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Araştırma Makalesi / Research Article

The Impact of Ryegrass Density and Different Herbicides on Wheat Yield and Efficacy of Various Herbicides against Ryegrass

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ABSTRACT

Herbicides are used to control ryegrass (*Lolium rigidum* Gaud.) in cereals. In 2011/12, an experiment was conducted in Mateur, to evaluate the effect of herbicide treatments on ryegrass biomass and wheat (*Triticum durum* Desf.) yield. Similarly, a second experiment was conducted in five locations (Mateur, Fritissa, Metline, Tinja and Menzel Bourguiba) to quantify the losses caused by ryegrass to wheat yield. The results of the first experiment showed that Tolurex proved the most effective in reducing ryegrass biomass by 96.4%. The analysis of variance showed significant effect of herbicide treatments on wheat yield. The highest wheat yield was recorded with Tolurex (6.15 t ha^{-1}), which improved the yield by 59%. The results of the second experiment indicated that the highest losses in ryegrass biomass were recorded with Menzel Bourguiba (1.5 t ha^{-1}) with average density of ryegrass (393 plants m^{-2}). The lowest losses (0.38 t ha^{-1}) in ryegrass biomass were recorded with Metline, heavily infested with ryegrass (450 plants m^{-2}). Yield of wheat was not correlated ($r = 0.18$ and $p = 0.77$) with ryegrass density. The average loss in yield was 0.9 t ha^{-1} (±0.4) with an average density of more than 390 plants m^{-2}. Tolurex, inhibitor of photosystem II (PSII), reduced ryegrass biomass, while improved wheat yield. It is recommended to use Tolurex for the control of ryegrass in the north of Tunisia. Moreover it is suspected that ryegrass has evolved resistance against commonly used acetyl Coenzyme A carboxylase (ACCase) and acetolactate synthase (ALS) inhibitor hericides.

Key Words: Density, Herbicide, Losses, Resistance, Ryegrass, Yield.

İnce Delice Yoğunluğu ve Farklı Herbisit Uygulamalarının Buğday Verimi ve İnce Deliceye Etkisi

ÖZET

Tahıllarda *Lolium rigidum* Gaud. kontrolü için herbisitler kullanılmaktadır. 2011-2012 yılları arasında Mateur'da herbisit uygulamalarının ince delice (*Lolium rigidum* Gaud.) biomass ve buğday verimine etkisini belirlemek amacıyla bu çalışma yürütülmüştür. Buna benzer şekilde Mateur, Fritissa, Metline, Tinja and Menzel Bourguiba lokasyonlarında ince delicenin buğday verimine etkisini belirlemek için ikinci denemeler yürütülmüştür. 1. denemede Tolurex uygulamasının en iyi sonucu verdiği ve ince delice biomasını % 96,4 azalttığı tespit edilmiştir. varyans analizinde herbisit uygulamasının buğday verimine önemli oranda etkisi gözlemlenmiştir. en yüksek buğday verimine Tolurex (6,15 t ha^{-1}) ile elde edilmiş bu uygulama verimin % 59 arttırılmıştır. İkinci denemede Menzel Bourguiba (1,5 t ha^{-1}) uygulamasında ince delice biomasında en yüksek kayıp gözlemlenmiş ve ortalama yoğunluk m^2'de 393 bitki olarak sayılmıştır. en düşük kayıp ise (0.38 t ha^{-1}) ile Metilen uygulamasında görülmüş ve alan ince delice ile yoğun bulaşık bulunmuştur (450 bitki metrekare). Buğday verimi ile ince delice yoğunluğu arasında korrelasyon ($r = 0,18$ and $p = 0,77$) bulunmamıştır. Verimde ortalama azalma 0,9 t ha^{-1} (±0,4) ile 390 dan fazla bitki ile elde edilmiştir Fotosistem 2 inhibitörü Tolurex ince delice biomasını azalltmış buğday verimini arttırmıştır. Kuzey Tunusta ince delice mücadelesinde Tolurex kullanımı önerilmektedir. Bununla birlikte ince delicenin acetyl Coenzyme A carboxylase (ACCase) ve acetolactate synthase (ALS) inhibitorü herbisitlere dayanıklılık kazandığı düşünülmektedir.

