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Margaux Guy, Mathieu Lorin, Xavier Bousselin, Guénaëlle Corre-Hellou. Intercropping chickpea with a competitive service plant and mowing the inter-rows controls weeds and ascochyta blight while mitigating interspecific competition. *European Journal of Agronomy*, 2026, 178, pp.128112. <10.1016/j.eja.2026.128112>. <hal-05627550>

HAL Id: hal-05627550

<https://hal.science/hal-05627550v1>

Submitted on 20 May 2026

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Intercropping chickpea with a competitive service plant and mowing the inter-rows controls weeds and ascochyta blight while mitigating interspecific competition

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ARTICLE INFO

Keywords:

Cicer arietinum
Companion plant
Inter-row mowing
Weed control
Disease control
Row intercropping

ABSTRACT

Chickpea (*Cicer arietinum* L.) is a promising crop for adapting to climate change and reducing the reliance of cropping systems on synthetic N fertilizers. However, its yield is highly variable, mainly due to weed competition and ascochyta blight (*Ascochyta rabiei*). Hence, this study investigated the effects of intercropping chickpea with a mowed service plant to control both weeds and ascochyta blight, while mitigating competition to minimise yield reductions.

In a two-year field experiment in Western France, chickpea was grown as sole crop and intercropped with four single service plants (Egyptian clover, faba bean, oat, and Sudan grass) in alternate rows. These species were chosen for their contrasted traits, allowing to create different levels of interspecific competition. Chickpea's inter-rows were either mowed at the beginning of flowering or left without mechanical regulation.

Introducing oat decreased weed biomass in both years. Under high weed and disease pressures, adding unmowed oat reduced both weed biomass and ascochyta blight severity by 66% and 56% compared to the unmowed sole chickpea, respectively. No differences were found between the sole chickpea and the other intercrops. Unlike the other species, oat had a high biomass production early in the crop cycle, which partly explains its weed-suppression effect. However, adding oat reduced chickpea grain yield in 2023 by 72%, although mowing limited this reduction to 48%.

This study highlights that intercropping chickpea with a mowed competitive service plant that generates an aerated canopy, like oat, can help to control both weeds and ascochyta blight, while mitigating interspecific competition.

1. Introduction

European arable cropping systems have become highly dominated by high-yielding cereal and oilseed crops, and strongly dependent on fertilisers and pesticides. The detrimental impacts on the environment by the current agricultural model have been widely acknowledged, and the past shift from diversified to specialised high-input cropping systems is now being called into question (Campbell et al., 2017; Tilman et al., 2002; Wan et al., 2025). There is also a growing interest in promoting plant-based alternatives to animal proteins for both environmental and human health (van Loon et al., 2023; Watson et al., 2017).

Grain legumes have emerged as promising candidates to address these issues (van Loon et al., 2023; Watson et al., 2017). Growing these crops provides protein-rich grains and reduce the reliance of cropping

systems on nitrogen inputs, thanks to the symbiotic fixation of atmospheric nitrogen (Jensen et al., 2020; Peoples et al., 2009). Introducing grain legumes in cereal and oilseed-based rotations can also contribute to pest regulation, and thus limit the need for pesticide use at the crop succession scale (Guinet et al., 2023; Zander et al., 2016). Chickpea (*Cicer arietinum* L.) is one of the most commonly grown grain legumes worldwide and has multiple agronomic advantages (FAO, 2025). Among others, chickpea can withstand drier growing conditions than other grain legumes (Benjamin and Nielsen, 2006; Farooq et al., 2017), which is of particular interest given the expected increase in frequency and intensity of drought in Western Europe (IPCC, 2023). Moreover, in this area, chickpea has few insect pests (Romeis et al., 1999; Rubiales et al., 2015), which is particularly interesting for reducing pesticides use at the crop rotation scale. Still, chickpea is not a common crop in Europe,

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<https://doi.org/10.1016/j.eja.2026.128112>

Received 26 May 2025; Received in revised form 6 March 2026; Accepted 31 March 2026

Available online 6 May 2026

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especially in France, where only 26,534 ha were cultivated in 2023 (Colas and Boudour, 2024).

Like other grain legumes, chickpea has a high inter-annual yield variability, notably due to its strong sensitivity to weeds (Cernay et al., 2015). Chickpea has a slow crop establishment and a low ground cover, which results in a poor competitive ability for light interception. Previous studies have documented yield reductions of at least 50% when no weed management practices are carried out (Banik et al., 2006; Whish et al., 2002).

In addition to weeds, ascochyta blight (caused by *Ascochyta rabiei*)—a foliar disease that causes necrotic lesions on all aerial plant parts—is also responsible for high yield reductions, potentially even leading to complete crop failure (Singh et al., 2022). The causal agent exhibits both asexual (*Ascochyta rabiei*) and sexual (*Didymella rabiei*) stages in its life cycle. A single sexual cycle is completed during the growing season, resulting in the production of airborne ascospores that are dispersed over long distances (Trapero-Casas et al., 1996). By contrast, the sexual phase is polycyclic, and leads to the production of conidia that are dispersed over short distances by rain splash. Thus, *A. rabiei* is responsible for spreading the disease on the infected host and to the neighbouring plants (Singh et al., 2022). The causal agent is pathogenic to *Cicer* species only (Hernandez-Bello et al., 2006), although alternative hosts can be infected and may serve as a source of inoculum (Hernandez-Bello et al., 2006; Khan et al., 1999; Trapero-Casas and Kaiser, 2009). Despite extensive research on genetic breeding, the pathogen can overcome host resistance (Bar et al., 2021; Mehmood et al., 2017). Therefore, agroecological practices are needed to address weed and disease control issues in chickpea, without resorting to pesticides.

Intercropping consists in growing two or more species in the same field for a significant period of their life cycle (Willey, 1990). Among the different types of intercrops, introducing a service plant—a non-harvested species grown to provide supporting and regulating services—is an interesting option (Gardarin et al., 2022; Moreau et al., 2025). Service plants are also named companion plant, living mulch, subsidiary crop, or cover crop in the scientific literature. This type of intercrop can provide ecosystem services, such as weed and pest control, while focussing on a single cash crop production. Higher competition for light and soil resources is a mechanism often cited in studies to explain the weed-suppressive ability of intercrops compared to sole crops. This leaves fewer resources available to weeds, limiting their biomass production (Bedoussac et al., 2015; Corre-Hellou et al., 2011). In a meta-analysis on various types of species combinations, Gu et al. (2021) found that intercropping reduced weed biomass by 58% on average relative to the less weed suppressive sole crop, which was often a legume.

Intercropping can also improve disease control (Boudreau, 2013). Previous studies on ascochyta blight of various grain legume species (Fernández-Aparicio et al., 2010; Hauggaard-Nielsen et al., 2008; Schoeny et al., 2010), including chickpea (Zhou et al., 2022), reported a disease-suppression effect of intercropping. Research on pea-cereal intercrops attributed this effect to the combination of a diversity of mechanisms including i) microclimate alteration, ii) barrier effect by a non-host plant decreasing splash dispersal, and iii) host dilution (Fernández-Aparicio et al., 2010; Schoeny et al., 2010). Ascochyta blights of pea and chickpea have different causal agents but are both splash-dispersed and require similar microclimatic conditions for epidemiological development (Tivoli and Banniza, 2007). Hence, previous results on ascochyta blight reduction in pea-based intercrops may apply to chickpea-service plant intercrops.

Little research has been published in North-West Europe on chickpea-based intercropping systems, with chickpea as the cash crop. In prior studies, chickpea was often studied for its effects, as a secondary crop, on the nutrition of a cereal in both field (Gunes et al., 2007; Xia et al., 2013) and greenhouse experiments (Betencourt et al., 2012; Li et al., 2003, 2004). Besides, a majority of the previous studies that

examined chickpea-based intercropping systems in field conditions were conducted under high input conditions. Also, most of them were located in the main areas of chickpea production such as India, Australia, and North America, under contrasted pedoclimatic conditions compared to North-West Europe (Banik et al., 2006; Dowling et al., 2023; Heineck et al., 2025; McAuley et al., 2025; Zhou et al., 2022). Furthermore, they all reported that chickpea yield was reduced by intercropping, while the production of the associated species was not or less affected. Hence, chickpea is often dominated by the other component in intercrops.

Thus, introducing a service plant could be an interesting approach for harnessing the agronomic benefits of intercropping in a low-input cropping system, while limiting the intensity of interspecific competition compared to mixing chickpea with another cash crop. Nevertheless, to our knowledge, no previous works have studied chickpea-service plant intercrops.

Spatial arrangements in alternate rows and relative sowing densities in favour of the cash crop can also limit interspecific competition. However, they are usually not sufficient to prevent yield reductions (Carton et al., 2020; Cheriére et al., 2020). Still, growing the cash crop and the service plant on separate rows enables one to manage them differently, and paves the way for implementing additional levers to reduce interspecific competition. For instance, Thorsted et al. (2006) effectively reduced interspecific competition in wheat-clover intercrops by cutting the legume in the inter-rows of the cereal. Thus, this work offers prior knowledge about mechanically regulating the service plant to mitigate interspecific competition in intercrops. Moreover, Rowland et al. (2023) reported that mowing the inter-rows in no-till soybean planted into roller-crimped cereal rye decreased weed biomass by at least 60% compared to an unweeded control. Hence, as chickpeas are very sensitive to competition, mechanical regulation could be a key lever for driving the dominance relationship between the cash crop, the associated species, and weeds in intercrops.

