Université catholique de Louvain
École de biologie

Université de Namur
Département de biologie

Impact of agricultural practices on carabid communities and the associated ecosystem services in Wallonia

Laroy Corentin

Mémoire présenté en vue de l'obtention du
diplôme de Master en Biologie des
Organismes et Ecologie

Supervisors: Prof. Thierry Hance (UCLouvain)
Mr. Daniel Jamar (CRA-W)
Mr. William Gyselynck (CRA-W)

Année académique 2021-2022

Table of contents

Résumé: Impact des pratiques agricoles sur les communautés de carabes et les services écosystémiques associés en Wallonie

L’agriculture intensive a permis une augmentation drastique des rendements, mais cette forme d’agriculture est aujourd’hui remise en question en raison, notamment, de ses impacts écologiques majeurs. Parmi les nouvelles formes d’agriculture, nous pouvons citer l’agriculture biologique, l’agriculture de conservation et l’agriculture biologique de conservation. La première interdit notamment l’usage de pesticides de synthèse, la seconde impose un travail du sol réduit, un couvert végétal permanent et une rotation des cultures, et la troisième combine les deux précédentes. Ces agricultures plus raisonnées dépendent fortement de certains services écosystémiques comme la prédation des ravageurs et des adventices. Les carabes sont des coléoptères très étudiés qui peuvent fournir ces services écosystémiques. Dans le cadre de ce mémoire, nous avons donc collaboré avec le CRA-W pour déterminer l’effet qu’avaient l’agriculture biologique, l’agriculture de conservation et l’agriculture biologique de conservation sur les communautés de carabes dans 12 champs wallons. Nous avons identifié une partie des carabes échantillonnés lors d’une précédente campagne ayant eu lieu en 2020 et réalisé une campagne d’échantillonnage de début mars à fin juin 2021.
Le poids sec d’une partie des individus capturés a également été déterminé, et l’effet du travail du sol sur le poids sec des espèces >6mm a également été évalué. Lors de la campagne de 2020, les carabes ont été piégés à l’aide de pitfalls, alors que deux designs de piège, les pitfalls et les pièges d’émergence, ont été utilisés et comparés lors de la campagne de 2021.

Les communautés ont été caractérisées par leurs abondances spécifiques, leur biomasse totale, ainsi que le régime alimentaire et la phénologie des espèces les constituant. Nous avons réalisé des analyses multivariées (ACP, AFC, ACC et AFC en codage flou) pour déterminer l’effet sur les communautés de carabes de certaines pratiques agricoles (modalité, travail du sol et culture) et paramètres relatifs au site (site et région) pour les échantillonnages des deux années. En plus de ces paramètres, les analyses des échantillons de 2021 comprenaient également la date d’échantillonnage et le type de piège utilisé.

Nous avons mis en évidence que le poids sec individuel de *Nebria salina* était plus important quand le travail du sol était plus superficiel. Les analyses multivariées ont révélé que le site était en général la source de variation la plus importante. De plus, elles ont également indiqué que les prédateurs généralistes étaient proportionnellement plus abondants dans les parcelles en agriculture de conservation, alors que les granivores et omnivores étaient présents en plus grande proportion dans les parcelles en agriculture biologique. Cette différence pourrait être due à de nombreux facteurs comme l’utilisation d’herbicides en agriculture de conservation qui priverait certains granivores et omnivores de nourriture ou d’habitats favorables, la plus grande sensibilité au travail du sol de grands prédateurs généralistes comme *Pterostichus melanarius* ou encore des interactions interspécifiques. Nous pouvons donc supposer une meilleure prédation des ravageurs en agriculture de conservation et une meilleure gestion des adventices en agriculture biologique, mais cette conclusion reste à vérifier. L’agriculture biologique de conservation, tant qu’à elle, présente des proportions plus égales de prédateurs généralistes et de granivores et omnivores. Les pièges d’émergence ont capturé moins de carabes que les pitfalls, mais une plus grande proportion d’espèces à plus faible biomasse individuelle. Ils ne semblent donc pas soumis aux biais d’activité reprochés aux pitfalls.

Le travail se terminera par quelques pistes d’amélioration du design expérimental.

Abstract: Impact of agricultural practices on carabid communities and the associated ecosystem services in Wallonia

Intensive agriculture has raised yields dramatically, but this way of farming is today questioned, notably because of its major environmental impacts. Among the new ways of farming, we can cite biological agriculture, conservation agriculture and biological agriculture of conservation. The first one notably prohibits the use of synthetic pesticides, the second one imposes reduced tillage, permanent vegetative cover and crop rotation, and the third one combines the two previous ones. Those more sustainable forms of agriculture are highly dependant on some ecosystem services like pest predation. Carabids are very studied Coleoptera that can provide those ecosystem services. For this work, we have collaborated with the CRA-W to determine the effect biological agriculture, conservation agriculture and biological agriculture of conservation had on carabid communities in 12 Walloon fields. We have identified a part of the carabids sampled during a preceding campaign that occurred in 2020 and realised a new sampling campaign from early March to late June 2021.
The dry mass of a part of the captured individuals was also determined, and the effect of tillage on dry mass of individuals >6mm was evaluated as well. During the 2020 campaign, carabids were trapped with pitfalls, while two trap designs, pitfalls and emergence traps, were used and compared during the 2021 campaign.

Communities were characterized by their specific abundances, total biomass, as well as the diet and phenology of the species constituting it. We have realised multivariate analyses (PCA, FCA, CCA, fuzzy coding FCA) to determine the effect on carabid communities of some agricultural practices (modality, tillage and crop) and parameters relative to the site (site, region) for the samplings of both years. In addition to these parameters, the analyses on the 2021 samplings also included the sampling date and the type of trap used.

We have demonstrated that individual dry mass of *Nebria salina* was more important when tillage was more superficial. Multivariate analyses showed that the site was generally the most important source of variation. Furthermore, they indicated that generalist predators were proportionally more abundant in conservation agriculture plots, while granivorous and omnivorous were present in higher proportion in plots under biological agriculture. This difference might be due to several factors such as a more important use of herbicides in conservation agriculture that would deprive some granivorous and omnivorous of food or suitable habitats, the greater sensitivity to tillage of some large generalist predators like *Pterostichus melanarius* or even interspecific interactions. We can therefore assume a better predation of animal pests in conservation agriculture and a better weed control in organic agriculture, but this conclusion remains to be verified. Biological agriculture of conservation, as for it, has more evenly distributed proportions of generalist predators and of granivorous and omnivorous. Emergence traps captured less carabids than the pitfalls did, but a higher proportion of species with lower individual biomass. They thus do not seem subject to activity biases reproached to pitfalls.

The work will end by some propositions to improve the experimental design.

Introduction

Context

Farmland accounts for roughly 40% of Wallonia's surface (Antier *et al.*, 2015). Thanks to the green revolution, agricultural yields have been increasing dramatically (Figure 1) since the '60 thanks to agricultural intensification, allowing to meet a greater food demand worldwide (Venturini, 2006; FAOSTAT).

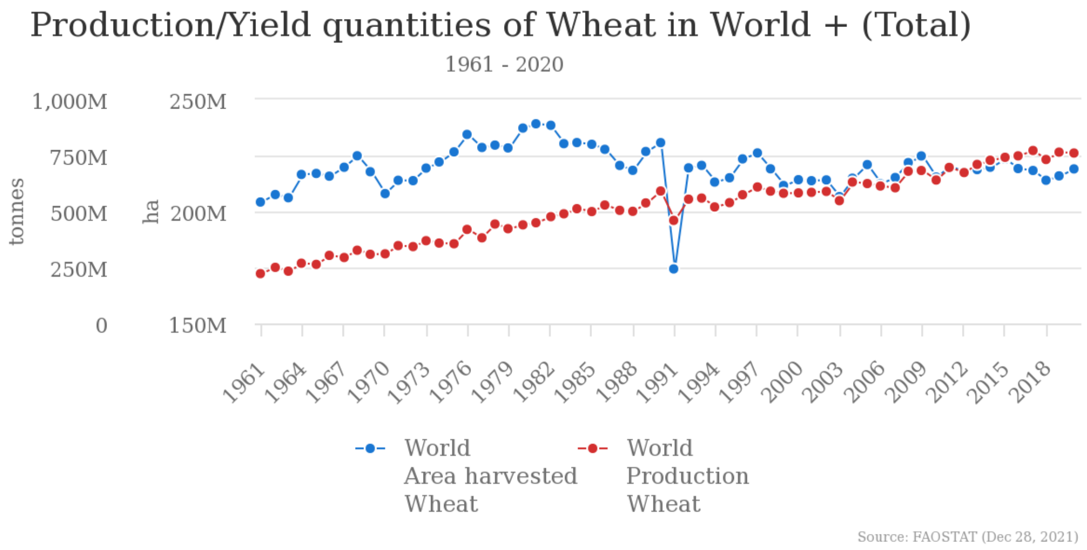


Figure 1 : Worldwide area harvested and production of wheat from 1961 to 2020. Source: FAOSTAT, 2021 Available at [FAOSTAT]()

However, those increasing yields come with several drawbacks, including landscape simplification, eutrophication, pollution, soil erosion and heavy biodiversity losses (Tscharntke *et al.*, 2005; Bommarco *et al.*, 2013; Withers et al 2014; Kassam *et al*, 2018). Therefore, nowadays, there is an increasing will to shift agriculture towards more « eco-friendly » practices. Those practices include for example organic agriculture, in which the use of chemical pesticides and fertilizers are forbidden (FAO, 2006; Fleury *et al.*, 2011). In Wallonia, the surface dedicated to organic agriculture is clearly raising, as shown in Figure 2. The number of organic farms is also increasing (Figure 2), even though the total number of farms in Wallonia has been reduced by more than 50% since 1990 (Figure 3) (Walloon agriculture in Figures 2020, 2020). Conservation agriculture is another form of sustainable agriculture, whose principles aim to preserve the soil ecosystem (FAO, 2006; Kassam *et al*, 2018; Donovan, 2020; Pierre, 2020). Finally, biological agriculture of conservation, applying conservation agriculture principles to organic agriculture, also exists (Fleury *et al.*, 2011; Pierre, 2020).

