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Weed density assessment with crop establishment in forage crops

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ABSTRACT

Biodiversity is a key to achieve sustainable agriculture. The use of forage crop can promote biodiversity in small holder farming. This study analyzed the establishment of three forage crops (berseem clover (*Trifolium alexandrinum* L.), ryegrass (*Lolium multiflorum* Lam.) and oat (*Avena sativa* L.) with the aim to introduce them into the farmer's crop system. Their competitive ability against weeds was also evaluated. Establishment rate was 33, 40.8 and 97% for berseem, ryegrass and oat, respectively. The low establishment for berseem and ryegrass may be attributed to inadequate sowing period characterized by high temperature and low soil humidity. This is in addition to the allelopathic effect of previous crop for berseem. There was a statistically significant interaction between forage crops and sampling dates on weed density ($p < 0.000$). Berseem was able to suppress weed more than other crops with the lowest weed densities in three sampling dates (56.7, 37.3 and 23.7 plants/m^2). Berseem clover was more competitive due to its leaf area and plant architecture as a leguminous plant. Furthermore, its ability to fix atmospheric nitrogen permits to suffer less than ryegrass and oat in deficiency of fertilizer. At third sampling date, ryegrass was able to restrain weed density with an intermediate developed canopy. It did not differ significantly from weed density in berseem. Oat crop was the most weed invaded along the season. Weeds represented 43.2% and 47.8% in second and third sampling date, respectively. Poor soil, fertilizer absence and lack of moisture influenced negatively oat growth causing this invasion. A negative Pearson correlation ($p<0.001$) between crop biomass and weed density was assessed in berseem and oat indicating that weed competition was translated into a decrease of these crop biomass. Crop management created a more favorable environment for the success of these forage crops in the small holders crop system.

Key words: Competitiveness, Crop establishment, Crop management, Forage, Weed density

Agricultural system based on monoculture to optimize the productivity are widely criticized today (Malézieux *et al.* 2009). A more sustainable, socially just, and secure global food system may be created based on agroecological principles (Kremen *et al.* 2012).The successful introduction of sustainable agriculture into small holder farming system requires discontinuing unsustainable aspects of the current agricultural system specially by practicing diversified crop rotations (Wall 2007). Diversified farming system includes functional biodiversity at multiple spatial and/or temporal scales, through practices developed via traditional and/or agroecological scientific knowledge. Farmers manage this functional biodiversity to generate critical ecosystem services to agriculture (Zhang *et al.* 2007). This may provide critical inputs to agriculture, such as soil fertility, pest and disease control, water use efficiency, and pollination (Kremen *et al.* 2012).

However, Mediterranean climate areas are characterized by their high climatic variability and long drought periods during the growing season, make alternative crop choice difficult and influence competitive effects of weeds (Izquierdo *et al.* 2003).The use of forage crops is an option of income to farmers in between harvests and it permit, with other crops, to diversify the farm production (Pin *et al.* 2011). Forage crops studied in this paper are berseem clover (*Trifolium alexandrinum* L.), Italian ryegrass (*Lolium multiflorum* Lam.) and oat (*Avena sativa* L.). Berseem clover has been an important legume forage crop in semi-arid and arid areas of the world for many years (Day and Taher 1984). It contributes to soil fertility and improves soil physical characteristics (Graves *et al.* 1996) and its forage is superior to grasses in protein and mineral contents (Laghari *et al.* 2000). In Tunisia, it is traditional winter forage on small irrigated farms. Some small farmers cultivate berseem for its seed availability, its high yield and its advantage in crop rotations because it is a good precursor for cereals (Kayouli 2000). Ryegrasse is grown increasingly in rotations with potatoes and other crops to maintain a soil's content of organic matter, to improve its structure, and to reduce erosion. Ryegrass helps to alleviate problems

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associated with intensified row-crop farming and shorter rotation periods (Kunelius and Boswall 2003). Regarding oat, it is a significant crop worldwide, used in animal feed as well as human food (Rivera-Reyes *et al.* 2009).

