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# Potential effect of intercropping in the control of weeds, diseases, and pests in a wheat-faba bean system

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**Potential effect of intercropping in the control of weeds, diseases, and pests in a wheat-faba bean system**

**Abstract:** Intercropping has proved to be a promising alternative in the biological control of biotic factors by reducing the excessive use of plant protection products that are harmful to the environment and human health. In this study, aimed to examine the effect of intercropping systems on diseases, weeds and pests control in organic field experiments in Western Morocco. Two field experiments were conducted during 2017-2018 and 2018-2019. Three cropping regimes (monocropped wheat, monocropped faba bean, and intercropped wheat-faba bean) and three nitrogen levels $N_0$ (0 kg N ha$^{-1}$), $N_1$ (50 kg N ha$^{-1}$), and $N_2$ (100 kg N ha$^{-1}$) were evaluated. Compared with monocropping, intercropping ($N_0$ level) reduced the incidence of stripe rust by 71–120 % and severity by 244–337 % in 1$^{st}$ and 2$^{nd}$ experiments respectively. In addition, the incidence of septoria was reduced by 236 % and severity by 276 %. Obviously, the intercrops significantly decreased the total weed biomass by more than 40 % in both experiments. Black aphid populations in faba bean were reduced by 80 %. In contrast, the nitrogen fertilizer increased the attack of diseases and black aphids. It is concluded that wheat-faba bean intercrops can be used as a method of reduction of inputs, reduction of environmental impacts of crops, and stability in the face of biotic factors.

**Key words:** diseases; faba bean; intercropping; nitrogen treatment; pests; sole crops; weeds; wheat

**Potencialni učinek medsetve na nadzor plevelov, bolezni in škodljivcev v sistemu krušna pšenica-bob**

**Izvleček:** Medsetev se je izkazala kot obetajoča alternativa pri biološkem nadzoru biotičnih dejavnikov za zmanjšanje prekomerne uporabe sredstev za zaščito, ki so škodljiva okolju in zdravju ljudi. Namen raziskave je bil preučiti učinek medsetve na plevele, bolezni in škodljivce v poljskem poskusu organske pridelave v Zahodnem Maroku. V obdobjih 2017-2018 in 2018-2019 sta bila izvedena dva poljska poskusa. Ovrednoteni so bili trije načini setve (čist posevek pšenice, čist posevek boba in mešani posevek pšenice in boba) in trije odmerki dušikovih gnojil: $N_0$ (0 kg N ha$^{-1}$), $N_1$ (50 kg N ha$^{-1}$), in $N_2$ (100 kg N ha$^{-1}$). V primerjavi s čistimi posevki je medsetev pri načinu gnojenja $N_0$ zmanjšala pojavljanje progaste rje za 71–120 % in jakost okužbe za 244–337 % v prvem in drugem obdobju poskusa. Dodatno je bila pojavnost listne pegavosti pšenice zmanjšana za 236 % in jakost njene ukužbe za 276 %. Zelo očitno je medsetev značilno zmanjšala celokupno biomaso plevelov za 40 % v obeh poskusih. Populacija črnih fižolovih uši na bobu se je zmanjšala za 80 %. Nasprotno je povečano dodajanje dušikovih gnojil povečalo napad bolezni in črnih fižolovih uši. Zaključimo lahko, da bi z mešanim posevkom krušne pšenice in boba zmanjšali stroške pridelave in negativne vplive pridelave na okolje kot tudi izboljšali stabilnosti pridelave glede na biotske dejavnike

**Ključne besede:** bolezni; bob; medsetev; obravnavanja z dušikovimi gnojili; škodljivci; čisti posevki; pleveli; krušna pšenica

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## 1 INTRODUCTION

In terms of ecology and environment, monospecific crops have caused a series of serious problems. Excessive use of chemical products promotes the development and extreme spread of biotic factors. The agricultural system should not only meet the needs of todays and future generations, but they should also be environmentally friendly, logistically feasible and economically worthwhile. It, therefore, seems essential to achieve sustainable agriculture. One of the key strategies of sustainable agriculture is the diversity of agricultural ecosystem restoration and its effective management. Various researches have made it possible to highlight the advantages of intercropping both in terms of productivity and ecological services (increase of biodiversity, control of bio-aggressors and weeds, limitation of pollution) (Konlan et al., 2013; Corre Hellou et al., 2015; Lopes et al., 2015; Luo et al., 2021). In fact, according to the farmers, these systems would be more competitive vis-a-vis weeds because of a better soil cover allowed by the intercropping compared to the sole crops. Intercropping can actually be seen as a way of securing crop production against biotic factors, which is particularly interesting in biological systems where the use of synthetic phytosanitary products is not allowed (Boyeux and Magnard, 2013; Mamine and Farès, 2020; Victoria et al., 2022).

In intercropping, the arrangement of plant stems and leaves is different in the vertical and horizontal directions. This allows agricultural crops to better utilize solar radiation, while weeds receive less light and thus are suppressed (Yadollahi et al., 2014; Li et al., 2019). Combination crops are often less invasive than single crops. By planting a mixture of plants, more ecological niches can be filled, providing fewer opportunities and resources for weeds to thrive (Sturm et al., 2018). Mennan et al. (2020) also point out that crop association, particularly the inclusion of plants with allelopathic properties, can be an ecological alternative to chemical weed control.

Reductions in plant diseases and pests have also been recorded for varietal mixtures. Zhu et al. (2000) reported a 94 % reduction in rice plant diseases in the intercropping. Previous studies have shown that the intercropping of faba bean and wheat reduces yield losses associated with powdery mildew and yellow rust in wheat (Jiang et al., 2012; Xiao et al., 2018). In addition, crop association is a practicable alternative that controls crop pests (Rao et al., 2012; Sharaby et al., 2015; Sulvai et al., 2016). Letourneau et al. (2011) reported positive effects of crop association on pest management based on a meta-analysis of 522 experiments. It was suggested that intercropping can potentially be used to improve the abundance and diversity of natural enemies (natural enemy hypothesis) or cause a reduction in pest food concentration, thereby reducing their numbers (resource concentration hypothesis).

Nitrogen is not only an important nutritional factor that promotes crop growth and increases yield, but it is also known to have a direct impact on disease severity (Devadasa et al., 2014; Zhu et al., 2017a; Luo et al., 2022). These results are attributed to the increase in canopy density resulting from the application of nitrogen fertilizer, providing a favorable microclimate for the development and spread of pathogenic fungi (He, 2009). Other studies have suggested that the effects of nitrogen on pathogenic fungi are mediated by increasing the nitrogen content of the host tissue by acting as a substrate for pathogen growth (Chen et al., 2013; Zhu et al., 2017a). Obviously, the rational use of nitrogen fertilizers is a key factor in the control of powdery mildew and stripe rust in wheat, thereby increasing yields in these cropping systems (Chen et al., 2013; Yang et al., 2013; Zhu et al., 2017a). Therefore, it is relevant to analyze the interaction between the effects of intercropping and nitrogen fertilizers on the performance of the crop association.