The main issue of service plant-cash crop intercropping systems is to find the right trade-off between service provision and their impact on the cash crop growth through competition (Verret et al., 2017; Gardarin et al., 2022; Moreau et al., 2025). Thus, the purpose of this study was to test whether intercropping chickpea with different species of service plants and inter-row mowing allows to control both i) weeds and ii) ascochyta blight while iii) mitigating interspecific competition to stabilise chickpea yield without resorting to pesticides.

We particularly made the assumptions that the species of service plant sown in the inter-row of chickpea impacts the level of weed and ascochyta blight regulation. More specifically, we expect the species with a higher and earlier biomass production to be more effective at providing these services but also more impactful on chickpea growth. We also hypothesised that mowing the service plants that are effective at weed and ascochyta blight control could mitigate their impact on chickpea, and that the service plant's ability to regrow after mowing could be an asset for weed control until the harvest.

2. Material and methods

2.1. Experimental site and pedoclimatic conditions

An experiment was conducted in farmer fields for two consecutive years (2023 and 2024) in La Ménitère, France (47°23'37.3"N, 0°14'57.6"W, altitude 20 m). Separate plots from the same site were used for each year of the experiment. In 2023, the trial was undertaken on a clay loam soil. In 2024, the soil was a sandy clay loam. Both soils were at least 90 cm deep (Table 1). The soil mineral nitrogen content at sowing in the 0–90 cm soil layer was 88 kg ha⁻¹ in 2023 and 99 kg ha⁻¹ in 2024. In both years, the preceding crop was winter wheat in a two-year crop rotation with maize.

The precipitation levels were much higher in the second year of the experiment (Fig. 1). Between sowing and harvest (from late April to August), there was 342 mm of total rainfall in 2024, which was 58% and

Table 1
Description of the topsoil (0–30 cm) of the experimental fields.

	2023	2024
Clay (%)	42.0	43.9
Silt (%)	49.9	41.1
Sand (%)	8.1	15.0
Organic matter (%)	2.9	4.4
pH _{H2O}	6.8	7.1
P _{Olsen} (g kg ⁻¹)	0.057	0.032
Exchangeable K ⁺ (g kg ⁻¹)	0.208	0.214
CEC (meq 100 g ⁻¹)	28.7	29.6

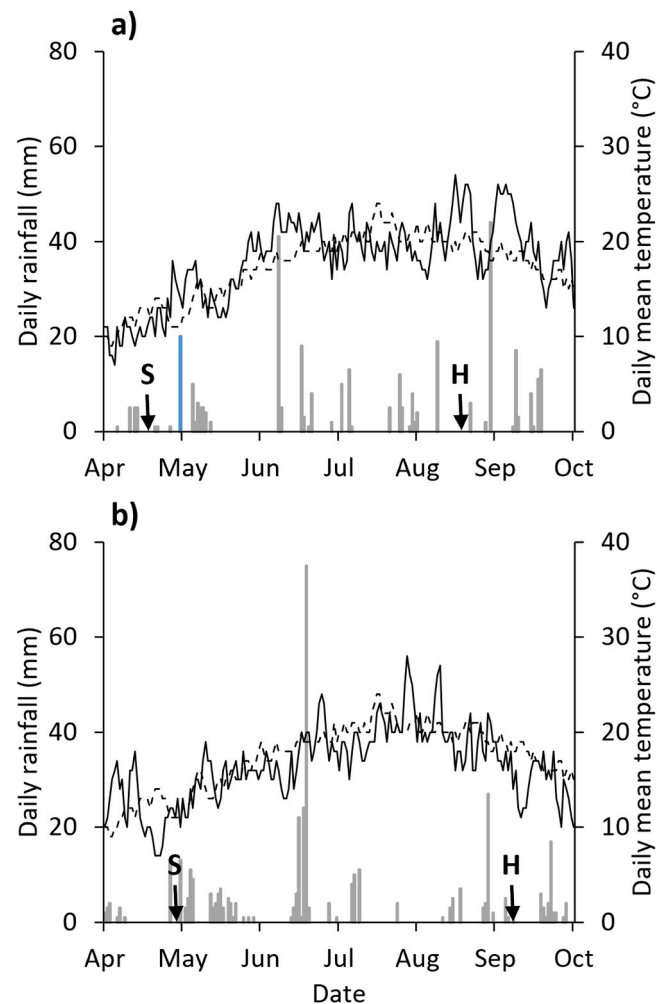


Fig. 1. Daily rainfall and mean daily temperature recorded near the experimental site in 2023 (a) and 2024 (b) (Météo France, 2024). The black solid line is the mean daily temperature during the time of the experiment. The dashed line shows the mean daily temperature averaged over a ten-year period (2013–2022). Grey bars stand for daily rainfall and blue bars correspond to irrigation. S: sowing date, H: harvest date.

60% higher than 2023 and the 10-year average (2013–2022), respectively (Fig. 1). Specifically, the weather in June, which corresponded to the beginning of chickpea flowering, was particularly contrasted between the two years of the experiment. In June 2024, the total rainfall was 142 mm, which was 71% and 125% higher than in 2023 and the 10-year average, respectively. The weather conditions during crop establishment were also very contrasted between the two years of the experiment. Indeed, the experimental field only received 5 mm of rain during the first ten days after sowing the 2023 trial, versus 45 mm in 2024. Therefore, the weather was much more humid in 2024 than in

2023, especially during crop establishment and at the beginning of chickpea flowering (Fig. 1).

2.2. Experimental design

Two factors were tested in this experiment (Fig. 2). We first compared the effect of four species of service plant with contrasted traits sown in chickpea’s inter-rows: spring oat (*Avena sativa* L., cv. Celeste), Sudan grass (*Sorghum x drummondii* (Nees ex Steud.) Millsp. & Chase, cv. Piper), Egyptian clover (*Trifolium alexandrinum* L., cv. Akenaton) and spring faba bean (*Vicia faba* L., cv. Nanaux). These four intercrops were compared with chickpea grown as sole crop (*i.e.* five treatments). Then, we compared two chickpea inter-row management practices: with or without chickpea inter-row mowing (*i.e.* two treatments). The experiment was arranged in a randomised complete block design with four replicates. In 2023, the plots were 20 m long and 3 m wide consisting of nine chickpea rows. In 2024, due to the field configuration, they were 22 m long and 2.3 m wide with seven chickpea rows (33.2 cm inter-row spacing). In both years, only the two central rows of chickpeas were used for samplings.

2.2.1. Service plant species

Four annual service plant species with contrasted traits were selected to be intercropped with chickpea. Spring oat has an erect growth habit, a deep fibrous root system, and has a high competitive ability for resource acquisition and high biomass production from the early stages of growth (Tribouillois et al., 2015; Wendling et al., 2016). After mowing, oat was expected to regrow and maintain competition with weeds, while leaving a substantial amount of biomass on the ground. Conversely, Sudan grass was expected to be less competitive during the early growth stages of chickpea, but able to produce a much higher amount of biomass after mowing. Egyptian clover is a fodder legume with a shallow tap root system, a semi-erect growth habit, a slow crop establishment, and the ability to regrow after mowing (Ouattara et al., 2023; Wendling et al., 2016). This species is commonly used as service plant in intercrops (Bousselin et al., 2024; Lorin et al., 2015; Verret et al., 2017). Spring faba bean is a grain legume with a shallow tap root system, an erect growth habit, a higher nitrogen fixation rate than Egyptian clover, and was expected to wither after mowing unlike the other species (Büchi et al., 2015; Wendling et al., 2016). The erect growth habit was a critical criterion to ensure that all the service plants could be mowed. Among the service plant and weed species examined in this study, only faba bean was previously identified as a potential alternative host of *Ascochyta rabiei* (Trapero-Casas and Kaiser, 2009).

2.2.2. Trial management

In the 2023 experiment, the soil was ploughed during winter to incorporate stubble and destroy volunteers and weeds. Before sowing, the seedbed was prepared using a rotary harrow and a tine weeder to break the clods and control the remaining weeds. In 2024, the field could not be ploughed during winter because of the high amount and frequency of rainfall. Instead, the field was spaded in January, and three passes were done with a disc cultivator, a rotary harrow, and a tine weeder in April. The chickpea in sole cropping and intercropping conditions were sown on 20th April 2023 and 30th April 2024. The chickpea cultivar sown in this experiment is Twist. This Kabuli-type cultivar, susceptible to ascochyta blight, is the most commonly grown in France.