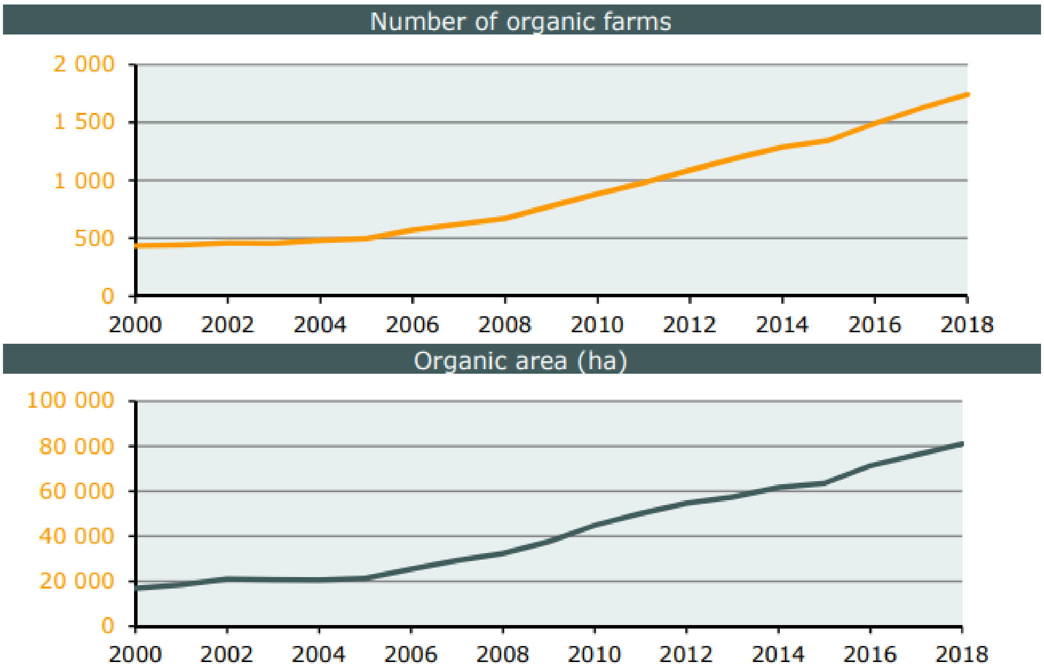


Figure 2 : Number of organic farms and their total surface in Wallonia from 2000 to 2018. Source: Walloon agriculture in figures 2020, 2020.
Available at [81e1d857-00be-4b39-b232-dff9c2374635 (wallonie.be)]

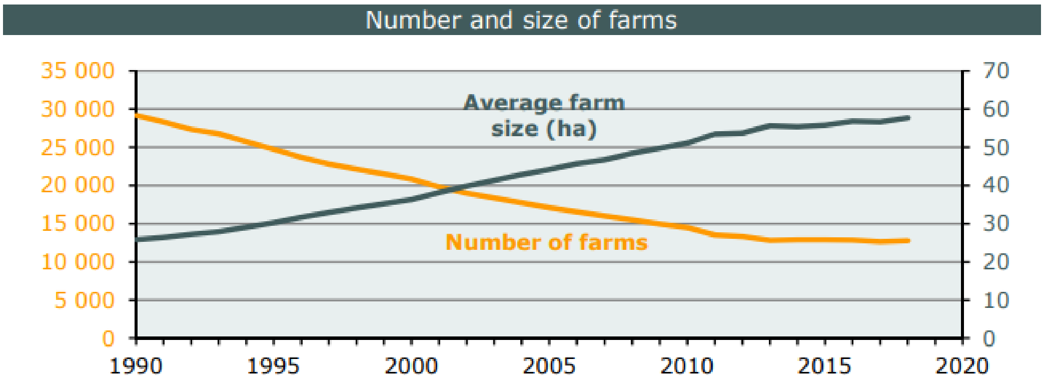


Figure 3 : Number and size of farms in Wallonia from 1990 to 2020. Source: Walloon agriculture in figures 2020, 2020.
Available at [81e1d857-00be-4b39-b232-dff9c2374635 (wallonie.be)]

However, those alternatives are associated with risks, including of course losses of yield, because intensive agriculture is designed to maximize it (Venturini, 2006). To address this fundamental issue, we need to introduce the concept of ecosystem services.

Ecosystem services (ES) are one of the key concepts on which agriculture is based. It can be defined as the benefits that ecosystems can provide to the human species (Alcamo *et al.*, 2003). They are traditionally divided into four categories: provisioning, regulating, supporting and recreational services (Alcamo *et al.*, 2003). Because the connection of the latter to agriculture is very weak, it will not be discussed in the present work.

Provisioning services, as their name suggests, are the material goods provided by ecosystems, for example food. Agriculture itself can thus be basically seen as an optimisation of food provisioning by ecosystems (Zhang *et al.*, 2007), and this optimisation was the leitmotiv of the green revolution (Venturini. 2006). However, in an agroecosystem, there are also organisms that reduce the productivity of the field, known as pests. Those organisms include animals (e.g., slugs like *Deroceras reticulatum* (El-Danasouri *et al.*, 2017)), microbial plant pathogens (e.g., *Blumeria graminis* (Oerke, 2006)) and weeds (e.g., *Elylmus repens* or quackgrass (Néron, 2018)) (Oerke, 2006). Management of those pests is an essential activity because they can be responsible for heavy losses of yield. For example, in wheat, those losses can be as high as 50% (Oerke, 2006).

The management of those pests was traditionally made by ploughing and synthetic pesticides (Venturini, 2006), but it led to the consequences we mentioned above. In addition to those consequences, we must quickly discuss about the problem of pesticides resistance.

More than one century ago, the paper “Can insect become resistant to sprays?” was published (Melander, 1914). Despite the author’s warnings, pesticides were used intensively (Gould *et al.,* 2018). Through simple evolutionary processes, it led to the apparition and expansion of resistant phenotypes, and resistance to pesticides is nowadays a crucial field in agronomy (Coelho, 2009; Barrès *et al.*, 2016; Gould *et al.*, 2018; Søgaard Jørgensen *et al.*, 2020; Arthur *et al.*, 2021). Pesticide resistance is also responsible for heavy economic losses, costing several billions of dollars to the USA each year (Gould *et al.*, 2018) and might get even worse because of climate change, since this phenomenon can expand the range of some pests (Ma *et al.,* 2021).

Rather than relying exclusively on ploughing and pesticides to deal with pests, the alternative forms of agriculture we discussed earlier also rely on the second category of ecosystem services, the regulating services. Regulating services is the regulation of environmental hazards including notably pathologies and pests (Alcamo *et al.*, 2003). A key idea of the non-intensive farming practices is that a reduced environmental impact of agriculture can promote regulation services by natural enemies, in that case pest control (Néron, 2018; Rowen *et al.*, 2020; Duflot *et al.*, 2022). Indeed, since the ecosystem is not as deeply modified and simplified as in intensive agriculture, populations of natural enemies of pests can thrive (without the need to introduce these natural enemies). This idea is also known as conservation biological control (Begg *et al.*, 2017; Cloyd, 2020). This process could also increase overall biodiversity, which could reduce plant diseases or support other ES like pollination (Figure 4) (Clergue *et al.*, 2005). However, the link between biodiversity and ES is not clearly established (Prasad and Snyder, 2006; Lami *et al.*, 2020).

Conservation biological control can target a wide range of natural enemies, including for example parasitoids or spiders (Begg *et al.*, 2017). One of the most studied targets of conservation biological control, however, are the Carabidae, a family of Coleoptera also known as carabids (Kromp, 1999; Holland, 2002; Bohan *et al.*, 2011; Kotze *et al.*, 2011; Kennedy *et al.*, 2013; Rusch *et al.*, 2013).

It should be noted that the new ways of farming presented in this work can also promote the third category of ecosystem services, the supporting services, which are the maintenance of the Earth’s habitability (Alcamo *et al.*, 2003). Indeed, a lower use of pesticides can reduce soil pollution, and a more superficial tillage can preserve the soil and thus biogeochemical cycles of some elements like carbon (Fleury *et al.*, 2011; Peigné *et al.*, 2016; Donovan, 2020). However, in this work, we will primarily focus on pest control by carabids.

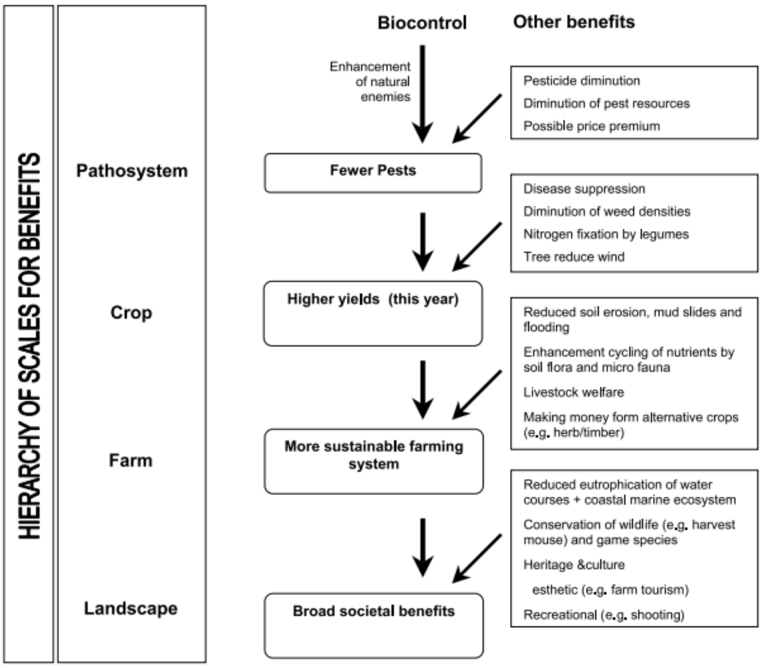


Figure 4 : Hierarchy of beneficial effects of biodiversity in agriculture. Source: Clergue et al.*, 2005*

We will now further detail the different types of agriculture used in this study, the biology of carabids, their link with agriculture and the ways to sample them.