Therefore, the objective of this study was to evaluate the effects of nitrogen fertilization and wheat-faba bean intercropping on the regulation of diseases occurrence, weeds and pests control efficiency.

## 2 MATERIALS AND METHODS

### 2.1 CROPPING SYSTEMS AND EXPERIMENTAL DESIGN

The field experiments were carried out over two cropping seasons in the same region but in different soils in 2017–2018 (1st experiment) and 2018–2019 (2nd experiment). The 1st experiment was located in the Saada station of National Institute of Agronomic Research (INRA) in Marrakesh, Morocco, about 7 km to the south of Marrakesh, Morocco; the 2nd experiment was located in the experimental station (31°37′46.7″ N; 8°09′23.4″ E) of the National Institute of Agronomic Research (INRA) in Marrakesh, Morocco. The wheat (W) (*Triticum aestivum* L.) cultivar 'Wafia' and faba bean (F) (*Vicia faba* L.) cultivar 'Alfia' were grown as sole crops (SC) in full density, half density sole crops (SC/2) and as intercrops (IC). Three nitrogen (N) treatments: $N_0$ – 0 kg N ha$^{-1}$, $N_1$ – 50 kg N ha$^{-1}$ and $N_2$ – 100 kg N ha$^{-1}$, were evaluated on IC, wheat SC and SC/2, while faba bean SC and SC/2 were grown without N application. It was effectively hypothesized that N is not a limiting resource for legumes because of their ability to increase the symbiotic N fixation from the air to meet their needs; SC and SC/2 were considered as controls. No herbicides or fungicides were applied; the weeding was done manually. The irrigation system was gravity type. The soil plots undergoing the two experiments have never been before cultivated or treated by chemical fertilizers or organic manures.

The experimental design was a randomized complete block with three replicates (Table 1). The dimension of each elementary plot was 1.60 × 1.20 m. The seedlings were planted manually in January for both experiments and crops, 8 rows of wheat and 6 rows of faba bean (inter-rows 20 cm) for full density SC, whereas 4 rows of wheat and 3 rows of faba bean for IC (inter-rows 20 cm) and SC/2 (inter-rows 40 cm). The harvesting of the whole plots was done manually in July for wheat and in May for faba bean for both experiments. The seeding density was 320 plants per $m^2$ for soft wheat as a SC, 40 plants per $m^2$ for faba bean as a SC, and 160 per $m^2$ plants for soft wheat as SC/2 and 20 plants per $m^2$ for faba bean as SC/2 and IC.

Before the field experiment, the soil chemical properties in 0–30 cm layer were analysed (Table 2). Soil texture was determined by Robinson's method (Baize, 2018); soil organic carbon (SOC) and soil organic matter (SOM) were determined according to Aubert (1978); total nitrogen ($N_{tot}$) – by the Kjeldhal method (ISO 11261:1995. Soil quality - Determination of total nitrogen - Modified Kjeldahl method); available phosphorus ($P_2O_5$) content was measured by the method of Olsen and Sommers (1982); available ($K_2O$) was determined according to Gueguen and Rombauts (1961).

During the experiments, the dry season was from May to October. The annual average rainfall was 232 mm (1st experiment) and 100 mm (2nd experiment). The average air temperature was 20 °C and 18.7 °C in autumn, 11.6 °C and 15.3 °C in winter, 19.2 °C and 22.8 °C in spring and 26.5 °C and 27.8 °C in summer, respectively (Figure 1).

## 2.2 EVALUATION OF BIOTIC FACTORS PRESSURE

### 2.2.1 Diseases

The diseases studied were those usually encountered on the territory for these crops. For each plot of wheat, each plant was inspected for the presence of various leaf cryptogamic diseases. Septoria and stripe rust of wheat were studied on the same plot at the same time, and the incidence and severity of both diseases were recorded at the wheat heading stage for each plot. The severity of each disease was evaluated according to grades 1-9 (ICARDA, 1986). Grade 0 indicated the absence of visible spore spot symptoms on wheat leaves; grade 1 indicated spore spots covering 5 % of the total leaf area; grade 3 indicated spore spots covering 6-25 % of the total leaf area; grade 5 indicated spore spots on 26-50 % of the total leaf area; grade 7 indicated spore spots on 51-75 % of the total leaf area; and grade 9 indicated extensive spore spots on leaves and stems (76 %). Cryptogamic diseases were diagnosed and identified based on their typical symptoms (Zillinsky, 1983), and on the microscopic observation of spores. In 2018-2019, only yellow rust was observed in the experimental station.

These data were used to calculate the disease incidence, severity, and relative control efficacy for each plot, as follows (Luo et al., 2021):

$$\%\,Incidence = \frac{Number\ of\ infected\ plants}{Total\ number\ of\ plants\ assessed} \times 100$$

$$\%\,Severity = \frac{Number\ of\ diseased\ leaves\ in\ each\ grade \times value\ of\ the\ corresponding\ grade}{Total\ number\ of\ leaves\ scored \times maximum\ disease\ grade} \times 100$$

$$\%\,Relative\ control\ efficacy = \frac{Incidence\ or\ severity\ of\ monocrops - Incidence\ or\ severity\ of\ intercrops}{Incidence\ or\ severity\ of\ monocrops} \times 100$$

**Table 1**: Planting patterns in the field experiments at different N levels

| Crops | Treatment |
|---|---|
| Faba bean sole crops in full density | $N_0$F-SC |
| Faba bean sole crops in half density | $N_0$F-SC/2 |
| Wheat sole crops in full density at three N levels | $N_0$W-SC, $N_1$W-SC, $N_2$W-SC |
| Wheat sole crops in half density at three N levels | $N_0$W-SC/2, $N_1$W-SC/2, $N_2$W-SC/2 |
| Wheat faba bean intercrops at three N levels | $N_0$IC, $N_1$IC, $N_2$IC |

**Table 2**: Chemical characteristics of soils during the two experimental seasons (2017-2018 and 2018-2019)

| Treatment | Depth cm | Texture | pH | SOC % | SOM % | $N_{tot}$ % | $P_2O_5$ mg $kg^{-1}$ | $K_2O$ mg $kg^{-1}$ |
|---|---|---|---|---|---|---|---|---|
| 1st experiment | 0–30 | clay-loam | 8.7 | 0.95 | 1.64 | 0.15 | 20 | 220 |
| 2nd experiment | 0–30 | clay-loam | 8.5 | 0.77 | 1.34 | 0.11 | 14 | 850 |