In all experimental conditions, the chickpea and the service plant were sown simultaneously with a farmer disc seeder allowing for separate control of the seeding densities and sowing depths of the two species (Easydrill 3020 Fertisem, Sky Agriculture, Châteaubourg, France). Chickpea was sown at a density of 70 seeds m⁻², at an average depth of 3.5 cm and with an inter-row spacing of 33.2 cm, corresponding to the full density and the spatial arrangement recommended by the local agricultural institutes both for conventional or organic cultivation (Lambert, 2023). In the intercrops, the service plants were sown in the

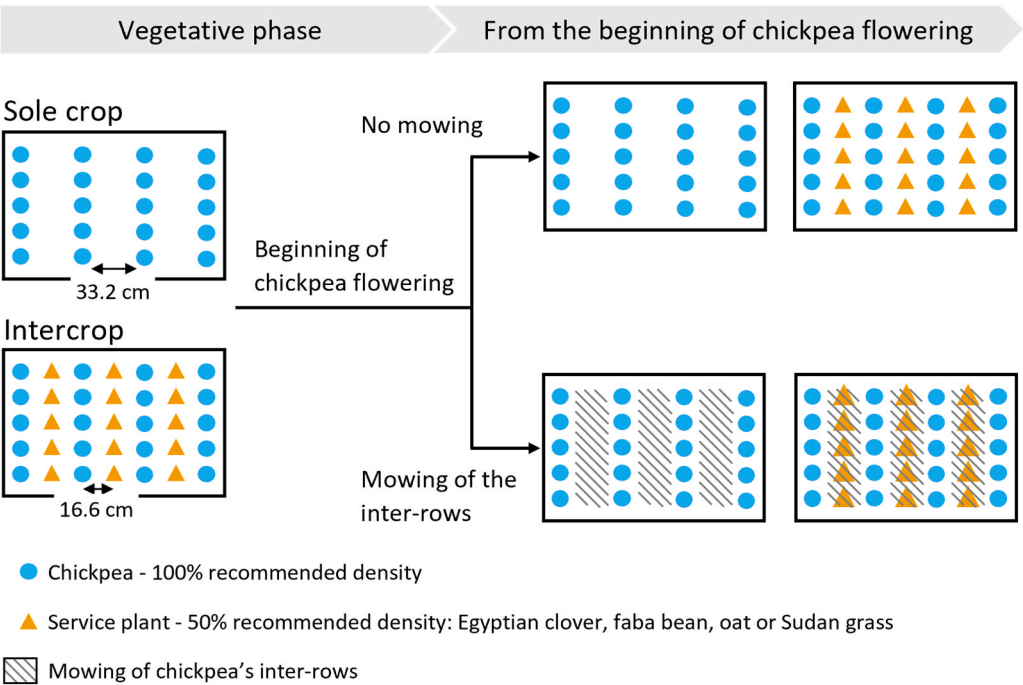


Fig. 2. Spatial arrangement and mowing design of the field trials.

middle of chickpea’s inter-rows at 50% of their recommended densities following an additive design (Fig. 2). The seeding densities for the service plants were 250, 30, 175 and 54 seeds m⁻² for Egyptian clover, faba bean, oat and Sudan grass respectively. These densities correspond to 83, 10, 58 and 18 seeds per linear meter, respectively. In 2023, the service plants were sown at a depth of 1 cm. In 2024, they were sown a bit deeper, at a depth of 1.5 cm on average, in the event that the growing conditions during crop establishment were as dry as in the previous year. All seeds used were certified.

As the rhizobia specific to chickpea were absent from the soils of the area of study, the seeds were inoculated before sowing with a *Mesorhizobium muleiense* strain supplied by UMR Agroécologie, INRAE (Dijon, France). Inoculation was not necessary for faba bean and Egyptian clover, as their rhizobia are already present in the soil. The presence of active nodules was later confirmed for chickpea, faba bean, and Egyptian clover.

In 2023, a single application of the molluscicide SLUXX HP (containing 29.7 g kg⁻¹ of ferric phosphate) was done at sowing, at a rate of 7 kg ha⁻¹, to prevent slug damage at emergence. Before crop emergence, weeds were destroyed using a non-selective herbicide (with glyphosate as the active ingredient) applied once at 3 l ha⁻¹. In 2024, the same molluscicide was applied weekly for three consecutive weeks in light of the high amount and frequency of rainfall. In 2023, the field was irrigated once ten days after sowing with 20 mm of water to secure the experiment (Fig. 1). No irrigation was needed in 2024.

2.2.3. Inter-row mowing

The inter-rows of chickpea were either mowed (4–8 cm cutting height) at the beginning of chickpea flowering or left without mechanical regulation (Fig. 2). At the time of mowing, faba bean, Egyptian clover and oat were all at the flowering stage, and Sudan grass was at the tillering stage.

The inter-rows were mowed using a brush cutter equipped with a 23-cm-wide cutting head (RG-KM rotary cutting head KombiTool, Stihl, Waiblingen, Germany). After mowing, the service plant and weed residues were left on the ground between the chickpea rows.

In 2024, a third level of inter-row mowing was added in the chickpea-oat intercrops to investigate the effects of adding an earlier

mowing date. In this treatment, the inter-rows were mowed firstly at the 10-leaf stage (BBCH 19) of chickpea, and then a second time at the beginning of chickpea flowering. At the time of the first mowing, Egyptian clover, faba bean, and Sudan grass were at the 5-leaf stage (BBCH 15), and oat was at the beginning of stem elongation.

2.3. Measurements

2.3.1. Plant sampling

The above-ground biomass of chickpea, service plants, and weeds was sampled from the two central rows of chickpea over 0.8 m long and 0.664 m wide. Thus, the harvested area contained two rows of chickpea and two rows of service plant. Sampling was done at six stages throughout the growing cycle of chickpea, with an emphasis on the early growth and the period following the mowing date at the beginning of chickpea flowering (BBCH 61) (Table 2). At maturity, chickpea samples were threshed to separate the grains from the straw. The grains were then cleaned using a densiometric cleaning and sorting column in order to remove pods residuals. All samples were dried at 70°C for 48 h and then weighed.

Weeds were counted and species were identified on each sampling plot at the beginning of chickpea flowering (BBCH 61) and at the grain-filling stage (BBCH 75).

Table 2
Distribution of the six plant samplings throughout chickpea’s cycle.

Chickpea phenological stage	DAS ⁽¹⁾		GDD ⁽²⁾	
	2023	2024	2023	2024
5-leaf	26	22	228	200
10-leaf	42	37	402	356
Beginning of flowering	54	55	586	558
Mowing of the inter-rows	55	59	602	625
End of flowering (2023) or pod set (2024)	70	71	832	776
Grain-filling	89	90	1101	1054
Maturity	123	132	1593	1655

⁽¹⁾ Number of days after sowing
⁽²⁾ Growing degree days, computed using a base temperature of 6°C for chickpea (Soltani et al., 2006)

2.3.2. Assessment of ascochyta blight severity

Ascochyta blight severity was visually assessed at the grain-filling stage on ten random chickpea plants per plot. Disease severity was scored on leaves at each node of the main stem via a 0–4 scale: 0 = no symptoms, 1 = 1–25% of the leaf area necrotic, 2 = 25–50% of the leaf area necrotic, 3 = 50–75% of the leaf area necrotic, and 4 = 75–100% of the leaf area necrotic. Similarly to Schoeny et al. (2010), we then computed a mean disease score at the plant scale by averaging the scores of all nodes of each of the ten plants per plot.

2.4. Statistical analysis

All statistical analyses were performed using the R software (R Core Team, 2025). Plant biomass (chickpea, service plants, weeds), mean disease score, and chickpea yield data were analysed by performing linear mixed models using the lme4 package (Bates et al., 2015). As the two experimental years were highly contrasted, the data were analysed separately. A model was fitted for each sampling date. The service plant treatments (sole chickpea, clover, faba bean, oat, Sudan grass) and the mowing treatments of chickpea's inter-rows (no mowing, one mowing at the beginning of chickpea flowering) were fixed factors. The experimental block was defined as a random factor. The effects of the fixed factors and their interaction were tested by performing type II ANOVAs. The validity of the model assumptions was systematically checked on the residuals with the Shapiro-Wilk test for normality, and the Bartlett test for homoscedasticity. The multiple comparisons were performed using Dunnett's test with the sole chickpea as the control treatment. In case of significant interaction between service plant treatments and mowing treatments, the reference was the unmowed sole chickpea. The proportion of variance attributed to each fixed effect and their interaction, namely the part R^2 , was computed using the partR2 package (Stoffel et al., 2021).

To evaluate the effects of adding an earlier mowing date in the chickpea-oat intercrops in 2024, we compared this treatment to the chickpea-oat intercrops with one mowing date at flowering, or with no mowing. The analysis was conducted by performing linear mixed models as previously described, with the inter-row mowing treatments as the only fixed factor. In case of significant differences, the multiple comparisons were performed using Tukey's HSD test. When non-normality and heteroscedasticity were not resolved by log-transformation, the Mann-Whitney U Test or Kruskal-Wallis test were used, depending on the number of mowing treatments to compare. After a significant Kruskal-Wallis test, the multiple comparisons were conducted using Dunn's test.

The mowed and unmowed treatments of the service plants biomass data were analysed separately, using Tukey's HSD test to compare the means. For the yield data of 2024, only the mowed treatments were analysed by testing the effect of the service plant species.

