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RESEARCH ARTICLE

Effect of Different Levels of Nitrogen Fertilization on Forage Yields and Quality of Hairy Vetch (*Vicia villosa*, Roth) Triticale (*Xtriticosecale*, Witmack) Mixtures

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Abstract:

Background:

Intercropping legumes with cereals for forage production is a sustainable technique showing several environmental benefits.

Aim:

This study aimed to investigate the effect of different levels of nitrogen fertilization on forage yields and quality of hairy vetch (*Vicia villosa*, roth) –triticale (*X triticosecale*, witmack) mixtures.

Methods:

The effect of five increasing nitrogen rates (0, 10, 20 30 and 50 kg N ha⁻¹) on the growth rate, forage yield, quality and interspecific competition of hairy vetch-winter triticale mixture was investigated under rainfed regime at the INRAT experimental station of Mornag.

Results:

Nitrogen application induced an increase in dry matter yield from 7.6 to 9 T DM ha⁻¹ obtained with 30 kg N ha⁻¹. This rate corresponds to the most efficient nitrogen rate as expressed by kg DM per Kg of added N. It reached a mean value of 47 kg DM kg⁻¹ N. Moreover, application of increasing nitrogen rate caused an increase in LER (Land Equivalent Ratio) of the mixture over the unit (LER=1.58 at 30 kg N ha⁻¹) and the competition ability of the triticale through CRT increase, suggesting the advantage of the mixture over sole crops. Crude protein content has been increased by two points from zero nitrogen application to other rates. However, no evident variation in fibers and Metabolizable Energy (ME) content was detected along with nitrogen application, but, mean values of 18% of CP content, 34% of NDF content and 9.7 Mj kg⁻¹ DM of ME were denoted as high forage nutritional values compared to other most Tunisian conventional forages.

Conclusion:

The results of this study indicate that hairy vetch intercrops with winter triticale produced higher dry matter than the common vetch sole crop.

Keywords: Nitrogen, Mixture, Vetch, Triticale, Yield, Quality.

Article History

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1. INTRODUCTION

The global human population is projected to reach beyond 9.8 billion by the end of the year 2050 [1]. Thus, productivity must be increased through sustainable production by taking into account climate change, rarefaction of resources like phosphorus and water, and losses of fertile lands. Crop production should be increased further without deteriorating the soil fertility, environment, and food quality [2, 3]. Diversi-

fication strategies include enhancing crop genetic diversity recognized as a crucial tool for sustainable agro-ecological development. Legumes can play an important role being a major biological nitrogen source, which are also a powerful option to reduce synthetic nitrogen fertilizers use and associated fossil energy consumption. Nevertheless, restoring a high crop-specific and genetic diversity will be difficult to achieve over the next 40 years [4] because most of these traditional crops and varieties are unattractive in comparison to modern, valuable and high-yielding crops. Grasses and other forage crops provide nutrients at low cost, maintain rumen function, thus supporting animal health, and add value to the products [5,

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6]. The use of forage grasslands to feed livestock, aiming at both higher forage productivity and quality, is a potential solution [7]. Intercropping of cereals and legumes for forage production also has major advantages compared to forage sole crops like better utilization of abiotic resources [8], higher and more stable yields [9], better land use efficiency [10], and complementarity in the use of the available resources [11].

Intercropping of annual forage legumes with winter cereals for forage production is used extensively in the Mediterranean region [12]. Systems involving legumes as base crop and cereals as intercrops, have been observed to provide several major advantages such as higher total yield and better land use efficiency [13, 14], yield stability [9], better utilization of light, water, and nutrients [14, 15], improved soil conservation [14, 16], and maintenance of soil fertility. Inclusion of grain legumes in intercrops has increased forage protein yields, and improved forage nutritive value [17 - 19]. Niggli *et al.* [20] describe that intercropping is based on eco-functional intensification and may enhance crop productivity [21], increase the land utilization ratio [22] and emit significantly lower amounts of greenhouse gases compared to sole crops [23, 24]. Applying synthetic nitrogen fertilizers to increase farmland productivity in the short term and the overall farm production like for the Green Revolution, new systems could be designed based on symbiotic N₂ fixation by legumes. Synthetic N fertilizers are used in a substantial amount to increase crop productivity in the short term [2]. Unbalanced use of synthetic fertilizers, however, deteriorates the soil health in the long term [25]. Moreover, biological nitrogen fixation occurs mainly through symbiotic association as a major nitrogen source which is the main objective also because it means that less N fertilizer input is required [26], reducing CO₂ emissions [27] and lowering the carbon footprints of agricultural products [28]. The new sustainable crop production systems will heavily rely on symbiotic N fixation by legumes [29].

Indeed, the mixture interactions based on functional complementarity could be a more suitable way to obtain high yield stability along with simultaneous atmospheric nitrogen inputs as compared to the more classical introduction of legumes as sole crops [30]. With intercropping vetch and triticale, low N external input should partially level out the difference without a decrease in the yield of the two species. The objective of the research was to determine the effect of nitrogen fertilizer rates on the performance of hairy vetch-winter triticale intercrop in terms of forage yield, nitrogen content and feed quality.

2. MATERIALS AND METHODS

2.1. Site and Experiment Set Up

A field experiment was performed during 2011-2012 at the INRAT experimental station of Mornag situated in the north of Tunisia (36°37'20" N; 10°17'29" E) under rainfed conditions. The total precipitation from September 2011 to June 2012 was 667 mm (Table 1). The texture of the soil was clay-loam. The experimental structure was a replacement series, consisting of vetch (*Vicia villosa*, Roth) and triticale (*X tritosecale*, Witmack) in pure stands and different mixtures. Table 1

presents the mean monthly temperature and monthly precipitation of the experimental location during the growing season 2011-2012.

2.2. Measurements and Calculations

2.2.1. Agronomic, Yield and Quality Measurements

The experimental design was a Randomized Complete Block (RCB) design with 15 treatments (three treatments: triticale alone crops, hairy vetch alone crops, and triticale-vetch intercrops) and five doses of nitrogen giving place to 15 possible combinations which were arranged according to a model of replacement series of the additive type with three replications. Nitrogen treatments were applied by manually broadcasting dry ammonium nitrate (NH₄NO₃) to the soil surface. The experimental plots consisted of six rows, 1,2 x 3 m long and with 0.20 m spacing between rows. Blocks were separated by 0.5 m buffer zone. The number of seeds sown for vetch and triticale crops was 250 seeds m⁻². For the intercrops, the number of seeds sown was 200 and 50 seeds m⁻² for vetch and triticale, respectively, corresponding to a vetch-triticale ratio of 80%-20%. The applied ratio of the intercrops was selected because it was proposed as the most productive for crude protein and achieved the best LER for the local conditions [31]. All the plants in each plot were hand-harvested at full maturity, and grain yields (dry weight basis) were determined for sole crops and intercrops individually. In the intercrop treatments, triticale and vetch were harvested separately. Forage quality was assessed on dried material after it was subsampled and ground on a laboratory mill using a 1 mm screen. Analyses were conducted for Crude Protein concentration (CP) by the Kjeldahl method. Acid Detergent Fiber (ADF) and Neutral Detergent Fiber (NDF) were analyzed as described by Goering and Van Soest [32].

Nitrogen Use Efficiency (NUE) is defined as production per unit of N available in the soil. This is represented by the amount of grain or forage produced divided by the amount of N supplied to the plant by the soil. The two components of NUE are the efficiency of uptake and N utilization to produce grain or forage [33].

Metabolizable Energy (ME) content of forages was calculated according to Menke and Steingass, [34] using the equation given below:

$$ME \text{ (MJ/Kg DM)} = 2.20 + 0.136 \text{ GP} + 0.0574 \text{ CP}$$

Where; GP, 24 h net gas production (mL/200 mg DM); CP, crude protein (%).