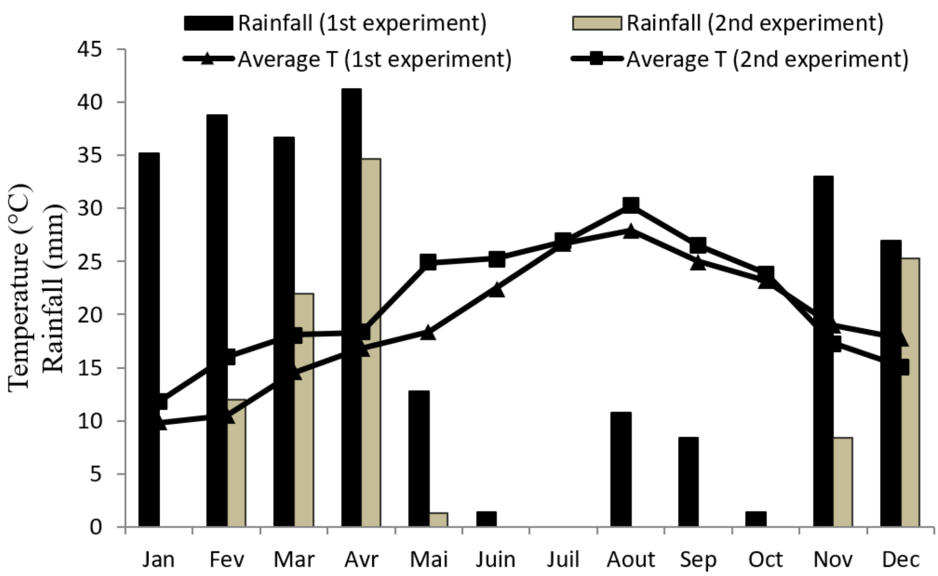


**Figure 1**: Precipitation and average air temperature during the 1st and 2nd experiments (data of the Marrakesh Meteorological Station)

### 2.2.2 Weeds

Weeds were studied during the crop, in all plots. They were characterized by their distribution (homogeneous, intermediate or heterogeneous) at the scale of the observation area, their percentage of cover, estimated from a photograph of the plot, and by the number of species present, for each plot. During the 1st experiment, there were six weed species, while in the 2nd experiment, only one species was observed at the field level. These species were counted in each plot and identified by the Laboratory of Microbial Biotechnologies, Agrosciences and, Environment, Cadi Ayyad University.

### 2.2.3 Pests

During the 1st experiment, no pest population was detected. However, during the 2nd experiment, an estimation of the population of black aphids on faba bean (*Aphis fabae* Scopoli, 1763) was performed. For this purpose, aphid counts were conducted on all plants in each plot.

## 3 RESULTS

### 3.1 EFFECT OF N LEVELS AND INTERCROPPING ON WHEAT DISEASE DEVELOPMENT

In the first experiment, stripe rust (*Puccinia striiformis* Westend f.sp. *tritici* Erikss.) and septoria (*Septoria tritici* Desm.) were observed on soft wheat. In the 2nd experiment, only stripe rust was observed on soft wheat. While faba bean was not affected by any disease in both experiments.

Without fertilizer application, the intercropping compared to the monoculture (B-SC) reduced the incidence of stripe rust by 71.55 % and 120.90 % for 1st and 2nd experiments respectively, and the severity by 244.55 % and 337.85 % for 1st and 2nd experiments (Figure 2). In the case of septoria, the intercropping without nitrogen application reduced significantly ($p < 0.05$) the incidence by 236.48 % and the severity by 276.50 % compared to the $N_0$B-SC (Figure 3). In addition, the soft wheat intercrops without nitrogen supply had a lower level of diseases than the treated ones. Therefore, faba bean-wheat intercropping regressed the symptoms of septoria and stripe rust, indicating a positive effect of intercropping compared to sole crops.

In the two-year experiment, the incidence and severity of both diseases in monoculture and intercropping wheat showed an increasing trend with increasing N levels. Compared to $N_0$, $N_1$-$N_2$ treatments increased the incidence of wheat stripe rust in monoculture (SC) and intercropped plants by 19.14-41.82 % and 16.37-25.21 %, respectively (2017-2018); and by 17.20-42.43 % and 20.34-36.07 %, respectively (2018-2019). Compared to $N_0$, $N_1$-$N_2$ treatments increased wheat stripe rust severity in monoculture and intercropped plants by 37.75-21.25 % and 37.57-60.48 %, respectively (2017-2018); and 39.54-61.81 and 47.95-70.46 %, respectively (2018-2019)

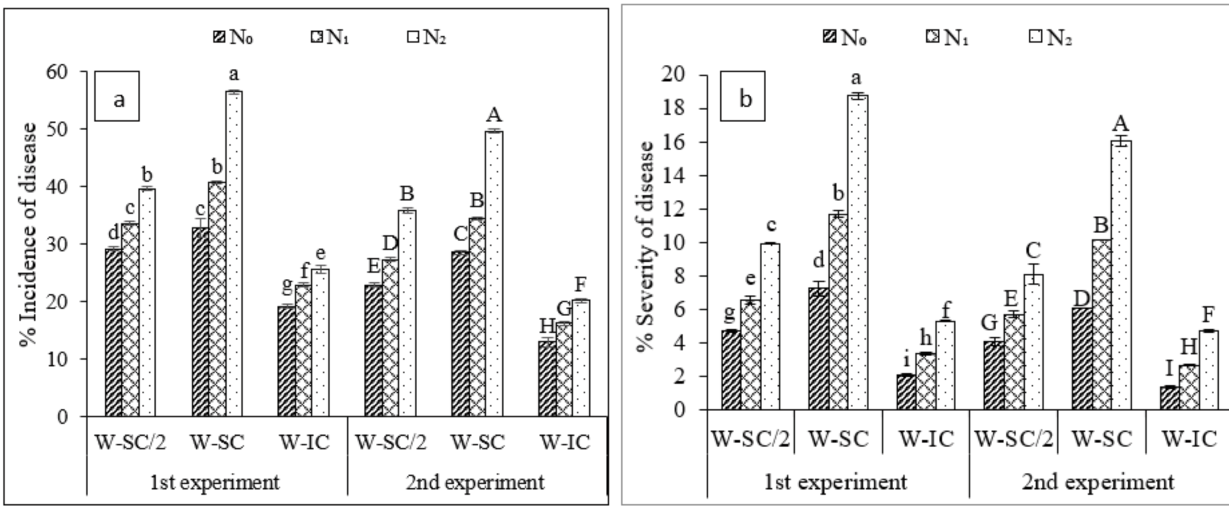


**Figure 2**: Incidence (a) and severity (b) of stripe rust in sole crops soft wheat (W-SC and W-SC/2) and intercropping (IC) under three nitrogen treatments in 1st and 2nd experiments. Values represent the mean of three replicates ± standard errors within the same graphic followed by different letters are statistically significant ($p < 0.05$)

(Figure 2). In addition, compared to $N_0$, $N_1$-$N_2$ treatments increased the incidence of septoria in wheat in monoculture and intercropped plants by 10.37-16.40 % and 10.26-29.36 %. respectively. As well as the severity was increased by 41.20-54.45% and 42.16-50.88% (Figure 3). The effects of nitrogen fertilizer application on disease severity were greater than the incidence of wheat stripe rust. Compared to the monoculture, the intercropping reduced the incidence and severity of wheat diseases caused by nitrogen application.

