Turkish Journal of Agriculture and Forestry

Volume 36 | Number 1 Article 11

1-1-2012

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Turk J Agric For
36 (2012) 121-131
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doi:10.3906/tar-1003-754

Research Article

The effect of ryegrass (*Lolium italicum* L.) stand densities on its competitive interaction with cleavers (*Galium aparine* L.)

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Received: 11.03.2010

Abstract: Italian ryegrass (*Lolium italicum* L. cv. Tetraflorum) seed production is an important industrial activity in Serbia. Cleavers (*Galium aparine* L.) interferes in Italian ryegrass seed production as well as in many other crops. The effect of stand density of Italian ryegrass on its competitive interaction with cleavers was investigated in western Serbia in the 2005-2006 and 2006-2007 cropping seasons. The established density treatments of Italian ryegrass were 5 kg ha^{-1} seeding rate with 60 cm row spacing (SD_1), 5 kg ha^{-1} with 20 cm (SD_2), 20 kg ha^{-1} with 60 cm (SD_3), and 20 kg ha^{-1} with 20 cm (SD_4). The interaction between Italian ryegrass and cleavers was evaluated by SPAD reading, relative nitrogen content (RNC) in the leaf, total nitrogen content (TNC) in the leaf, and seed yield. The rank order of the competitive ability of Italian ryegrass was $SD_4 > SD_3 > SD_2 > SD_1$ under optimal weather conditions for crop development. Under climatic stress conditions, however, neither effect of ryegrass densities nor cleavers was pronounced on competitive ability of ryegrass with different stands.

Key words: Relative nitrogen content (RNC) in the leaf, SPAD reading, total nitrogen content (TNC)

İtalyan çiminin (*Lolium italicum* L.) farklı yoğunluklarının yoğurtotu (*Galium aparine* L.) ile rekabetine etkileri

Özet: İtalyan çimi (*Lolium italicum* L. cv. Tetraflorum) tohumu üretimi Sırbistan'da önemli bir endüstriyel faaliyet alanıdır. Yoğurtotu (*Galium aparine* L.), diğer birçok üründe olduğu gibi, İtalyan çimi tohumu üretimini de olumsuz etkilemektedir. İtalyan çiminin farklı ekim normlarının, yoğurtotunun rekabetine etkisi Batı Sırbistan'da 2005-2006 ve 2006-2007 üretim mevsimlerinde araştırılmıştır. Sıra aralığı ve tohum miktarı değiştirilerek dört farklı İtalyan çimi yoğunluğu oluşturulmuştur: SD_1 (5 kg ha^{-1} İtalyan çimi tohumu ve 60 cm sıra aralığı), SD_2 (5 kg ha^{-1} ve 20 cm), SD_3 (20 kg ha^{-1} ve 60 cm), SD_4 (20 kg ha^{-1} ve 20 cm). İtalyan çimi ile yoğurtotunun ilişkisi SPAD okuması, yapraktaki nisbî azot (RNC), yapraktaki toplam azot (TNC) ve verim aracılığıyla değerlendirilmiştir. Ürünün gelişme dönemindeki normal iklim şartlarında İtalyan çiminin rekabet kabiliyeti $SD_4 > SD_3 > SD_2 > SD_1$ olarak belirlenmiştir. Ancak, iklimin baskı oluşturduğu durumlarda, ne İtalyan çiminin farklı yoğunlukları ne de yoğurtotunun rekabeti etkili olmuştur.

Anahtar sözcükler: Yapraktaki nisbî azot (RNC), SPAD okuması, yapraktaki toplam azot (TNC)

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Introduction

Side effects of intensive herbicide use such as herbicide resistant weeds, pollution in water and soil, and residues in products are commonly known. The evolution of herbicide resistance and public concerns about the detrimental effects of weed control on the environment have created a need for more sustainable systems with less reliance on chemical weed control. Techniques to grow crops that are more competitive than weeds are crucial for developing reduced herbicide use strategies (Paolini et al. 1999). Improved crop competitiveness can be achieved by specific breeding programs (Paolini et al. 1998), or by modifying crop husbandry methods, e.g., by adjusting crop density and its spatial arrangement (Walker et al. 2002; Oljača et al. 2007), sowing time (Paolini et al. 1998), using optimal nitrogen fertilizers and low doses of herbicides (Blackshaw et al. 2004; Kim et al. 2006), observing critical periods for weed control (Uremis et al. 2009), or by growing more aggressive crop genotypes (McDonald 2003). Spatial distribution of individual crop plants in the field is important for crop growth, yield production, and crop-weed interaction, and the role of plant spatial patterns is therefore particularly appreciated in agricultural research. Many studies have detected significant differences in competitiveness of crops and weeds depending on crop seedling rate (Grundy et al. 1993; Kristensen et al. 2006). Optimization of crop seedling rate can have significant agronomic advantages, such as improved crop germination and yield uniformity and quality, as well as increased weed suppression.

