

Soil in the experimental area was humofluvisol (2.54% humus), with rinsed limestone. The main characteristics of the soil (depth: 0-30 cm) were as follows: soil texture: clay; $CaCO_3$: 0.36%; pH in KCl: 5.25; K_2O: 15 mg kg^{-1}; P_2O_5: 3 mg kg^{-1}. Meteorological data were collected from the Mitrovica Weather Station located near the experimental site. Monthly precipitation and temperature during the 4 years of the study varied widely; thus, the use of growing degree days (GDDs) was considered more acceptable for comparing the rate of plant development between years instead of single or average monthly temperatures. Accumulated GDDs were calculated with the formula $\{[(T_{max} - T_{min})/2] - T_{base}\}$, where T represents daily maximum and minimum temperatures. The T_{base} for Italian ryegrass was 0 °C, and values were summarized from the first of January (Griffith et al., 1997). Accumulated precipitation during the period implied by GDDs is compared and presented in Figures 1 and 2.

Results

Environmental conditions and lodging

GDD curves during the 4 years of the experiment were similar (Figure 1), but the 2003 crop year was warmer and drier than the others. Accumulated precipitation during the spring of 2003 was deficient (Figure 2). Total precipitation between the first of January and the date of seed harvest was only 147 mm in 2003, versus 373, 365, and 332 mm in the subsequent years 2004-06, respectively. The critical period for Italian ryegrass growth was April-June. During the spring of 2004 and 2005, precipitation was abundant, while the spring of 2006 had moderate to normal precipitation. The winter of 2006 was characterized by high precipitation and longevity of snow cover, resulting in some plant injury and loss, especially in 40 cm row spacing plots.

Lodging is ubiquitous in Italian ryegrass grown for seed. It occurred at different rates during the period of 2004-2006, with the exception of 2003, which was an arid year. In the spring of 2004 and 2005, during the high precipitation period, lodging was extremely high and the percentage of crop lodging increased as crop density increased. There was also some crop lodging in 2006, but it occurred late and in the seed-filling period.

Generative tiller characteristics

Until recently, research on grassland populations has focused on grass production per unit area, in which an individual plant was generally regarded as the minimum unit of a physiological individual in grassland components. For the characteristic of grass tillering, a tiller is taken as the basis for a new study—a sub-unit of an individual plant—according to Emoto and Ikeda (1999).

The highest and lowest tiller lengths were observed in 2005 and 2003, respectively. The maximum difference between treatments was observed in 2003 (dry) (Table 1). The seeding rate had less of an impact on seed yield than row spacing (Tables 2 and 3). The greatest tiller length was achieved in crops with narrow spacing in all years, with the exception of 2006, which was without clear regularity as a result of a high level of seedling mortality during the spring. As expected, as seeding rates increased tiller length increased. Increased stand density had the greatest

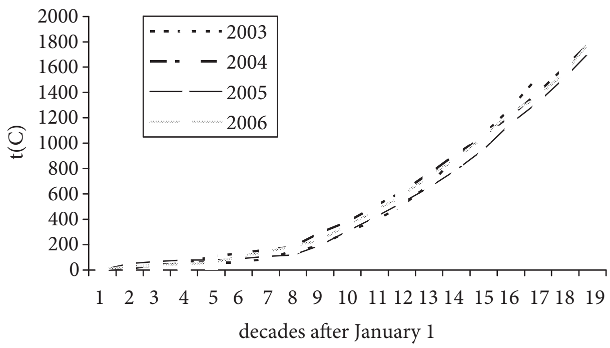

Figure 1. Growing degree days during 4 consecutive years in Italian ryegrass grown for seed.