Anahtar Kelimeler : Yoğunluk, Herbisit, Kayıp, Direnç, İnce delice, Verim

INTRODUCTION

The north of Tunisia is classified as vocation cereal zones, where mainly wheat (*Triticum durum* Desf.) and barley (*Hordeum vulgare* L.) are cultivated. The cereal production is mainly located in northern locations of Tunisia where weather conditions are more favourable. The production varied, during the past two decades, from 0.51 million tons to 2.9 million tons, with 1.9 million tons as an annual average (unpublished data). In Tunisia, cereal production is affected by climatic conditions, inappropriate farming techniques (Daaloul, 1988) and weed infestation (Aubry et al., 1994; Skouri and Latiri, 2001). Indeed, weeds are one of the main factors causing yield losses due to competition for light, water and nutrients (Caussanel, 1989). Ryegrass (*Lolium rigidum* Gaud.) is among the weeds that are very competitive for several crops, including cereals (Reeves and Broke, 1977). The species is characterized by great genetic variability, easy adaptation under different environmental conditions (Gill, 1996), enormous seed production (Davidson, 1990), high seed survival in summer and fall (Gramshaw and Stern, 1977) and rapid increase in the soil seed bank (Gill, 1996). In Tunisia, ryegrass is the most dominant weed infesting the majority of cereal fields in the north. It is localized in all areas and on different types of soil (Khammassi et al., 2013). Losses caused by ryegrass are becoming increasingly important in Mediterranean climates (Monaghan, 1980; Gonzalez-Andujar and Saavedra, 2003). These losses vary according to ryegrass density, sowing date of cereals and soil seed bank (Reeves, 1976). The density of 200 plants m^{-2} can reduce wheat yield by 20 to 50%, equivalent a cost that ranges from 100 to \$250 (Porter and Gawith, 1999). Other studies reported that wheat yields decreased from 23.1 to 47.8% with high densities (1500 plants m^{-2}) of ryegrass (Reeves and Brooke, 1977). The control of ryegrass in cereal crops is key to their successful production, which improve grain yield (Lumb and McPherson, 1964; Reeves and Tuohey, 1972; Reeves and Smith, 1975). Management options for ryegrass control include increasing tillage, delaying fall wheat planting, increasing wheat seeding rate, seeding wheat in narrow rows, rotating crops and using herbicides (Appleby and Brewster 1992; Brewster et al., 1997). Several herbicides are registered or are being developed for ryegrass control in wheat. Trifluralin was used as preemergence herbicide against ryegrass in the 1970s (Lowe, 1973) followed by diallate and triallate in wheat (Reeves and Tuohey, 1972). Since then, the development of chemical control did not stop and continued with the appearance of families of Aryloxyphenoxypropionate (FOPs), Cyclohexanediones (DIMs) and sulfonylureas, which showed conclusive results against this weed. This successful chemical control of ryegrass encouraged farmers to use effective herbicides, sometimes at low doses (Gasquez, 2005; Neve and Powles, 2005). Reliance on herbicides and their continuous use accelerate development of weed resistance, hence reducing their effectiveness (Gasquez, 2005, Hole and Powles, 1997, Neve and Powles, 2005). The evolution of herbicide resistance in ryegrass has been documented in many countries, including Tunisia (Heap, 2018). As ryegrass is becoming one of the most widespread and troublesome weed species in cereal crops in the north of Tunisia, this study was undertaken to (i) evaluate the effect of herbicide treatments on ryegrass biomass and wheat yield, ii) evaluate the effect of herbicide treatments on wheat yield components and iii) quantify the losses in wheat yield caused by densities of ryegrass.