Italian ryegrass (*Lolium italicum* L. Syn *L. multiflorum* L.) is a cool-season tillering grass originating from southern Europe. In Serbia, it is a dense-growing winter crop characterized by fast growth that secures quick tillering, high yield potential, fitness for reduced cultivation, good adaptability to heavy and moist soils, etc. (Minpolj 2010). Annual demands for Italian ryegrass seeds in Serbia are around 200 t, and 50% is being provided from domestic sources (Simić et al. 2009). Seed production of this species is one of the most cost-efficient branches of industrial grass seed production (Young et al. 2001).

Cleavers (*Galium aparine* L.) is a frequent and harmful weed species in Serbia. It is reported that it causes the highest yield losses in small grain crops in Serbia (Vrbničanin et al. 2008) because it is a major consumer of soil nutrients, especially nitrogen and phosphorus (Taylor 1999). It is widespread throughout Europe from northern Norway (70°N) to the southern parts of the Mediterranean (40°N). Cleavers sticks to the above-ground parts of cultivated plants and suffocates them, thus making the harvest difficult by clogging machinery and contaminating the material harvested (Froud-Williams 1985).

Recent studies have indicated a close relation between chlorophyll content and leaf N content, which makes sense because most of the leaf N is constrained in chlorophyll molecules (Samdur et al. 2000; Nageswara et al. 2001). The Minolta chlorophyll meter (SPAD-502, Minolta Corp., Ramsey, NJ, USA) enables users to measure leaf greenness quickly and easily, which is determined by chlorophyll content. Chlorophyll content or leaf greenness is affected by a number of factors, one being the N status of a plant. Previous studies have demonstrated the utility of the SPAD meter for nondestructive and rapid estimation of leaf N in plants, including rice (Takeba et al. 1990), maize (Schepers et al. 1992; Bullock and Anderson (1998), sugarbeet (Paolini et al. 1999; Sexton and Carroll 2002), wheat and barley (Blackshaw 2004, Ponce, 1998), and Italian ryegrass (Sunaga et al. 2006).

It is clear that manipulating the density of crop and/or weeds affects competition between crop and weed. The objective of the present study was to determine competitiveness between Italian ryegrass and cleavers in different seeding rates and plant distances in a row of Italian ryegrass. In addition, interactions between the ryegrass seed yield and chlorophyll meter reading (SPAD reading), relative nitrogen content (RNC) in the leaf, and total nitrogen content (TNC) in the leaf were evaluated.

Materials and methods

The study was conducted in Western Serbia (44°47′N, 19°35′E, 80 m a.s.l.), which is located in a semi-humid region with unstable weather conditions year to year. Precipitation and temperature also varied in the 2 cropping seasons, 2005-2006 and 2006-2007, in which the experiments were conducted (Table 1).

Soil in the experimental area was humofluvisol. The main characteristics of the soil at sowing depth (0-30 cm layer) were determined before the experiment was set up each year. Soil was categorized as acid soils with medium humic aspect regarding humus content and with well-supplied total nitrogen (Table 2). The soil is also well-provided with available nitrogen, primarily ammonia, which is consistent with the pH measured (Haynes 1986).

Before the experiment was set up, phosphorus, potassium, and nitrogen were applied in the autumn of each year (250 kg ha^{-1} of 8-16-24 NPK fertilizer). The tetraploid Italian ryegrass cv. Tetraflorum was sown in the autumn of 2005 and 2006 (Table 3). Cleavers was undercropped in the spring of 2006 and 2007 as a competitor species to maintain a density that might cause a competitive effect.