The biodiversity of arable fields can be divided into planned and associated biodiversity (Vandermeer *et al.* 2002). Planned biodiversity refers to the diversity directly manipulated by a farmer, for instance, the crops chosen for planting. Associated biodiversity consists of the organisms that have colonized the field and thrive there, depending on the way the planned biodiversity is managed. Weed species, *i.e.* all non-cropped plant species encountered in the field, constitute an important part of the associated biodiversity of arable fields.Few studies have focused on the crop/weed interaction process. If advice is to be generated for farmers on how to achieve a competitive crop, the likely variability in crop/weed relationship should be known (Izquierdo *et al.* 2003).

Weeds often form a major problem in weak competitive crops, particularly in low input systems.The relationship between forage crops and weeds in small holder fields is poorly understood. The density of crop plants and weeds is among the various factors that influence the crop-weed balance in a field. It plays a major role in the outcome of competition between them (Altieri 1983). Further, the most accurate method of quantifying the importance of species in the weed vegetation is to count the number of plants/shoots or to measure the biomass per species (Hald 1999). The current study focused on studying the establishment of three forage crops (berseem clover, ryegrass and oat) and evaluating their competitive ability against weeds from October 2013 to April 2014 in order to be introduced into the crop system of the region.

MATERIALS AND METHODS

Vegetation sampling was conducted in three neighboring plots in the experimental field of the higher Institute of Agronomy at Chott Meriem-Tunisia (Latitude: 35.919897; Longitude: 10.565203 (in decimal degrees)). Berseem clover '*Khadhraoui*' and Italian ryegrass '*Thibar*' were sown at the rate of 20 kg/ha on 10th October 2013 instead of recommended rates of 25-30 and 30-40 kg/ha, respectively . Oat '*Meliane*' was sown at the recommended rate (100 kg/ha) on 1st November 2013. All were certified seeds.

All the three forage crops were seeded by manual broadcast onto the soil surface.Cultural operations consisted of a deep ploughing in June 2013 after previous crop harvest was done. Crops did not receive fertilizers or chemical treatments.

Vegetation samplings were carried out in a plot of 90 m^2 (15 × 5 m) in the middle of each field. Vegetation density assessment was recorded separately for crop and weeds by 0.25 m^2 quadrants. There were five sampling dates for vegetation density assessment. It was 7, 10, 18, 23 and 28 weeks after sowing for berseem and ryegrass and 4, 7, 15, 20 and 25 WAS for Oat. Biomass measurements were taken at 7, 23 and 28 weeks after sowing (WAS) for berseem and ryegrass and 4, 20 and 25 WAS for Oat. Six samples using 0.5 m^2 quadrants were taken at randomly from each crop plots. The weed dry matter was assessed by cutting the weeds at ground level, drying them in an oven at 60°C, and recording the final dry weight. The average weed dry biomass per treatment was calculated and expressed in g/m^2.

A two-way ANOVA (in IBM SPSS statistical software, version 20) was conducted to examine the effects of forage crops and sampling dates on weed density. A bivariate correlation was also performed to assess the relationship between crop biomass and weed density; and between total vegetation biomass (crop and weeds) and total vegetation density.

RESULTS AND DISCUSSION

Assessment of forage crop establishment

Mean berseem clover density was 221.3 plants/m^2, (SD=78.6, with an emergence rate of 3% (Fig. 1). The crop was rainfed, so low rainfall in the sowing period (< 1 mm) may affect germination rate. The temperature and rainfall data for the study period, collected from a weather station located near the experimental site, are shown (Fig. 2).

Kayouli (2000) found high sensitivity of berseem clover to soil moisture that can significantly reduces its establishment. It is for this reason that berseem clover is traditionally recommended for irrigated farms in Tunisia. Sub-optimal temperatures (< 25-30°C) after berseem sowing also affected germination (Dalianis 1980). The low germination may also result from high allelopathic effect of barley (Kremer and Ben-Hammouda 2009), which was the previous crop of berseem clover.