Different kinds of agriculture

Biological agriculture (BA)

Biological (or organic) agriculture is a form of agriculture in which the use of chemical pesticides and fertilizers are strictly forbidden (EUR-Lex, 2018). If inputs are used, it must be « natural » products like biopesticides, which can help to mitigate the pollutions associated with agriculture. In Wallonia, organic area accounts for 11% of the global agricultural area (Walloon agriculture in Figures 2020, 2020).

Globally, organic agriculture seems to be associated with a higher global biodiversity (Kromp, 1999; Tuck *et al.*, 2014) than conventional fields. However, the organic farmer can do any kind of intervention that does not require any sort of compound. Typically, to deal with weed in the absence of chemical herbicide, heavy tillage like deep ploughing can be made (Fleury *et al.*, 2011).

Conservation agriculture (CA)

Conservation agriculture is another way to rethink agriculture. The main principle of this approach is to consider the soil as a living ecosystem and take advantage of the associated ES. It is defined by three fundamental principles reducing tillage, permanent vegetative cover of at least 30% and crop rotation (Nichols *et al.*, 2015; Kassam *et al*, 2018; Donovan, 2020; Pierre, 2020; Landers *et al.*, 2021). In 2015-2016, CA accounted for 12.5% (180Mha) of the worldwide agricultural surface, the vast majority being in South and North America. In Belgium, this surface was estimated to be 270 ha (Kassam *et al.*, 2018).

As we just mentioned, reducing tillage is a key principle in CA. Tillage is an agricultural practice that consists in modifying the soil structure to set up optimal conditions for sowing (Néron, 2018). Concretely, this practice kills weeds, integrates fertilizers and crop residues in the soil, exposes parasites to kill them, aerates the soil and increases its porosity, leading to easier rootedness of the future crop, as well as better water infiltration (Néron, 2018). It can be done by turning over, cracking, crumbling or tamping down the soil (Néron, 2018). The depth of classical tillage is comprised between 15 and 40cm (deep tillage); if it is less than 15cm deep, it is qualified of superficial tillage (Néron, 2018).

Because of all the effects we just mentioned, tillage is very helpful for the farmer, but it is also probably one of the most perturbating interventions for the soil ecosystem (Baguette and Hance, 1997; Kennedy *et al.*, 2013; de Graaf *et al.*, 2019; Rowen *et al.*, 2020). Indeed, besides parasites and roots of weeds, it exposes pupae and other underground organisms to the surface, where they are exposed to climate and predation (Roger-Estrade, 2010; Néron, 2018). It is also very disturbing for nutrient cycling and microbial activity, especially since most of it occurs at 20 to 30cm depth (Clapperton, 2003), a depth that deep tillage usually reaches (Néron, 2018). For example, deep tillage is known to break the mycorrhizal networks (Roger-Estrade, 2010). It also decreases the soil organic content and increases its susceptibility to erosion (Néron, 2018). Globally, tillage is thus considered bad for soil biodiversity (Kennedy *et al*, 2013; de Graaf *et al.*, 2019). It is also a non-negligeable workload, associated with costs (Fleury *et al.*, 2011; Néron, 2018). Finally, it frees CO_2 from the soil, which contributes to climate change (Fleury *et al.*, 2011; Donovan, 2020). For all these reasons, it appears clearly that reducing tillage is consistent with CA's main objective, respecting the soil ecosystem functioning.

Techniques with reduced ploughing are known as TCS (Techniques Culturales Simplifiées (in French)) or TSL (Travail Sans Labour (French)) (Néron, 2018). Of course, those techniques are associated with risks, since it is a more complex way of cultivating, and it can therefore be difficult for a farmer without the necessary knowledge to start using these techniques (Fleury *et al.*, 2011). Regarding this, some authors denounce a lack of research and, even more, education (Fleury *et al.*, 2011). Applying TCS requires step by step progress, and farmers have to gradually build their own knowledges about those techniques (FAO, 2006; Fleury *et al.*, 2011).

Other less damaging methods also exist. For example, striptill consists in ploughing in lines across the preceding crop residues, thus keeping an undisturbed soil between the ploughed lines (Néron, 2018). Finally, direct sowing (DS) is the most extreme reduction of tillage, because, as the word suggests, the seedbed is directly set on the ground (Néron, 2018).

Another pilar of CA is permanent vegetative cover. The first undeniable advantage of a permanent cover is a protection against soil erosion (Néron, 2018). Furthermore, this permanent cover inhibits weeds (Peigné *et al.*, 2016; Néron, 2018), which is especially important in a system without tilling. The vegetative cover also serves as a shelter for natural enemies (Kromp, 1999; O'Sullivan and Gormally, 2002; Néron, 2018).

Finally, crop rotation, or in some cases intercropping (several crops grown at the same time) can enhance the soil nutrient content, especially if Fabaceae are part of the rotation. If a crop is sown specifically to improve the soil fertility, the process is known as green manuring

(Kassam *et al.*, 2018; Néron, 2018). Since green manuring tends to increase the soil organic content, this practice can also provide food for natural enemies (Peigné *et al.*, 2016).

In opposition to BA, synthetic pesticides and fertilizers are allowed (Fleury *et al.*, 2011).

Importantly, it should be noted that, according to several sources, CA does not automatically provide a worse yield than an intensive agriculture (Kassam *et al*, 2018; Donovan, 2020). It is also associated to a reduced degradation and an enhanced fertility of the soil (Rivers *et al.*, 2016; Tamburini *et al.*, 2016)

Biological agriculture of conservation (BAC)
It appears that, taken individually, both BA and CA surely have qualities, but they also have defects. Indeed, in BA, heavy tillage is often required, mainly to deal with weed. On the other hand, even though several farmers in CA try to reduce the quantity of inputs they use, they do use chemical pesticides, which are of course associated with pollution (Fleury *et al.*, 2011). To cope with both of those problems, BAC, which is the application of CA's principles to BA, has been proposed (Peigné *et al.*, 2016; Boeraeve, 2019). BAC is thus the fusion of BA and CA.

At first glance, it may seem impossible to combine those approaches. Indeed, since organic agriculture prevents the use of chemical inputs, how could it be possible to deal with weeds, for example, if tillage is also forbidden (Pierre, 2020)?

But if we take a closer look, except for tilling, BA and CA have much in common. Indeed, the European specification about BA requires the farmers to use green manuring and to make crop rotations (EUR-Lex, 2018). Since green manuring requires a vegetative cover, we can see that two pillars of CA are met by BA.

A European survey realised by Peigné *et al.* (2016) revealed five global strategies used by farmers practising BCA. The first two strategies implying moderate to heavy tillage, and being mostly used in Spain, they will not be discussed. The third strategy was based on an intensive use of green manuring and long crop rotation. The fourth one consisted in a very long period of soil cover and the use of intercropping (several crops growing together) of cereals and Fabaceae. The last strategy was similar to the fourth one, except for the fact that companion plants were sown after the main crop (undersowing). The popularity of companion plants in BAC is not surprising, because those plants act as competitors for weeds, which are the most problematic pests in BAC. Some of them (e.g., rye) can also produce allelopathic compounds that further weaken weeds (Peigné *et al.*, 2016).

However, it is pretty clear than the most extreme form of BAC, with direct sowing and a total prohibition of pesticides, is nowadays very difficult (Pierre 2020). In addition to that, knowing which techniques to use in a given context is a challenging task, and mistakes can of course be detrimental to the farmer. For example, an excess in green manuring can promote nematode development (Fleury *et al.*, 2011). This highlights the need for real agricultural skills and formation needed to start BAC.

Globally speaking, a lot of BA farmers are reluctant to shift towards CA, and vice versa (Fleury *et al*, 2011). Indeed, CA, as we have already discussed, requires a lot of experience, and can be accompanied with losses of yield the first years (Fleury *et al.*, 2011). On the other hand, some CA farmers do not have a lot of interest for BA in general, considering it is does not fit their view of agriculture, in which knowledge and agronomy are of first importance. Other CA farmers try to reduce their inputs, but since BA’s restriction are very strict, they do not try to get the certification of organic farmer (Fleury *et al.*, 2011). Although they are very interesting and important, those sociological aspects of agricultural practices will not be further discussed in this work.

Despite all the difficulties mentioned above, BAC exists in Belgium, and no-ploughing becomes possible in BAC (Fleury *et al.*, 2011).