A factorial experiment was set in a randomized complete block design with 3 replications. The plot size was 10 m^2 (2.5 × 4 m). The treatments were 4 stand densities of Italian ryegrass (SD_1 to SD_4) and 4 sampling times (GS_1 to GS_4) (Table 3). The cleaver density was 25-35 plants per m^2, which has been observed during earlier field studies. In addition to crop-weed mixture plots, monoculture ryegrass plots were constituted with the same crop densities. In order to evaluate SPAD readings, RNC, and TNC of cleavers, cleavers plots were set with the same cleavers density in the absence of Italian ryegrass. All weeds except cleavers in mixture (Italian ryegrass + cleavers) and pure cleavers stands were removed biweekly by hand during the growing seasons. In the monoculture crop, all weeds were removed by herbicide (1 L ha^{-1} Starane 250, a.i. 250 g fluroxypyr) application. Ryegrass was harvested in June. Relative seed yield was calculated by dividing yield in

Table 1. Rainfall and average temperatures during the growing seasons at the study site.

Production season	Temperature (°C)								
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.
2005-2006	11.6	4.9	2.2	−1.4	0.9	5.6	12.5	16.4	19.6
2006-2007	13.1	7.1	2.7	5.2	5.8	8.6	13	18.5	22
	Precipitation (mm)								
2005-2006	6.8	19.6	58.5	29.8	37.8	55.6	107	54.1	100.6
2006-2007	28.7	23.0	33.1	40.2	49.5	80.3	0	79	85.2

Table 2. Soil chemical properties measured before sowing of Italian ryegrass in experimental site in 2005 and 2006.

Year	pH (KCl)	OM (%)	Total N (%)	Available N (mg kg^{-1})		
				NH_4-N	NO_3-N	Sum
2005	5.40	2.80	0.20	13.90	8.70	22.60
2006	5.18	3.18	0.23	13.40	10.00	23.40

Table 3. Overview of agricultural practices and data sampling.

Sowing dates of Italian rye grass	15 October 2005 12 October 2006
Under cropping dates of cleavers	25 March 2006 20 March 2007
Stand density (SD) (kg seed × cm interrow spacing)	SD_1- 5 kg ha^{-1} seeds, 60 cm row spacing SD_2- 5 kg ha^{-1} seeds, 20 cm row spacing SD_3- 20 kg ha^{-1} seeds, 60 cm row spacing SD_4- 20 kg ha^{-1} seeds, 20 cm row spacing
Sampling times (growth stage, GS)	GS_1- tillering GS_2- stem extension GS_3- flag leaf GS_4- earing
Italian ryegrass harvest dates	23 June 2006 15 June 2007

mixture of ryegrass and cleavers by yield in ryegrass monoculture.

A hand-held chlorophyll meter (SPAD-502, Minolta Corp., Ramsey, NJ, USA) was used for measuring light absorption at different wavelengths: 660 nm and 940 nm (Nageswara et al. 2001) and stated as SPAD readings throughout this paper. SPAD readings were carried out on the leaves of the 2nd, 3rd, and 4th nodes from the tip of the main shoot axis down, on 30 randomly chosen plants in each plot.

Just after SPAD reading was completed, 10 leaves were taken from each plant. The leaves were dried in an oven at 80 °C for 48 h, and weighed. The same leaves were used for TNC determination using the Kjeldahl method (Munsinger and McKinney 1982). A standard curve was constructed on the basis of SPAD readings and nitrogen values from laboratory analysis. For making the standard curve, random SPAD readings were made for each replication in each variant. Based on standard curves and "n" SPAD readings, RNC was determined, which is particularly convenient for a fast screening in the field aimed to check nitrogen availability to plants. SPAD reading, and TNC and RNC determinations were carried out 4 times during the growing season at given growth stages (Table 3).

The effects of stand densities on the relative competitiveness of crop and weed were determined by calculating relative yields (RYr = relative yield of ryegrass, RYw = relative yield of cleavers), relative yield total (RYT) of the mixture, and relative crowding coefficient (RCC). According to the method of Spitters and Van den Bergh (1982), the RY of each species was calculated as yield per area in mixture/ yield per area in monoculture. RYT was calculated according to de Wit and Van den Berg (1965) as the mean of relative yields 0.5 × (RYr + RYw). RCC was calculated as the ratio of relative yields (RYr/RYw). RY, RYT, and RCC were determined by using SPAD readings, relative N contents in leaves (RNC), and total N content in leaves (TNC).