The control effect of two experiments intercropping wheat on stripe rust was 41.71–54.62 % and 52.94–59.24 % when based on incidence, for which the $N_2$ level was relatively superior. The corresponding values were 70.98–71.54 % and 70.47–77.16 % when based on severity, for which the $N_0$ level was superior. Moreover, the control effect of wheat intercropping on septoria was 64.82-70.32 % for incidence, which $N_0$ scored well, and 73.00-75.36 % for severity which $N_2$ scored well (Table 3). After evaluate the overall effects of nitrogen level and

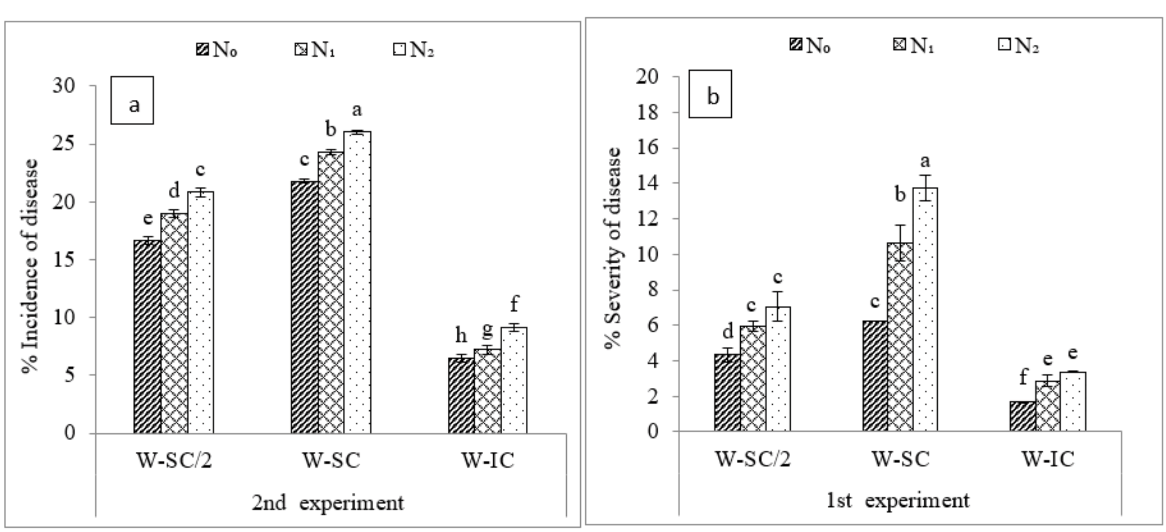


**Figure 3**: Incidence (a) and severity (b) of septoria in sole crops soft wheat (W-SC and W-SC/2) and intercropping (IC) under three nitrogen treatments in 1st experiment. Values represent the mean of three replicates ± standard errors within the same graphic followed by different letters are statistically significant ($p < 0.05$)

**Table 3**: Relative control efficacy (%) for wheat stripe rust and Septoria at different N levels in 1st and 2nd experiments

| | 1st experiment | | | | 2nd experiment | |
|---|---|---|---|---|---|---|
| | Stripe rust | | Septoria | | Stripe rust | |
| N level | Incidence | Severity | Incidence | Severity | Incidence | Severity |
| $N_0$ | 41.71±2.00b | 70.98±0.52a | 70.28±0.53a | 73.44±0.05b | 54.73±1.08b | 77.16±0.05a |
| $N_1$ | 43.64±0.63b | 71.06±0.25a | 70.32±0.56a | 73.00±1.37b | 52.94±0.54b | 73.47±0.05b |
| $N_2$ | 54.62±0.99a | 71.54±0.25a | 64.82±0.54b | 75.36±0.77a | 59.24±0.72a | 70.47±0.39c |

Letters represent significant differences between different N levels at $p < 0.05$

**Table 4**: Effects of N levels and cropping system on stripe rust and septoria

| | 1st experiment | | | | 2nd experiment | |
|---|---|---|---|---|---|---|
| | Stripe rust | | Septoria | | Stripe rust | |
| Factors | Incidence | Severity | Incidence | Severity | Incidence | Severity |
| Cropping system | 0.93** | 3.36** | 3.14** | 3.90** | 1.52** | 3.79** |
| N levels | 0.32** | 1.64** | 0.14** | 0.97** | 0.52** | 1.89** |
| Cropping system × N levels | 0.017** | 0.010** | 0.006* | 0.021ns | 0.006** | 0.039** |

The data in the table are F-values of the interaction between N levels and planting patterns (two-way ANOVA, $p < 0.05$). *Represents significant difference ($p < 0.05$), **represents significant difference ($p < 0.001$), ns represents no significant difference

mode of intercropping on the occurrence of diseases, there was a significant interaction between cropping system and N levels ($p < 0.01$) (Table 4).

## 3.2 EFFECT OF N LEVELS AND INTERCROPPING ON WEEDS DEVELOPMENT

In the case of wheat sole crops, there was no significant difference between the two densities seeded for certain weed species (*Spergularia flaccida* (Madden) I.M. Turner, *Malva sylvestris* L., *Chenopodium album* L., *Aizoon hispanicum* L.). However, in the case of faba bean sole crops, the infestation was higher on half density compared to full density seedlings, except *Spergularia flaccida*, which was largely the majority in both cases. It should be noted that soft wheat and faba bean intercrops decreased significantly the total biomass of weeds ($p < 0.001$).

An infestation of all test plots was observed, with differences in weed species and biomass. *Spergularia flaccida, Malva sylvestris, Sinapis arvensis* L., *Chenopodium album, Aizoon hispanicum* and *Mesembryanthemum nodiflorum* L. were the predominant species (Figure 4). In the case of wheat sole crops, there was no significant difference between the two seeded densities for some weed species (*Spergularia flaccida, Malva sylvestris, Chenopodium album, Aizoon hispanicum*). However, in the case of the faba bean sole crops, the infestation was higher on the half density than on the full density seedlings, except *Spergularia flaccida*, which was largely the majority in both cases.