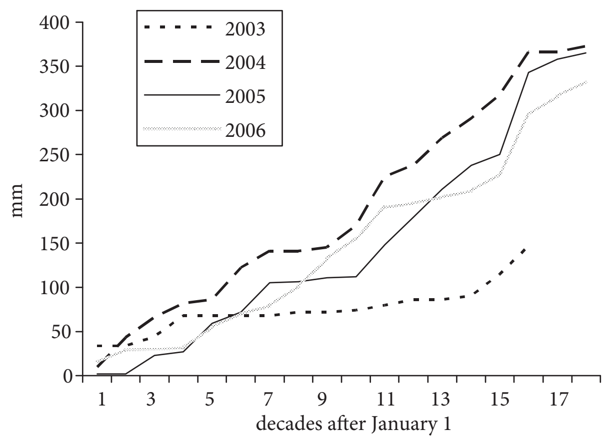

Figure 2. Accumulated precipitation during 4 consecutive years in Italian ryegrass grown for seed.

Table 1. The effect of inter-row spacing and seeding rate on tiller characteristics during the 2003-2006 period.

	Tiller length (cm)	Spike length (cm)	Spikelets per spike (no. tiller^{-1})
Inter-row spacing A		**2003**	
20 cm	79^{a*}	25.3^{a}	25.7^{a}
40 cm	70^{b}	23.7^{b}	24.5^{b}
60 cm	68^{b}	23.4^{b}	24.0^{b}
Seeding rate B			
5 kg ha^{-1}	61^{c*}	22.4^{c}	23.2^{b}
10 kg ha^{-1}	69^{b}	23.9^{b}	24.8^{a}
15 kg ha^{-1}	78^{a}	25.2^{a}	25.2^{a}
20 kg ha^{-1}	80^{a}	25.0^{a}	25.7^{a}
Average	**72**	**24.1**	**24.7**
Inter-row spacing A		**2004**	
20 cm	136^{a}	35.2^{a}	27.5^{a}
40 cm	133^{a}	35.2^{a}	27.2^{a}
60 cm	123^{b}	34.8^{a}	26.8^{a}
Seeding rate B			
5 kg ha^{-1}	130^{a}	35.1^{a}	27.0^{a}
10 kg ha^{-1}	133^{a}	35.1^{a}	27.5^{a}
15 kg ha^{-1}	130^{a}	34.8^{a}	27.2^{a}
20 kg ha^{-1}	130^{a}	35.1^{a}	27.0^{a}
Average	**131**	**35.0**	**27.2**
Inter-row spacing A		**2005**	
20 cm	118^{a}	31.9^{a}	21.6^{a}
40 cm	115^{b}	32.6^{a}	21.7^{a}
60 cm	112^{c}	32.1^{a}	21.4^{a}
Seeding rate B			
5 kg ha^{-1}	112^{b}	32.5^{a}	21.0^{b}
10 kg ha^{-1}	116^{a}	32.3^{a}	22.1^{a}
15 kg ha^{-1}	117^{a}	32.4^{a}	21.6^{ab}
20 kg ha^{-1}	116^{a}	31.6^{a}	21.5^{ab}
Average	**115**	**32.2**	**21.6**
Inter-row spacing A		**2006**	
20 cm	97^{c}	28.1^{b}	25.8^{a}
40 cm	87^{b}	29.0^{b}	24.7^{b}
60 cm	111^{a}	31.4^{a}	26.3^{a}
Seeding rate B			
5 kg ha^{-1}	93^{b}	28.9^{a}	25.1^{b}
10 kg ha^{-1}	97^{a}	29.5^{a}	25.7^{ab}
15 kg ha^{-1}	101^{a}	29.3^{a}	25.5^{ab}
20 kg ha^{-1}	101^{a}	30.2^{a}	26.2^{a}
Average	**98**	**29.5**	**25.6**

* Means in columns followed by the same letter are not significantly different according to Fisher's protected LSD values (P = 0.05)

Table 2. The effect of inter-row spacing and seeding rate on harvest characteristics during the 2003-2006 period.