To investigate the relationship between disease severity and plant biomass, linear models were fitted with the mean disease score as the response variable, and the biomass of the different components of the mixture as the explanatory variable for each experimental year. The residuals were checked for normality with the Shapiro-Wilk test and visually checked for homoscedasticity.

All statistical tests were considered significant when the p-value was lower than 0.05.

3. Results

3.1. Biomass accumulation dynamics

3.1.1. Chickpea biomass

Chickpea biomass varied greatly between the two years of experiment. In the unmowed sole crop, chickpea accumulated 705 g m⁻² of biomass at maturity in 2023 as opposed to 111 g m⁻² in 2024. In the unmowed intercrops, chickpea biomass at maturity varied between

214 g m⁻² and 677 g m⁻² in 2023, while it ranged from 29 g m⁻² to 158 g m⁻² in 2024 (Fig. 3).

Adding oat decreased chickpea biomass compared to the sole crop in both years, while the other service plants had seldom an effect (Fig. 3). In 2023, intercropping chickpea with oat reduced chickpea biomass from the beginning of flowering ($p < 0.001$, part $R^2 = 0.89$) until maturity ($p < 0.001$, part $R^2 = 0.43$, Fig. 3d) compared to the sole crop. For instance, chickpea accumulated 214 g m⁻² of biomass by maturity in the unmowed intercrop with oat, which was 70% lower than the unmowed sole crop. At the 5-leaf stage, adding Sudan grass reduced chickpea biomass by 25% ($p < 0.01$, part $R^2 = 0.48$, Fig. 3e), and adding unmowed clover decreased it by 34% at the grain-filling stage ($p < 0.001$, part $R^2 = 0.44$, Fig. 3b) relative to the unmowed sole crop. No other significant differences were found between the sole crop and clover or Sudan grass intercrops for the rest of the crop cycle. Faba bean did not have any significant effect on chickpea biomass. In 2024, adding unmowed oat decreased chickpea biomass by 44% at pod set ($p < 0.05$, part $R^2 = 0.18$, Fig. 3i), and adding unmowed faba bean decreased it by 74% at maturity ($p < 0.05$, part $R^2 = 0.13$, Fig. 3h), compared to the unmowed sole crop. No significant effect of the other species of service plants was found at any of the six chickpea phenological stages studied.

Mowing the inter-rows led to a higher chickpea biomass in most treatments in both years (Fig. 3). In 2023, mowing increased chickpea biomass at the grain-filling stage ($p < 0.05$, part $R^2 = 0.08$), although this was not visible in the intercrop with Sudan grass. Still, no significant interaction between the service plant treatments and the inter-row mowing treatments was ever detected. In the mowed sole crop, chickpea accumulated 768 g m⁻² of biomass, which was 24% higher than in the unmowed treatment (Fig. 3a). In the mowed intercrops with Egyptian clover, faba bean, and oat, chickpea biomass was 63%, 11%, and 49% higher relative to the corresponding unmowed treatment, respectively (Fig. 3b–d). Chickpea biomass at maturity also tended to be twice as high in the intercrop with mowed oat compared to the unmowed intercrop ($p = 0.072$, Fig. 3d). In 2024, the positive effect of mowing on chickpea biomass was visible in all treatments at all sampling dates. In the mowed sole crop, chickpea accumulated 301 g m⁻² of biomass at maturity, which was 2.7-fold higher than in the unmowed treatment (Fig. 3f). In the intercrops, chickpea biomass was 1.5- (chickpea-oat) to 8.6-fold higher (chickpea-faba bean) in the mowed treatment compared to the corresponding unmowed intercrop ($p < 0.001$, $R^2 = 0.32$, Fig. 3g–j).

3.1.2. Service plants biomass

The service plants differed in their biomass accumulation dynamics, with oat having the highest biomass production from the 5-leaf stage in both years ($p < 0.001$, Fig. 3). After oat, faba bean had the second highest biomass production from the 5-leaf stage to the beginning of chickpea flowering in 2023, and to the 10-leaf stage in 2024 ($p < 0.001$, Fig. 3). However, with a biomass of 40 g m⁻² at the beginning of chickpea flowering in 2023 ($p < 0.001$, $R^2 = 0.93$, Fig. 3c), and of 65 g m⁻² in 2024 ($p < 0.001$, $R^2 = 0.98$, Fig. 3h), faba bean accumulated six and five times less biomass than oat, respectively. Moreover, faba bean only contributed to 20% of the total biomass of the mixture at this date, while oat accounted for 74% of it, on average. Egyptian clover had a slower crop establishment but tended to surpass the biomass production of faba bean at the later stages of the cycle. Thus, the biomass of clover at the grain-filling stage was 135 g m⁻² in 2023 and 189 g m⁻² in 2024, which was 1.5 and 2 times higher on average than faba bean, respectively (Fig. 3). Sudan grass had the lowest biomass production from the 5-leaf stage ($p < 0.001$, $R^2 = 0.97$, Fig. 3e) to the beginning of chickpea flowering in both years ($p < 0.001$, $R^2 = 0.98$, Fig. 3j). In 2023, its biomass sharply increased at the end of the crop cycle, but remained low in 2024 (Fig. 3j, e).

The response of service plants to mowing varied between species and years (Fig. 3). Faba bean withered after mowing in both years. In 2023, Egyptian clover and oat had a very limited regrowth. Indeed, mowed oat

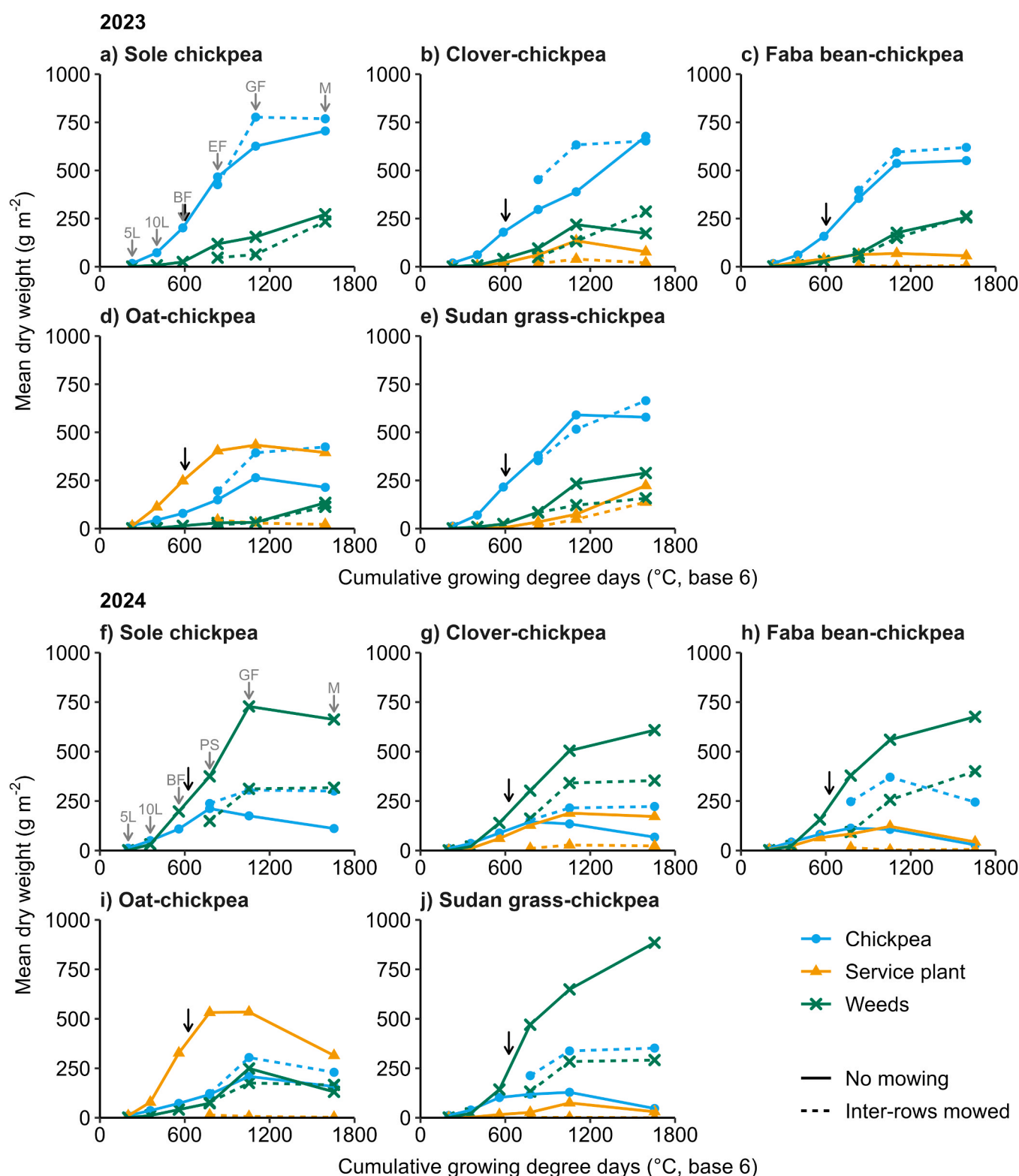


Fig. 3. Dry matter accumulation of chickpea, service plants, and weeds in the different treatments during the two years of the experiment. Each symbol corresponds to the averaged value of the blocks for each treatment ($n = 8$ until the 3rd sampling then $n = 4$). The mowing date is indicated by a black arrow. 5 L: 5-leaf stage of chickpea, 10 L: 10-leaf stage, BF: beginning of flowering, PS: pod set, EF: end of flowering, GF: grain-filling stage, M: maturity.

accumulated 44 g m^{-2} of biomass at most by the end of chickpea flowering, while unmowed oat biomass was nine times higher (Fig. 3d). After mowing, clover produced 39 g m^{-2} of biomass at most at the grain-filling stage, while unmowed clover biomass was 3.4 times higher (Fig. 3b). Sudan grass stood out by having a fast regrowth, producing at

least six times more biomass at harvest than the other mowed service plants. In 2024, oat regrew after being mowed at the 10-leaf stage, but did not when the first mowing was at the beginning of chickpea flowering (Fig. 3i, supplementary material Table S1). None of the other service plants resumed their growth after mowing apart from Egyptian

clover, which had a very limited regrowth (Fig. 3). Indeed, mowed clover only accumulated 28 g m^{-2} of biomass at most by the grain-filling stage, which was 6.8 times lower than the unmowed clover at the same date (Fig. 3g).