Carabids and biological control

Taxonomy and life cycle

Carabids (or Carabidae) are a family of running beetles gathering 40 000 species worldwide, and 2700 in Europe, mostly in western Europe (Kromp, 1999). Most of the carabids found in agricultural landscapes are nocturnal (Kromp, 1999; Holland, 2002). Initially, Larrson (1939) split carabids into two different categories, based on their phenology: spring breeders and autumn breeders (Kromp, 1999; Matalin, 2007). As their name suggests, spring breeders reproduce in spring, the adult emerges during the summer and overwinters. Autumn breeders, as for them, reproduce in autumn, the larva overwinters and emerges in spring (den Boer and den Boer Daanje, 1990; Delacre, 2019; Kromp, 1999; Matalin, 2007). Although this simple classification has been the classic view for a very long time, it is now clear that it is a very naïve view of the reality, which is way more complex (den Boer and den Boer Daanje, 1990; Kromp, 1999; Matalin 2007; Kotze *et al.*, 2011).

It turns out that the phenology of carabids is, in practice, a continuum (den Boer and den Boer-Daanje, 1990; Kromp, 1999; Matalin 2007; Kotze *et al.*, 2011), some of them even being able to reproduce during winter (den Boer and den Boer-Daanje, 1990; Matalin, 2007) and other purely seem unseasonal (Matalin, 2007). Actually, even the same species can have different life cycles, depending on the environment (Matalin, 2007), mainly the temperature (Kotze *et al*, 2011). Nevertheless, we can affirm some generalities.

Carabids are generally univoltine (Matalin, 2007) and lay between 30 and 600 eggs in the soil (Kromp, 1999; Delacre, 2019), at a depth of maximum 50 cm for most species (Kennedy *et al*, 2013). A predatory (in most cases) larva emerges from it and goes through 3 larval stages (2 for the genera *Harpalus* and *Amara*) before turning into a pupa. The larva and the pupa are the most vulnerable life stages because of their weak mobility and chitinization (Lövei and Sunderland, 1996). A teneral emerges, and then turns into an adult that can, for some species, live a few years (Kromp, 1999; Matalin, 2007; Delacre, 2019).

Diet of carabids and usefulness as cultural auxiliaries

Most adult carabids, and almost all carabid larvae, are predators (often generalist, even though some species like *Trechus quadristriatus* are specialists, in that case of springtails) (Kromp 1999; Holland and Luff, 2000; O’Sullivan and Gormally, 2002; Sasawaka, 2010; Kennedy *et al*, 2013; Jowett *et al.*, 2021). However, a non-negligible portion of the carabids consume seeds of weed (genus *Amara* and *Harpalus*) and some species are omnivorous (Sasakawa, 2010; Carbonne *et al.*, 2020). Thus, since they are also very common in our landscapes, ubiquitous (Kromp, 1999; O’Sullivan and Gormally, 2002), very active (Delacre, 2019) and well known (Kotze *et al.*, 2011), it is natural to think of them as cultural auxiliaries.

Carabids are known to feed on several pests highly problematic in our regions, like aphids (Hance, 1987; Kromp, 1999) or slugs (Kromp, 1999; El-Damasouri *et al.*, 2017). Indeed, in a field experiment realised by Symondson *et al.*, 84% of the captured *Pterostichus melanarius* had eaten slugs (Symondson *et al.*, 1996). Slug predation by carabids has long been considered as an opportunistic behaviour, but evidence of aggregation around slugs exists in the literature (Bohan *et al.*, 2000; Roubinet *et al.*, 2017). About aphids, it has been shown that some genera like *Bembidion* could act as efficient buffers against winter wheat aphids, reducing their population by over 50%. Those carabids being unable to climb to the summit of the plant, the use of cultivars that makes the aphids fall easier can help the *Bembidion* to accomplish this role (Kromp, 1999). Carabids have also demonstrated an ability to control cereal and sugar beet aphid populations (Kromp, 1999) and aphid vectors of some plant viruses like beet yellow virus (Kromp, 1999; Kennedy *et al.*, 2013). Those kinds of ES are especially relevant in BA, since slugs and aphids are particularly problematic in that type of farming (Kromp, 1999). And since no-tillage fields can have bigger slug populations and increased leaf damages because of those molluscs (Kennedy *et al.*, 2013), the predation of slugs by carabids can be an important ES in CA too.

Of course, slugs and aphids are not the only preys of carabids. Their list of potential preys includes other molluscs, Lepidoptera (including codling moths, and potentially woodpeckers), Coleoptera (e.g., wireworms), Hemiptera, Thysanoptera, dipteran eggs and springtails (Kromp, 1999; Holland and Luff, 2000; Prasad and Snyder, 2004; O’Neal *et al.*, 2015; Jowett *et al*, 2021). Globally, carabids are regarded as the most important predators of cereal pests in Europe, and they can increase the farmer’s yield (Kennedy *et* al, 2013). However, it should be noted that the real impact of predation by carabids on those pests is often unclear: indeed, a lot of experiments have been made in laboratory conditions, where the beetles do not have any other feeding option. Predation of dipteran eggs, for instance, has probably been overestimated in the past (Kromp, 1999).

As their part, weeds represent a major challenge in CA, and even more in BAC, since they are traditionally removed either by ploughing or herbicides (Fleury *et al.*, 2011; Kennedy *et al.*, 2013). Hence, in addition to predation, granivory can be a very useful ES in this kind of farming. This ES can be provided by some genera like *Amara* and *Harpalus*, whose adult can eat high amounts of weed seeds under favourable conditions (Kromp, 1999; Menalled *et al.*, 2007; Jowett *et al.*, 2021). For example, in a field experiment, Brust and House have observed that >50% of seed predation was due to carabids (Brust and House, 1988). Carabids have also demonstrated significant effects on weed seedbanks (Bohan *et al.*, 2011; Kulkarni *et al.*, 2015; Diekötter *et al.*, 2016; Carbonne *et al.*, 2020).

So, carabids are interesting cultural auxiliaries. However, their populations have been decreasing dramatically in our regions. A possible reason for that is that carabids can be very sensitive to agricultural intensification (Kromp, 1999; Holland and Luff, 2000; O’Sullivan and Gormally, 2002; Desender *et al.*, 2010). But as discussed earlier, more environment-friendly agricultural modalities like BA, CA and BAC are developing. Hence, we will now discuss the influence these modalities have on carabid communities and their associated ES.

Sensitivity to agricultural practices

Since the highest mortality of carabids occurs at larval stages in the soil (Lövei and Sunderland, 1996; Kromp, 1999) and the underground pupa is also a vulnerable stage (Lövei and Sunderland, 1996), tillage can clearly have a tremendous impact on their populations, either by direct mortality or habitat destruction (Baguette and Hance, 19997; Kromp, 1999; Holland and Luff, 2000; Menalled *et al.*, 2007; Shearin *et al.*, 2007; Kennedy *at al.*, 2013; Blubaugh and Kaplan, 2015). Of course, those changes can be associated with changes in the ES provided by the implied species. For example, in the above-mentioned experiment of seed predation conducted by Brust and House, 2.3 times more seed were consumed in the no-tillage fields than in conventional tillage ones (Brust and House, 1988). To support those result, it has also been demonstrated that intensive tillage decreased the abundance of the seed eater genus *Harpalus* (Jowett *et al.*, 2021).

Besides direct effects on diversity, removing tillage can shift the community composition. Indeed, in another experiment carried by Menalled *et al.*, the activity-density of carabids was two times higher in conventional agriculture than in no-tillage. However, seed predation was three times higher in the no-tillage modality than in the conventional system (Figure 5), despite this lower activity-density (Menalled *et al.*, 2007). This was due to a radical shift in community composition: indeed, in the no-till fields, 32% of the caught carabids were granivores, while only 4% were so in the tilled fields. Besides this specific change, carabid diversity was also higher overall in the no-tillage field (Menalled *et al.*, 2007).

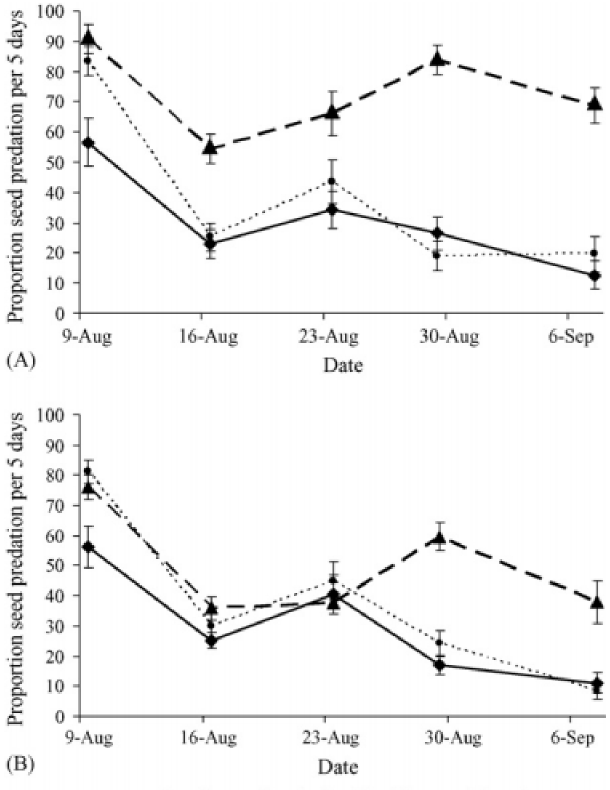


Figure 5 : Proportion of seeds of (A) fall panicum and (B) common lambsquarters seeds removed by granivory per 5 days. Source: Menalled et al., 2007

This experiment was not the only case where different community compositions were observed in no-tillage versus tillage systems (e.g., Tamburini *et al.*, 2016). Generally, it seems that larger species like *Pterostichus melanarius* are more abundant in no-tillage systems, whilst smaller species like *Bembidion spp.* or *Notiophilus biggutatus* are more abundant in tilled fields (Holland and Reynolds, 2003, Kennedy *et al.*, 2013). However, this pattern does not seem to be universal: for example, Baguette and Hance found a higher number of *P. melanarius* in ploughed soils than in no-tillage systems (Baguette and Hance, 1997). The authors provide explanations based on timing of the tillage, according to which tillage occurred at periods when it was not harmful for *P. melanarius*. Besides this timing-based explanation, some authors argue that tillage might not be the only factor regulating carabid populations, nor the most important one (Kennedy, 2013). According to other authors, those discrepancies could also be explained by interspecific interactions, which would of course highly complicate the interpretations of such studies (Cárcamo, 1995; Prasad and Snyder, 2004 and 2006).