	Seed yield (kg ha^{-1})	Shoot DM (kg ha^{-1})	Harvest index (%)
Inter-row spacing A		**2003**	
20 cm	961^{a*}	2102^{a}	30.72^{a}
40 cm	808^{b}	1818^{b}	30.17^{a}
60 cm	587^{c}	1497^{c}	27.79^{b}
Seeding rate B			
5 kg ha^{-1}	327^{d*}	851^{d}	27.27^{c}
10 kg ha^{-1}	640^{c}	1478^{c}	29.65^{b}
15 kg ha^{-1}	1005^{b}	2313^{b}	30.24^{ab}
20 kg ha^{-1}	1168^{a}	2581^{a}	31.08^{a}
Average	**785**	**1806**	**29.56**
Inter-row spacing A		**2004**	
20 cm	852^{b}	6427^{b}	12.03^{b}
40 cm	866^{b}	6974^{a}	11.20^{b}
60 cm	1146^{a}	6836^{a}	14.64^{a}
Seeding rate B			
5 kg ha^{-1}	972^{a}	6068^{c}	14.01^{a}
10 kg ha^{-1}	969^{a}	6624^{b}	12.92^{b}
15 kg ha^{-1}	937^{a}	7118^{a}	11.85^{b}
20 kg ha^{-1}	941^{a}	7174^{a}	11.72^{b}
Average	**955**	**6746**	**12.62**
Inter-row spacing A		**2005**	
20 cm	1364^{b}	6414^{c}	17.95^{c}
40 cm	1616^{a}	5944^{b}	21.49^{b}
60 cm	1698^{a}	5466^{a}	23.96^{a}
Seeding rate B			
5 kg ha^{-1}	1492^{a}	4967^{c}	23.46^{a}
10 kg ha^{-1}	1607^{a}	5804^{b}	21.79^{b}
15 kg ha^{-1}	1586^{a}	6520^{a}	19.72^{c}
20 kg ha^{-1}	1552^{a}	6474^{a}	19.57^{c}
Average	**1559**	**5941**	**21.13**
Inter-row spacing A		**2006**	
20 cm	881^{a}	3963^{b}	18.93^{b}
40 cm	737^{b}	2212^{c}	25.52^{a}
60 cm	899^{a}	4344^{a}	18.01^{b}
Seeding rate B			
5 kg ha^{-1}	681^{b}	2400^{c}	23.01^{c}
10 kg ha^{-1}	873^{a}	3475^{c}	21.26^{b}
15 kg ha^{-1}	911^{a}	4021^{a}	19.69^{a}
20 kg ha^{-1}	890^{a}	4128^{a}	19.31^{a}
Average	**839**	**3506**	**20.82**

* Means in columns followed by the same letter are not significantly different according to Fisher's protected LSD values (P = 0.05)

Table 3. Statistical summary of changes in tiller and harvest characteristics according to stand density (LSD test).

Main factors	2003	2004	2005	2006
		Tiller length		
Inter-row spacing A	**	**	**	**
Seeding rate B	**	NS	NS	**
A × B	NS	NS	NS	NS
		Spike length		
Inter-row spacing A	**	NS	NS	*
Seeding rate B	**	NS	NS	NS
A × B	*	NS	NS	NS
		Spikelets per spike		
Inter-row spacing A	**	NS	NS	**
Seeding rate B	**	NS	*	**
A × B	NS	NS	NS	NS
		Seed yield		
Inter-row spacing A	**	**	**	**
Seeding rate B	**	NS	NS	**
A × B	*	NS	**	NS
		Shoot dry mass		
Inter-row spacing A	**	*	**	**
Seeding rate B	**	**	**	**
A × B	NS	NS	NS	NS
		Harvest index		
Inter-row spacing A	**	**	**	**
Seeding rate B	**	**	**	**
A × B	NS	NS	NS	NS

effect on spike length and spikelets per spike in dry conditions during the first experimental year, while tiller characteristics were relatively independent of plant density in humid years (2004 and 2005).