MATERIALS and METHODS

Experiment 1

Effect of herbicide treatments on ryegrass biomass and wheat yield

Field experiment was carried out during the cropping season of 2011/12 in Mateur (37°00′40.8"N 9°38′56.3"E) at the north of Tunisia, in a field naturally infested with ryegrass. The yearly average rainfall was around 640 mm. The soil was a clay-loam with a pH of 8.5 and 2.3% organic matter. The seedbed was mouldboard ploughed and land levelled prior to crop sowing. Durum wheat cv. Karim was sown on December 12th, 2011 and fertilized with Super 45® at the rate of 100 kg ha^{-1} two weeks before planting and ammonium nitrate was fractioned at the 2-3-leaf stage (100 kg ha^{-1}), end of tillering (150 kg ha^{-1}) and stem extension (50 kg ha^{-1}). The experiment was performed according to a randomized complete block design with thirteen herbicide treatments, untreated control and with four replications. The experimental unit was 40 m² (4 m × 10 m). The herbicides included are currently recommended for grass weeds control in wheat. Herbicides were applied at their recommended rates (Table 1) at three-leaf stage of wheat and at one leaf stage of ryegrass. The herbicides were applied with a backpack sprayer calibrated to deliver 200 l/ha at 2 KPa (Figure 1).

Figure 1. Herbicide treatments applied in field experiments.

The effect of herbicide treatments on ryegrass biomass and wheat yield was evaluated at maturity. In the north of Tunisia, the wheat crop is generally harvested during the second half of the month of June after maturity. At June 25th, 2012 the wheat yield was sampled, in each experimental unit, from four quadrates of 1 m² at maturity and yield was determined in tons per hectare (t ha^{-1}). Similarly, ryegrass biomass was sampled, in each experimental unit, from four quadrates of one square meter (1 m²) at maturity and yield was determined in gram per square meter (g m^{-2}).

Table 1. List of herbicides used in field experiments in 2011/12.

Trade name	Active substance	Rates (ha^{-1})
Amilcar OD	Mesosulfuron-methyl + iodosulfuron-methyl-sodium	1 l
Amilcar WG	Mesosulfuron-methyl + iodosulfuron	330 g
Apyros	Sulfosulfuron	26.6 g
Axial	Pinoxaden	1 l
Tolurex	Clortoluron	4.8 l
Dopler plus	diclofop-methyl + fenoxapropo-p-ethyl	2.5 l
Evrest	Flucarbazone sodium	43 g
Grasp	Tralkoxydim	0.8 l
Illoxan CE	Diclofop-methyl	2 l
Pallas OD	Pyroxsualm	0.5 l
Puma Evolution	Fenoxaprop-P-ethyl + iodosulfuron-methyl-sodium	1 l
Topik	Clodinafop-propargyl	0.5 l
Traxos	Pinoxaden + Clodinafop-propargyl	1.2 l

Effect of herbicide treatments on yield components of wheat

To measure the wheat yield components, 100 plants were randomly selected from each plot, and all the yield components were measured. To determine the number of grains per ear (NGE), 10 ears were selected from these plants, and the mean number of grains per ear was calculated. After weighing the total biological crop weight (grain and stubble) in each plot, the grain was separated from stubble by a laboratory threshing machine. To determine 1000-grain weight, five groups of 1000-grain samples were randomly selected from each experimental plot and weighed after seed reached its maturity, and the mean 1000-grain weight was calculated.

Experiment 2

Effect of ryegrass density on wheat yield

Field experiments were carried out during the cropping season 2011/12 in five locations (Fritissa, Mateur, Metline, Tinja and Menzel Bourguiba) at the north of Tunisia. The GPS coordinates, climate zone, rainfall and density of ryegrass for each location are listed in Table 2. In each location, experiment was performed according to randomized complete block design with four replications and experimental unit by 40 m² (4m×10m). Herbicides were applied at recommended rates (Table 1). Field experiment was carried out according to the technical package (seedbed, seeding dates and fertilizer) applied to the field experiment carried out in Mateur. In each location, wheat yield was sampled from four quadrates of 1 m² at maturity and determined in t ha^{-1}. The average of the yield (RM) of the treated plots (average of all herbicide treatments) and the average yield of untreated control plots (RMT) were evaluated for five locations (Mateur, Fritissa, Metline, Tinja and Menzel Bourguiba). The difference between RMT and RM determines the loss in yield (LY) of wheat caused by ryegrass for each location (LY = RMT - RM). An average loss of the yield was calculated for all locations to determine the losses in wheat yields (t ha^{-1}) caused by ryegrass.