2.2.2. Competition Ratio (CR)

The competitive ratio gives a good measure of the competitive ability of the component crops in an intercropping system [35] represents the individual Land Equivalent Ratios (LERs) of the component crops and also takes into account the proportion of the crops sown in intercropping.

$$CR_{\text{legume}} = LER_{\text{legume}} / LER_{\text{cereal}} * Z_j / Z_i$$

$$CR_{\text{cereal}} = LER_{\text{cereal}} / LER_{\text{legume}} * Z_i / Z_j$$

Z_i = sown proportion of legume in combination with intercrop cereal

Z_j = sown proportion of cereal in combination with intercrop legume

If the values of CR < 1, there is a positive benefit. It means there is limited competition between component crops and they can be grown as intercrops [36].

2.2.3. Land Equivalent Ratio (LER)

Land Equivalent Ratio (LER) is a basic criterion for intercropping advantage and is closely related to the efficiency of intercrops on using the environmental resources in comparison with their monocrops. The LER designates the relative land area required for monocrops to achieve the yield produced by an intercrop [37]. Based on grain yield and the areas each intercrop occupied, the Land Equivalent Ratio (LER) was calculated using the following equation:

$$LER_{Yield} = \frac{LER_{Yield-Cereal} + LER_{Yield-Legume}}{LER_{Yield-Solecrop}} = \frac{Yield_{Cereal-Intercrop} + Yield_{Legume-Intercrop}}{Yield_{Cereal-Solecrop} + Yield_{Legume-Solecrop}}$$

An LER >1 meant the intercropping had a yield advantage over sole crops, and an LER <1.0 meant there was no yield advantage [38].

2.3. Statistical Analyses

All of the measured parameters for forage yield and nutritional value were subjected to analysis of variance using the GLM procedure of SAS version 8 (SAS, 2000). The sources of variation considered were treatment (mixture, triticale alone, hairy vetch alone), nitrogen dose factor (0, 10, 20, 30 and 50 kg N ha⁻¹) block factor, and interactions. The chosen device is a completely random block model with two factors and 3 repetitions. For competition parameters (LER and CR), the percentage of the vetch in the mixture that concerns only the treatments with the intercropping system, the sources of variation are the nitrogen dose factor and the block factor. The average values for each parameter were compared with each other using the Duncan test at 5% threshold.

3. RESULTS AND DISCUSSION

3.1. Dry Matter Yield, Quality and Agronomic Traits

Triticale alone had the highest rate of dry matter with an average value of 19.2% (Table 2). The hairy vetch had the lowest rate of 13.7%. Yasar and Ugar [39] reported that Triticale (*Triticosecale* Wittmack) grown with legume has a better forage quality and greater yield potential than triticale grown alone. The mixture presented an intermediate DM rate reaching an average value of 15.4%, thus registering a gain of 2 points compared to that of the legume. Whether for the intercropping legumes with cereals or for its two partners grown in monoculture, the rates of DM found in this study were still comparable with those found in the previous work initiated on the same plant material [31, 40]. The increase of the DM content of the intercrops compared to that of the legume in monoculture is one of the advantages of the intercropping system. It has been confirmed for the vetch-oat combination [41] and the bean-durum combination [42]. The

intercropping soybean with pearl millet recorded the lowest yield and harvest index as compared to the sole crop especially when the cereal counterparts raised with a higher dose of N [43]. The increase in the yield of sole soybean was mainly due to the increased growth parameters and their positive influence on the yield parameters. Moreover, intercropping brings some advantages and it can be greater when the yield of one or both of the respective sole crops is quite low, thus suggesting that intercropping could be a more suitable way to obtain stable yields in organic farming and low-nitrogen availability systems. These results confirm those obtained both in conventional agriculture and organic farming, showing a higher grain yield in intercrop when compared to the respective sole crops and in particular for cereal/legume mixtures [44]. Intercropping systems have been shown to be more productive than monocropping [36]. This may be through the efficient use of light energy and other growth resources. Also, the optimization of land resource use could be achieved when crops are grown under intercropping and in this way, plant population density also increases. Intercropping represents a more efficient use of natural resources, with decreased inputs and increased sustainability in crop production [45]. The intercropping of maize and sorghum with soybean supplied with all levels of N to intercrops (except no N) resulted in significantly higher net returns [46, 47]. Different types of intercrops can be designed depending on the objective and outlet. For example, combining a cereal and a grain legume allows wheat (*Triticum aestivum* L.) to be grown with a smaller supply of nitrogen (N) than wheat grown as a sole crop [48, 49] or to produce grain legumes without the limiting factors usually observed in sole crops such as lodging and weeds [50]. The legume-based intercropping produces higher yield from a unit area by making the optimal use of all available resources that could not be utilized by a single crop [47].

Results revealed that with increasing nitrogen fertilizer levels, the yield of intercropping systems with N fertilizer application decreased but the yield of triticale and hairy vetch sole cropping increased (Table 1) [51]. Sadeghi and Kazemeini

Table 1. Monthly precipitation (mm) and mean monthly temperature (°C) during the growing season of experimentation at INRAT experimental station of Mornag situated in the North of Tunisia.

Month	Precipitation (mm)	Temperature (°C)
September	22	25
October	233	19,2
November	111,5	15
December	84,7	11,5
January	27	9
February	68,5	8,5
March	59,5	12,8
April	55	16
May	6	21,5
June	0	25,8
Total	667,2	Mean 16,4

Table 2. Average dry matter content (DM) values for three combinations (triticale alone, hairy vetch alone and triticale-hairy vetch mixture) receiving 5 levels of nitrogen intake (0, 10, 20, 30 and 50 u N ha⁻¹). Different letters indicate significant difference among the levels of nitrogen treatment at P<0.05.

	Rate of DM (%)					Average
	Level of Nitrogen Fertilization (kg N ha ⁻¹)					
	0	10	20	30	50	
Triticale	20,1±1,4	18,8±0,3	18,7±1,1	19,2±1,6	19,3±0,0	19,2±0,9a
Hairy vetch	13,8±0,5	12,5±0,8	12,4±1,1	14,5±0,9	15,2±2,1	13,7±1,1c
Mixture	15,8±2,6	13,6±0,4	17,4±4,3	14,9±1,9	15,4±0,6	15,4±1,9b
Average	16,6±1,5a	15±0,5a	16,2±2,2a	16,2±1,5a	16,6±0,9a	16,1±1,3

conducted an experiment on bean+maize intercropping systems where the intercrop received 0, 100 and 200 kg N. Results showed that with increasing the levels of N fertilizer, the yield of bean sole cropping decreased but the yield of maize sole cropping increased. On the other hand, in intercropping systems with N fertilizer application, the yield of both the crops increased [16]. Layek *et al.* [13] also reported that the application of N significantly increased the crop yield, grain yield, maize equivalent yield, and economic benefits of maize-legume intercropping systems. Increased diversification by the use of alternative crops, diversifying agro-ecosystems and rotations or cultivating mixtures is also more likely to fulfil multiple objectives like, for example: (i) increasing yield and quality of grain and forage, (ii) providing ecological services, (iii) improving adaptability of production systems to climate change [52] and (iv) potentially allowing a greater resilience of systems to biotic and abiotic stresses [53].

However, the Nitrogen Use Efficiency (NUE) of the combination, expressed in kg of DM per kg of the supplied nitrogen increased by an average value of 10 with the dose of 10 u N ha⁻¹, reaching a maximum of 47 kg MS Kg⁻¹ nitrogen at a dose of 30 u N ha⁻¹ and then dropped drastically to a value of 13.4 at the dose of 50 u N ha⁻¹ (Fig. 2). Therefore, the maximum dose of the test does not necessarily correspond to the level of “economic” nitrogen fertilization, which would make it possible to have the highest efficiency. A similar result was reported by Hassen *et al.* [54] for the vetch-oat association, where it has been shown that a twice-divided intake of 20 u N ha⁻¹ is likely to provide efficient fertilization for optimal forage yield. Noulas *et al.* [55] concluded that there is a large potential

for increasing NUE by improving N recirculation, use of fast and inexpensive crop N monitoring tools and higher yield and sustainability [56]. Hawkesford mentioned that NUE is a complex trait comprising two key major components, N uptake and N utilization efficiency, both also complex traits in themselves, each involving many physiological processes and biochemical pathways.