Harvest characteristics

The lowest average seed yield was observed in 2003, while the highest was in 2005, with a difference of almost 100% (785 and 1559 kg ha^{-1} in 2003 and 2005, respectively, Table 2). Seed yields were impacted by inter-row spacing all 4 years, marked, however, by an opposite impact in arid and humid weather conditions. A favorable effect of increased seeding rates and narrow row spacing on seed yield was observed in 2003. Furthermore, a remarkably positive effect of increased row spacing was observed on seed yield in 2004 and 2005. Shoot dry mass accumulation was strongly influenced by stand establishment throughout the experiment, and the biomass yield response to density was more consistent than that of seed yield. The harvest index, as an indicator of seed production efficiency, was impacted significantly by the applied treatments. The highest harvest index was achieved in 2003, which was unexpected. Regarding low seed yield and reduced dry mass production, the harvest index could not be considered an objective indicator in this production year. Harvest components compared with tiller parameters allowed comparison through regression equations (Figures 3-5), showing the highest correlation between seed yield and tiller length, as well as shoot dry mass and tiller length. There was much less influence of spike length and spikelets per spike on harvest components. The harvest index was affected less by the tiller parameters and decreased under humid conditions, while tiller length increased (Figure 5).

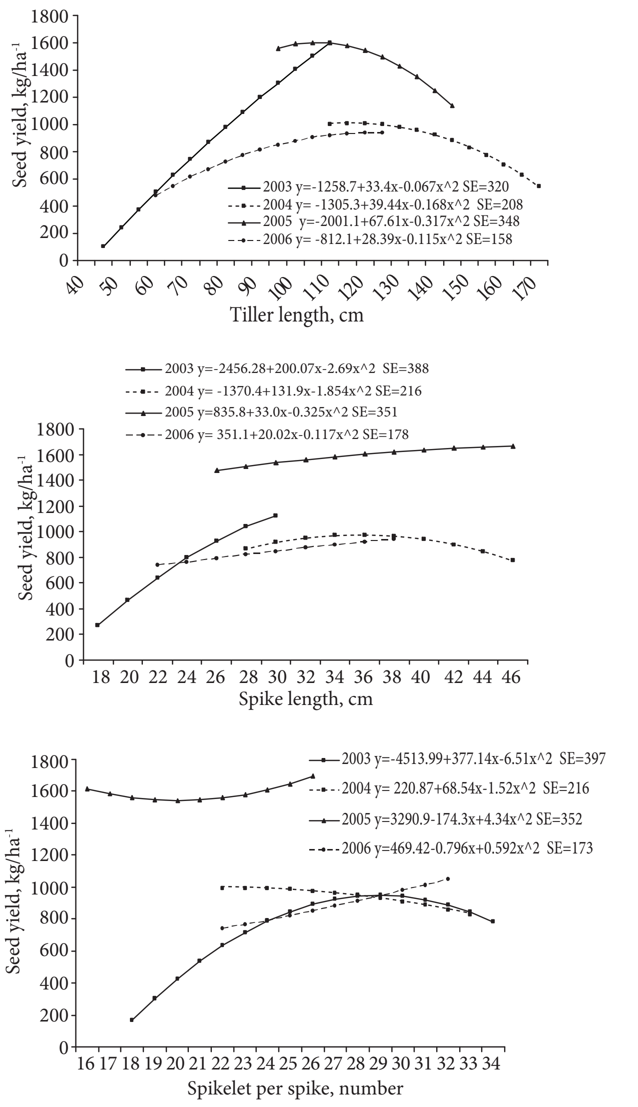

Figure 3. Impact of tiller characteristics on seed yield.