Data analysis

The influence of herbicide treatments on ryegrass biomass and wheat yield and yield components were analyzed using analysis of variance technique (ANOVA) using SAS statistical package (SAS, 2013). A second analysis was done using the data collected from field experiments of five locations (Mateur, Fritissa, Metline, Tinja and Menzel Bourguiba) and analyzed by ANOVA. Locations were kept as main plots, while ryegrass densities were assigned to sub-plots. When F-values were significant at the P = 0.05 level, the means were compared using Fisher's least significant difference test. A Person correlation was computed between ryegrass density and the losses in wheat yields by using the statistical software SAS (SAS, 2013).

Table 2. GPS coordinates, climate zone, rainfall and density of ryegrass for each location.

Loction	GPS coordinates		Climate	Rainfall (mm)	Density of ryegrass (plants m^{-2})
	N	E			
Fritissa	36°55′0.8"	9°37′11.8"	Sub-humid	773	407
Mateur	37°00′40.8"	9°38′56.3"		750	320
Metline	37°05′9.5"	9°49'34.5"		749	450
Tinja	37°10′41.7"	9°45'27.4"		820	395
Menzel Bourguiba	37°07′42.2"	9°45'45.0"		773	393

GPS: Global Positioning System.
N: North.
E: East.

RESULTS

Effect of herbicides on ryegrass biomass

The most of tested herbicide treatments had not satisfactory effect on ryegrass biomass. The lowest ryegrass biomass was obtained from the plots treated with Tolurex (0.6 g m^{-2}). The highest ryegrass biomass was recorded in the untreated control (16.5 g m^{-2}) and in the plots treated with Illoxan EC36 (19.8 g m^{-2}) and Apyros (14.9 g m^{-2}). Other herbicides (Amilcar OD, Amilcar WG, Puma Evolution, Grasp, Traxos, Pallas OD, Evrest, Topik and Dopler plus) affected ryegrass biomass by an average of 64.7% but were not statistically different with untreated control plot. Tolurex proved the best herbicide which reduced ryegrass biomass by 96.4% compared to the untreated control (Figure 2).

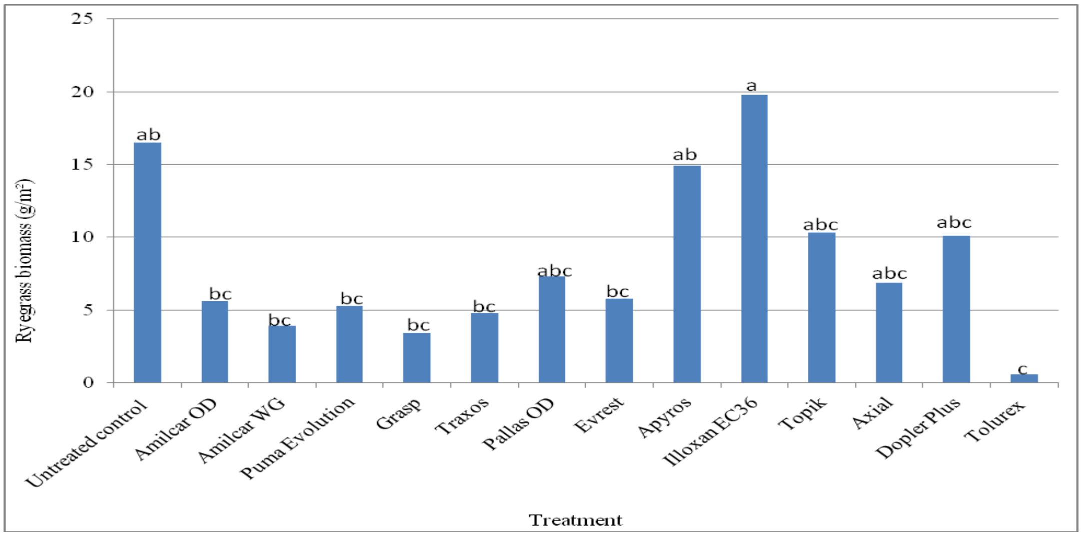

Figure 2. Effect of herbicide treatments on ryegrass yield (Treatments with the same letter are not significantly different, $LSD_{0.05}$ = 1.37).