Besides directly decreasing larval and pupal mortality, no-tillage has also a range of indirect effects that could also explain the observed variation. Indeed, since tillage removes weed, it decreases vegetative cover, and it appears that an important vegetative cover and complexity are favourable to carabids (Jowett *et al.*, 2021). Strong correlations between carabid species richness and vegetative species richness (r = 0.679) as well as with herbaceous cover (r = 0.704) have been demonstrated in potato crops (O'Sullivan and Gormally, 2002). More specific positive correlations between some genera like *Amara* and the weed cover can also be found in literature (Kromp, 1999). This beneficial effect of vegetative cover and diversity could be the direct or indirect food source it represents for some species, as well as the shelter (including the roots underground) and favourable microclimatic conditions (hotter and wetter microclimate) it provides (Kromp, 1999; O'Sullivan and Gormally, 2002). To summarise, a more heterogeneous and complex landscape is beneficial for carabids (Holland and Luff, 2000). For example, the efficiency of the genera *Amara* and *Harpalus* as granivores is much lower if the density of plant assemblages is weakened (Kromp, 1999).

BA can also have tremendous effects on carabid abundance and diversity. Indeed, in an experiment comparing carabid communities in BA and conventional agriculture potato fields, 82.4% of the catches were made in BA fields (Figure 6). The diversity was also higher in this field, with a reciprocal Berger-Parker diversity index of 3.4, compared to 2.2 for the conventional agriculture fields (O'Sullivan and Gormally, 2002). Globally speaking, BA fields are often more diversified than conventional ones, being more attractive and easier to settle in (Kromp, 1999). Thus, it seems that removing inputs like chemical pesticides can have beneficial effects on carabid communities.

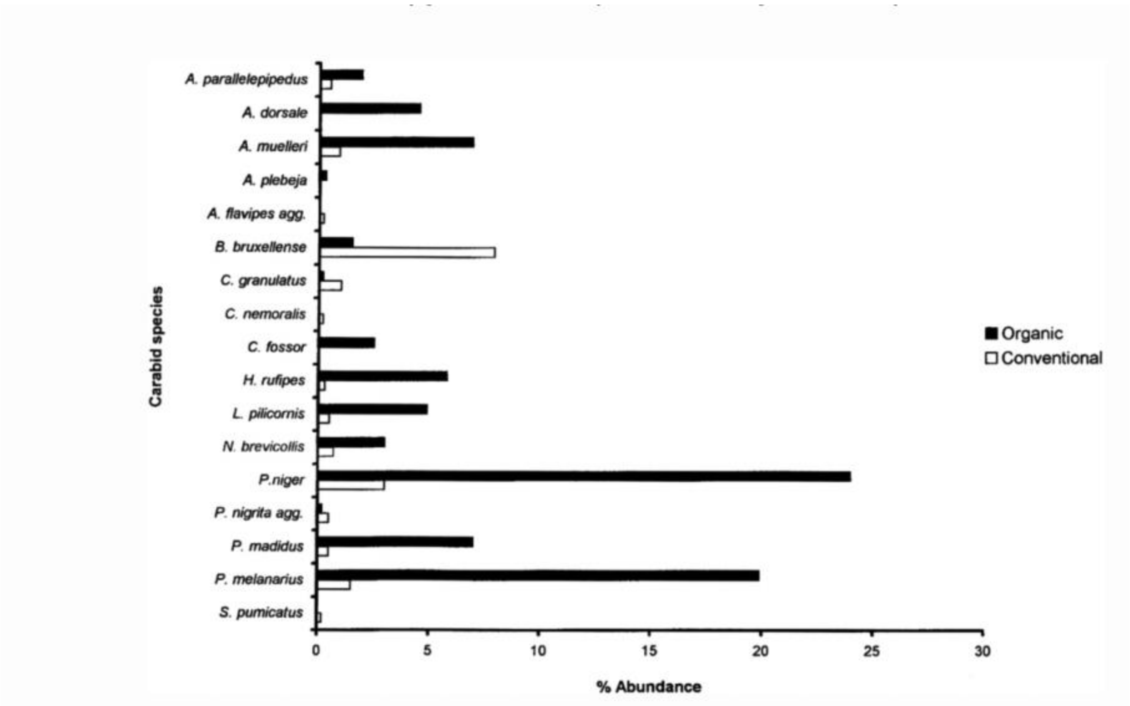


Figure 6 : Relative abundance of carabid species in organic (black) and conventional (white) agriculture. Source: O'Sullivan and Gormally, 2002

Regarding the direct effect of pesticides, literature is divided. Some authors claim that carabids are very sensitive to pesticides (e.g., Vickerman and Sunderland, 1977; Kromp, 1999, Navntoft *et al*, 2006) while others affirm that, even if the effect of insecticides is strong when the farmer sprays, carabids can easily recolonize the field afterwards, even for big fields (Holland and Luff, 2000). At least, we can say that pesticides effects are specific, some genera like *Pterostichus, Loricera and Demetrias* increasing in abundance if pesticides are reduced, while other like *Bembidion, Synuchus* and *Trechus* increasing in abundance in presence of pesticides (Navntoft *et al.*, 2006). Those result might be partially explained by a diminution of the predation pressure from large carabids like *Pterostichus spp.* against smaller carabids like *Bembidion spp* (Navntoft *et al.*, 2006).

The effect of a pesticide can also be very depending on whether it is sprayed towards the soil or the plant, and whether the carabid species climbs or not (Holland and Luff, 2000). However, long-term effect of insecticides and their sub-lethal effects are extremely difficult to assess, despite being potentially important (Holland and Luff, 2000). Indeed, one of the possible explanations of the overall decline of carabids populations in Europe could be the increasing use of pesticides, that could affect carabids through sub-lethal effects, for example a decrease in their fertility (Holland and Luff, 2000).

Indirect effects of other pesticides like herbicides or fungicides could also play an important role, even if they are not by themselves toxic for carabids (Holland and Luff, 2000). As already discussed, plant cover is an important factor for carabids, and their removal through herbicides can mean a loss of the advantages those plants provide for carabids. But besides that, knowledge about the global indirect effects of pesticides remains widely incomplete. The project SCARAB that assessed those effects in UK did not detect any harmful long-term effect, but since the used dose were very small, conclusions can not easily be drawn (Holland and Luff, 2000).

Finally, some other agricultural practices can also affect carabids. For example, crop rotation (which is another pillar of CA) seems to have an overall beneficial effect for carabids (O'Sullivan and Gormally, 2002), even though their abundance seems reduced if the previous crop in the rotation was clover (Kromp, 1999). This last effect is strange, since carabids also seem to be more abundant if this plant is present (Jowett *et al.*, 2021). Organic fertilizers like manuring seem to increase carabid abundance (Kromp, 1999; Holland and Luff, 2000) although it might not always be the case (Holland and Luff, 2000). Inorganic fertilization with nitrogen, in opposition, tends to decrease abundance of carabids, except for *Pterostichus melanarius*, which tends to increase in abundance with this kind of fertilization (Kromp, 1999).

Limitations

As we have seen throughout this section, a lot of contradictions can be found in literature, and many confounding factors also exist (Kromp, 1999). For example, other parameters than agricultural practices are of the utmost importance for carabid communities: crop type, humidity, microclimates or pH might be key factors as well (Kromp, 1999; Holland and Luff, 2000; Kennedy *et al*, 2013). In the same way, the effects of structures like hedges or flower strips in the field vicinity can strongly influence the results, since it can have very useful effects for carabids as shelters for example (Kromp, 1999; O'Sullivan and Gormally, 2002; Langellotto and Denno, 2004). Interferences from other fields around are also possible (O'Sullivan and Gormally, 2002). Also, in several experiments, removing the carabids does not alter the beneficial effect for the farmer (e.g., reduction of slugs), which could mean that carabids are not always the cause of this effect (Kromp, 1999).

Finally, trapping methods could induce several biases; the pitfall trap, which is the most used methods, has been very criticized for this reason (Andersen, 1995; Melbourne, 1999; Holland, 2002; Pekár, 2002; Ulyshen *et al.*, 2005; Hancock and Legg, 2012; Yi *et al.*, 2012). According to some authors, this method simply cannot provide reliable results (Jowett *et al.*, 2021). Thus, it appears interesting to focus on the different possible trapping methods used to sample carabids in agroecosystems.

As a conclusion to this part, we can say that, even though the literature about carabids is abundant (Kotze *et al.*, 2011), unbiased and consistent knowledge is still required to formulate appropriate instructions to the farmers needing carabids as cultural auxiliaries.

Methods of carabids sampling

Pitfall traps

Pitfall traps are very simple traps commonly used. It consists in a small container[1], usually a pot[2], placed in a hole in the soil so that the opening of the pot reaches the surface of the hole. The hole must not be larger than the pot, so that there is a continuity between the soil and the trap. Running insects therefore walk and fall into the pot, where there is usually a killing solution (often ethanol, salt-saturated water, ethylene glycol or propylene glycol, formaldehyde) to prevent predation between trapped animals. The trap can be covered with a small lid[3] (of course the lid must be high enough not to hinder the insects that would fall into the trap) to avoid overflows due to rain. If it is not the case, the traps must be removed weekly

---

[1] However, the diameter of this container is extremely variable (between 2cm and 2m) (Yi *et al*, 2012)

[2] The material constituting the pot is also very variable (plastic, glass, metal) (Yi *et al*, 2012)

[3] Some authors dissuade the use of lids for carabids (Yi *et al.*, 2012)

because of this risk of overflows (Andersen, 1995; Melbourne, 1999; Holland, 2002; Pekár, 2002; Ulyshen *et al.*, 2005; Epsky *et al.*, 2008; Hancock and Legg, 2012; Yi *et al.*, 2012).