In the present study, CP of intercrops with different levels of nitrogen was significantly similar than that of zero N application. This was obviously the effect of the high vetch contribution (80%) in the mixtures tested in the present work (Fig. 3). Similarly Dordas *et al.* [57], reported that when the contribution of legume in the intercrops was high, then there was a significant increase in CP. The CP content of the mixture studied remains very high compared with the conventional fodder usually used in Tunisian, in this case, oats which, at best, have a protein content of just over 8% [58]. With a moderate nitrogen intake, the hairy vetch-winter triticale mixture studied had a CP content well above the average of 14% content reported by Mariotti *et al.* [59]. for the durum-bean combination, in the average vetch-oats content 17%, [60] and the ability of legumes to biologically fix N² allows grasses to accumulate higher concentrations of tissue N in mixture than in monoculture [61]. Grass monocultures had lower CP than legume monocultures and legume-grass mixtures.

Variance analysis revealed a significant effect of the nitrogen fertilizer factor as the percentage of the vetch in the mixture was at its maximum level (80% on average) with treatments at 0 and 10 kg N ha⁻¹. This proportion decreased to 62% for the treatment corresponding to 50 kg N ha⁻¹ (Table 3). Bennila and Rebai [31] concluded that hairy vetch should be sown at a proportion in the mixture greater than 60%. Other works conducted on the association between hairy vetch and cereal have proved that hairy vetch should be in a greater amount in the initial mixture to ensure good attendance at adult plant stage. We cite, among other studies, the work done on the vetch-barley association by Shobeiri *et al.*, and Tosti *et al.*, and those conducted on the association between vetch-triticale by Yucel and Avci [61 - 63]. Common vetch (*Vicia sativa* L.) is frequently grown in the Mediterranean countries for animal feeding, a yearly legume with a climbing habit and high protein, is very popular to grow with cereals in intercropping [64]. Various distinctive cereal crops like wheat, oat (*Avena sativa* L.), and barley are tried to fit in intercropping with the common vetch [65].

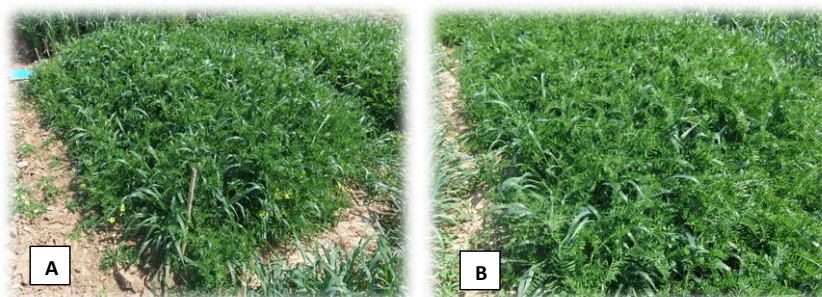


Fig. (1). Intercropping systems tested at Mornag experimental station, Tunisia, with A 30 u N ha⁻¹ and B 0 u N ha⁻¹ at their growth period.

Table 3. Mean value of the proportion of hairy vetch (%) in the final mixture at harvest. Different letters indicate significant difference among levels of nitrogen treatment at $P < 0.05$.

Dose of Nitrogen (u N ha ⁻¹)	Proportion of Hairy Vetch (%)
0	79.0 ab
10	81.5 a
20	77.3 ab
30	72.9 b
50	62.5c
PPDS	8,1

hourgidis *et al.* 2006). Intercropping of cereal/legume enhances soil preservation, smothers weed, gives anchorage to crops, yields strength, and feeds curing and may expand crude protein rate, protein yield, and length of an ideal harvest period of hay over grasses [66]. Crops such as grain legumes are of particular interest in organic farming where nitrogen availability is often limited especially in the absence of livestock [67] causing yield depressions and lower protein concentrations of non-legume products as compared to conventional agriculture. Cereal/legume intercropping plays an important role as highly relevant in low-N-input systems and organic farming where nitrogen is often a limited resource for crop growth [68, 69].

Table 4. Acid Detergent Fiber (ADF) and Metabolizable Energy (ME) for 3 combinations (triticale alone, hairy vetch alone and triticale-hairy vetch mixture). Different letters indicate significant difference among levels of nitrogen treatment at $P < 0.05$.

Treatments	NDF (%)	ME (MJ/kg DM)
Triticale	41.1a	13.4a
Hairy vetch	33.8b	9.7b
Mixture	34.8b	9.7b

The analysis of variance (Table 5) for the three combinations (triticale alone, hairy vetch alone and association) and for the 5 doses of nitrogen showed a highly significant variation in the NDF content between the three combinations but did not show any apparent effect on nitrogen fertilization. For example, triticale in monoculture had the highest NDF content of 41.1%. The intercrops and hairy vetch in monoculture exhibited average grades of 34.8 and 33.8%, respectively (Table 4). These intercropping and monocropping systems are significantly equivalent and this can be explained by the preponderance of the hairy vetch in the final mixture regardless of the nitrogen dose used. These levels can be compared to those obtained on triticale alone or on the triticale-vetch mixture described by Yucel and Avci, or durum wheat-vetch studied by Kara and Sirin [70 - 74].

The LER index was greater than high levels of nitrogen intake (20, 30 and 50 kg N ha⁻¹), suggesting a definite advantage in yield in intercropping against the cultivation of cereal and legume (intercrops) in isolation (sole cropping). (Fig. 4). In contrast, LER is lower than one (1.0) for 0 and 10 Kg N ha⁻¹, suggesting a disadvantage of vetch-triticale's association with monocultures of both the crops. The highest LER was obtained with the 30 kg ha⁻¹ treatment, reaching a

value of 1.58. This value means that to achieve the same yield of the combination, monocultures require 58% more surface area. In addition, an intake higher than 30 u N ha⁻¹ is not accompanied by a significant increase in the LER index suggesting that the dose 30 u N ha⁻¹ is the optimum dose for improving the productivity in relation to the pure cultures of its two crops. Moreover, this dose also corresponds to the maximum efficiency of an intercropping system to use the limited available resources as against their pure stand (Fig. 4).

The LER of the maize-soybean intercropping system was recorded to be about 1.30, which means that there was 30% advantage in intercropping against the sole cropping of maize and soybean separately [75]. In several studies, the LER index has always been reported to be higher in the absence or in the presence of low nitrogen fertilization of intercropping system [76]. This is the case for common vetch-barley [77], soybean-corn and the pea-durum combination [78] because the mineral nitrogen supply hinders the symbiotic fixation and consequently the growth of the legume, thus making it more vulnerable to the competition of the cereal. However, our results are in agreement with those of [79] Mariotti *et al.* (2011) who found that for the faba bean-durum combination, the LER index increased with the addition of nitrogen. The analysis of the variance relative to the two competition parameters LER (Land Equivalent Ratio) and CRT (Competition Ratio) of triticale, calculated for the forage yield is recorded in Table 5. It reveals a significant variation of these two parameters with the nitrogen fertilization factor.

Similarly, the results related to the competitiveness index of triticale against the legume (CRt) revealed a significant variation of this parameter with the different nitrogen dose used. Thus, CRt was the lowest at the dose of 10 u N ha⁻¹. It increased thereafter with the increase of the level of the nitrogen supply to reach a maximum at the dose 50 u N ha⁻¹ (Fig. 5).

This suggests that the contribution of nitrogen to the association has led to a significant increase in the competitiveness of triticale compared to the legume through the stimulation of its growth and the increase of the contribution of triticale in the final mixture. Moreover, a positive and highly significant correlation coefficient was calculated between the competitiveness index CRt and the proportion (%) of triticale in the final mixture ($r = 0.68^{***}$, $n = 15$) (Table 5).