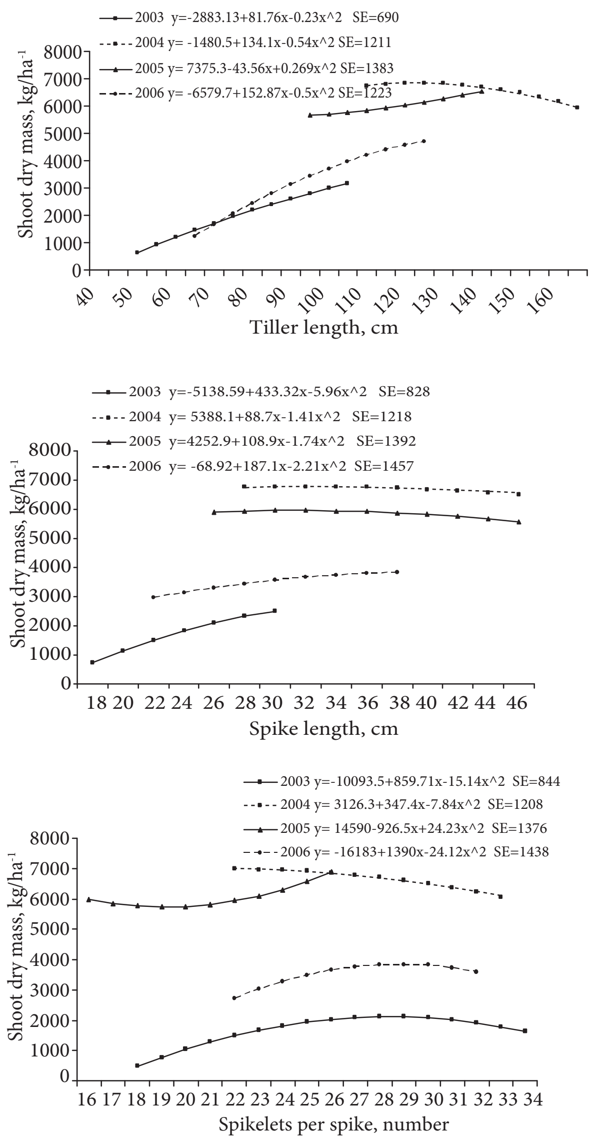

Figure 4. Impact of tiller characteristics on shoot dry matter.

Discussion

Recommended seeding rates and row spacing for Italian ryegrass vary considerably (Young et al., 1996; Vučković et al., 2003), indicating that at very low seeding rates differences could affect early season yields, while at high rates seedling competition for resources may actually reduce yields. In freely tillering grasses the main advantage of dense sowing is weed control, as the effect of tillering on sward development will increase competition, leading to plant death and, consequently, to the maintenance of a smaller population of plants (Jewiss, 1972). Maximization of the first-year seed yield is more of a priority than the cumulative productivity over several consecutive crops due to disorganization of established spatial conditions and an inability to predict the next stand density. As the amount of seed shattered can easily be 10% of the harvested crop (Young et al., 1996), it can develop into a very dense stand in the next season, thus increasing the optimal rate more than 10-fold.

Climatic conditions, temperature, and precipitation played a major role in determining the level of influence of seeding rate and inter-row spacing on Italian ryegrass seed yield during the 4