Compared to the wheat and faba bean sole crops, the intercropping significantly ($p < 0.001$) reduced the development of *Spergularia flaccida*. The intercropping reduced the development of *Malva sylvestris, Chenopodium album and Aizoon hispanicum* compared to F-SC/2. While *Sinapis arvensis* and *Mesembryanthemum nodiflorum* were decreased under the intercropping compared to B-SC/2.

During the 2nd experiment, soft wheat and faba bean sole crops showed a higher degree of infestation in the case of crops sown at half density compared to crops sown at full density. However, weed biomass in the intercropping was significantly lower than that of the monospecific legumes and cereals. It decreased by 92.14 %; 91.51 %; 49.01 % and 51.03 % compared to F-SC/2; B-SC/2; F-SC and B-SC respectively (Figure 5). Finally, we observe that the number of weeds was lower in B-SC/2 compared to F-SC/2 for both experiments. It should be noted that the soft wheat and faba bean intercrops decreased very significantly ($p < 0.001$) the total weed biomass. This de-

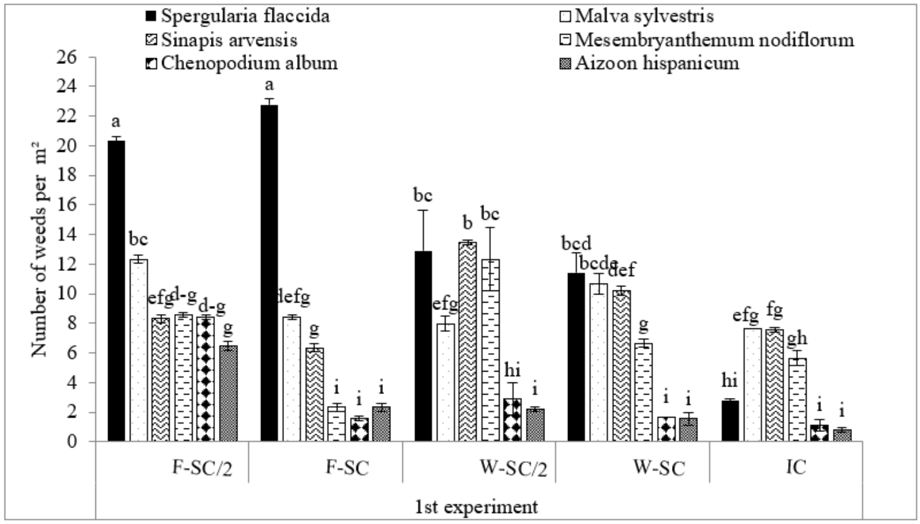


**Figure 4**: The number of weeds developed per m² in sole crops and intercrops of soft wheat and faba bean in 1st experiment. Values represent the mean of three replicates ± standard errors within the same graphic followed by different letters are statistically significant at ($p < 0.05$)

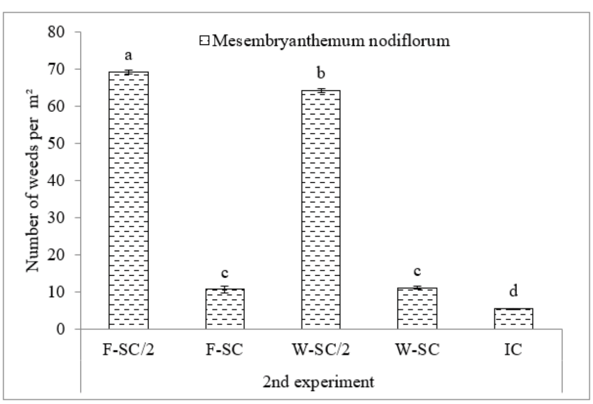


**Figure 5**: The number of weeds developed per m² in sole crops and intercrops of soft wheat and faba bean in 2nd experiment. Values represent the mean of three replicates ± standard errors within the same graphic followed by different letters are statistically significant ($p < 0.05$)

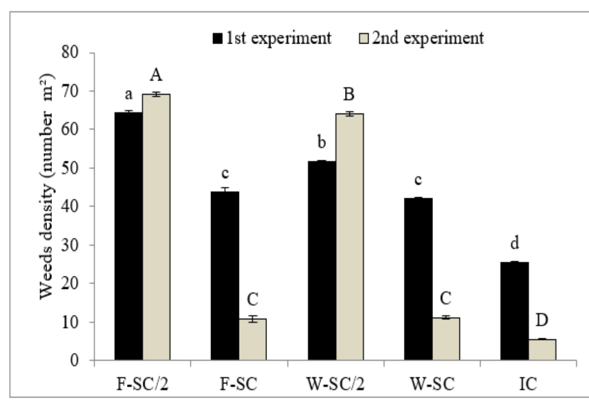


**Figure 6**: Total number of weeds developed per m² in sole crops and intercropping of soft wheat and faba bean. Values represent the mean of three replicates ± standard errors within the same graphic followed by different letters are statistically significant ($p < 0.05$)

crease was of the order of 60.38 %; 41.66 %; 50.68 % and 39.51 % compared to the F-SC/2; F-SC; B-SC/2 and B-SC respectively in the 1st experiment (Figure 6).

### 3.3 EFFECT OF N LEVELS AND INTERCROPPING ON FABA BEAN PEST DEVELOPMENT

Figure 7 shows the number of black faba bean aphids measured by average accounts made on March 25, 2019 and April 25, 2019 expressed as aphids per plant and aphids per square meter. Faba bean sole crops and faba bean half density sole crops had higher population levels than faba bean intercropped with soft wheat, both in terms of the number of aphids per plant and per square meter. Indeed, under nitrogen treatment, the significant differences were found between intercrops treated, both per plant and per square meter. Finally, in none N-fertilized plots, the intercrops significantly reduced the attack by aphid populations than sole crops.