3.1.3. Weed biomass

Weed biomass was much higher in 2024 than in 2023. In the unmowed sole chickpea, weed biomass at the grain-filling stage was 155 g m^{-2} in 2023, as opposed to 728 g m^{-2} in 2024 (Table 3,). At the same date, weed density was 84 plants m^{-2} in 2023, compared to $214 \text{ plants m}^{-2}$ in 2024. In both years, the dominant weed species were barnyardgrass (*Echinochloa crus-galli* (L.) P.Beauv.), lady's thumb (*Periscaria maculosa* Gray), and manyseed goosefoot (*Chenopodium polyspermum* L.).

Intercropping chickpea with oat decreased weed biomass in both years, but no significant effect of the other service plants was found (Table 3, Table 4). In 2023, introducing unmowed oat led to a weed biomass of 29.6 g m^{-2} at the end of chickpea flowering ($p < 0.01$, part $R^2 = 0.23$, Table 3), and of 32.5 g m^{-2} at the grain-filling stage, which was 75% and 79% lower than the unmowed sole crop, respectively ($p < 0.001$, part $R^2 = 0.37$, Table 3). At chickpea maturity, weed biomass was on average 51% lower in the intercrop with unmowed oat relative to the unmowed sole crop ($p = 0.099$, part $R^2 = 0.14$, Table 3). In 2024, intercropping chickpea with oat significantly reduced weed biomass from the 10-leaf stage ($p < 0.05$, part $R^2 = 0.45$, Table 4) until maturity ($p < 0.001$, part $R^2 = 0.32$, Table 4). At the beginning of chickpea flowering, there was 41.2 g m^{-2} of weed biomass in the chickpea-oat intercrop, which was 79% lower than the sole crop ($p < 0.001$, part $R^2 = 0.52$, Table 4). In both years, there were no significant differences between the sole chickpea and the other intercrops (Table 3, Table 4).

Mowing the inter-rows reduced weed biomass in most treatments in 2024, but had no significant effect in 2023 (Table 3, Table 4). Although it was not significant, mowing tended to decrease weed biomass at the end of chickpea flowering in 2023, except in the intercrop with Sudan grass ($p = 0.108$, Table 3). Indeed, there was 118.4 g m^{-2} of weed biomass in the mowed sole crop, which was 61% lower than the unmowed treatment. In the mowed intercrops with Egyptian clover, faba bean, and oat, weed biomass was on average 47%, 25%, and 34% lower compared to their corresponding unmowed treatment, respectively (Table 3). In 2024, mowing the inter-rows reduced weed biomass at all sampling dates (Table 4). At the grain-filling stage, mowing reduced weed biomass by 57% in the sole crop, and by 29% (chickpea-oat) up to 56% (chickpea-Sudan grass) in the intercrops ($p < 0.001$, part $R^2 = 0.32$, Table 4). A significant interaction was found at pod set ($p < 0.001$,

Table 4) and at chickpea maturity ($p < 0.01$, Table 4). Indeed, mowing reduced weed biomass in all treatments except in the intercrop with oat. At pod set, mowing reduced weed biomass by 60% in the sole crop, and by 47%, 75%, and 72% in the intercrops with clover, faba bean, and Sudan grass, respectively ($p < 0.001$, part $R^2 = 0.34$, Table 4). At these two dates, weed biomass was always lower in the mowed treatments compared to the unmowed sole chickpea (Table 4).

In both years, a strong gradient of weed biomass was observed between experimental blocks. For instance, weed biomass at the beginning of flowering in the sole chickpea varied between 5.4 g m^{-2} and 53.8 g m^{-2} in 2023, and between 97.6 g m^{-2} and 427.6 g m^{-2} in 2024.

3.2. Ascochyta blight severity

The disease pressure was much higher in 2024 than in 2023. The first symptoms were detected at the end of chickpea flowering in 2023, and at the 10-leaf stage in 2024. In the unmowed sole chickpea, the mean disease score at the grain-filling stage was 0.7 in 2023, while it was 3.2 in 2024, on a 0–4 scale (Table 5).

Introducing a service plant had no significant effect on disease severity in 2023, but adding oat strongly decreased it in 2024 ($p < 0.001$, part $R^2 = 0.11$, Table 5). Indeed, the mean disease score was 2.3-fold lower in the intercrop with unmowed oat relative to the unmowed sole crop. None of the other service plants had a significant effect (Table 5).

In 2023, mowing increased the mean disease score by 0.1–0.2 points in both the sole crop and the intercrops ($p < 0.001$, $R^2 = 0.33$, Table 5). By contrast, mowing highly decreased disease severity in the sole crop and in the intercrops with clover, faba bean, and Sudan grass in 2024. Indeed, the mean disease score was 2.7-fold lower in the mowed sole crop, and 1.6- (chickpea-faba bean) to 3-fold lower (chickpea-clover) in the mowed intercrops relative to the corresponding unmowed treatment ($p < 0.001$, $R^2 = 0.53$, Table 5). The interaction between the two fixed factors was significant, as mowing did not decrease disease severity in the intercrop with oat ($p < 0.01$, Table 5).

3.3. Relationship between biomass accumulation and ascochyta blight severity at the grain-filling stage

Ascochyta blight severity at the grain-filling stage was not related to the total chickpea, service plant and weed biomass in 2023, but significantly increased with plant biomass in 2024 ($p < 0.001$, $R^2 = 0.30$, Fig. 4a). At grain-filling, ascochyta blight severity slightly decreased with weed and service plant biomass in 2023 ($p < 0.001$, $R^2 = 0.40$, Fig. 4b), while it highly increased in 2024 ($p < 0.001$, $R^2 = 0.43$,

Table 3

Weed dry weight (g m^{-2}) in the sole crop and the intercrops at 6 sampling dates in 2023. Chickpea's inter-rows were either mowed at flowering (M) or without mechanical regulation (WM).

		5-leaf	10-leaf	Beginning flowering	End flowering	Grain-filling	Maturity
Sole chickpea	WM	1.0 ± 0.7	7.4 ± 5.2	24.6 ± 15.6	118.4 ± 155.8	155.0 ± 93.7	272.4 ± 123.0
	M				46.6 ± 14.0	63.5 ± 41.5	234.8 ± 148.1
Clover-chickpea	WM	1.0 ± 0.4	7.3 ± 3.9	40.5 ± 29.0	94.8 ± 67.4	218.4 ± 148.1	173.3 ± 104.4
	M				49.8 ± 30.0	132.2 ± 99.2	286.5 ± 112.7
Faba bean-chickpea	WM	1.7 ± 1.7	7.6 ± 7.9	29.7 ± 26.0	67.3 ± 38.0	176.5 ± 187.1	256.0 ± 146.7
	M				50.7 ± 27.3	150.1 ± 122.2	262.0 ± 183.4
Oat-chickpea	WM	1.3 ± 1.2	2.7 ± 1.8	14.5 ± 13.7	29.6 ± 20.5	32.5 ± 51.4	133.9 ± 92.1
	M				18.4 ± 13.0	32.2 ± 16.9	112.9 ± 55.8
Sudan grass-chickpea	WM	1.1 ± 1.4	8.5 ± 7.2	23.7 ± 14.6	85.3 ± 61.5	233.3 ± 174.3	288.6 ± 130.7
	M				83.1 ± 66.8	121.5 ± 92.7	157.4 ± 85.6
Species part R^2		0.05 ns	0.12.	0.15 *	0.23 ** (log)	0.37 *** (log)	0.14.
Mowing part R^2					0.03 ns (log)	0.01 ns (log)	0.00 ns
Interaction part R^2					0.02 ns (log)	0.06 ns (log)	0.08 ns

Values are means $\pm$ standard deviation ($n = 8$ until the beginning of flowering then $n = 4$). For each intercrop, asterisks indicate a significant difference in comparison with the sole chickpea according to Dunnett's test. ns: non-significant, . $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. (log) Indicates that the response variable was log-transformed prior to model fitting.