Data analysis was done on the basis of cumulative samples, i.e. a single data set was made using figures for all of the 4 sampling stages, whence descriptive statistics indices were found. The data were analyzed using appropriate statistical analyses in STATISTICA v. 7.1. Variance homogeneity was tested and the homogeneity condition was met in most cases. Where homogeneity was missing, original data were transformed and parameter tests were used for further testing.

Results

Ryegrass yield was evaluated separately for 2006 and 2007 because it significantly differed between years. In 2006, the highest seed yield was obtained from treatment SD_4 for both mixture of crop and weed and monoculture while in 2007 it was from SD_1 for mixture and SD_4 for monoculture (Table 4). The highest relative seed yield was 0.81 (SD_2) in 2006 and 0.85 (SD_1) in 2007 while the lowest was from SD_1 (0.70) in 2006 and SD_4 (0.68) in 2007 (Table 4).

SPAD reading, relative N content (RNC) and total N content (TNC) were measured 4 times over the growing season, and the data were processed as a single data set; their average values are shown in Table 5. Values of each parameter are not discussed individually; they were rather assessed in correlation with Italian ryegrass yields (Figures 1 and 2).

A very high and statistically significant correlation was detected between crop yield and TNC at all seeding rates of Italian ryegrass both in monoculture ($R^2 = 0.88$) and mixture ($R^2 = 0.84$) in 2006 based on regression analysis and the calculated coefficients of correlation. Another high correlation was found between yield and SPAD readings (0.77 and 0.76) in 2006. However, in 2007, both correlations were lower. Correlation between yield and RNC was somewhat lower in both years (Figure 1).

The effect of stand densities on the competitive ability was examined by calculating RYr, RYw, RYT, and RCC (Table 6). Throughout the experiment, the RYr was < 1 (except RYr for SPAD readings at SD_1, and RNC at SD_3). The RYT was < 1 for all measurement parameters in both years. Generally, RYTs for SPAD readings and TNC were consistently higher in both years than RCCs and were close to unity. RCC values were over 1 for all measurements except SD_2 in 2006.

Discussion

As expected, in both years seed yield of Italian ryegrass was higher in monoculture than in mixture for all corresponding ryegrass stand densities (Table 4), which shows the effect of cleavers on seed yield of Italian ryegrass. Cleavers reduced seed yield of Italian ryegrass by 19.5%-29.6% in 2006 and 14.7%-31.8% in 2007 depending on stand density. Mennan and Zandstra (2005) reported wheat yield losses between 10.3% and 48.8% depending on cultivar, weed density, location, and year under standard seeding rate of wheat due to cleaver competition.

Table 4. Effect of Italian ryegrass stand densities on seed yield and relative seed yield.

Year	Stand density	Seed yield, kg ha^{-1}		Relative seed yield
		In the mixture of crop and weed	In monoculture	
		$\bar{x} \pm S\bar{x}$	$\bar{x} \pm S\bar{x}$	
2006	SD_1	591.00 c ± 1.22	840.20 c ± 32.80	0.70
	SD_2	679.80 b ± 43.17	844.20 c ± 29.23	0.81
	SD_3	849.20 a ± 20.71	1097.40 b ± 23.49	0.77
	SD_4	911.00 a ± 17.15	1210.20 a ± 15.13	0.75
2007	SD_1	834.00 a ± 100.08	978.00 b ± 29.05	0.85
	SD_2	602.20 b ± 41.84	817.40 c ± 12.72	0.74
	SD_3	775.00 ab ± 114.42	1060.40 ab ± 53.32	0.73
	SD_4	781.67 a ± 19.12	1146.00 a ± 24.78	0.68

LSD test, Probabilities for Post Hoc Tests (P = 0.05).

Table 5. Effect of Italian ryegrass stand densities on SPAD readings, RNC and TNC (%) of crop and cleavers.