Because of their simplicity, effectiveness and low cost, they are very popular. However, they suffer from several biases. Firstly, to be captured, an insect must fall into the trap, and thus to walk until he reaches the exact spot on the field where the trap is. Therefore, the more active the insect is, the more likely it is to be caught. And since bigger insects are usually more active, pitfall traps tend to overestimate the average size of the insects in the field (Andersen, 1995; Holland, 2002; Ulyshen *et al.*, 2005; Epsky *et al.*, 2008; Hancock and Legg, 2012; Yi *et al.*, 2012).

Secondly, comparing different studies that used pitfall can also be challenging, since there is no clear standardization for this trap. Thus, if the killing solution, the shape of the trap, the material constituting it or any particularity of the trap has an attractive or repulsive effect, it also induces a bias (Hancock and Legg, 2012; Yi *et al*, 2012). For example, it has been shown that glass pitfalls catch more insects (Luff, 1975), and that bigger traps are more effective to capture big insects, while smaller ones are more effective to capture small insects (Luff, 1975; Hancock and Legg, 2012). Formaldehyde, as for it, can also induce a bias since it has an attractant effect on carabids (Pekár, 2002). An obvious solution would be to set a universal standard design, but efforts have been made in this direction for almost 50 years, and such a universal design still does not exist (Hancock and Legg, 2012).

Thirdly, pitfalls can also trap small vertebrates like rodents, that emit a very strong smell while rotting, thus potentially having a repulsive or attractive effect (Yi *et al*, 2012). Bigger vertebrates can interfere with the trap as well, by destroying it (Gouix and Brustel, 2012) or feeding on the caught insects (Yi *et al.*, 2012).

Fourthly, other factors can also modify the pitfall trap’s efficiency, such as the soil relief (Epsky *et al.*, 2008), the microclimatic conditions and the vegetative cover (Melbourne, 1999; Holland, 2002; Ulyshen *et al.*, 2005; Epsky *et al.*, 2008; Hancock and Legg, 2012; Yi *et al.*, 2012) or even the behaviour of the species (Hancock and Legg, 2012).

Finally, pitfalls seem less effective in capturing carabid larvae (since, as we have already mentioned, they live mostly underground) and phytophagous species, in comparison to predatory ones (Andersen, 1985; Jowett *et al.*, 2021).

To cope with those issues, several authors have proposed partial solutions. First, during the same experiment, is important to keep the same design (Holland, 2002; Hancock and Legg, 2012). Next, adding fences with an entry around the pitfall can partially solve the bias towards more active species by guiding the less active ones towards the trap (Holland, 2002; Epsky *et al.*, 2008). Considering as much as potentially disturbing factors as possible, such as vegetative cover around the trap, is also a good approach to correct the biases (Melbourne, 1999; Holland, 2002; Ulyshen *et al.*, 2005; Epsky *et al.*, 2008; Hancock and Legg, 2012; Yi *et al.*, 2012). Finally, Hancock and Legg have proposed a mathematical transformation to correct the bias towards bigger species. According to this transformation, the biomass of a given species i captured by a pitfall is obtained by multiplying the biomass estimated by the pitfall trap (i.e. the total biomass of all the individuals of the species i caught) by the correcting factor $\lambda = e^{1.43\ln\left(\frac{Mmin}{Mi}\right)}$, where Mmin is the biomass of the lightest species of the experiment, and Mi the biomass of the considered species i. This way, for the smallest species, Mmin = Mi, thus λ = 1, and no correction is applied. For any other species, $\frac{Mmin}{Mi} < 1$, so $0 < \lambda < 1$, and the correction decreases the biomass (Hancock and Legg, 2012). With this correction, a more representative view of the carabid community can be achieved, but, of course, it remains an estimation and does not deal with behavioural biases or species not captured at all for example.

Even with those corrections, pitfall traps are still a biased method. Their qualities (easy to use, effectiveness and low cost) make it still worth using it when other methods would be too time-consuming (Kromp, 1999).

Quadrat sampling
Quadrat sampling consists in using squares in which insects are identified and counted. It can be made directly on the field, but it is also possible to extract all the arthropods *in situ* and then making the identification and count *ex situ* (Andersen, 1995; Hancock and Legg, 2012). This method is less biased than pitfalls since it consists of a comprehensive analysis of a small portion of the field. Nevertheless, it also has some flaws. Indeed, it can underestimate the abundance of some underground individuals (thus including carabid larvae). It is also important to mention that it is only a snapshot of a tiny space, which makes data harder to generalize, especially since carabids found in agroecosystems are mostly nocturnal (Kromp, 1999; Holland, 2002). Besides that, it is generally considered as a representative method (Hancock and Legg, 2012), even, for Andersen, “nearly perfect”, and especially good for abundant species (Andersen, 1995).

Suction sampling
Suction sampling is basically an enhanced version of quadrat sampling, where all the animals of a given surface are sucked into a hoover before identification and counting. It of course requires less time on the field than quadrat sampling, but it suffers from the same problem of being only a snapshot of the community composition. It is also harder to do when vegetative cover is important, and impossible when leaves are wet, which is especially problematic for nocturnal species like carabids (Holland, 2002). Nevertheless, it is recognized as a representative and effective (but expensive) way to assess invertebrate community compositions (Holland, 2002; Yi *et al.*, 2012).

Underground pitfalls
Underground pitfalls are a form of enhanced pitfalls, completed with an underground part allowing for the capture of underground organisms like carabid larvae (Figure 7). This trap model has shown effectiveness in catching underground insects, and, in a recent experiment carried by Jowett *et al.*, it revealed a higher diversity than the surface pitfall (Jowett *et al.*, 2021). That trapping method therefore corrects one of the biases from the classic pitfall trap, but besides this one, it suffers from the same biases as discussed above.

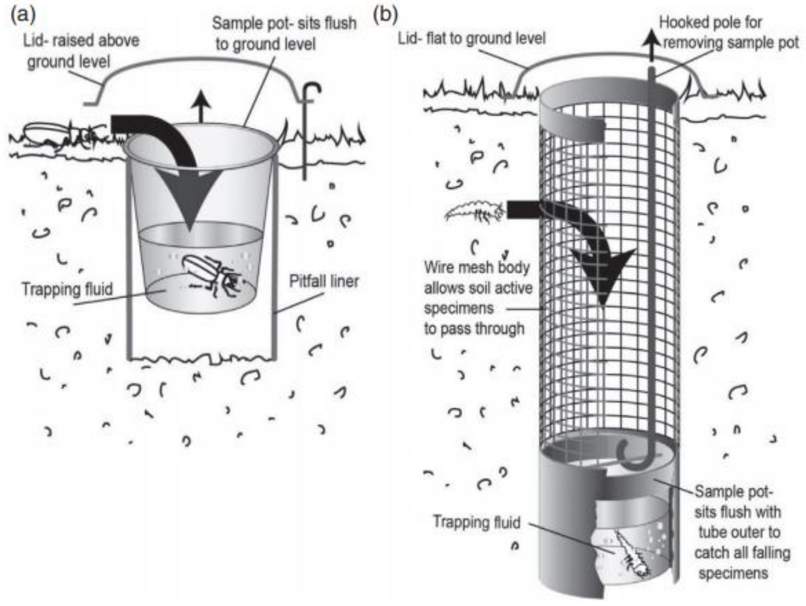


Figure 7 : Comparison of classic pitfall trap (a) and underground pitfall trap (b). Source: Jowett et al.*, 2021*

Emergence traps

Like underground pitfalls, emergence trap can give information about soil communities composition. Globally, it consists in delimiting a surface, and capturing insects that emerge from this surface. The surface has therefore to be closed to avoid escapes after the emergence, and the emerged individuals must be collected regularly, which can be facilitated thanks to a collecting device. Of course, this method is completely inappropriate for species that never go through an underground stage in the duration of the experiment (Ulyshen *et al.*, 2005; Epsky *et al.*, 2008; Resende *et al.*, 2020). It has been proven that it can uncover species that are not detected with simple pitfall traps, but, similarly, some species are found in pitfall traps and not in emergence traps (Ulyshen *et al.*, 2005). For our experiment, a new design emergence trap will be used, since we think it can solve several biases from the classic pitfall traps (see "Hypotheses and objectives").

Predation plates

Unlike the previous traps, predation plates are not used to learn about the composition of communities, but rather to estimate the predation pressure of a given place. Sentinel preys (e.g., seeds of weeds, dead insects) are sticked on a plate that is next placed on the field (either on the soil or hung on a plant). Then, the estimation of predation pressure is estimated based on the quantity of these sentinel preys that have been removed during a given time (Lescaudron, 2020; Boetzl *et al.*, 2020). Of course, this method can be accompanied with a classic sampling method like pitfall trapping to check which species could be responsible for the assessed predation pressure (Boetzl *et al.*, 2020). However, it also induces a bias, since these cards carrying dead preys are not a natural situation, and it could therefore be possible that an ineffective predator ate a quantity of sentinel preys higher than it could if the preys were alive. The opposite, where an effective predator does not attack the sentinel preys because of the particular situation, is also possible (Boetzl *et al.*, 2020).