Effect of herbicides on wheat yield

The ANOVA showed significant effect of herbicide treatments on wheat yield. The lowest wheat yield was obtained in the untreated control (3.9 t ha^{-1}) and in the plots treated with Illoxan EC36 (3.33 t ha^{-1}), Apyros (3.98 t ha^{-1}) and Traxos (3.96 t ha^{-1}). So, there were no differences between the untreated control and the plots treated with these herbicides (Illoxan EC3, Apyros and Traxos) regarding wheat yield. The highest wheat yield was recorded from the plot treated with Tolurex (6.15 t ha^{-1}) and Pallas OD (6.05 t ha^{-1}). However, Tolurex and Pallas OD favoured an improvement in wheat yield by 59% and by 56%, respectively. The average wheat yield of the treated plots (average of all herbicide treatments) was 4.71 t $ha^{-1}$and wheat yield of untreated plot was 3.88 t ha^{-1} (Figure 3).

Effect of herbicides on wheat yield components

The ANOVA showed no significant effect of herbicide treatments on the number of grains per ear. Similarly, the data regarding 1000-grain weight revealed that there was no significant difference between the herbicide treatments (Table 3). Indeed, the herbicide treatments did not show any effect on the yield components (number of grains per ear and 1000-grain weight of wheat) and these parameters are comparable to that of the untreated control.

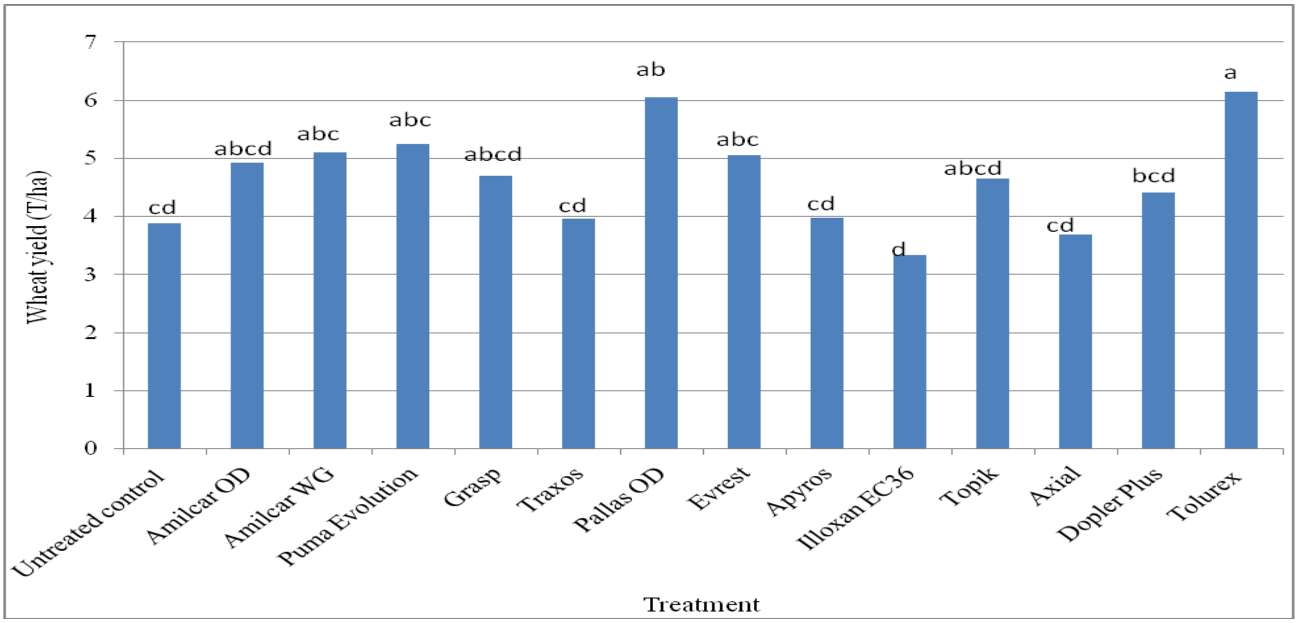

Figure 3. Effect of herbicide treatments on wheat yield (Treatments with the same letter are not significantly different, $LSD_{0.05}$ = 1.65).