Year	Stand density	In the mixture of crop and weed		In either monocultures	
		Italian ryegrass	Cleavers	Italian ryegrass	Cleavers*
		$\bar{x} \pm S\bar{x}$	$\bar{x} \pm S\bar{x}$	$\bar{x} \pm S\bar{x}$	$\bar{x} \pm S\bar{x}$
		SPAD readings			
2006	SD_1	44.13 a ± 0.69	30.35 b ± 0.39	44.04 a ± 0.61	34.93 ± 0.23
	SD_2	39.44 b ± 0.52	34.58 a ± 0.50	40.36 b ± 0.50	
	SD_3	39.69 b ± 0.63	28.71 c ± 0.37	40.12 b ± 0.59	
	SD_4	35.50 c ± 0.43	30.56 b ± 0.64	36.31 c ± 0.39	
2007	SD_1	33.62 b ± 0.30	25.48 c ± 0.28	35.03 b ± 0.22	29.37 ± 0.22
	SD_2	31.08 c ± 0.33	27.62 ab ± 0.61	33.05 c ± 0.25	
	SD_3	29.93 d ± 0.38	26.78 b ± 0.33	31.79 d ± 0.31	
	SD_4	35.10 a ± 0.45	28.20 a ± 0.68	35.88 a ± 0.45	
		RNC			
2006	SD_1	2.17 a ± 0.09	1.10 c ± 0.05	2.73 a ± 0.05	1.77 ± 0.03
	SD_2	1.24 d ± 0.11	1.72 a ± 0.05	1.99 c ± 0.02	
	SD_3	1.89 b ± 0.05	1.10 c ± 0.03	2.32 b ± 0.05	
	SD_4	1.46 c ± 0.04	1.41 b ± 0.08	1.76 d ± 0.0	
2007	SD_1	1.59 b ± 0.04	2.15 b ± 0.07	2.02 a ± 0.02	2.98± 0.06
	SD_2	1.62 b ± 0.03	2.69 a ± 0.14	1.66 c ± 0.01	
	SD_3	1.87 a ± 0.03	2.24 b ± 0.09	1.63 c ± 0.03	
	SD_4	1.68 b ± 0.09	2.79 a ± 0.16	1.75 b ± 0.02	
		TNC			
2006	SD_1	2.34a ± 0.13	1.37 b ± 0.04	2.51 a ± 0.11	1.56 ± 0.04
	SD_2	2.09a ± 0.09	1.52 a ± 0.06	2.27 ab ± 0.09	
	SD_3	2.02a ± 0.14	1.40 ab ± 0.05	2.21 b ± 0.13	
	SD_4	1.64b ± 0.10	1.23 c ± 0.06	1.82 c ± 0.08	
2007	SD_1	1.53 ± 0.15	2.22 ± 0.20	1.74 ± 0.17	2.31 ± 0.10
	SD_2	1.74 ± 0.17	1.77 ± 0.14	1.92 ± 0.17	
	SD_3	1.98 ± 0.19	1.92 ± 0.17	2.19 ± 0.20	
	SD_4	1.66 ± 0.14	2.07 ± 0.20	1.79 ± 0.14	

LSD test, Probabilities for Post Hoc Tests (P = 0.05).
*Values for cleavers are not dependent on crop stand density, samples collected only from pure cleavers plots.