The contribution of mineral nitrogen to the intercrops stimulated the development of the cereal, increased its proportion in the mixture and the competitiveness with respect to the majority vetch in the mixture as confirmed by the coefficient of competitiveness CRt. Thus the triticale could play its role of tutor facilitator for vetch hair naturally with tendrils. In fact, the height of triticale and vetch increased significantly with the increase in nitrogen intake. This gain in height is of some agronomic interest in that the triticale hairy vetch intercropping recorded the highest value of a cutting height which makes it easier to harvest mechanically compared to the hairy vetch in the monoculture. Moreover, Rakeih *et al.* [80], concluded that the CR values of cereals exhibited an increasing trend from the first cutting date through the second one, while the opposite was observed in CR of legumes which

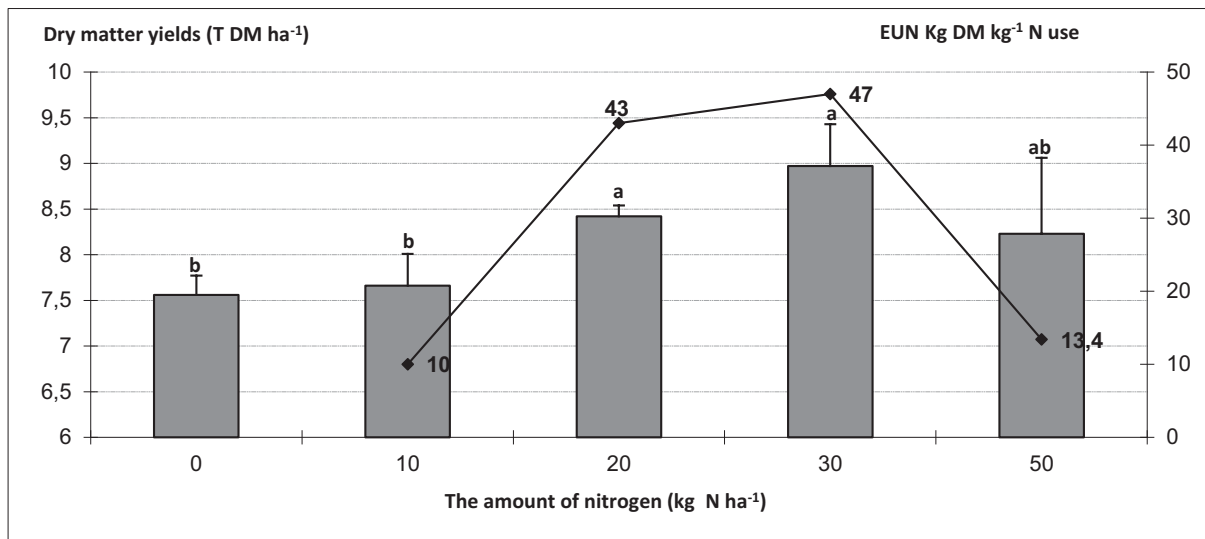


Fig. (2). Variation in forage yield with different levels of nitrogen and nitrogen use efficiency (NUE) at zero N application. The bars at the top of each histogram represent the standard deviations. Histograms with different letters represent significantly different yields.

Table 5. Analysis of variance of hairy vetch-triticale intercrops for Dry Matter Yield (DM), Land Equivalent Ratio (LER), Competition Ratio (CR_i), crude protein concentration (MAT), Acid Detergent Fiber (ADF) and Neutral Detergent Fiber (NDF) across treatments of nitrogen level (N) and blocs.

Source of Variation	Df DM t ha ⁻¹	LER	CR _i MAT NDF ADF		
Bloc	2 Ns	Ns	Ns	Ns	Ns
N	4 **	*	*	*	*
erreur	6 -	-	-	-	-
Modèle	6 -	-	-	-	-
R ²	- 70.6	78.5	76	77.4	68.7
CV	- 6.18	18	22	4.56	8.8

*Significant at 0.05 level of probability. ** Significant at 0.01 level of probability.

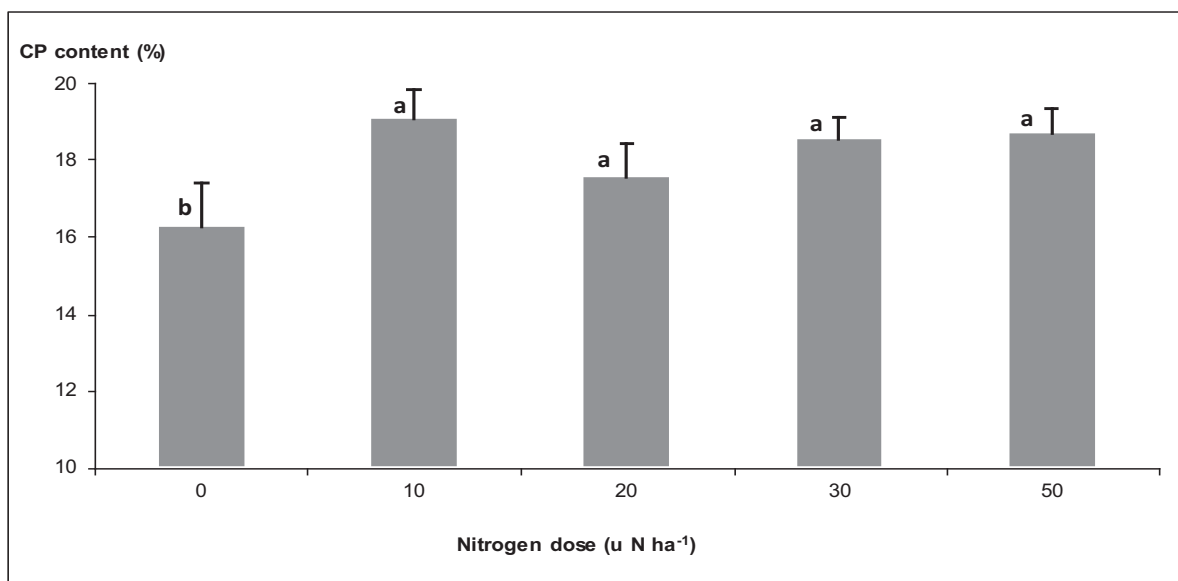


Fig. (3). Variation of the crude protein content of the hairy vetch-triticale mixture as a function of the nitrogen doses. Histograms with different letters are significantly different at the 5% threshold.

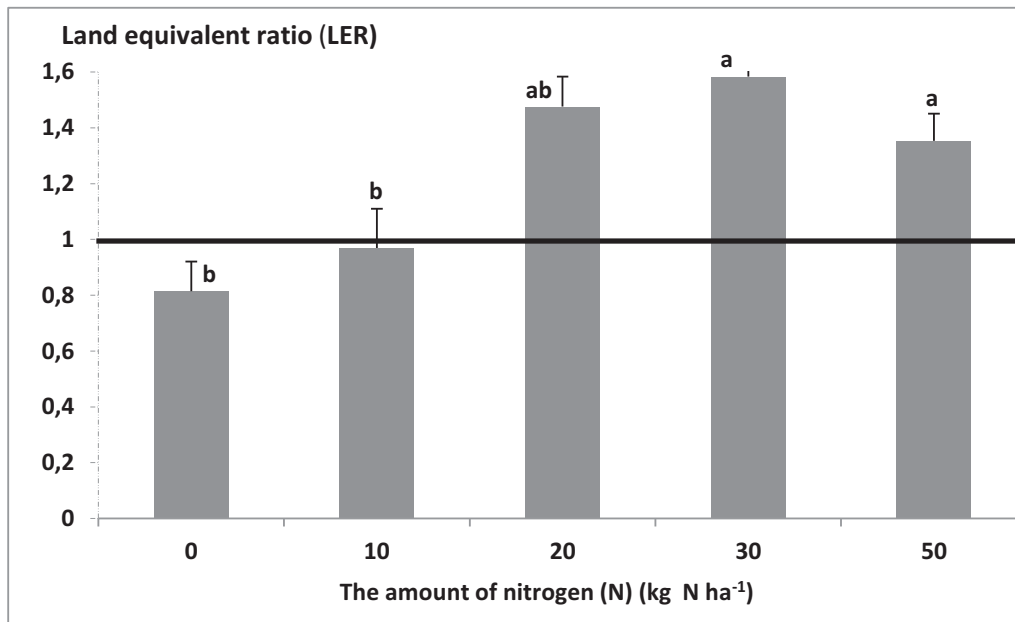


Fig. (4). Variation of the LER index with the different levels of nitrogen applied to the hairy vetch-winter triticale mixture. Different letters indicate significant difference among levels of nitrogen treatment at $P < 0.05$.