## 4 DISCUSSION

Intercropping is known to have interesting effects in terms of productivity, especially when available resources

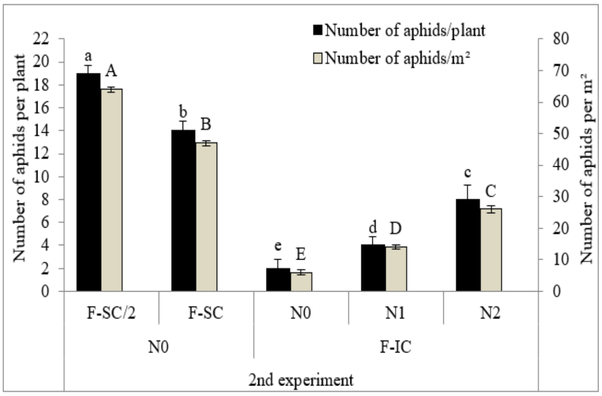


**Figure 7:** The number of black aphids per plant per $m^2$ in faba bean sole crops (F-SC and F-SC/2) and intercropping (IC) under three nitrogen treatments in 2nd experiment. Values represent the mean of ten replicates ± standard errors within the same graphic followed by different letters are statistically significant ($p < 0.05$)

are limited, and good weed, disease and pest management (Shtaya et al., 2021). The reduction of weed density and biomass in intercropped plants compared to monocrops has long been mentioned in the literature (Bedoussac et al., 2015; Hamzei and seyedi, 2015). Several studies have explained weeds reduction by two phenomena: (i) higher interspecific competition combined with complementarity between species grown in intercrops, which allows them to use the available resources more efficiently and thus limits the access of weeds to those resources. (ii)the depressive effect of some species in intercrops on weeds through allelopathy by producing phenolic compounds and root exudates toxic for their growth (Norsworthy et al., 2011; Amosse et al., 2013; Saudy, 2015).

At the plot level, intercropping would also make it possible to reduce diseases compared to pure crops. Recent study reported that intercropping reduced stripe rust and powdery mildew diseases in wheat, and chocolate spot and fusarium wilt diseases in faba bean incidence by 45 % on average (Zhang et al., 2019). The effectiveness of this control depends on microclimate conditions such as ventilation conditions, which weaken the disease conditions and reduce its reproduction and spread (Guo et al., 2020). Moreover, the effect of host dilution by changing the planting ratio and arrangement of the cereal in intercropping. The difference in plant height between wheat and faba bean forms a "ventilation corridor", which alters the uniform canopy structure of the cereal in sole crops, enhances airflow, and effectively improves moisture and temperature in the field (Zhu et al., 2020). In addition, modification of host physiology and resistance, as well as direct inhibition of pathogens by antagonistic chemical exudates (Boudreau, 2013; Corre-Hellou et al., 2014).

The intercropping was an effective way to reduce the black bean aphid populations in faba bean compared to pure crops. Similar findings were reported by Ndzana et al. (2014) in pea-wheat intercrops. Plant diversity promotes pest regulation using several mechanisms. Non-host crops grown in intercropping can emit volatile chemicals that harm insect pests, thus providing a degree of protection (Ninkovic et al., 2013; Shalaby and Fouad, 2016; Sulvai et al., 2016). In addition, natural enemies can exert top-down control over pests (Song et al., 2013; Dassou and Tixier, 2016). Other mechanisms can also affect the visual location of host plants, such as greener and/or taller non-host plants, which can camouflage the host plant, or even lead to its physical obstruction (Parker et al., 2013; Gardarin, et al., 2021). All of these factors therefore make it more difficult to recognize the host plant and reduced both the aphid's settlement and mobility in the canopy, affecting its spread dynamics.

On the other hand, nitrogen fertilizer is generally considered a key force leading to disease development due to its effect on plant nutritional status and their ability to multiply pathogens (Dordas, 2008). Along this line, Zhang et al. (2019) and Zhu et al. (2020) indicated that nitrogen fertilizer greatly increased the incidence of wheat powdery mildew. The higher N application can lead to a denser canopy, resulting in a more favorable microclimate for infection (Chen et al., 2013; Guo, 2016; Zhu et al., 2017a). This indicates that the disease occurrence was related to the colonization and spore transmission conditions during the season (Guo et al., 2020). Furthermore, high nitrogen content in plants leaves leads to a reduction in total phenols, flavonoids and peroxidase activity, which affects the epidermal characteristics, cell wall structure and metabolic activity of host crop leaves (Li et al., 2006; Lu et al., 2008). Nevertheless, potassium is beneficial in increasing phenolic and polyphenol oxidase activity in crop leaves. It promotes protein synthesis, sugar and starch synthesis and transport, reduces the source of carbon and nitrogen required by phytopathogenic bacteria and fungi. Therefore, improves the disease resistance of crops (Zhu et al., 2017b). In our most recent publication, the intercropping increased the potassium content of wheat leaves (Sammama et al., 2021), thus, the incidence and severity of diseases in intercropping at various nitrogen levels were significantly lower than those in sole crops. It is deduced, that intercropping is an effective control measure for these two diseases at low input levels, indicating that intercropping should be used as a management strategy for disease control.

## 5 CONCLUSION

The present study reveals the great resilience of intercropping in reducing weeds, diseases, and pests. Compared to the wheat and faba bean sole crops, the intercropping significantly ($p < 0.001$) reduced the total weed biomass by more than 40 %. Moreover, it reduced the attack of the two diseases in wheat and the black aphid populations in faba bean. When nitrogen was applied to intercropping an increase in the incidence (+ 10 %) and severity (+ 40 %) of yellow rust and septoria was remarkable compared to the untreated intercropping. Thus, the effect of nitrogen fertilizer application on disease severity was greater than incidence. The use of intercropping systems adapted to difficult conditions could be an interesting sustainable agriculture tool to help plants tolerate environmental constraints.

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## 7 REFERENCES

Aubert, G. (1978). *Méthodes d'analyses des sols* (2ème ed.). Centre régional de Documentation Pédagogique, 191 p. (in French).

Amossé, C., Jeuffroy, M.H., Celette, F., & David C. (2013). Relay-intercropped forage legumes help to control weeds in organic grain production. *European Journal Agronomy, 49*, 158-167. https://doi.org/10.1016/j.eja.2013.04.002

Baize, D. (2018). *Guides des Analyses Courantes en Pédologie* (3e éd.). INRA, 328 p. (in French).

Bedoussac, L., Journet, E.P., Hauggaard-Nielsen, H., Naudin, C., Corre-Hellou, G., Jensen, E S., & Justes, E. (2015). Ecological principles underlying the increase of productivity achieved by cereal-grain legume intercrops in organic farming. A review. *Agronomy for Sustainable Development*, *35*(3), 911-935.https://doi.org/10.1007/s13593-014-0277-7

Boudreau, M.A. (2013). Diseases in intercropping systems. *Annual Review of Phytopathology*, *51*, 499–519. https://doi.org/10.1146/annurev-phyto-082712-102246

Chen, Y.X., Li, L., Tang, L., Zheng, Y., Li, Y.J., & Zhang, C.C. (2013). Effect of nitrogen addition on nitrogen nutrition and strip rust occurrence of wheat in wheat/faba bean intercropping system. *The Journal of Agriculture Science*, *27*(7), 1020–1028. https://doi.org/10.11869/hnxb.2013.07.1020

Corre-Hellou, G., Baranger, A., Bedoussac, L., Cassagne, N., Cannavacciuolo, M., Fustec, J., Elise Pelzer, E., & Piva, G. (2014). Interactions entre facteurs biotiques et fonctionnement des associations végétales. *Innovations Agronomiques, 40*, 25-42. (in French).