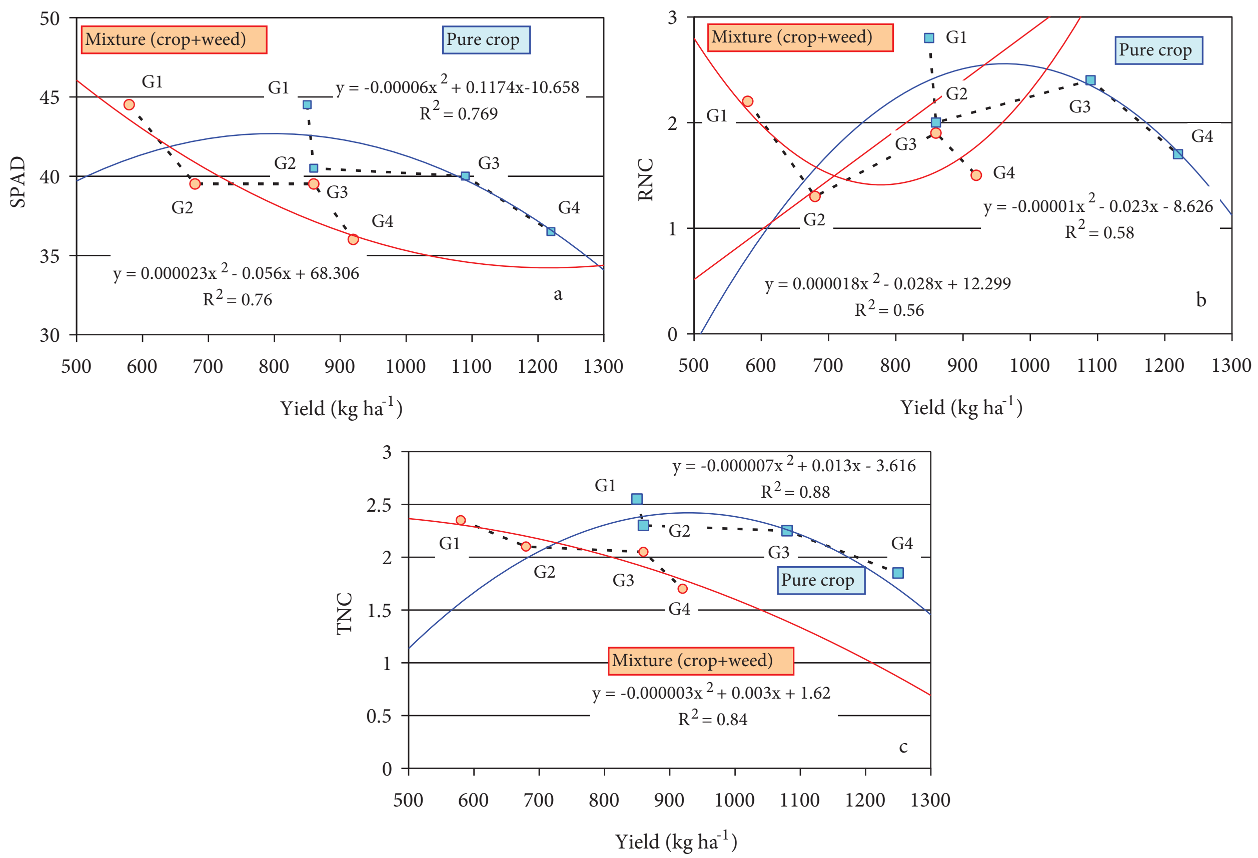

Figure 1. The relationship between seed yield and SPAD reading (a), RNC (b) or TNC (c) under crop-weed mixture and pure stand of crop in 2006.

In monoculture, there was similarity between the 2 years, in which higher seed rates, especially with narrower row spacing, had a positive effect on ryegrass seed yield, although all treatments were statistically similar except SD_2 in 2007. This result is in accordance with the results reported by Simić et al. (2009). Choi et al. (2002) also concluded that the number of Italian ryegrass spikes (and seed yields) increased when interrow spacing was narrower.

Results were erratic in crop-weed mixture between years; yield increased in higher seeding rates in 2006 but not in 2007. The highest yield in 2007 was obtained from one of the narrower row spacing and the lowest one from the other narrower spacing. Mennan and Zandstra (2005) have found a positive effect of increased seeding rate on wheat yield under cleavers competition, but Young et al. (1996) have reported a higher yield of Italian ryegrass seed at a lower seeding rate.

Lewis and Clements (1999) noted that the yield of grasses may also be good under minimum investment on condition that the competitive effect of weeds has been avoided. In some cases, while an increase in seeding rates (15-20 kg ha^{-1}) in stand establishment provided higher seed yields in years with unfavorable weather conditions, seed rate had either no impact on seed yield or decreased it as a result of ryegrass lodging following seed shedding in years with favorable weather conditions (Simić et al. 2009). Thus, yield differences between the 2 years at the same stand densities may be attributed to different weather conditions. The amount and more regular distribution of precipitation in growing season in 2006, especially in April (Table 1) might have helped to secure a more stable yield under the higher seeding rates both in pure and mixture crops, but the effect of interspecific competition was evident. Cleavers reduced the yield of Italian ryegrass