Table 4

Weed dry weight (g m^{-2}) in the sole crop and the intercrops at 6 sampling dates in 2024. Chickpea's inter-rows were either mowed at flowering (M) or without mechanical regulation (WM).

		5-leaf	10-leaf	Beg. flowering	Pod set	Grain-filling	Maturity
Sole chickpea	WM	1.5 ± 1.2	31.2 ± 11.5	197.6 ± 124.8	374.8 ± 88.2	728.2 ± 215.6	662.1 ± 248.2
	M				149.2 ± 97.1 **	311.6 ± 117.0	317.6 ± 177.4 *
Clover-chickpea	WM	1.0 ± 0.4	20.2 ± 6.7	139.4 ± 93.8	302.5 ± 131.6	504.4 ± 72.4	608.2 ± 199.2
	M				161.3 ± 123.9 **	341.2 ± 128.6	353.7 ± 175.1 *
Faba bean-chickpea	WM	1.5 ± 1.0	22.7 ± 5.7	156.3 ± 89.6	378.5 ± 94.6	559.9 ± 182.7	676.0 ± 164.4
	M				93.4 ± 55.4 ***	256.0 ± 151.0	400.4 ± 90.5
Oat-chickpea	WM	0.9 ± 0.5	11.0 ± 4.6 **	41.2 ± 5.2 ***	73.3 ± 47.7 ***	249.2 ± 144.8	131.0 ± 49.2 ***
	M				77.6 ± 63.5 ***	175.8 ± 145.9	166.0 ± 128.2 ***
Sudan grass-chickpea	WM	1.1 ± 0.4	22.3 ± 5.8	142.7 ± 69.6	470.1 ± 50.9	648.7 ± 140.7	884.8 ± 50.5
	M				132.2 ± 97.6 ***	284.0 ± 201.9	291.6 ± 88.6 **
Species part R^2		0.09 ns	0.45 *	0.52 *** (log)	0.23 ***	0.20 **	0.32 ***
Mowing part R^2					0.34 ***	0.32 ***	0.27 ***
Interaction part R^2					0.13 ***	0.07 ns	0.13 **

Values are means ± standard deviation ($n = 8$ until the beginning of flowering then $n = 4$). For each intercrop, asterisks indicate a significant difference in comparison with the sole chickpea according to Dunnett's test. In case of significant interaction, the control treatment was the unmowed sole chickpea. ns: non-significant, $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. (log) Indicates that the response variable was log-transformed prior to model fitting.

Table 5

Mean ascochyta blight severity score (0–4) on chickpea leaves at the grain-filling stage. Chickpea's inter-rows were either mowed at flowering (M) or without mechanical regulation (WM).

		2023	2024
Sole chickpea	WM	0.7 ± 0.0	3.2 ± 0.9
	M	0.8 ± 0.1	1.2 ± 0.3 ***
Clover-chickpea	WM	0.5 ± 0.0	3.4 ± 0.2
	M	0.7 ± 0.1	1.1 ± 0.3 ***
Faba bean-chickpea	WM	0.6 ± 0.2	2.6 ± 0.4
	M	0.8 ± 0.1	1.6 ± 0.4 ***
Oat-chickpea	WM	0.5 ± 0.1	1.4 ± 0.4 ***
	M	0.7 ± 0.2	1.2 ± 0.3 ***
Sudan grass-chickpea	WM	0.7 ± 0.1	3.1 ± 0.8
	M	0.8 ± 0.2	1.1 ± 0.1 ***
Species part R^2		0.13	0.11 ** (log)
Mowing part R^2		0.33 ***	0.53 *** (log)
Interaction part R^2		0.01 ns	0.15 ** (log)

Ascochyta blight severity was scored on leaves at each node via a 0–4 scale: 0 = no symptoms, 1 = 1–25% of the leaf area necrotic, 2 = 25–50% of the leaf area necrotic, 3 = 50–75% of the leaf area necrotic, and 4 = 75–100% of the leaf area necrotic. Values are means ± standard deviation ($n = 4$). For each treatment, asterisks indicate a significant difference in comparison with the unmowed sole chickpea according to Dunnett's test. ns: non-significant, $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. (log) Indicates that the response variable was log-transformed prior to model fitting.

Fig. 4b). Still, ascochyta blight severity at the grain-filling stage was better correlated with weed biomass alone in 2024 ($p < 0.001$, $R^2 = 0.51$, Fig. 4c), while no relationship was found in 2023. Thus, under high disease pressure, weed control played a key role in ascochyta blight severity: the lower the weed biomass, the better the disease control. Nevertheless, the service plant species also mattered. For instance, the mean disease score in the chickpea-clover intercrop was on average 31% higher than in the chickpea-faba bean intercrop, even though they had similar levels of weed biomass (Fig. 4c).

3.4. Chickpea grain yield

Chickpea grain yield was extremely variable between the two years of the experiment. Indeed, the unmowed sole chickpea yielded 3.59 t ha^{-1} (Mg ha^{-1}) in 2023, but no grains were harvested in 2024. This was mainly due to the high ascochyta blight pressure by the end of the growth cycle, which resulted in the loss of almost all pods. In the unmowed intercrops, chickpea grain yield varied between 0.99 t ha^{-1} and 3.54 t ha^{-1} in 2023, while the values ranged from 0.00 t ha^{-1} to 0.02 t ha^{-1} in 2024 (Table 6).

Introducing unmowed oat decreased chickpea grain yield by 72% compared to the unmowed sole crop in 2023 ($p < 0.001$, part $R^2 = 0.50$, Table 6). None of the other service plants significantly affected chickpea grain yield. In 2024, no significant effect of the service plants was found when the mowed sole crop and the mowed intercrops were compared ($p = 0.249$). Still, adding unmowed oat allowed a small yield of 0.02 t ha^{-1} while no grains were harvested in any of the other unmowed treatments (Table 6).

The mowing factor significantly affected the chickpea grain yield in all treatments in 2023, leading to a 19% higher yield in the sole crop ($p < 0.05$, part $R^2 = 0.04$, Table 6). In the intercrops with oat and Sudan grass, mowing increased chickpea yield by 89% and 22% relative to the corresponding unmowed treatments, respectively. Mowing did not seem to affect the grain yield in the intercrops with clover and faba bean (Table 6). Despite the positive impact of mowing, adding mowed oat still reduced chickpea grain yield by 48% compared with the unmowed sole crop. In 2024, mowing the inter-rows in the sole crop and the intercrops with clover, faba bean, and Sudan grass led to small quantities of chickpea grains. By contrast, no grains were harvested in the unmowed treatments (Table 6).

3.5. Effect of adding an earlier mowing date in the chickpea-oat intercrops

In 2024, a third mowing treatment was added in the chickpea-oat intercrops to investigate the effects of adding an earlier mowing date during the vegetative phase of chickpea. In this treatment, the inter-rows were first mowed at the 10-leaf stage, and then a second time at the beginning of chickpea flowering.

Oat grew back after the first mowing at the 10-leaf stage, accumulating 73.6 g m^{-2} of biomass by the beginning of chickpea flowering, which is more than four times lower than the oat biomass in the unmowed intercrop. However, oat did not grow back when mowed at the beginning of chickpea flowering, whether it was for the first or second time (supplementary material Fig. S1, Table S1).

Adding an earlier mowing date in the chickpea-oat intercrops led to a significant increase in chickpea biomass production at pod set and at the grain-filling stage ($p < 0.05$, supplementary material Table S1). Indeed, chickpea biomass at pod set was 55% and 61% higher in the intercrop with an additional earlier mowing date compared with a single mowing and no mowing, respectively. However, these differences were not detected by Tukey's HSD test. At the grain-filling stage, adding an earlier mowing date significantly increased chickpea biomass by 80% compared with the unmowed intercrop ($p < 0.05$, $R^2 = 0.51$). Chickpea biomass also tended to be 24% higher in the intercrop with an additional