Mean Italian ryegrass density was 96.0 plants/m^2 (SD=57.78). The emergence rate was 40.8% which was low due to the fact that it was sown at a period characterized by drought affecting soil moisture, essential for seed germination. According to Kunelius and Boswall (2003), successful

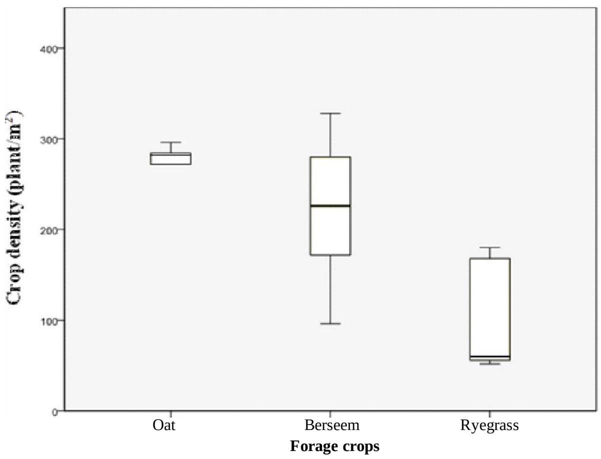

Fig. 1. Establishment of forage crop

(7 WAS Berseem clover and Italian ryegrass and 4 WAS Oat (plants/m^2)

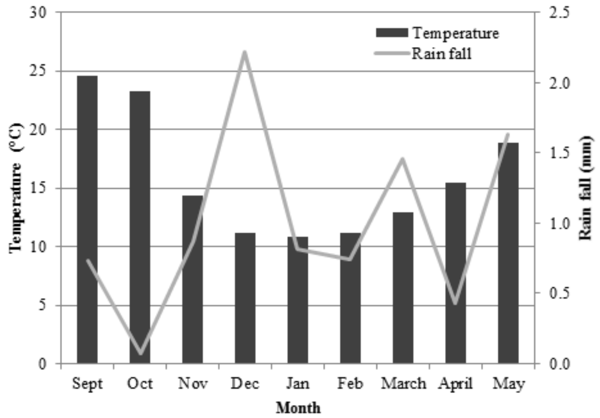

Fig. 2. Monthly mean temperature (°C) and rainfall (mm) from September 2013 to May 2014

establishment of ryegrass may be hampered by lack of moisture after seeding. Further, rapid establishment and homogenous growth can be achieved when ryegrass is sown late in August due to adequate temperature and long photoperiod (Gazwani 2012). Mean oat density was 277.3 plants/m^2, (SD=15.56). The emergence rate at four weeks after oat sowing was about 97%. Oat was sown under a favorable temperature (15°C). Vasilevski (2004) affirmed that optimum oat emergence temperature was 25°C. Sufficient soil moisture due to rainfall, assisted good emergence.

Berseem clover, ryegrass and oat shared the characteristic to be grown under rainfed conditions in areas where the annual rainfall exceeds 450 mm requirements, whereas Chott Meriem is characterized by an annual rainfall of 300 mm (Benzarti 2003). So, local irrigation was needed in this case. Irrigation before sowing was also recommended to help homogenous emerging (Gazwani 2012).

The standard deviation of the mean was important for berseem clover and ryegrass indicating high establishment variability among the field. Since sowing was unsuccessful, crop establishment was very heterogeneous. In fact, these two crops were not adapted to the soil moisture variability in rainfed conditions These are cultivated in the humid zones as well as in irrigated areas in Tunisia (Kayouli 2000). The heterogeneity was less pronounced in oat. This early age success was due to its easy establishment even on badly prepared fields (Kayouli 2000). This characteristic makes it a crop well rooted in the tradition of Tunisian small holders.

Effect of forage crop and sampling dates on weed density

There was a statistically significant interaction between forage crops and sampling dates on total weed density ($p < 0.000$). Therefore, an analysis of simple main effects for sampling dates was performed. All pairwise comparisons were run for each simple main effect with reported 95% confidence intervals and *p*-values Bonferroni-adjusted within each simple main effect (Table 1).

At the first sampling date, berseem clover was in elongation stem stage seven weeks after sowing. It was able to suppress weed more than crops with the lower weed density (56.7 plants/m^2, SD= 20.24), corresponding to 20% of total vegetation (Fig. 3). Oat and ryegrass were, statistically, more weedy. Weed density represented, 29% and 55% of total vegetation in oat and reygrass, respectively. Ryegrass at seven weeks after sowing was tillering. This low establishment might be the cause of its weed infestation. At equal crop densities, berseem clover suppressed weeds better than oat. Berseem clover was ahead of the oat that was at first leaves development stage. Plants were small and weak. Furthermore, the variability in morphological and physiological traits between the berseem clover as a leguminous and the oat as a cereal influences their competitiveness against weeds. Den Hollander *et al.* (2007) indicated that leaf area and plant architecture are considered important characteristics determining the competitive ability of species.