Hypotheses and objectives

Throughout our experiment, we will collaborate with the CRA-W to sample carabids from fields owned by farmers who collaborate with the research center. The goals of this experiment will be to determine the impact of agricultural practices on the carabid communities and imagine the consequences on the ecosystem services. We will also test the validity of the emergence trap compared with the pitfall trap. Hence, the following hypotheses will be tested.

I. The carabid community is the result of multiple interacting parameters.

Because of the complexity of the agroecosystem, it will be likely that multiple parameters will shape the community composition. Therefore, we will use multivariate analyses to determinate the effect of the site, the modality, the tillage, the crop (the crop itself, but also its sowing period), the sampling period and the type of trap used. Besides testing those effect on the specific composition, the total abundance, and the specific richness, we will also realise traits-based analyses. Specifically, we will also test the effect of the above-mentioned parameters on the proportions of the different trophic categories in the community. The proportions of different phenology-based traits (breeding season, length of life cycle and reproductive strategy) in the communities will also be determined.

Biomass measurements will also be performed and will be integrated in the analyses on the proportions of trophic categories, because this parameter is important when evaluating ES. Indeed, it has been shown for both carnivorous and phytophagous species that predation rate was proportional to the biomass of the predator (Honek *et al.*, 2007; Gaines and Gratton, 2010; Diekötter *et al.*, 2016; Fisher *et al.*, 2021*;* Perez-Alvarez *et al.*, 2021), even if some authors disagree wit that statement (Rusch *et al.*, 2015).

II. Ploughing reduces the individual biomass.

In addition to the effects ploughing might have on the community level, we suppose it can also have impacts on the individual level. Specifically, we think that ploughing might reduce the amount of food available to carabids (either directly by destroying plants or indirectly by degrading the ecosystem), and that individuals of the same species should thus have a lower biomass in the heavily tilled fields than in the ones where tillage is superficial.

III. Emergence traps should capture a higher proportion of small and phytophagous species.

The emergence traps sample a much smaller surface than pitfall traps, so less carabids should be captured. Pitfalls are biased towards bigger species while emergence traps are supposed to accurately represent the soil community composition. Therefore, we think that emergence traps will capture individuals of lower biomass, and thus a higher proportion of small-sized species and a lower proportion of large ones than pitfall traps. Similarly, since pitfall seem biased towards predatory species (Andersen, 1995), emergence traps should capture a higher proportion of phytophagous species than pitfall traps.

Material and methods

Study site and periods

The experiment consisted in two sampling campaigns, one in 2020 and the other in 2021. The samplings of 2020 were conducted by the Walloon Centre for Agronomical Research (CRA-W) alone, while the 2021 ones were accomplished in collaboration between the CRA-W and the UCLouvain. However, all the identifications were made at UCLouvain.

2020

A total of 12 fields were used for this study, but the data from one of them (the one owned by LB) had to be rejected for the analyzed period (see below) because the traps were destroyed twice in a row. On each field, two plots of one ha were delimited (except for the field owned by RB, where only one plot was delimited). Those plots were approximatively rectangular (30 to 45m wide and 200 to 300m long). Three sampling zones, each containing three pitfalls, were established along each plot.

For each site, one plot was used as a control regarding the modality, and the farmer applied his usual farming techniques. The other one (modality BAC) owed to test the effect of the BAC modality proposed by the CRA-W. The table 1 summarizes the characteristics of each plot (owner, crop, modality, tillage, weeding, region).

Table 1: Characteristics of each plot (2020). BA = Biological agriculture; CA = Conservation agriculture; BAC = Biological agriculture of conservation; LAB = Deep ploughing; TCS sup = Superficial TCS

Owner	Crop	Modality	Tillage	Weeding	Region
BC	Maize	BA	TCS deep	Mechanical	Tournai
BC	Maize	BAC	TCS deep	Mechanical	Tournai
CH	Maize	CA	TCS sup	Herbicide	Center
CH	Maize	BAC	Striptill + faba bean	Mechanical	Center
CS	Potato	BA	LAB	Mechanical	Huy
CS	Potato	BAC	TCS sup	Mechanical	Huy
ER	Soft wheat	BA	LAB	None	Tournai
ER	Soft wheat	BAC	TCS sup	None	Tournai
HB	Pea + wheat	BA	LAB	Mechanical	Center
HB	Pea + wheat	BAC	TCS sup	Mechanical	Center
HC	Beet	CA	TCS deep	Herbicide	Center
HC	Beet	BAC	Striptill	Mechanical	Center
JM	Potato	CA	TCS deep	Herbicide	Charleroi
JM	Potato	BAC	TCS deep	Herbicide	Charleroi
LL	Maize	CA	Striptill	Herbicide	Huy
LL	Maize	BAC	Striptill + trefoil	None	Huy
PM	Spelt + lentils	BA	LAB	None	Charleroi
PM	Spelt + lentils	BAC	DS	None	Charleroi
RB	Winter wheat	BA	DS	None	Charleroi
VR	Winter wheat	BA	TCS deep	Mechanical	Tournai
VR	Winter wheat	BAC	DS	White clover	Tournai

The traps were placed in mid-April 2020, and they were sampled every two weeks until mid-August 2020. Hence, the first sampling concerned the late April period, and the last one the early August period.

Because of the huge number of trapped individuals, only the two samples from June 2020 (analyzed period) were analyzed. Furthermore, for each sampling zone, only the individuals caught in one of the three pitfall traps were identified. To choose the trap, we took the one that, visually, seemed to have captured the highest number of individuals. Since this decision was made once the identifications had already begun, we identified more carabids (22 027) than we used in the analysis (18 410).

2021

A total of 11 fields were used for this second year of study, the field owned by JM having been dismissed. The organization of plots was similar to that of 2020, except for three sites: the field owned by RB, where a second plots was implemented, and the fields managed by HB and HC, where a third one was delimited. Once again, the three same sampling zones were established, but we placed only two traps: a pitfall trap and an emergence trap (see "Trap design" for details). The table 2 summarizes the characteristics of each plot.

Table 2: Characteristics of each plot (2021). For abbreviations, see Table 1

Owner	Crop	Modality	Tillage	Weeding	Region
BC	Spelt	BA	TCS deep	None	Tournai
BC	Spelt	BAC	DS	None	Tournai
CH	Winter bean	CA	TCS sup	Herbicide	Center
CH	Winter bean	BAC	Striptill + faba bean	Undersowing	Center
CS	Bean	BA	LAB	Mechanical	Huy
CS	Bean	BAC	TCS sup	Mechanical	Huy
ER	Maize	BA	LAB	Mechanical	Tournai
ER	Maize	BAC	Striptill + faba bean	Mechanical	Tournai
HB	Maize	BA	LAB	Mechanical	Center
HB	Maize	BA	TCS deep	Mechanical	Center
HB	Maize	BAC	TCS sup	Mechanical	Center
HC	Winter wheat	CA	LAB	Herbicide	Center
HC	Winter wheat	CA	TCS deep	Herbicide	Center
HC	Winter wheat	BAC	TCS sup	Herbicide	Center
LB	Winter wheat	CA	DS	NA	Center
LB	Winter wheat	BAC	DS	NA	Center
LL	Winter wheat	CA	DS	Herbicide	Huy
LL	Winter wheat	BAC	DS	Herbicide	Huy
PM	Rapeseed	BA	LAB	None	Charleroi
PM	Rapeseed	BAC	Striptill	None	Charleroi
RB	Oats	BA	TCS sup	None	Charleroi
RB	Oats	BAC	DS	None	Charleroi
VR	Maize	BA	TCS deep	Mechanical	Tournai
VR	Maize	BAC	Striptill	Mechanical	Tournai

The traps were placed in early March 2021, and they were sampled every two weeks until late June 2021. Hence, the first sampling concerned the early March period, and the last one the late June period.

Because of the large number of carabids, we decided not to identify the individuals in samplings 2 (late March), 4 (late April) and 6 (late May). Nevertheless, all the carabids caught in the other samplings were identified. We thus have data for early March (sampling 1), early April (sampling 3), early May (sampling 5), early June (sampling 7) and late June (sampling 8). However, ER and PM left the experiment underway. Thus, for the fields owned by those farmers, we only have data for early March (ER) and for early March and early April (PM).

Trap design

2020

Carabids were sampled using cup-shaped, slightly conic, plastic pitfall traps (Figure 8). The traps were approximatively 13.2cm high and 11cm in diameter (at the top), except for those used in Charleroi, which were roughly 13.6cm high and 11.2cm diameter (at the top). To install the trap, a small hole was dug and a first cup (cup1), with perforated bottom to allow rainwater to drain away, was installed. A second cup (cup2), intact, was then placed into the first one and half-filled with the killing solution, ethylene glycol 25% volume. No attracting chemical was added. A chicken wire mash was placed around the trap to partially cope with activity biases, and a small tile was placed above the trap, resting on the wire, to prevent flooding of the trap. A picture of the pitfall used is shown in Figure 8.

Figure 8: Picture of the pitfall traps used

At each sampling, cup2 was dug up and replaced by an identical cup half-filled with the killing solution, and the trap was brought to the CRA-W. All the trapped organisms were then transferred into ethanol 99% in plastic pots, and a small amount of cooling was added.

2021

The design of pitfall traps was almost identical as in 2020. The only difference lied in the killing solution, which was saturated salt water.
The emergence traps consisted in pitfall traps (with the same design as described above, with saturated salt water as killing solution) buried in the center of a one-meter diameter metallic circle that prevented non-flying insects from moving in and out of the surface delimited by the circle. Therefore, we supposed that only the carabids that emerged from this surface would be sampled.

The exterior pitfall trap was buried approximatively 1 meter away from the external board of the emergence trap, so that we could compare the results provided by both types of traps. A representation of a sampling zone is shown in figure 9.