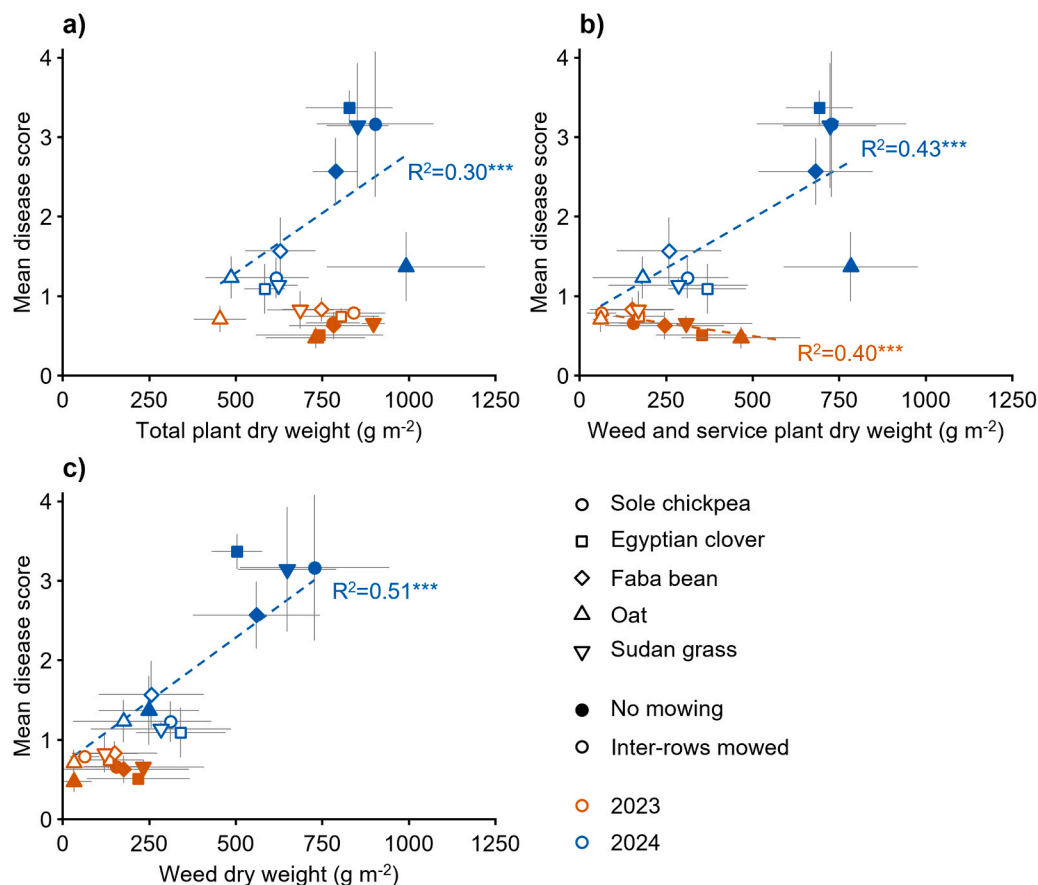


Fig. 4. Ascochyta blight severity on chickpea leaves at the grain-filling stage as a function of total chickpea, service plant and weed biomass (a), weed and service plant biomass (b) or weed biomass (c). Each symbol corresponds to the averaged value of the 4 blocks and error bars stand for the standard deviation of the mean. The dashed lines represent the regressions fitted to the data with significant p-values.

Table 6
Chickpea grain yield (t ha⁻¹) in the sole crop and intercrops in 2023 and 2024. Chickpea's inter-rows were either mowed at flowering (M) or without mechanical regulation (WM).

		2023	2024
Sole chickpea	WM	3.59 ± 1.04	0.00 ± 0.00
	M	4.28 ± 0.83	0.04 ± 0.08
Clover-chickpea	WM	3.54 ± 0.44	0.00 ± 0.00
	M	3.58 ± 0.42	0.03 ± 0.04
Faba bean-chickpea	WM	3.03 ± 0.43	0.00 ± 0.00
	M	3.22 ± 0.85	0.03 ± 0.06
Oat-chickpea	WM	0.99 ± 0.34	0.02 ± 0.02
	M	1.88 ± 0.71	0.02 ± 0.03
Sudan grass-chickpea	WM	3.05 ± 1.56	0.00 ± 0.00
	M	3.73 ± 1.22	0.06 ± 0.06
Species part R ²		0.50 ***	
Mowing part R ²		0.04 *	
Interaction part R ²		0.02 ns	

Values are means ± standard deviation (n = 4). For each intercrop, asterisks indicate a significant difference in comparison with the sole chickpea according to Dunnett's test. Empty cells indicate that the ANOVA assumptions were not met. ns: non-significant, * p < 0.05, ** p < 0.01, *** p < 0.001.

earlier mowing date compared to a single mowing, but these differences were not significant. Chickpea yielded 0.09 t ha⁻¹ in the intercrop with two mowing dates, which was not significantly different from the two other treatments.

Weed control was not improved by the addition of an earlier mowing at any sampling date (supplementary material Fig. S1, Table S1). Adding

an earlier mowing date led to a mean disease score of 1.3, which was not significantly different from the two other treatments.

4. Discussion

4.1. The competitive ability of the service plant during early growth shapes the dominance relationships in the intercrop

Testing a range of service plant species allowed us to explore various traits combinations and levels of interspecific competition between the intercrop components throughout chickpea's growing cycle.

Intercropping chickpea with a highly competitive service plant improved weed control regardless of the weed pressure level. In our study, introducing oat consistently decreased weed biomass compared to the sole chickpea. Indeed, cereals are known for their rapid crop establishment (Corre-Hellou et al., 2007; Hauggaard-Nielsen et al., 2009). Oat had the earliest and highest biomass production among the species we tested. Early growth was also previously identified as a key trait for weed control by service plant in intercropping systems (Gardarin et al., 2022; Moreau et al., 2025). Hence, adding a species in the inter-rows of chickpea that produces high amounts of biomass early in the crop cycle, like oat, gave a competitive advantage to the service plant at the expense of weeds, and thus compensated for the slow crop establishment of chickpea.

Nevertheless, our findings also revealed that intercropping chickpea with a highly competitive service plant impacted chickpea grain production. Indeed, introducing oat highly decreased chickpea biomass accumulation early in the crop cycle, which may have led to the grain yield reduction recorded in this treatment in 2023. Previous studies on

intercrops with grain legumes and other cash crops have identified a trade-off between weed control and yield (Carton et al., 2020; Cherie et al., 2020). As weed control can only be improved if the service plant is highly competitive, having an additional lever to mitigate interspecific competition, like mowing, is even more necessary to avoid high reductions in chickpea grain yield.

Initially, we expected that service plant species with lower and later biomass production than oat would lead to a better trade-off between weed control and chickpea competition. However, our results clearly show that introducing a service plant characterised by a slower crop establishment limited the competition exerted on chickpea, but did not improve weed control compared to the sole crop. In fact, under low input management and high weed pressure, a minimum level of competitiveness is essential to dominate weeds early in the growth cycle. In our experiment, Egyptian clover, faba bean, and Sudan grass produced low amounts of biomass during the vegetative phase of chickpea, thus giving a competitive advantage to weeds (Carton et al., 2020; Cherie et al., 2020). Consequently, as in the sole crop treatment, chickpea yield was very low in the intercrops with these service plant species. Hence, our results clearly indicate that adding a service plant with a low biomass production during the first stages of growth is not recommended as weeds can easily become highly dominant, particularly when no herbicide nor weeding practices are possible.

4.2. Intercropping chickpea with oat or mowing the inter-rows under high weed pressure limits ascochyta blight severity

In our study, the two experimental years varied greatly in terms of climatic conditions, which allowed us to test our treatments under contrasting biotic pressures. This also provided further evidence of the high yield variability of chickpea caused by weeds and ascochyta blight. Indeed, in 2024, the very high ascochyta blight pressure that occurred at the end of chickpea's growth cycle resulted in the loss of almost all pods. An extreme ascochyta blight pressure level was also recorded in 2024 in the other chickpea fields of the area because of the rainfall that was 58% higher than normal. In our case, our results show that the weed biomass further increased the damage caused by ascochyta blight, particularly when weeds were not controlled.

Our findings highlighted that ascochyta blight severity was related to plant biomass, with weed biomass explaining the highest proportion of variance under high disease pressure (Fig. 4). Intercropping chickpea with oat highly decreased the proportion of weed biomass in the mixture, leaving the service plant as the dominant component. Hence, the canopy of the chickpea-oat intercrops was dominated by oat, a species with an erect growth habit sown in the middle of the inter-rows of chickpea. By contrast, the canopy of the sole crop was dominated by weeds, of which we did not control the spatial arrangement. Thus, we can first assume that the architecture of the oat-dominated canopy in the chickpea-oat intercrops may have favoured air circulation between the chickpea rows compared to the dense weed cover in the sole crop. This better aeration of the canopy could have altered the microclimate, making it less favourable for pathogen development. Previous studies have also reported a reduction in ascochyta blight severity on several grain legume species when they were intercropped with a cereal (Fernández-Aparicio et al., 2011, 2010; Hauggaard-Nielsen et al., 2008; Schoeny et al., 2010). Schoeny et al. (2010) found that intercropping pea with either wheat or barley increased the air temperature within the canopy and shortened the leaf wetness duration, which ultimately decreased disease severity on pods. The optimum conditions for *Ascochyta rabiei* to cause severe infections are a constant temperature of 20°C with a leaf wetness duration of 17 h (Trapero-Casas and Kaiser, 1992). Hence, intercropping chickpea with oat may have altered those parameters and thus impeded the pathogen development.

Secondly, Schoeny et al. (2010) also recorded a sharp decrease in the splash-dispersal of conidia in the pea-wheat intercrops compared with the sole pea. The authors hypothesized that wheat acted as a physical

barrier of non-host plants between the pea rows, thus disrupting spore dispersal. In our study, oat produced high amounts of biomass early in chickpea's growing cycle, which may have created a dense barrier to spore dispersal. Also, our results show that adding oat decreased chickpea biomass at pod set because of interspecific competition. This decrease in host biomass could have also contributed to reducing disease severity in the chickpea-oat intercrops through the dilution effect (Fernández-Aparicio et al., 2010).