Three weeks later corresponding to second sampling date, berseem clover at 10 WAS reached the stage of axillary shoot formation. These plants were strong enough to continue suppressing weeds more than other crop. Weed density was 37.3 plants/m^2 (SD= 11.29) representing 22.1% of total vegetation. Its quick germination and growth enhanced the berseem competitiveness against weed. For this property, Clark (2007) suggested its sowing as a nurse crop during establishment of other crops such

Table 1. Pairewise comparisons evaluating forage crop and sampling date effects

Sampling date (WAS**)	Forage crop (I)	Forage crop (J)	Difference of means (I-J)	Sig.[b]	Confidence interval of 95%[b] Lower limit	Upper limit
7	Oat	Berseem	56.667*	0.009	11.071	102.262
		Ryegrass	-5.333	1.000	-50.929	40.262
	Berseem	Oat	-56.667*	0.009	-102.262	-11.071
		Ryegrass	-62.000*	0.004	-107.596	-16.404
	Ryegrass	Oat	5.333	1.000	-40.262	50.929
		Berseem	62.000*	0.004	16.404	107.596
10	Oat	Berseem	142.000*	0.000	96.404	187.596
		Ryegrass	39.333	0.115	-6.262	84.929
	Berseem	Oat	-142.000*	0.000	-187.596	-96.404
		Ryegrass	-102.667*	0.000	-148.262	-57.071
	Ryegrass	Oat	-39.333	0.115	-84.929	6.262
		Berseem	102.667*	0.000	57.071	148.262
18	Oat	Berseem	53.333*	0.016	7.738	98.929
		Ryegrass	40.000	0.106	-5.596	85.596
	Berseem	Oat	-53.333*	0.016	-98.929	-7.738
		Ryegrass	-13.333	1.000	-58.929	32.262
	Ryegrass	Oat	-40.000	0.106	-85.596	5.596
		Berseem	13.333	1.000	-32.262	58.929
23	Oat	Berseem	5.333	1.000	-40.262	50.929
		Ryegrass	-4.667	1.000	-50.262	40.929
	Berseem	Oat	-5.333	1.000	-50.929	40.262
		Ryegrass	-10.000	1.000	-55.596	35.596
	Ryegrass	Oat	4.667	1.000	-40.929	50.262
		Berseem	10.000	1.000	-35.596	55.596
30	Oat	Berseem	-13.333	1.000	-58.929	32.262
		Ryegrass	2.333	1.000	-43.262	47.929
	Berseem	Oat	13.333	1.000	-32.262	58.929
		Ryegrass	15.667	1.000	-29.929	61.262
	Ryegrass	Oat	-2.333	1.000	-47.929	43.262
		Berseem	-15.667	1.000	-61.262	29.929

*. The mean difference is significant at .05.
** WAS: (7, 10, 18, 23 and 28) weeks after Berseem and ryegrass sowing, corresponding to 4, 7, 15, 20 and 25 WAS Oat.
b. Adjustment for multiple comparisons: Bonferroni; Standard error= 18.852

as oats, annual ryegrass and alfalfa. Weed density increased in oat and ryegrass up to 179.3 plants/m^2, (SD= 90.96) and 140.00 plants/m^2 (SD= 56.31), respectively. This increase indicated that there was still an empty soil for seedling emergence of new individuals (Tilman 1997). Burke and Grime (1996) have explained that amount of bare ground was consistently the most important factor determining the probability of successful emergence of weeds in grassland systems.

Oat did not succeed to smother weeds that represent about the half (43.21%) of vegetation community. Oat plants, at the stem elongation stage were thin and could not cover the soil to compete with weed. In fact, oat is a relatively demanding plant that should not be installed on poor soils without addition of manure or fertilizer (Husson *et al.* 2012). Nitrogen deficiency symptoms of oat have appeared since the early growth stages and became more severe as the plant grew causing short and thin stems.