Effect of the ryegrass density on wheat yield

Statistical analysis of the data revealed that there was a significant effect of locations and of the density of ryegrass on the loss in yield (LY) of wheat, whereas the locations and their interaction with ryegrass density was non-significant. The most amount of LY of wheat was found in locations of Menzel Bourguiba (1.5 t ha^{-1}) followed by Tinja (1.2 t ha^{-1}) with a low average of ryegrass density 393 and 395 plants m^{-2}, respectively. On the other hand, the least amount of loss in yield of wheat was found in location of Mateur (0.8 t ha^{-1}) with a low average of ryegrass density 320 plants m^{-2}. The location of Metline that has the highest density of ryegrass (450 plants m^{-2}) showed the lowest losses (0.38 t ha^{-1}) in wheat yield (Table 4). The average loss of the wheat yield caused by ryegrass was 0.9 t ha^{-1} (±0.4) for all locations. The high density of ryegrass can also hinder the growth of the wheat and cause the fall of plants on the soil surface (Figure 4). The correlation between losses in yield and density showed that losses in yield of wheat are not correlated (r = 0.18 and p = 0.77) with the density of ryegrass during the cropping season 2011/12 in the north of Tunisia.

Table 3. Effect of herbicide treatments on yield components of wheat.

Treatment	**NGE**	**1000-grain weight (g)**
Témoin	34.3 a	49.3 ab
Amilcar OD	38.5 a	48.6 ab
Amilcar WG	33.8 a	49.6 ab
Apyros	34.9 a	47.1 ab
Axial	37.1 a	46.8 ab
Tolurex	37.3 a	49.8 ab
Dopler plus	34.8 a	47.1 ab
Evrest	36.7 a	43.7 b
Grasp	35.0 a	47.2 ab
Illoxan CE	37.4 a	52.1 a

Pallas OD	40.2 a	48.5 ab
Puma Evolution	32.6 a	47.9 ab
Topik	33.8 a	46.1 ab
Traxos	41.5 a	50.2 a
LSD (P= 0.05)	**10.09**	**6.22**

NGE: Number of grains per ear, 1000-grain weight: Weight of one thousand grain in g, Values followed by the same letter within a column do not differ significantly (P = 0.05).

Table 4. Effect of density of ryegrass on losses in yield (LY) of wheat in five locations.

Year	**Location**	**Density of ryegrass (plants m^{-2})**	**Losses (t ha^{-1}) LY= RMT- RM**
2011/12	Fritissa	407	0.83 c
	Mateur	320	0.70 d
	Metline	450	0.38 e
	Tinja	395	1.20 b
	Menzel Bourguiba	393	1.50 a
LSD (P= 0.05)			**0.086**

RM: yield of the treated plots (average of all herbicide treatments) in t ha^{-1}, RMT: yield of untreated control plots in t ha^{-1}, LY: loss in yield of wheat caused by ryegrass for each location (LY = RMT - RM) in t ha^{-1}, Values followed by the same letter within a column do not differ significantly (P = 0.05).

Figure 4. Effect of high density of ryegrass on wheat.