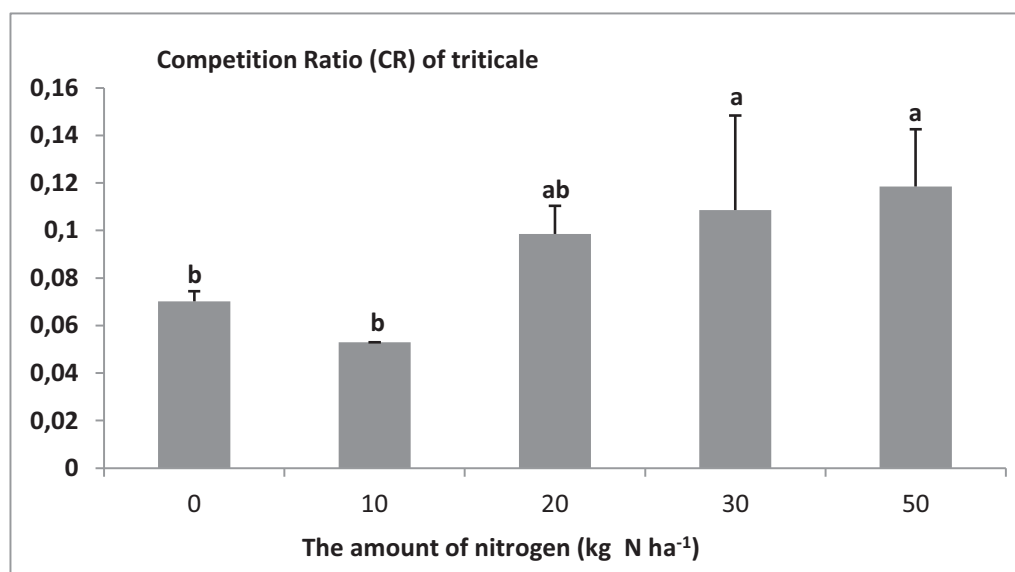


Fig. (5). Variation of the Competition Ratio (CR) of triticale with the different levels of nitrogen applied. Different letters indicate significant difference among levels of nitrogen treatment at $P < 0.05$.

decreased, indicating the dominance of cereals under these crop mixtures. Aşci *et al.* [81] indicated that increasing forage pea ratios in mixtures can also improve N supply to triticale. Therefore, increasing aggressivity levels were observed in triticale with decreasing triticale sowing rates in mixtures. The present findings comply with the results of Dordas *et al.* [82] indicating varying interspecies competition levels with species and sowing rates in mixtures. The growth rate of species was lower in the intercrops than in monocrops due to the strong competitive ability of triticale. Aggressivity and partial actual yield loss indicated cereals as the dominant species [83].

Intercropping has also been shown to: (i) improve soil conservation [84], (ii) favour weed control [85], (iii) reduce pests and diseases [86] and (iv) provide better lodging resistance [87]. Cereals nutrient uptake is the principal crop that absorbs nutrients from upper soil layers [88, 89]. Legume, being able to fix atmospheric N in the soil, improves the soil fertility and reduces the completion of limited soil nutrients within the soil [90, 91]. Although the cereal in an intercropping system that was reported to positively respond to a higher dose of N (120 kg N/ha), the associated legume (pigeon pea) responded only to the application of 80 kg N/ha [92]. The supply of biofertilizer (*Azotobacter*) along with 150 kg N/ha

also reported to increase the productivity of maize intercropped with soybean [92, 93]. Intercropping of suitable component crops has several socioeconomic [94] biological [95] and ecological [96] advantages over monocropping. Intercropping increased biodiversity, productivity and stability of agroecosystems [97] as the component crops provide a suitable habitat for a number of insects and soil organisms which otherwise is not present in a monocrop situation [98].

CONCLUSION

The triticale hairy vetch association increased the proportion of triticale in the final mixture and its competitiveness, expressed in terms of the CRt index, and thus its facilitating effect on the legume is proved beneficial for the intercrops whose yield in MS is higher at high doses of nitrogen. However, the maximum efficiency of nitrogen utilization was obtained with the 30 u N ha⁻¹ dose, which represents an optimal and economical dose for the biomass and should not be exceeded. In addition, the MAT content of the combination was higher in the presence of nitrogen. It reached an average value of 18.3% against 16.2% under the treatment 0 u N ha⁻¹. It is thought to be due to the increase in the triticale MAT content, since the MAT content of the monoculture hairy vetch, unlike that of the triticale alone,

did not change with increasing nitrogen doses. The average MAT content of the combination was 17.97%. It exceeds to that of triticale by 10 points and remains very close to that of hairy vetch alone (average of 19%) and indicates a high forage value of the intercropping system. In conclusion of this study, triticale-vetch hairy intercrop is a system efficiently acquiring nitrogen even when other resources are scarcely hindering dry matter accumulation by plants. The lower the external N input, the greater the gain from cereal-legume intercropping due to more effective biological N fixation. Our results suggest that under severe conditions of light, soil N fertilizer rate for triticale-vetch hairy intercrop should not exceed 30 kg/ha. That meets the requirements for a more sustainable low-input agriculture. Most intercrops of a legume with cereal showed significant advantages relative to their monocrops due to better DM production, resource-use efficiency and economics under low-input farming.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

Not applicable.

HUMAN AND ANIMAL RIGHTS

No animals/humans were used for studies that are the basis of this research.

CONSENT FOR PUBLICATION

Not applicable.

AVAILABILITY OF DATA AND MATERIALS

Not applicable.

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CONFLICT OF INTEREST

The authors declare no conflict of interest, financial or otherwise.

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References

- [1] United Nations, Department of Economic and Social Affairs, Population Division World. Population prospects: The 2017 revision, key findings and advance tables Working Paper 2017; No. ESA/P/WP/248
- [2] Bedoussac L, Journet EP, Hauggaard-Nielsen H, *et al.* Ecological principles underlying the increase of productivity achieved by cereal-grain legume intercrops in organic farming: A review. *Agron Sustain Dev* 2015; 35: 911-35. [<http://dx.doi.org/10.1007/s13593-014-0277-7>]
- [3] Meena RS, Meena VS, Meena SK, Verma JP. The needs of healthy soils for a healthy world. *J Clean Prod* 2015; 102: 560-1. b [<http://dx.doi.org/10.1016/j.jclepro.2015.04.045>]
- [4] Pardey PG, Pingali PL. Reassessing international agricultural research for food and agriculture. Report prepared for GCARD 2010 http://www.fao.org/docs/eims/upload/278047/3568_Pardey_Pingali_2010_GCARD_text_figs_tabs_1_.pdf
- [5] Broderick GA. Performance of lactating dairy cows fed either alfalfa silage or alfalfa hay as the sole forage. *J Dairy Sci* 1995; 78(2): 320-9. [[http://dx.doi.org/10.3168/jds.S0022-0302\(95\)76640-1](http://dx.doi.org/10.3168/jds.S0022-0302(95)76640-1)] [PMID: 7745 152]
- [6] Yolcu H, Gullap MK, Yildirim M, Lithourgidis A, Deveci M. Effects of organic solid cattle manure application on nutritive value of winter cereal forages. *J Plant Nutr* 2016; 39: 1167-73. [<http://dx.doi.org/10.1080/01904167.2016.1143496>]
- [7] Tsiplakou E, Anagnostopoulos CJ, Liapis K, Haroutounian SA, Zervas G. Pesticides residues in milks and feedstuff of farm animals drawn from Greece. *Chemosphere* 2010; 80(5): 504-12. [<http://dx.doi.org/10.1016/j.chemosphere.2010.04.069>] [PMID: 20537 679]
- [8] Sadeghpour A. Switchgrass stand density and yield as influenced by seedbed preparation methods in a sandy loam soil. *BioEnergy Res* 2015; 8: 1840-6. [<http://dx.doi.org/10.1007/s12155-015-9638-6>]
- [9] Lithourgidis AS, Vasilakoglou IB, Dhima KV, Dordas CA, Yiakoulaki MD. Forage yield and quality of common vetch mixtures with oat and triticale in two seeding ratios. *Field Crops Res* 2006; 99: 106-13. [<http://dx.doi.org/10.1016/j.fcr.2006.03.008>]
- [10] Lithourgidis AS, Vlachostergios DN, Dordas CA, Damalas CA. Dry matter yield, nitrogen content, and competition in pea-cereal intercropping systems. *Eur J Agron* 2011; 34: 287-94. [<http://dx.doi.org/10.1016/j.eja.2011.02.007>]
- [11] Varma D, Meena RS, Kumar S. Response of mungbean to fertility and lime levels under soil acidity in an alley cropping system in Vindhyan region, India. *Int J Chem Stu* 2017; 5(2): 384-9.
- [12] Hauggaard-Nielsen H, Ambus P, Jensen ES. The comparison of nitrogen use and leaching in sole cropped versus intercropped pea and barley. *Nutr Cycl Agroecosyst* 2003; 65: 289-300. [<http://dx.doi.org/10.1023/A:1022612528161>]
- [13] Jayanta Layek, Das Anup, Mitran Tarik, Nath Chaitanyaprasad, Meena Ram Swaroop. Cereal+Legume Intercropping: An Option for Improving Productivity and Sustaining Soil Health. *Legumes for Soil Health and Sustainable Management* 2018; 347-386
- [14] Dhima KV, Lithourgidis AS, Vasilakoglou AC, Dordas CA. Competition indices of common vetch and cereal intercrops in two seeding ratio. *Field Crops Res* 2007; 100: 249-56. [<http://dx.doi.org/10.1016/j.fcr.2006.07.008>]
- [15] Brooker RW, Bennett AE, Cong WF, *et al.* Improving intercropping: A synthesis of research in agronomy, plant physiology and ecology.