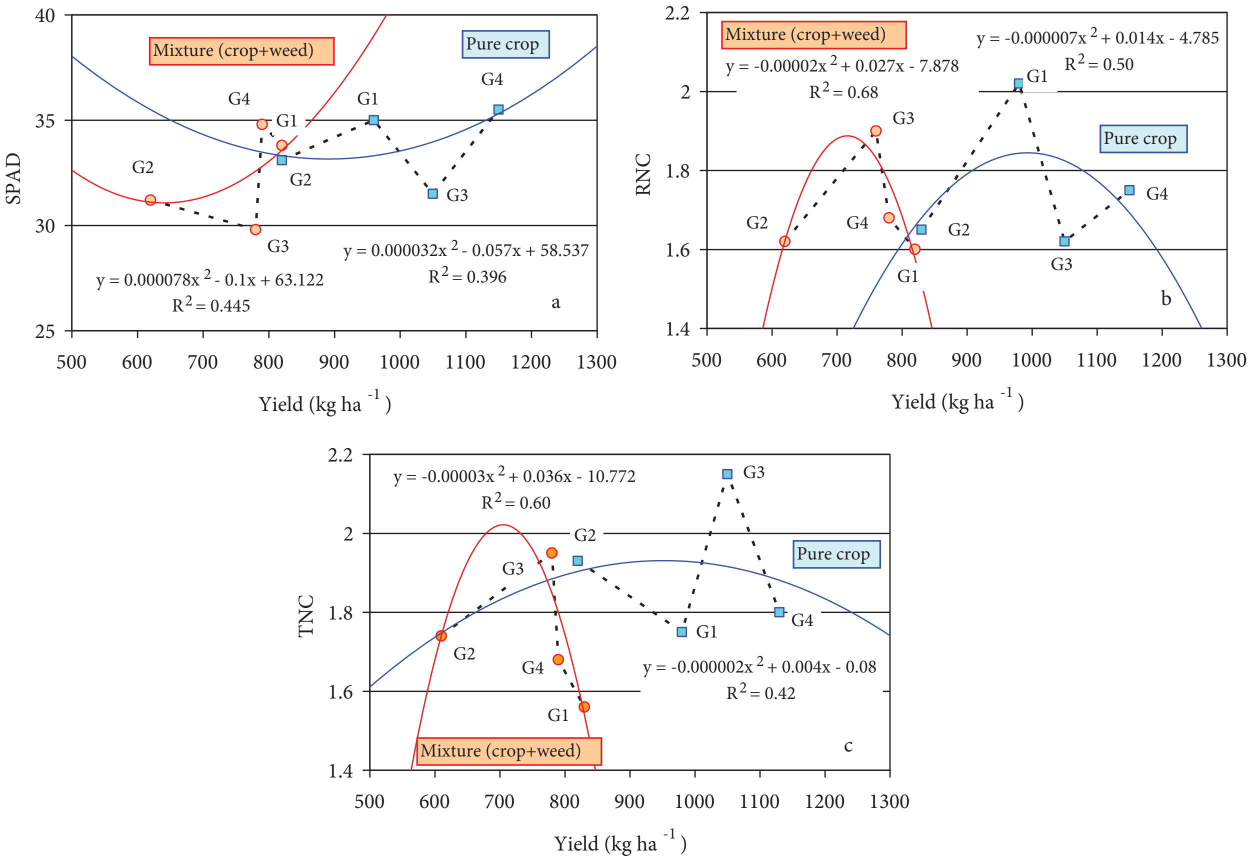

Figure 2. The relationship between seed yield and SPAD reading (a), RNC (b) or TNC (c) under crop-weed mixture and pure stand of crop in 2007.

Table 6. Influence of stand densities on the relative yield of Italian ryegrass (RYr) and cleavers (RYw), relative yield total (RYT) and relative crowding coefficient (RCC), calculated from SPAD reading, and RNC and TNC data for 2006 and 2007.

Year	SD	SPAD reading				Relative N content				Total N content			
		RYr	RYw	RYT	RCC	RYr	RYw	RYT	RCC	RYr	RYw	RYT	RCC
2006	SD_1	1.00	0.87	0.93	1.15	0.79	0.62	0.70	1.27	0.93	0.88	0.90	1.06
	SD_2	0.98	0.99	0.98	0.99	0.62	0.97	0.79	0.64	0.92	0.97	0.94	0.95
	SD_3	0.99	0.82	0.90	1.21	0.81	0.62	0.71	1.31	0.91	0.90	0.90	1.01
	SD_4	0.98	0.87	0.92	1.13	0.83	0.80	0.81	1.04	0.90	0.79	0.84	1.14
2007	SD_1	0.96	0.87	0.91	1.10	0.79	0.72	0.75	1.10	0.88	0.96	0.92	0.92
	SD_2	0.94	0.94	0.94	1.00	0.98	0.90	0.94	1.09	0.91	0.77	0.84	1.18
	SD_3	0.94	0.91	0.92	1.03	1.15	0.75	0.95	1.53	0.90	0.83	0.86	1.08
	SD_4	0.98	0.96	0.97	1.02	0.96	0.94	0.95	1.02	0.93	0.90	0.91	1.03