DISCUSSION

The current study indicated that commonly used herbicides by farmers for grass weed control in wheat did not provide a significant control over ryegrass biomass. Herbicides inhibitors of acetyl Coenzyme A carboxylase (ACCase) and acetolactate synthase (ALS) as Illoxan EC36, Apyros, Amilcar OD, Amilcar WG, Puma Evolution, Grasp, Traxos, Pallas OD, Evrest, Topik and Dopler plus have not satisfactory effect on ryegrass biomass. However, ryegrass escaped the herbicide treatments and produced seeds producing high biomass with most herbicides. On the other side, herbicides inhibitor of photosystem II (PSII) i.e., Tolurex significantly reduced ryegrass biomass by 96.4% compared to untreated control. Ryegrass escaped from the herbicides inhibitors of ACCase and ALS, but herbicides inhibitor of photosystem II (PSII) effectively controlled ryegrass. Similarly, the lowest wheat yield was obtained from untreated control and in the plots treated with ACCase and ALS inhibitors. Herbicide treatments have often been used for weed control in wheat. In our study, the highest wheat yield was recorded form the plots treated plot with Tolurex (6.15 t ha^{-1}) which improve wheat yield by 59%. Photosystem II (PSII) inhibitors, i.e., Tolurex reduced ryegrass biomass and improved wheat yield. In contrary, ACCase and ALS inhibitors have no satisfactory effect on ryegrass biomass and wheat yield. This is explained by the low efficacy of the ACCase and ALS inhibitors used for ryegrass control. Weed and crop densities (Radford et al., 1980; Scursoni et al., 2012), soil type, period of weed emergence and weed growth stage (O'Donovan et al., 1985) can influence herbicide efficacy. Although, the experimental field in Mateur was highly infested with ryegrass (320 plants m^{-2}), low herbicide efficacies could not be attributed to the high weed densities but due to evolution of herbicide resistance in ryegrass. Farmers in the north of Tunisia use primary herbicides to control ryegrass in wheat for several years. The repeated use of these herbicides has probably resulted in the evolution of herbicide resistance. The first report of rigid ryegrass resistant to diclofp-methyl (ACCase-inhibitor), was in 1996 in a ryegrass population in wheat crop from the North of the country (Souissi et al., 2004). Evolution of herbicide resistance in weeds is a worldwide phenomenon where over 254 species (148 dicotyledons and 106 monocotyledons) weed species have evolved resistance to one or more groups of herbicides (Heap, 2018). The herbicide treatments had no effect on the yield components (number of grains per ear and 1000-Grain weight of wheat). Akhtar et al. (1991) found that the application of grassy and broad leaf herbicides increased grain yield and yield components. High density of ryegrass in the fields and cropping system used by farmers in the north of Tunisia (Mateur) favoured the accumulation of ryegrass seed bank. Khammassi et al. (2016) reported that the north of Tunisia is heavily infested with ryegrass density may exceed 600 plants m^{-2}. Seed dormancy is a key trait playing an important role in the survival and spread of the weed in the fields for the season. The late emergence of ryegrass after seed dormancy release infested all plots. Jensen (1985) reported continuous cropping and the Mediterranean-type climate as suitable conditions for the rapid accumulation of the weed seed bank. Viable seeds germinate with the first autumn rainfall, thus permitting the successful establishment of seedlings in the crop. The influence of environmental factors on seed germination and seedling emergence of ryegrass has been investigated by Chauhan et al. (2006).

Our study showed that the loss in wheat yield was affected by ryegrass density but not correlated significantly. Ryegrass is the most prevalent grass weed in Tunisia and causing important losses in cereal yields mostly in wheat. The average loss of wheat yield was 0.9 t ha^{-1} (±0.4) t ha^{-1} with an average with a density of ryegrass more than 390 plants m^{-2}. The high density of ryegrass affected tillering and the fertility of wheat spikes, resulting in a significant decrease in yield up to 80% (Appleby et al., 1976; Palta and Peltzer. 2001). The density of ryegrass is not the only factor affecting wheat yield, but there are other factors that explain losses in yields. Losses in wheat yields are also explained by the sowing date and soil seed bank (Reeves 1976). The competition from Italian ryegrass with wheat resulted 92% losses in winter wheat yield (Hashem et al., 1998). Lemerle et al., (1996) showed that the losses caused by the ryegrass in wheat yield are influenced by the varietal competition and can vary from 20 to 60% according to the varieties. Nitrogen competition is high when ryegrass emerged with cereals, and losses in yields are in the order of 47%. Then, for a late emergence of ryegrass (6 weeks after wheat), ryegrass did not cause yield losses (Gill, 1996).

In front of this situation, it is necessary to educate farmers of the north of Tunisia about a lower effect o ACCase and of ALS inhibitors on ryegrass and the best effect of herbicides inhibitors of PSII on ryegrass and improved wheat yield. Large numbers of ryegrass populations should be collected from the north of Tunisia and tested by bioassay to confirm the herbicide resistance in ryegrass populations.

CONCLUSIONS

The highest ryegrass biomass and the lowest wheat yields were recorded in the untreated control plot and in the plots treated with ACCase and of ALS inhibitors. The lowest ryegrass biomass and the highest wheat yields were recorded in the plots treated PSII inhibitors. Tolurex is the best herbicide (PSII inhibitor) which reduced ryegrass biomass by 96.4%, while improved wheat yield by 59%.

Ryegrass that infested cereals in the north of Tunisia causes losses in yield of wheat and has probably developed resistance ACCase and of ALS inhibitors which needs to be investigated in detail. Furthermore, there is an urgent need to develop integrated weed management strategies to control ryegrass in wheat in Tunisia.

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