- New Phytol 2015; 206(1): 107-17.
[http://dx.doi.org/10.1111/nph.13132] [PMID: 25866856]
- [16] Anil L, Park RHP, Miller FA. Temperate intercropping of cereals for forage: A review of the potential for growth and utilization with particular reference to the UK. *Grass Forage Sci* 1998; 53: 301-17.
[http://dx.doi.org/10.1046/j.1365-2494.1998.00144.x]
- [17] Javanmard A, Nasab ADM, Javanshir A, Moghaddam M. Janmo hammadi H. Forage yield and quality in intercropping of maize with different legumes as double cropped. *J Food Agric Environ* 2009; 7: 163-6.
- [18] Carr PM, Martin GB, Caton JS, Poland WW. Forage and nitrogen yield of barley-pea and oat-pea intercrops. *Agron J* 1998; 90: 79-84.
[http://dx.doi.org/10.2134/agronj1998.00021962009000010015x]
- [19] Strydhorst SM, King JR, Lopetinsky KJ, Harker KN. Forage potential of strip intercropping: I. Yield advantage and interspecific interactions on nutrients. *Field Crops Res* 2008; 71: 123-37.
- [20] Niggli U, Fließbach A, Hepperly P, Scialabba N. Low greenhouse gas agriculture: Mitigation and adaptation potential of sustainable farming systems. Food and Agriculture Organization of the United 2009. Nations <http://www.fcrn.org.uk/sites/default/files/low-greenhouse-gas-agriculture.pdf>
- [21] Qin AZ, Huang GB, Chai Q, Yu AZ, Huang P. Grain yield and soil respiratory response to intercropping systems on arid land. *Field Crops Res* 2013; 144: 1-10.
[http://dx.doi.org/10.1016/j.fcr.2012.12.005]
- [22] Agegnehu G, Ghizaw A, Sinebo W. Yield potential and land-use efficiency of wheat and faba bean mixed intercropping. *Agron Sustain Dev* 2008; 28: 257-63.
[http://dx.doi.org/10.1051/agro:2008012]
- [23] Oelhermann M, Echarte L, Vachon K, Dubois C. the role of complex agroecosystems in sequestering carbon and mitigating global warming. *Earth Environ Sci* 2009; 6: 20-31.
[http://dx.doi.org/10.1088/1755-1307/6/24/242031]
- [24] Naudin C, vander Werf HMG, Jeuffroy MH, Corre-Hellou G. Life cycle assessment applied to pea-wheat intercrops: a new method for handling the impact of co-products. *J Clean Prod* 2014; 73: 80-7.
[http://dx.doi.org/10.1016/j.jclepro.2013.12.029]
- [25] Meena RS, Meena VS, Meena SK, Verma JP. the needs of healthy soils for a healthy world. *J Clean Prod* 2015; 102: 560-1. b
[http://dx.doi.org/10.1016/j.jclepro.2015.04.045]
- [26] Fustec J, Lesuffleur F, Mahieu S, Cliquet JB. Nitrogen rhizodeposition of legumes. *Rev Agron Sustain Dev* 2010; 30: 57-66.
[http://dx.doi.org/10.1051/agro/2009003]
- [27] Nieder R, Benbi DK. Carbon and nitrogen in the terrestrial environment. Dordrecht: Springer 2008; p. 430.
[http://dx.doi.org/10.1007/978-1-4020-8433-1]
- [28] Gan YT, Liang C, Hamel C, Cutforth H, Wang H. Strategies for reducing the carbon footprint of field crops for semiarid areas: A review. *Agron Sustain Dev* 2011; 31: 643-56.
[http://dx.doi.org/10.1007/s13593-011-0011-7]
- [29] Ladha JK, George T, Bohlool C. Biological nitrogen fixation for sustainable agriculture: extended versions of papers presented in the symposium, role of biological nitrogen fixation in sustainable agriculture at the 13th congress of soil science Springer, Japan. 2013
- [30] Hauggaard-Nielsen H, Gooding M, Ambus P, *et al.* Pea-barley intercropping for efficient symbiotic N₂ fixation, soil N acquisition and use of other nutrients in European organic cropping systems. *Field Crops Res* 2009; 113: 64-71. b
[http://dx.doi.org/10.1016/j.fcr.2009.04.009]
- [31] Bennila F, Rebai N. Effet des proportions du mélange et du stade de récolte sur le rendement fourager et la valeur nutritionnelle de l'association triticale (X triticosecale, Wittmack)- vesce bleue (*Vicia villosa*, Roth). *Projet de Fin d'Etudes* 2011; ESA-Mateur: 53.
- [32] Goering HK, Van Soest PJ. In Forage fiber analyses. US Dept of Agriculture. *Agr. Handbook n° 379*, 1970 20 p
- [33] Moll RH, Kambrath EJ, Jackson WA. Analysis and interpretation of factors, which contribute to efficiency of nitrogen utilization. *Agron* 1982; 74: 562-4.
[http://dx.doi.org/10.2134/agronj1982.00021962007400030037x]
- [34] Menke KH, Steingass H. Estimation of the energetic feed value obtained from chemical analysis and in vitro gas production using rumen fluid. *Anim Res Dev* 1988; 28: 7-55.
- [35] Willey RW, Rao MR. A competitive ratio for quantifying competition between intercrops. *Exp Agric* 1980; 16: 117-25.
[http://dx.doi.org/10.1017/S0014479700010802]
- [36] Ghosh PK. Growth, yield, competition and economics of groundnut/cereal fodder intercropping systems in the semi-arid tropics of India. *Field Crops Res* 2004; 88: 227-37.
[http://dx.doi.org/10.1016/j.fcr.2004.01.015]
- [37] Sullivan KT. Promoting health behavior change. (ERIC Document Reproduction Service no. 1998, ED 429053).
- [38] Caballero R, Goicoechea EL, Hernaiz PJ. Forage yield and quality of common vetch and oat sown at varying seed ratios and seeding rates of common vetch. *Field Crops Res* 1995; 41: 135-40.
[http://dx.doi.org/10.1016/0378-4290(94)00114-R]
- [39] Yasar C, Asiy U, Rkan D, Khawar KM, Atak M, Sebahattin Z. Use of gamma rays to induce mutations in four pea (*Pisum sativum* L.) cultivars. *Turk J Biol* 2006; 30: 29-37.
- [40] Jlidi R. Effet de la date de semis sur la productivité et la qualité fourragère du triticale (X tritico secale Wittmack). *Projet de Fin d'Etudes*. ESA-Chott Meriam 2011.
- [41] Ram K, Meena RS. Evaluation of pearl millet and mungbean intercropping systems in Arid Region of Rajasthan (India). *Bangladesh J Bot* 2014; 43(3): 367-70.
[http://dx.doi.org/10.3329/bjb.v43i3.21616]
- [42] Mariotti M, Masoni A, Ercoli A, Arduini I. Optimizing forage yield of durum wheat/field bean intercropping through N fertilization and row ratio. *Grass Forage Sci* 2011; 67: 243-64.
[http://dx.doi.org/10.1111/j.1365-2494.2011.00839.x]
- [43] Layek J, Shivakumar BG, Rana DS, Munda S, Lakshman K. Growth pattern, physiological indices and productivity of different soybean (*Glycine max*) based intercrops as influenced by nitrogen nutrition. *Indian J Agron* 2012; 57: 349-56.
- [44] Bedoussac L, Justes E. Dynamic analysis of competition and complementarity for light and N use to understand the yield and the protein content of a durum wheat-winter pea intercrop. *Plant Soil* 2010; 330: 37-54.
[http://dx.doi.org/10.1007/s11104-010-0303-8]
- [45] Bedoussac L, Justes E. Dynamic analysis of competition and complementarity for light and N use to understand the yield and the protein concentration of a durum wheat-winter pea intercrop. *Plant Soil* 2010; 330: 37-54. b
[http://dx.doi.org/10.1007/s11104-010-0303-8]
- [46] Hauggaard-Nielsen H, Gooding M, Ambus P, *et al.* Pea-barley intercropping and short-term subsequent crop effects across European organic cropping conditions. *Nutr Cycl Agroecosyst* 2009; 85: 141-55. a
[http://dx.doi.org/10.1007/s10705-009-9254-y]
- [47] Srivastava RK, Bohra JS, Singh RK. Yield advantage and reciprocity functions of wheat (*Triticum aestivum*) + Indian mustard (*Brassica juncea*) inter-cropping under varying row ratio, variety and fertility level. *Int J Agric Sci* 2007; 77(3): 139-44.
- [48] Egbe OM. Effects of plant density of intercropped soybean with sorghum on competitive ability of soybean economic yield at Otobi, Benue State, Nigeria. *J Cereals Oilseed* 2010; 1: 1-10.
- [49] Ghosh PK, Manna MC, Bandyopadhyay KK, *et al.* Acharya Subba Rao CL. Inter specific interaction and nutrient use in soybean/sorghum intercropping system. *Agron J* 2006; 98: 1097-108.
[http://dx.doi.org/10.2134/agronj2005.0328]
- [50] Naudin C, Corre-Hellou G, Pineau S, Crozat Y, Jeuffroy MH. The effect of various dynamics of N availability on winter pea-wheat intercrops: crop growth, N partitioning and symbiotic N₂ fixation. *Field Crops Res* 2010; 119: 2-11.
[http://dx.doi.org/10.1016/j.fcr.2010.06.002]
- [51] Pelzer E, Bazot M, Makowski D, *et al.* Pea-wheat intercrops in low-input conditions combine high economic performances and low environmental impacts. *Eur J Agron* 2012; 40: 39-53.
[http://dx.doi.org/10.1016/j.eja.2012.01.010]
- [52] Corre-Hellou G, Fustec J, Crozat Y. interspecific competition for soil N and its interaction with N₂ fixation, leaf expansion and crop growth in pea-barley intercrops. *Plant Soil* 2011; 282: 195-208.
[http://dx.doi.org/10.1007/s11104-005-5777-4]
- [53] Zhang G, Yang Z, Dong S. Interspecific competitiveness affects the total biomass yield in an alfalfa and corn intercropping system. *Field Crops Res* 2011; 124: 66-73.
[http://dx.doi.org/10.1016/j.fcr.2011.06.006]
- [54] Hassen H, Mansouri M. Intérêt de la fertilisation azotée pour l'association vesce - avoine en zone humide de Tunisie. *INRAT. Fourrage* 1996. 143, 173-180
- [55] Christos N, Juan MH, Miltiadis T, Qin R. Agronomic Assessment of Nitrogen Use Efficiency in Spring Wheat and Interrelations with Leaf Greenness Under Field Conditions. *Commun Soil Sci Plant Anal* 2018; 49(7): 763-81.
[http://dx.doi.org/10.1080/00103624.2018.1431267]