by as much as 30% (relative seed yield = 0.70) under lower seeding rate. In 2007, when meteorological conditions (precipitation) were generally less favorable during the growing season (for instance, precipitation in April was 0 mm), seeding rate had no effect, as it is evident from the smaller differences between stand densities both in monoculture and mixture crop. This is consistent with data reported by Chastain (2000), who considered occasional and short-interval rainfall as a much more important factor for seed yield than temperature throughout the season, as was the case in the current experiment in 2007. Missing rainfall in April, when Italian ryegrass was at the stage of intensive booting and initial stage of generative cycle, had an immediate effect on seed yield. Interspecific competition was also evident, i.e. cleavers was more tolerant of drought stress, as reflected by the highest yield difference between the mixture and monoculture crops at SD_4 (yield was 32% lower in mixture plots), where the crop was the densest and competition between crop and weed for water probably the highest.

Although there was a positive correlation between SPAD readings and yield, RNC and yield and TNC and yield, both in the mixed crop and monoculture in both years, the lower correlation between crop yield and SPAD reading, TNC, or RNC in 2007 also might be attributed to less favorable climatic conditions, in which plant fitness to deal with stress had primary effect, rather than stand density; on the other hand, in 2006, there were higher correlations. Sunaga et al. (2006) stated that the yield of some varieties of Italian ryegrass increased with the increase in SPAD readings, and maximum yields within a year were obtained with SPAD readings over 45 (maximum yield in our study was at SPAD reading 44). Schepers et al. (1992) and Bullock and Anderson (1998) have shown that SPAD readings at high fertilizer N rates demonstrate unique differences between plant species. Furthermore, favorable weather conditions are crucial for optimal crop development (Kalburtji and Mamolos 2001), which may correlate directly with SPAD readings, as our findings confirmed in 2006. It can be concluded that SPAD, RNC, and TNC measured under favorable weather conditions during the growing season may be considered as reliable indicators of crop yield and vice versa; those parameters would not be reliable data for predicting yield in less favorable seasons. Environmental conditions and weed characteristics may play a more important role in competition between weeds and crops (Mennan and Zandstra 2005). In addition, Roberts et al. (2001) suggested that environmental conditions may be more important for a good wheat yield than seeding rate. It is reported similarly that weather conditions during crop vegetation are more crucial for securing high and stable yield, and often more important than agricultural practices such as interrow spacing, seeding rate, and timing of sowing (Chastain 2000; Simić et al. 2009).

Generally the RYr was < 1 (Table 6), indicating that for Italian ryegrass the effect of interspecific competition was greater than the effect of intraspecific competition. The effect of wide interrow spacing was to decrease the relative yield of cleavers and increase the relative yield of Italian ryegrass. Investigating competition between wheat and weed, Iqbal and Wright (1997) found that low N decreased wheat relative yield and increased weed relative yield. The value RYT < 1 indicating possible mutual antagonism or allelopathy was occurring in those situations. The allelopathic potential of cleavers has been reported by several authors (Kadioglu and Yanar 2004; Ayiy et al. 2008). RYTs for SPAD reading and TNC were consistently higher in both years than RNCs and were close to unity, indicating that both species were competing for the same limited resources. The RCC > 1 indicates that Italian ryegrass was more competitive than cleavers considering all measurement parameters at almost all stand densities in both years.

The order of the competitive ability of Italian ryegrass under mixed cropping with 25-35 plants of cleavers per m^2 or monoculture, based on seed yield, SPAD reading, RNC, and TNC, considering different seeding rates was $SD_4 > SD_3 > SD_2 > SD_1$ when weather conditions were optimal for crop development. Under stress conditions, there was no certainty as to which seeding rate would produce better yield and higher competitiveness of Italian ryegrass against cleavers, and the outcome would depend on crop fitness under the existing weather conditions.

Acknowledgement

Authors thank The Ministry of Education and Science of the Republic of Serbia for its financial support for this study through Project III 046008.

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