At the third sampling date, we noted increase in ryegrass competitiveness due to decrease of weed density by near the half. Ryegrass weed density 37.08 plants/m^2 (SD= 32.44) did not differ from weed density in berseem clover 23.75 (SD= 18.96). It's known that ryegrass is susceptible to nitrogen fertilization which deficiency causes slow growth, however, deficiency needs were met through the previous crop that is sulla (*Hedysarum carnosum* Desf.). Thereby, ryegrass was able to regain partially to develop an intermediate canopy which makes it more competitive than weeds for light, moisture, and nutrients (Isik *et al.* 2009). Berseem clover success was due to its highly efficient water use (Clark, 2007) compared to the other two crops and so it could be adapted to rainfed conditions while ryegrass and oat could not adapted. Oat crop was, most invaded with weeds (53.33 plants/m^2) where weed presented 47.80% of the total vegetation density. It is important to mention that the use of recommended seeding rates in berseem clover and ryegrass, which are higher than the sown doses, helped to smother weed greater.

Crop growth remained relatively slow until the end of the season. We found that ar 28 WAS, berseem clover was at flowering stage. Oat and ryegrass required more than 20 weeks to reach the flag leaf stage. There were no significant differences in weed density between crops for the two last sampling dates. In fact, these two sampling dates coincided with the life-cycle end of weeds explaining decrease of weed density in all crops. New emergences were limited because of the drought season.

Standard deviations of weed density indicated the high variability among the field in most of the observations. In fact, all weed infestations had a patchy (aggregated or clumped) distribution. Weeds were never distributed uniformly throughout field because of variable characteristics of weeds. This heterogeneity can be explained by the sampling error in experimental fields.

Density and biomass relationship

Data on dry crop biomass and on weed density are summarized (Table 2, Fig. 4). Pearson correlation coefficients were -0.692 and -0.664, for berseem clover and oat crop, respectively representing a strong significant ($p< 0.001$) negative correlation between above ground crop biomass (g/m^2) and weed density (plants/m^2). Weed competition was translated directly in decrease of these crops biomass. In fact, Scrosati (2000) reported that plant density was negatively correlated to stand biomass in

Table 2. Pearson correlation between dry crop biomass and weed density

Dry Crop biomass	Weed density		
	Berseem clover	Ryegrass	Oat
Pearson Correlation	-0,692**	-0,119	-0,664**
Sig. (two-tailed)	0,001	0,637	0,003

**The correlation is significant at the 0.01 level (two-tailed)

Table 3. Pearson correlation between dry vegetation biomass and vegetation density

Dry Vegetation biomass	Vegetation density		
	Berseem clover	Ryegrass	Oat
Pearson Correlation	-0,314	0,495*	-0,561*
Sig. (two-tailed)	0,204	0,037	0,015

*The correlation is significant at the 0.01 level (two-tailed)