Dassou, A.G., & Tixier, P. (2016). Response of pest control by generalist predators to local-scale plant diversity: a meta-analysis. *Ecology and Evolution*, *6*, 1143–1153. https://doi.org/10.1002/ece3.1917

Devadasa, R., Simpfendorferb, S., Backhousec, D., & Lamb, D.W. (2014). Effect of stripe rust on the yield response of wheat to nitrogen. *Crop Journal*, 2, 201–206. https://doi.org/10.1016/j.cj.2014.05.002

Dordas, C. (2008). Role of nutrients in controlling plant diseases in sustainable agriculture. A review. *Agronomy Sustainable Development, 28*(1), 33-46. https://doi.org/10.1007/978-90-481-2666-8_28

Gardarin, A., Pigot, J., & Valantin-Morison, M. (2021). The hump-shaped effect of plant functional diversity on the biological control of a multi-species pest community. *Scientific Reports*, *11*, 21635. https://doi.org/10.1038/s41598-021-01160-2

Gueguen, L., & Rombauts, P. (1961). Dosage du sodium, du potassium, du calcium et du magnésium par spectrophotométrie de flamme dans les aliments, le lait et les excreta. *Annales de Biologie Animale, Biochimie, Biophysique*, *1*(1), 80–97 (in French). https://doi.org/10.1051/rnd/19611080

Guo, Z.P., Dong, K., Zhu, J.H., Ma, L.K., & Dong, Y. (2020). Effects of nitrogen management and intercropping on faba bean chocolate spot disease development. *Crop Protection*, *127*, 104972. https://doi.org/10.1016/j.cropro.2019.104972

Hamzei, J., & Seyedi, M. (2015). Evaluation of the effects of intercropping systems on yield performance, land equivalent ratio, and weed control efficiency. *Agricultural Research, 4*(2), 202-207. https://doi.org/10.1007/s40003-015-0161-y

Hao, W., Ren, L., Ran, W., & Shen, Q. (2010). Allelopathic effects of root exudates from watermelon and rice plants on *Fusarium oxysporum* f.sp. *niveum*. *Plant and Soil*, *336*(1), 485-497. https://doi.org/10.1007/s11104-010-0505-0

He, F. (2009). Effect of N rates on canopy microclimate and population health in irrigated rice. *Agricultural Science Technology*, *10*, 79–83. https://doi.org/

ICARDA (1986). Screening Techniques for Disease Resistance in Faba Bean. Aleppo: *International Center for Agricultural Research in the Dry Areas*, *59*.

Jiang, H., Zhao, P., Tang, L., Zheng, Y., & Xiao, J.X. (2012). Analysis and evaluation of yield advantages in wheat and faba bean intercropping system in yunnan province. *Journal Yunnan Agriculture University*, *27*(5), 646–652. https://doi.org/

Konlan, S., Sarkodie-Addo, J., Kombiok, M.J., Asare, E., & Bawah I. (2013). Yield response of three groundnut (*Arachis hypogaea* L.) varieties intercropped with maize (*Zea mays*) in the guinea savanna zone of Ghana. *Journal of Cereals Oilseeds*, *6*, 76-84. https://doi.org/ 10.5897/JCO2013.0112

Letourneau, D.K., Armbrecht, I., Rivera, B.S., Lerma, J.M., Carmona, E.J., & Daza, M.C. (2011). Does plant diversity benefit agroecosystems? a synthetic review. *Ecological Applications*, *21*, 9-21. https://doi.org/10.1890/09-2026.1

Li, M., Li, R., Zhang, J., Liu, S., Hei, Z., & Qiu, S.A. (2019). Combination of rice cultivar mixed-cropping and duck co-culture suppressed weeds and pests in paddy fields. *Ba-*

*sic Applied Ecology*, *40*, 67–77. https://doi.org/10.1016/j.baae.2019.09.003

Lopes, T., Hatt, S., Xu, Q., Chen, J., Liu, Y., & Francis F. (2016). Wheat (*Triticum aestivum* L.)-based intercropping systems for biological pest control. *Pest Management Science*, *72*, 2193–2202. https://doi.org/10.1002/ps.4332

Luo, C., Ma, L., Zhu, J., Guo, Z., Dong, K., & Dong, Y. (2021). Effects of nitrogen and intercropping on the occurrence of wheat powdery mildew and stripe rust and the relationship with crop yield. *Frontiers in Plant Science*, *12*, 637393.

Luo, C., Lv, J., Guo, Z., & Dong, Y. (2021). Intercropping of faba bean with wheat under different nitrogen levels reduces faba bean rust and consequent yield loss. *Plant disease*, *106*(9), 2370-2379. https://doi.org/10.1094/PDIS-11-21-2451-RE

Mamine, F., & Farès, M. (2020). Barriers and levels to developing wheat–pea intercropping in Europe: A Review. *Sustainability*, *12*(17), 6962.https://doi.org/10.3390/su12176962

Mennan, H., Jabran, K., Zandstra, B.H., & Pala, F. (2020). Non-chemical weed management in vegetables by using cover crops. *A Review Agronomy*, *10*(2), 257. https://doi.org/10.3390/agronomy10020257

Ndzana, R.A., Magro, A., Bedoussac, L., Justes, E., Journet, E.P., & Hemptinne J.L. (2014). Is there an associational resistance of winter pea-durum wheat intercrops towards *Acyrthosiphon pisum* Harris. *Journal of Applied Entomology*, *138*(8), 577-585. https://doi.org/10.1111/jen.12119

Ninković, V., Dahlin, I., Vučetić, A., Petrović-Obradović, O., Glinwood, R., & Webster, B. (2013). Volatile exchange between undamaged plants - a new mechanism effecting insect orientation in intercropping. *PLoS POne*, *8*,1-9. https://doi.org/10.1371/journal.pone.0069431

Norsworthy, J.K., McClelland, M., Griffith, G., Bangarwa, S.K., & Still, J. (2011). Evaluation of cereal and Brassicaceae cover crops in conservation-tillage, enhanced, glyphosate-resistant cotton. *Weed Technology*, *25*(1), 6-13. https://doi.org/10.1614/WT-D-10-00040.1

Parker, J.E., Rodriguez-Saona, C., Hamilton, G.C., & Snyder, W.E. (2013). Companion planting and insect pest control. *INTECH Open Access Publisher*. https://doi.org/10.5772/55044

Olsen, S.R., & Sommers L.E. (1982). Phosphorus. Page A. L. (ed.). *Methods of Soil Analysis*. Part 2. American Society of Agronomy, Soil Science Society of America, 403–430. https://doi.org/10.2134/agronmonogr9.2.2ed.c24

Poggio, S.L. (2005). Structure of weed communities occurring in monoculture and intercropping of field pea and barley. *Agriculture, Ecosystems & Environment*, *109*(1-2), 48-58. https://doi.org/10.1016/j.agee.2005.02.019

Rao, M.S., Rama Rao, C.A., Srinivas, K., Pratibha, G., Vidya Sekhar, S.M., Sree Vani, G., & Rizk, A.M. (2012). Effect of strip-management on the population of the aphid, aphis craccivora koch and its associated predators by intercropping faba bean, *Vicia faba* L. with coriander, *Coriandrum sativum* L. *Egyptian Journal of Biological Pest Control*, *21*, 81-87.