In situations of high weed infestation, mowing removed high amounts of biomass between the chickpea rows, which may have also acted on the canopy microclimate. Hence, our results demonstrate that weed control and ascochyta blight severity are related, which implies that they need to be considered simultaneously. Our findings revealed that under high weed pressure, mowing the inter-rows of chickpea can help to limit ascochyta blight epidemics.

Beyond weed control, other factors linked to the characteristics of the service plants also affected ascochyta blight severity. Indeed, adding clover led to a higher mean disease score than adding faba bean, even though the levels of weed biomass were similar between the two unmowed intercrops (Fig. 4). These differences could be linked to the aerial architecture of the service plants. Egyptian clover had a bushy growth habit compared to faba bean and the other species we tested, which had a more upright architecture. Hence, the high canopy density in the chickpea-clover intercrops may have reduced air circulation and promoted humid conditions favourable for pathogen development (Richard et al., 2013; Tivoli et al., 2013).

4.3. Mechanically regulating a highly competitive service plant to simultaneously control weeds and ascochyta blight while mitigating interspecific competition

As detailed above, our work highlights that intercropping chickpea with a service plant displaying a high competitive ability and generating an aerated canopy like oat, helps to control weeds and to limit ascochyta blight severity under contrasting pressures. However, we also show evidence for a trade-off between chickpea production and weed control (Carton et al., 2020; Cherie et al., 2020). Mowing the inter-rows is a promising lever to mitigate interspecific competition and manage this trade-off during the growth cycle. Indeed, adding oat reduced weed biomass and disease severity, while mowing the inter-rows tended to limit the decrease in chickpea biomass and grain yield due to interspecific competition.

Still, our findings suggest that the initial mowing strategy needs improvement. Indeed, adding mowed oat still decreased chickpea yield by half compared to the unmowed sole crop in 2023. By the 10-leaf stage, chickpea biomass was already lower in the chickpea-oat intercrop compared to the sole crop. Moreover, mowing improved weed control only in 2024. This year, the weather was colder and wetter than the previous one which delayed chickpea phenology and, by extent, delayed the mowing date. Hence, weeds may have been mowed at a later stage than in the previous year, limiting their regrowth ability (Meiss et al., 2008). The dead mulch left between the chickpea rows after mowing had also a much higher biomass in 2024, which may have impeded the regrowth of weeds, but also service plants (Teasdale and Mohler, 2000). Overall, these results indicate that a single mowing at the beginning of chickpea flowering is not sufficient and/or too late to control both weeds and the service plant, and avoid high yield reductions due to interspecific competition.

The mowing strategy could be easily improved by adjusting its timing and increasing its frequency. In their study, Thorsted et al. (2006) reported that white clover had to be cut at least twice in the inter-rows of wheat to get a similar or higher yield than the sole crop wheat. Although these species are different from the ones we studied, this suggests that mowing the inter-rows several times may further limit yield reductions due to interspecific competition in such cropping systems. The authors also found that the increase in wheat yield varied depending on the

timing of the cut. Besides, [Butler et al. \(2013\)](#) reported that repeated cuttings reduced the growth of several common weed species, while a single cutting was not sufficient.

In our study, adding one mowing date at the 10-leaf stage in the chickpea-oat intercrops tended to further increase chickpea biomass and grain yield compared to a single mowing. This suggests that the first mowing should be done earlier, depending on the relative biomass accumulation of chickpea and oat, rather than considering chickpea phenology alone. Another mowing date could also be added later in the crop cycle to keep controlling weeds and prevent an increase in the weed seed-bank ([Butler et al., 2013](#); [Tipping, 2008](#)). Furthermore, under conditions of high ascochyta blight pressure by the end of the growth cycle, as observed in 2024, adding a late mowing date could also slow down the disease spread and limit yield losses. An additional mowing operation at the end of the growth cycle may also facilitate the mechanical harvest of chickpea.

Overall, more research is needed in field conditions to evaluate the effects of increasing the mowing frequency on interspecific competition and weed biomass in chickpea-based intercrops, but also to better understand its effects at the cropping system scale.

Indeed, under low-input or organic conditions, the combination of mechanical weeding during the crop cycle with intensive tillage for seedbed preparation, is a much more commonly used strategy. Nevertheless, the efficacy of cultivation methods to control weeds depends on a variety of factors including the quality of the seedbed preparation, the soil type, the species and phenological stages of the weeds, and the weather ([Kurstjens and Kropff, 2001](#); [Rasmussen et al., 2010](#); [Richard et al., 2023](#)). Frequent soil cultivation can also deteriorate its structure and promote soil erosion ([Hamza and Anderson, 2005](#)). In addition, mechanical weeding can trigger new weed emergence flushes and cause crop damage ([Lundkvist, 2009](#); [Rasmussen et al., 2008](#)). Besides, the presence of a highly competitive service plant allows to control weeds within the chickpea rows, which are otherwise unattainable with mechanical weeding. This supports the interest of introducing a mowed service plant to control weeds, rather than growing chickpea as a monocrop and only relying on mechanical weeding. Besides, our results show that weed biomass was on average twice as high in the mowed chickpea sole crop than in the mowed chickpea-oat intercrop. Moreover, the introduction of a mowed service plant gives greater flexibility, and offers additional levers to manage interspecific competition in the course of the crop cycle without pesticides nor tillage use.

Still, the mechanical regulation strategy could be completed by combining mowing with other types of no-till mechanical weeding. During the vegetative phase of chickpea, mowing has the advantage of allowing the service plant to grow back for maintaining competition with weeds, which may impede their regrowth. In addition, destroying oat early in the crop cycle might diminish its positive impact on disease reduction. However, mowing may not be sufficient to control weeds when there is a majority of grasses. In our trials, mowing gave weeds the opportunity to grow back while oat had a very limited regrowth—which ultimately gave a competitive advantage to weeds. Hence, combining mowing with other mechanical operations that are usually used to terminate cover crops in no-till cropping systems, such as roller-crimpers, could be an interesting option to prevent weed regrowth later in the crop cycle ([Davis, 2010](#); [Mirsky et al., 2011](#)).

Overall, our findings indicate that mowing the service plant in the inter-rows of the cash crop is a promising lever for controlling weeds, mitigating interspecific competition, and limiting the drawbacks of mechanical weeding. This lever is of particular interest even under highly fluctuating growing conditions. Indeed, it offers greater management flexibility by making it possible to readjust and adapt the dominance ratio between species in real time during the growing season. Thus, the two very contrasting years of our experiment allow us to make the assumption that this combination could be implemented in various growing conditions, although the very low yields in 2024 are a limit to our study. Besides, the mechanical control strategy could be improved

by increasing the frequency, adjusting the timing, and/or combining mowing with other types of no-till mechanical weeding. Further research is also necessary to compare this strategy to other cropping systems, notably to a conventional chickpea production, while including aspects that couldn't be evaluated in our work such as the technical and economic feasibility. Indeed, although inter-row mowers are still under development, it would be interesting to compare the costs of “conventional” mechanical weeding, which often relies on the use of a combination of operations with different complementary tools (e.g. harrow and hoes) and requires intensive tillage for seedbed preparation, with mowed intercrops. This complementary research should also be conducted under other pedoclimatic conditions than those of our study, and with other types of weed communities.

5. Conclusion

The findings presented here highlight the potential of intercropping chickpea with a mowed competitive service plant for controlling weeds and ascochyta blight under contrasting biotic pressures. We found that cereals with a high competitive ability and generating an aerated canopy like oat are the most promising for chickpea-based intercrops, but can have a drastic impact on chickpea yield when left unmowed. Still, more research is needed to better adjust and explore various combinations of mechanical control to further attenuate the competition exerted by such competitive service plants, and to keep controlling weeds later in the crop cycle. Also, inter-row mowers are still under development and currently remain expensive. Overall, this work contributes to exploring levers meant to stabilise the production under low-input or organic conditions, and improve the robustness of cropping systems in a time when the inter-annual variability is predicted to increase.

Data statement

The data generated and analysed in this study are available on the Recherche Data Gouv repository: <https://doi.org/10.57745/05KBPZ>.

Funding

This work was partly funded by the Regional Council (Pays de la Loire) and INRAE as part of the SPECIFICS project. This work was part of the 3rd Programme for Future Investments (France 2030) and operated by the SPECIFICS project (ANR-20-PCPA-0008) funded by the “Growing and Protecting crops Differently” French Priority Research Program (PPR-CPA), part of the national investment plan operated by the French National Research Agency (ANR).

CRediT authorship contribution statement

Margaux Guy: Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Conceptualization. **Xavier Boussetin:** Writing – review & editing, Supervision, Methodology, Investigation, Conceptualization. **Mathieu Lorin:** Writing – review & editing, Supervision, Methodology, Investigation, Funding acquisition, Conceptualization. **Guénaële Corre-Hellou:** Writing – review & editing, Supervision, Methodology, Investigation, Funding acquisition, Conceptualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

We are grateful to Vincent Oury, Julien Poret, Sylvie Vincent and

Chloé Gaudinat for their contribution to the data collection and assistance on the field trials. We also thank UMR Agroécologie (Dijon, France) for supplying the rhizobial strain.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at [doi:10.1016/j.eja.2026.128112](https://doi.org/10.1016/j.eja.2026.128112).

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