- [56] IAASTD. International assessment of agricultural knowledge, science and technology for development. Global Report <http://apps.unep.org/publications/pmtdocuments/-Agriculture%20at%20a%20crossroads%20%20Synthesis%20report2009AgricultureatCrossroadsSynthesisReport.pdf>
- [57] Dordas CA, Vlachostergios DN, Lithourgdis AS. Growth dynamics and agronomic-economic benefits of pea-oat and pea-barley intercrops. *Crop Pasture Sci* 2012; 63: 45-52. [<http://dx.doi.org/10.1071/CP11181>]
- [58] Noulas C, Herrera JM, Teziouvalekas M, Qin R. Agronomic Assessment of Nitrogen Use Efficiency in Spring Wheat and Interrelations with Leaf Greenness under Field Conditions. *Commun Soil Sci Plant Anal* 2018; 49. [<http://dx.doi.org/10.1080/00103624.2018.1431267>]
- [59] Mariotti M, Masoni A, Ercoli L, Arduini I. Optimizing forage yield of durum wheat/field bean intercropping through N fertilization and row ratio. *Grass Forage Sci* 2012; 67: 243-54. [<http://dx.doi.org/10.1111/j.1365-2494.2011.00839.x>]
- [60] Sibakov J, Myllymäki O, Holopainen U, *et al.* Lipid removal enhances separation of oat grain cell wall material from starch and protein. *J Cereal Sci* 2010; 54: 104-9. [<http://dx.doi.org/10.1016/j.jcs.2011.04.003>]
- [61] Padulosi S, Hodgkin T, Williams JT, Haq N. Underutilized crops: trends, challenges and opportunities in the 21st century. *Managing plant genetic resources*. Wallingford: CAB International 2002; pp. 323-38. [<http://dx.doi.org/10.1079/9780851995229.0323>]
- [62] Nefzaoui A, Chermiti A. Composition chimique et valeur nutritive pour les ruminants des fourrages et concentrés d'origine tunisienne. *Annales de l'INRAT* 1989; 13: 3-35.
- [63] Hassen H. Les associations fourragères annuelles : Cas de la vesce - avoine (*Vicia sativa* L.) - (*Avena sativa* L.). *Annales de l'INRAT* 2009; 81: 125-258.
- [64] Qamar IA, Keatinge JDH, Mohammad N, Ali A, Khan MA. Introduction and management of common vetch/barley forage mixtures in the rainfed areas of Pakistan. 3. Residual effects on following cereal crops. *Aust J Agric Res* 1999; 50: 21-7. [<http://dx.doi.org/10.1071/A98043>]
- [65] Tosti G, Benincasa P, Guiducci M. Competition and facilitation in hairy vetch-barley intercrops. *Ital. J. Agron. Riv Agron* 2010; 3: 239-47.
- [66] Bennila F, Rebai N. Effet des proportions du mélange et du stade de récolte sur le rendement fourrager et la valeur nutritionnelle de l'association triticale (X triticosecale, Wittmack)- vesce belue (*Vicia villosa*, Roth). *Projet de Fin d'Etudes. ESA-Mateur* 2011.
- [67] Shobeiri SS, Habibi D, Kashani A, *et al.* Evaluation of hairy vetch (*Vicia villosa* Roth) in pure and mixed cropping with barley (*Hordeum vulgare* L.) to determine the best combination of legume and cereal for forage production. *Am J Agric Biol Sci* 2010; 5(2): 169-76. [<http://dx.doi.org/10.3844/ajabssp.2010.169.176>]
- [68] Yucel C, Avci M. Effect of different ratios of common vetch (*vicia sativa* L.) -triticale (*triticosecale wittmack*) mixtures on forage yields and quality in cukurova plain in turkey. *Bulg J Agric Sci* 2009; 15: 323-32.
- [69] Banik P, Midya A, Sarkar BK, Ghosh SS. Wheat and chickpea intercropping systems in an additive series experiment: Advantages and weed smothering. *Eur J Agron* 2006; 24: 325-32. [<http://dx.doi.org/10.1016/j.eja.2005.10.010>]
- [70] David C, Jeuffroy MH, Henning J, Meynard JM. Yield variation in organic winter wheat: A diagnostic study in the Southeast of France. *Agron Sustain Dev* 2005; 25: 213-23. [<http://dx.doi.org/10.1051/agro:2005016>]
- [71] Desclaux D, Nolot JM, Chiffolleau Y, Gozé G, Leclerc C. Changes in the concept of genotype x environment interactions to fit agriculture diversification and participatory plant breeding. *Pluridisciplinary point of view. Euphytica* 2008; 163: 533-46. [<http://dx.doi.org/10.1007/s10681-008-9717-2>]
- [72] Delogu G, Faccini N, Faccioli P, Reggiani F, Lendini M, Berardo N. Dry matter yield and quality evaluation at two phenological stages of forage triticale grown in the Po Valley and Sardinia, Italy. *Field Crops Res* 2002; 74: 207-15. [[http://dx.doi.org/10.1016/S0378-4290\(02\)00002-3](http://dx.doi.org/10.1016/S0378-4290(02)00002-3)]
- [73] Royo C, Tribó F. Triticale and barley for grain and for dual-purpose (forage + grain) in a Mediterranean-type environment. II. Yield, yield components and quality. *Aust J Agric Res* 1997; 48: 423-32. [<http://dx.doi.org/10.1071/A96115>]
- [74] Kara NT, Sirin Y. The effect of mixture rate and cutting time on hay quality in winter and spring sown vetch+Wheat mixture under rainfed conditions. *African Crop Sciences* 2007; 8: 173-7.
- [75] Marchiol L, Miceli F, Pinosa M, Zerbi G. Intercropping of soybean and maize for silage in northern Italy: effect of nitrogen level and plant density on growth, yield and protein content. *Eur J Agron* 1992; 1: 207-11. [[http://dx.doi.org/10.1016/S1161-0301\(14\)80071-3](http://dx.doi.org/10.1016/S1161-0301(14)80071-3)]
- [76] Ofori F, Stern WR. Cereal-legume intercropping systems. *Adv Agron* 1987; 41: 41-90. [[http://dx.doi.org/10.1016/S0065-2113\(08\)60802-0](http://dx.doi.org/10.1016/S0065-2113(08)60802-0)]
- [77] Mohsenabadi GH, Jahansooz MR, Chaichi MR, Mashhadi HR, Liaghat AM, Savaghebi GR. Evaluation of barley-vetch intercrop at different nitrogen rates. *J Agric Sci Technol* 2008; 10: 23-31.
- [78] Ibrahim M. Influence of arbuscular mycorrhizal fungi (AMF) on the nutrition of the cotton (*Gossypium hirsutum* L) and its tolerance to water stress. Belgium: PhD, Liege-Gembloux Agro-BioTech 2010.
- [79] Hauggaard-Nielsen H, Ambus P, Jensen ES. Temporal and spatial distribution of roots and competition for nitrogen in pea-barley intercrops—a field study employing P-32 technique. *Plant Soil* 2001; 236: 63-74. a [<http://dx.doi.org/10.1023/A:1011909414400>]
- [80] Rakeih N, Kayyal H, Larbi A, Habib N. Forage yield and competition indices of triticale and barley mixed intercropping with common vetch and grass pea in the Mediterranean region. *Jordan J Agric Sci* 2010; 6: 194-207.
- [81] Onal Asci O, Acar Z, Kasko Arici Y. Hay yield, quality traits and interspecies competition of forage pea – triticale mixtures harvested at different stages. *Turk J Field Crops* 2015; 20(2): 166-73.
- [82] Layek J, Anup D, Ramkrushna GI, *et al.* Improving productivity of jhum rice through agronomic management practices. In: *Book of abstracts. National seminar on shifting cultivation (jhum) in 21st century: fitness and improvement*. 28–29 November 2014, at CPGS, CAU, Umiam, Meghalaya, 2014a, p 65
- [83] Nazeih R, Hamed K, Asamoah L, Nabil H. Forage Yield and Competition Indices of Triticale and Barley Mixed Intercropping with Common Vetch and Grasspea in the Mediterranean Region. *Jordan Journal of Agricultural Sciences* 2010; 6: 2.
- [84] Ratnadass A, Fernandes P, Avelino J, Habib R. Plant species diversity for sustainable management of crop pests and diseases in agroecosystems: a review. *Agron Sustain Dev* 2012; 32: 273-303. [<http://dx.doi.org/10.1007/s13593-011-0022-4>]
- [85] Ali RI, Awan TH, Ahmad M, Salem MU, Akhtar M. Diversification of rice-based cropping systems to improve soil fertility, sustainable productivity and economics. *J Anim Plant Sci* 2012; 22(1): 108-12.
- [86] Fujita K, Ofosubudu KG, Ogata S. Biological nitrogen fixation in mixed legume-cereal cropping systems. *Plant Soil* 1992; 141: 155-75. [<http://dx.doi.org/10.1007/BF00011315>]
- [87] Meena RS, Yadav RS, Meena H, Kumar S, Meena YK, Singh A. Towards the current need to enhance legume productivity and soil sustainability worldwide: A book review. *J Clean Prod* 2015; 104: 513-5. [<http://dx.doi.org/10.1016/j.jclepro.2015.05.002>]
- [88] Satyam B, Masthan SC, Bucha Reddy B. Economics of different levels of nitrogen application in maize based intercropping systems with legumes under rainfed conditions. *Indian J Dry land Agril. Res Dev* 2008; 23(2): 74-9.
- [89] Buragohain S, Sharma B, Nath JD, Gogaoni N, Meena RS, Lal R. Impact of ten years of bio- fertilizer use on soil quality and rice yield on an inept soil in Assam, India. *Soil Res*.
- [90] Kremen C, Miles A. Ecosystem services in biologically diversified versus conventional farming systems: benefits, externalities, and trade-offs. *Ecol Soc* 2012; 17: 40. [<http://dx.doi.org/10.5751/ES-05035-170440>]
- [91] Seran TH, Brintha I. Review on maize based intercropping. *J Agron* 2010; 9: 135-45. [<http://dx.doi.org/10.3923/ja.2010.135.145>]
- [92] Tschernatke T, Klein AM, Krueß A, Steffan-Dewenter I, Thies C. Landscape perspectives on agricultural intensification and biodiversity—ecosystem service management. *Ecol Lett* 2005; 8: 857-74. [<http://dx.doi.org/10.1111/j.1461-0248.2005.00782.x>]
- [93] Cai H, You M, Lin C. Effects of intercropping systems on community composition and diversity of predatory arthropods in vegetable fields. *Acta Ecol Sin* 2010; 30: 190-5. [<http://dx.doi.org/10.1016/j.chnaes.2010.06.001>]
- [94] Ghosh PK. Growth, yield, competition and economics of groundnut/cereal fodder intercropping systems in the semi-arid tropics