Sammama, H., El kaoua, M., Hsissou, D., Latique, S., Selmaoui, K., & Alfeddy, M.N. (2021). The impact of wheat and faba bean intercrop on the competitive interactions, grain yield, biochemical parameters and mineral content of leaves. *Zemdirbyste-Agriculture*, *108*(3), 233-240. https://doi.org/10.13080/z-a.2021.108.030

Saudy, H.S. (2015). Maize-cowpea intercropping as an ecological approach for nitrogen use rationalization and weed suppression. *Archives of Agronomy and Soil Science*, *61*, 1-14. https://doi.org/10.1080/03650340.2014.920499

Sekamatte, B.M., Ogenga-Latigo, M., & Russell-Smith, A. (2003). Effects of maize-legume intercrops on termite damage to maize, activity of predatory ants and maize yields in Uganda. *Crop Protection*, *22*(1), 87-93. https://doi.org/10.1016/S0261-2194(02)00115-1

Shalaby, S., & Fouad, A.H. (2016). Effect of intercropping agroecosystem on the population of black legume aphid, *Aphis craccivora* Koch and yield of faba bean crop. *Journal of Entomology and Zoology Studies*, *4*(4), 1367-1371.

Sharaby, A., Abdel-Rahman, H., & Sabry, S. (2015). Moawad intercropping system for protection the potato plant from insect infestation. *Ecologia Balkanica*, *7*, 87-92. http://eb.bio.uni-plovdiv.bg

Song, B., Tang, G., Sang, X., Zhang, J., Yao, Y., & Wiggins, N. (2013). Intercropping with aromatic plants hindered the occurrence of aphis citricola in an apple orchard system by shifting predator-prey abundances. *Biocontrol Science and Technology*, *3*, 381-395. https://doi.org/10.1080/09583157.2013.763904

Shtaya, M.J., Emeran, A.A., Fernández-Aparicio, M., Qaoud, H.A., Abdallah, J., & Rubiales, D. (2021). Effects of crop mixtures on rust development on faba bean grown in Mediterranean climates. *Crop Protection*, *146*, 105686. https://doi.org/10.1016/j.cropro.2021.105686

Sturm, D.J., Peteinatos, G., & Gerhards, R. (2018). Contribution of allelopathic effects to the overall weed suppression by different cover crops. *Weed Research, 58*, 331–337. https://doi.org/10.1111/wre.12316

Sulvai, F., Chauque, B.J.M., Macuvele, D.L.P. (2016). Intercropping of lettuce and onion controls caterpillar thread, agrotis ipsilon major insect pest of lettuce. *Chemical and Biological Technologies in Agriculture*, *3*, 28. https://doi.org/10.1186/s40538-016-0079-z

Victoria, G., Chadfield, A., Hartley, S.E., & Redeker, K.R (2022). Associational resistance through intercropping reduces yield losses to soil-borne pests and diseases. *New phtologist*, *235*, 2393–2405. https://doi.org/10.1111/nph.18302

Xiao, J.X., Yin, X.H., Ren, J.B., Zhang, M., Tang, L., & Zheng, Y. (2018). Complementation drives higher growth rate and yield of wheat and savesnitrogen fertilizer in wheat and faba bean intercropping. *Field Crops Research*, *221*, 119–129. https://doi.org/ 10.1016/j.fcr.2017.12.009

Yang, W.T., Wang, X.W., Wang, J.W., & University, J.A. (2013). Crop-and soil nitrogen in legume-Gramineae intercropping system: research progress. *Chinese Journal of Ecology*, *32*, 2480–2484. https://doi.org/ 10.13292/j.1000-4890.2013.0342

Yadollahi, P., Abad, A.R.B., Khaje, M., Asgharipour, M.R., & Amiri A. (2014). Effect of intercropping on weed control in sustainable agriculture. *International Journal of Agriculture and Crop Sciences*, *7*(10), 683-686.

Zhang, C., Dong, Y., Tang, L., Zheng, Y., Makowski, D., Yu, Y., Zhang, F., & Werf, W.V.D. (2019). Intercropping cereals with faba bean reduces plant disease incidence regardless of fertilizer input; a meta-analysis. *European Journal Plant Pathology*, *154*(4), 931-942. https://doi.org/10.1007/s10658-019-01711-4

Zhu, Y.Y., Chen, H.R., Fan, J.H., Wang, Y.Y., Li, Y., Chen, J.B., Fan, J.X., Yang, S.S., Hu, L.P., Leung, H., Mew, T.W., Teng, P.S., Wang, Z.H., & Mundt, C.C. (2000). Genetic diversity and disease control in rice. *Nature*, *406*, 718–722. https://doi.org/10.1038/35021046

Zhu, J.H., Dong, K., Yang, Z.X., & Dong, Y. (2017a). Advances in the mechanism of crop disease control by intercropping. *Chinese Journal Ecology*, *36*, 1117–1126. https://doi.org/10.13292/j.1000-4890.201704.016

Zhu, J., Dong, K., & Yang, Z. (2017b). Effects of N application on wheat powdery mildew occurrence, nitrogen accumulation and allocation in intercropping system. *Chinese Journal of Applied Ecology*, *28*, 3985–3993. https://doi.org/10.13287/j.1001-9332.201712.029

Zhu, J.H., Guo, Z.P., Dong, K., & Dong, Y. (2020). Effects of N application on nitrogen and potassium nutrition and stripe rust of wheat in an intercropping system. *Chinese Journal Ecology and Agriculture*, *28*, 236–244. https://doi.org/10.13930/j.cnki.cjea.190473

Zillinsky, F.J. (1983). *Les maladies communes des céréales à paille*: Guide d'identification. Eds. CIMMYT, Mexico. 141p. (in French).