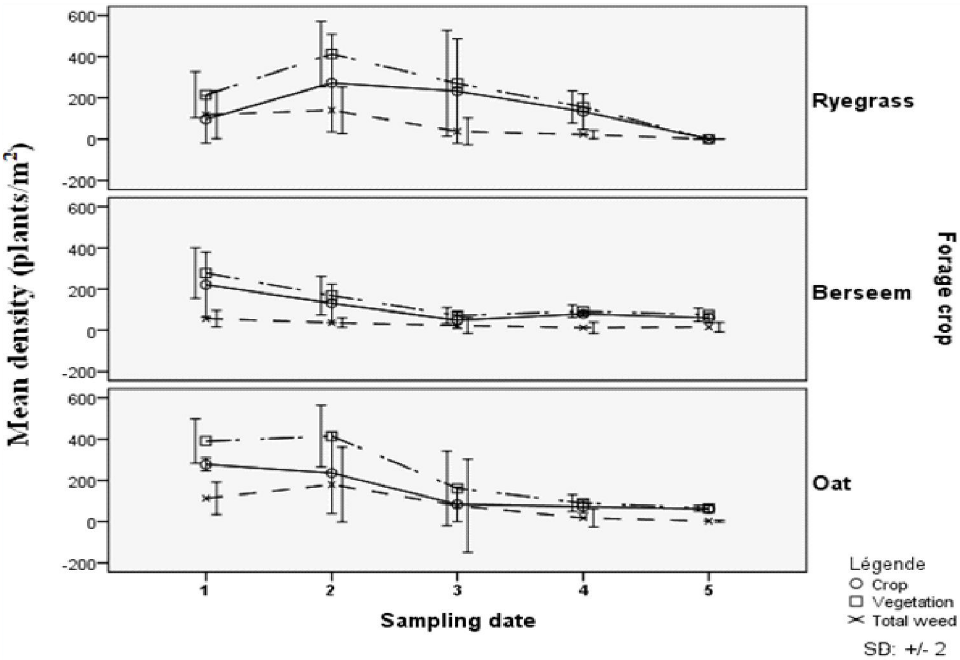

Fig. 3. Evolution of total vegetation, crop and weed densities through sampling dates across the cropping season (plants/m^2)

(Sampling dates: 1, 2, 3, 4, and 5 corresponded to 7, 10, 18, 23 and 28 weeks for berseem and ryegrass sowing, respectivelly, and to 4, 7, 15, 20 and 25 WAS for oat)

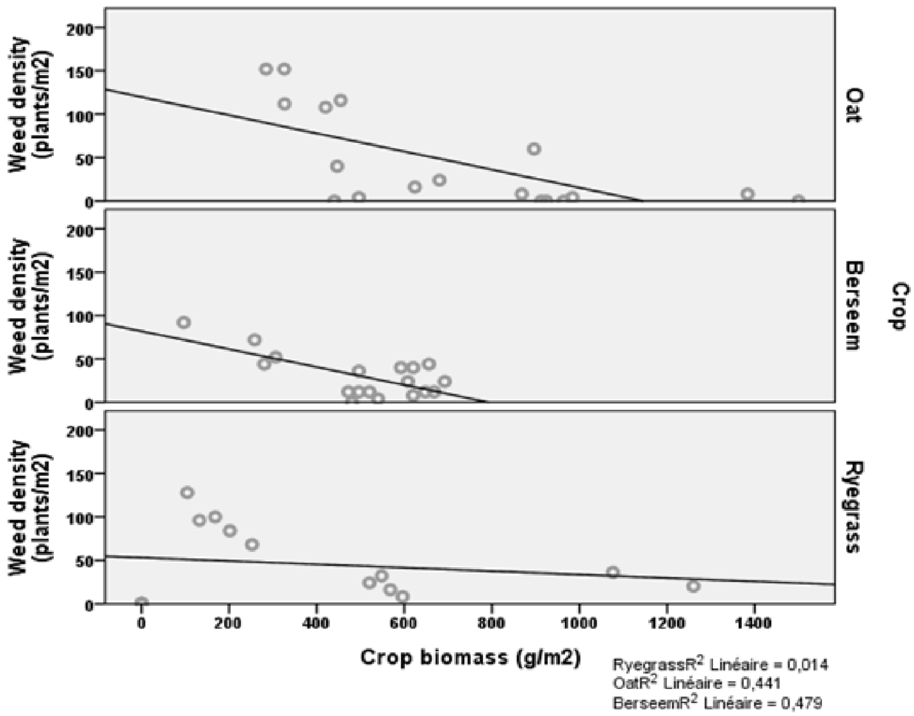

Fig. 4. Relationship between crop biomass (g/m^2) and weed density (plants/m^2) in oat, berseem and ryegrass crops

case of crowded stands. However, such correlation was not found in ryegrass crop (r=-0.119, p= 0.637) suggesting that there were other factors more important in accounting for variability in ryegrass biomass than weed presence. It was suggested that lack of moisture, as crop was carried in rainfed, has a great effect on biomass rate. Moreover, insufficient moisture stoped tiller emergence and reduce significantly ryegrass biomass production compared to irrigated plots (Korte and Chu 1983).