- of India. *Field Crops Res* 2004; 88: 227-37.
[<http://dx.doi.org/10.1016/j.fcr.2004.01.015>]
- [95] Laurent B, Etienne PJ, Henrik N, *et al.* Ecological principles underlying the increase of productivity achieved by cereal-grain legume intercrops in organic farming. *Agron Sustain Dev* 2015; 35: 911-35.
[<http://dx.doi.org/10.1007/s13593-014-0277-7>]
- [96] Francis O, Stern WR. Cereal–Legume Intercropping Systems. *Adv Agron* 1987; 41: 41-90.
[[http://dx.doi.org/10.1016/S0065-2113\(08\)60802-0](http://dx.doi.org/10.1016/S0065-2113(08)60802-0)]
- [97] Tscharntke T, Klein AM, Kruess A, Steffan-Dewenter I, Thies C. Landscape perspectives on agricultural intensification and biodiversity–ecosystem service management. *Ecol Lett* 2005; 8(8): 857-74.
[<http://dx.doi.org/10.1111/j.1461-0248.2005.00782.x>]
- [98] Tscharntke T, Bommarco R, Clough Y, *et al.* Conservation biological control and enemy diversity on a landscape scale. *Biol Control* 2007; 43(3): 294-309.
[<http://dx.doi.org/10.1016/j.biocontrol.2007.08.006>]

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