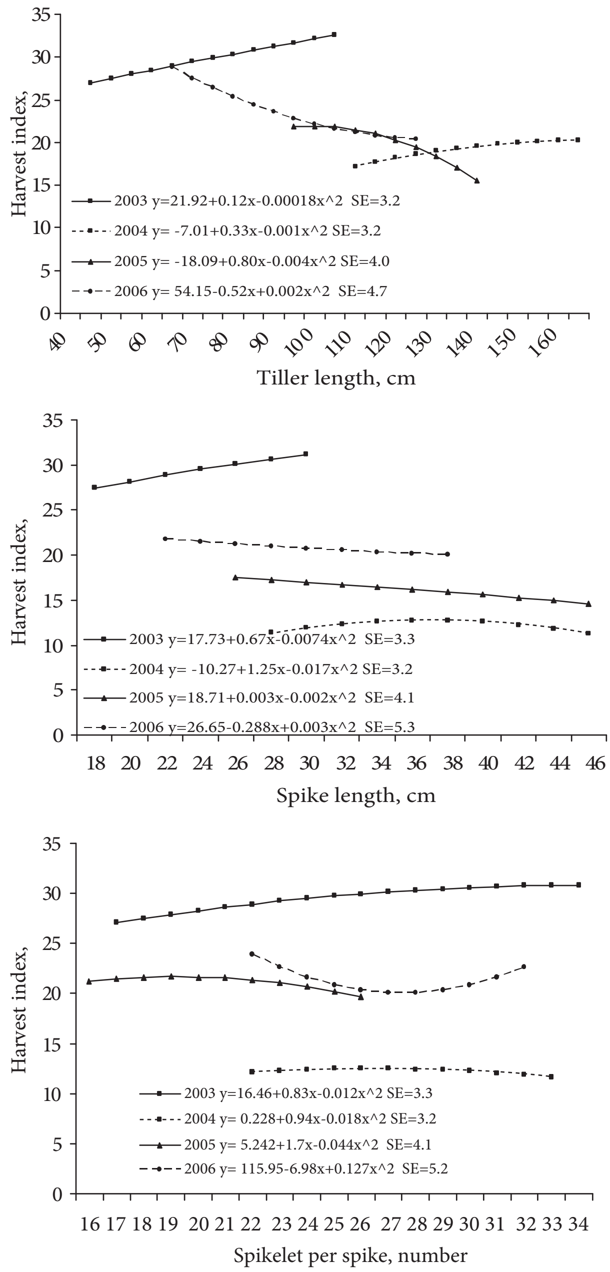

Figure 5. Impact of tiller characteristics on harvest index.

years of the present study. Reduced seed yield and biomass, which occurred in 2003, as compared to other years, was most likely the result of a spring rainfall shortage and a significant effect of the treatments. The spring drought in 2003 affected tiller characteristics, which were shortest in the sparse plant establishment (5 kg ha^{-1} and 60 cm row spacing). The seed and shoot dry mass yields in 2003 were the highest with 20 cm row spacing and the 20 kg ha^{-1} seeding rate, while they were the lowest with 60 cm row spacing and 5 kg ha^{-1} seeding rate, showing that seed yield can be managed by increasing stand density during drought stress conditions. The results indicate that there was no interaction effect of the applied factors, and that they influenced seed yield independently. Higher precipitation during the 2 consecutive years resulted in abundant biomass accumulation. As a result, lodging and photomorphogenic plant reactions were observed. Thus, tillers in dense sward with low red/far-red ratios developed longer leaves and longer shoots, as was reported by Casal et al. (1985), achieving the greatest tiller length in 2004 and 2005. Furthermore, the adverse effect of lodging on seed yield may be attributed to a reduced photoassimilate supply for developing seeds (Griffith, 2000), as pre- and post-anthesis assimilate reserves play an important role in seed filling when current photoassimilate supply is reduced. Lodging, combined with climatic conditions favoring new tiller growth during 2004 and 2005, hampered mechanical harvest and promoted assimilate limitation at seed sinks due to assimilate demands of young vegetative tillers. As plant density increased, individual plants and spikes each contributed less to the final seed yield, and while vegetative tiller production increased, seed yield decreased, which is why there was a lack of seed yield reaction to higher seeding rates. There were high red/far-red ratios in sparse canopies, with ryegrass plants investing more resources in new tillers, providing an equation effect of photomorphogenic reaction under different stand densities. Lodging tolerance appeared to be the highest in the 60 cm row spacing treatment, as compared with the other treatments, as was reported by Choi et al. (2002). The difference in results achieved in 2004 and 2005 was due to a low accumulation of assimilates and early season lodging at the time of heading in 2004. Furthermore, the 2004 conditions favored new tiller promotion and development during seed filling, resulting in new tillers competing for assimilates with seed sinks. The differences in dry mass accumulation, seed yield, and harvest index between 2004 and 2005 were the result of these factors. The reduced seed yield in the fourth experimental year with 40 cm row spacing was the result of specific and atypical winter and spring conditions, and not a natural decrease at this row spacing. As the seeding rate increased so did the range of tiller characteristics and harvest components.

Regression curves developed during this study show a low correlation between tiller characteristics and seed yield. According to Nelson et al. (1997), genetic correlations of seed yield components with seed yield in Italian ryegrass are generally low. Inflorescence number, inflorescence length, number of spikelets per spike, and spikelet length all have considerable additive genetic variation and high heritability. The results of the present study indicate that in order to maximize seed productivity in the first production year a high seeding rate is preferable (15-20 kg ha^{-1}), and that medium row spacing (40 cm) is the least risky. Some recent studies on crop competition and plant spatial arrangement (Choi et al., 2002) reported that moderate densities maximize seed yield. The results of the present study support the use of a relatively low seeding rate for Italian ryegrass seed production in the first harvest year. Future studies should focus on including additional sites with different soil drainage classes in contrasting climatic years.

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