Total vegetation density, composed by both the crop and the weeds, has a negative correlation with total vegetation above ground biomass in oat (r= -0.561, p= 0.015) and a negative trend was not statistically significant in berseem (r= -0.314, p= 0.204) (Table 3, Fig.5). In fact, as density increased, growth of plants becames limited by shortage of environmental supply factors such as light, water and nutrients. Lonsdale (1990) reported that stands of small plants end to accumulate biomass and increase in size until they approach the thinning line. Then, they suffer mortality in a relation to this biomass accumulation (mortality derived from "self-thinning" inside pure stand or from inter-specific competition. In ryegrass case, there was a significant positive correlation (r= +0.495, p= 0.037) between total vegetation density and total vegetation above ground biomass. Density and size of the vegetation community were huge enough to compete and interfere with each other, and increasing density resulted in an increase in vegetation biomass.

Conclusion

This study evaluated the establishment of three crops (berseem clover, Italian ryegrass and oat) and their ability to suppress weeds. It assessed the

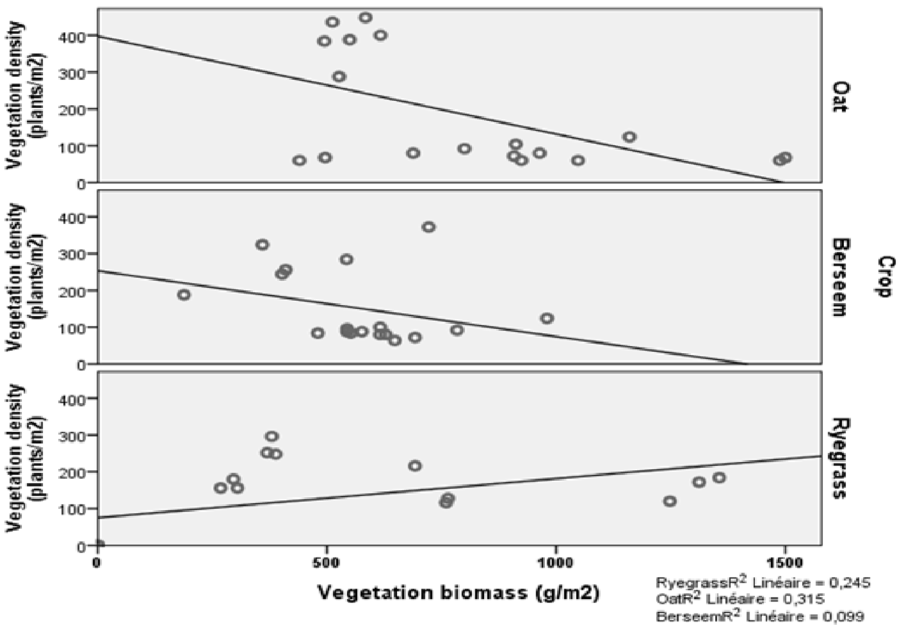

Fig. 5. Relationship between total vegetation biomass (crop and weeds) (g/m^2) and total vegetation density (plants/m^2) in oat, berseem and ryegrass crops

possibility of their introduction to diversify the cropping system since diversification is a key for sustainable agricultural development. Crop establishment hasn't been very successful, which weakened the competitiveness of crops and allowed weeds to invade the field. If we consider weed density as one of the most important factors in competition (Gherekhloo *et al.* 2010), berseem clover was the most competitive crop against weeds and so less invaded. Italian rye-grass has an intermediate competitive strength. In general, the trajectory of weed density dynamic was decreasing through the season. However, weed competition was strong enough to translate weed density increase into a biomass decrease for both berseem clover and oat.

Poor establishment and weed-crop competition were especially influenced by management-related factors, including late sowing, low seeding rate, lack of irrigation and fertilization. Nevertheless, adjusting the crop management enhanced crop competitiveness and aided to suppress weeds. Earlier sowing than those of this experiment offered better conditions for these forage crops. It was reported that berseem clover and rye-grass should be sown better in late August. "*Meliane*" oat cultivar sowing should be done preferably in early October. Irrigation is necessary in the region of Chott Meriem since annual rainfall is less than 450 mm. Fertilizer application is required, especially, in poor soils to enhance crop performance. To reduce fertilizer's charges, it is possible to include forage crops in cropping systems where it can benefit from the back-effects of fertilization made to the main crops (after growing potatoes for example).

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