Figure 9: Sampling zone, with an exterior pitfall trap and an emergence trap (interior pitfall trap + metallic barrier)

Identifications

Carabid beetles were identified using Roger *et al.* (2012), Hackston (2013), Lindroth (1974) and Jeannel (1941). Insects were identified to the species level, except for the genus *Amara*, whose precise identification requires a dissection and an analysis of genitalia (Roger *et al*, 2012). Some species being extremely hard or impossible to distinguish without a dissection (*Asaphidion flavipes* and *Asaphidion curtum*; *Trechus quadristriatus* and *Trechus obtusus*; *Calathus melanocephalus* and *Calathus cinctus*) (Roger *et al.*, 2012), they were not differentiated during the identification. Also, the taxonomy of several *Ophonus* species being uncertain, the individuals matching the description of *Ophonus puncticeps* provided by Roger *et al.* (2012) were identified as *Ophonus gr. puncticeps*. The identification for those species was therefore slightly more precise than an identification to the genus level, but not as precise as an identification to the species level.

After identification, the carabids were placed into ethanol 70% in glass pill boxes. One pill box was used for every individual from the same species sampled at the same trap at the same date.

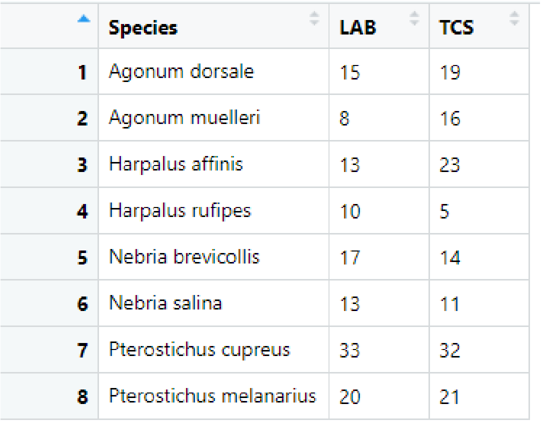
Dry mass measurements

Only the most abundant species were weighed. Those individuals were taken from the 2020 early June sampling (sites CS, ER, HB and PM) and 2021 early May, early June and late June samplings (sites CS, HB and HC). Those periods were chosen because the targeted species were the most abundant there. The above-mentioned sites were selected because one of the plots was heavily tilled (tillage LAB) while the other one was only superficially tilled (tillage

TCS superficial or DS for PM). This way, we could assess the effect of tillage on the species >6mm, except for the genus *Amara* because they were not identified to the species level, which could strongly interfere with our interpretations. To avoid strong site and date effect, we never weighed more than 2 individuals of the same species from the same 2020 sampling (i.e., never more than two individuals from the same site, plot and sampling date) and never more than three for the 2021 ones.

The table 3 summarizes the total number of individuals of each species >6mm weighed for both types of tillage, except for the genus *Amara*.

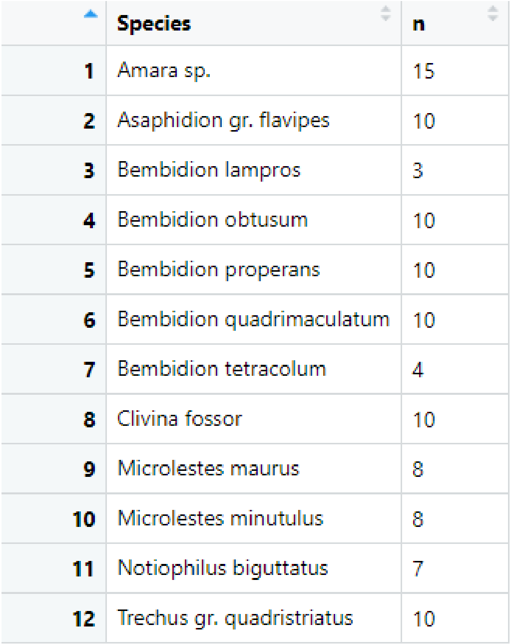
Table 3 : Number of individuals of each species >6mm weighed. LAB = Heavily tilled soil; TCS = Superficially tilled soil (TCS superficial or DS)



	Species	**LAB**	**TCS**
1	Agonum dorsale	15	19
2	Agonum muelleri	8	16
3	Harpalus affinis	13	23
4	Harpalus rufipes	10	5
5	Nebria brevicollis	17	14
6	Nebria salina	13	11
7	Pterostichus cupreus	33	32
8	Pterostichus melanarius	20	21

The abundant smaller (<6mm) species were taken randomly in the same subset as for >6mm species. When possible, we weighed 10 individuals. The table 4 summarizes the number of individuals of each species weighed. The individuals of the genus *Amara* were weighed using the same protocol, except for the fact that we weighed 15 individuals instead of 10, because we supposed that the variation would be higher since we potentially had several species.

Table 4: Number of individuals of each species <6mm (+ Amara sp.) weighed.



	Species	**n**
1	Amara sp.	15
2	Asaphidion gr. flavipes	10
3	Bembidion lampros	3
4	Bembidion obtusum	10
5	Bembidion properans	10
6	Bembidion quadrimaculatum	10
7	Bembidion tetracolum	4
8	Clivina fossor	10
9	Microlestes maurus	8
10	Microlestes minutulus	8
11	Notiophilus biguttatus	7
12	Trechus gr. quadristriatus	10

The selected carabids were placed into glass Petri dishes into a 60°C proofer. Four days later (day 4), 49 individuals (37 individual belonging to the largest species and 12 belonging to smaller ones) were removed from the proofer and the Petri dishes and individually weighed on a scale (d = 0.0001g). The carabids were then reset on the Petri dishes, which were put back in the proofer. The same manipulations were made again two (day 6) and four (day 8) days after on the same individuals. Since no diminution of weight was observed between day 4 and day 6, and the mean weight differences between day 4 and day 8 were neglectable ($< 10^{-4}$ g), we assumed that all carabids were dry (since the largest ones were so), and we weighed most of them on day 8. The remaining ones were weighed three days after.

Analysis

All the analyses were conducted with RStudio. To avoid pseudoreplication, the catches from all the traps of the same type on the same plot on the same sampling date were added and treated as one observation. If the trap had encountered too severe problems (completely flooded or completely dry), it was discarded.

Dry mass

For each weighed species >6mm, linear mixed models of the individual dry mass according to the tillage, the site (random effect) and the date (random effect) were elaborated. The outliers were spotted using a Grubbs's test and then discarded. The homoscedasticity was checked with a Bartlett's test and the normality of the residuals with a Shapiro's test. If one of those characteristics was not verified, we used the square root of the individual mass instead of the individual mass. The significance of the tillage as a parameter of the model was finally checked using an anova.

Assessment of categories to the carabids

Six traits were associated to each species: the mass, the diet, the size category the breeding season, the length of life cycle (strictly annual of possible biennial, as defined by Matalin (2007)) and the reproductive strategy (semelparous or iteroparous, as defined by Matalin (2007)).

Individuals were denoted as "small" when their size was <5mm. They were qualified of "medium" if their size was comprised between 5 and 9mm, and the "big" species were >9mm long.

For the mass of the species we weighed, we simply attributed the mean mass we obtained. For the species we did not weigh, we approximated the individual mass by attributing the mean mass of the weighed species that had the closest size. However, three species that were both rare (<10 individuals) and small (<5.5mm) were neglected for the analyses implying the biomass: *Acupalpus meridianus, Bembidion semipunctatum* and *Demetrias atricapillus*.

The diet of the species was determined using Roger *et al.* (2012), Carbonne *et al.* (2020), Corfdir (2020), Saska (2008), Honek *et al.* (2007), Brandmayr *et al.* (1980) and Brandmayr and Brandmayr (1975). Further prospection in the literature was made for *Pterostichus melanarius*, whose diet could not be determined with enough certainty using the above-mentioned sources because of an important amount of contradictory information. The species were separated into four categories: generalist predators, granivorous, omnivorous and specialist predators of springtails. We finally considered *P. melanarius* as a generalist predator.

The three last traits were attributed using Matalin (2007), following the same classification and definitions he uses in his paper. Since only a few species data are provided in the paper, the author generously gave us his information regarding the species we caught. However, since a lot of species were identified as *Amara sp.* and, potentially, *Ophonus gr. puncticeps*, we neglected those species in the realisation of those categories. Similarly, since data were missing for *Agonum sexpunctatum* and *Harpalus luteicornis* (two rarely caught species in our experiment), they were also dismissed from this categorization.

Multivariate analyses
Multivariate analyses were conducted for early June 2020, late June 2020, all the 2021 samplings altogether and the pitfall traps of early June 2021. The purpose of this last analysis was to compare both years. The very rare species (<5 individuals for the analysis of all the 2021 samplings and <3 individuals for the others) were not considered.

Firstly, a PCA with three axes on the following characteristics of the community was conducted: the total number of individuals, the total biomass, the species richness, the proportions of the trophic categories among the individuals and the proportions of those same trophic categories among the total biomass. The position of the following parameters in all the planes of the axes system was then evaluated: The site, the modality, the tillage, the crop the region, the tillage simplified and the sowing period (winter or spring crop). The tillage simplified, as its name suggests, is a simplified version of the tillage, with less levels: the superficial and the deep TCS are assembled under the appellation “TCS” and all types of striptill, as well as the DS, were reassembled under the term “DS”. For the analysis on all the 2021 data, the sampling period and the type of trap were also added.

To select the most important parameters, a second PCA, using the maximum number of axes, was then conducted. Afterwards, a BCA based on this second PCA was realised for each parameter. The significance of the part of inertia explained by those BCA was tested using Monte-Carlo tests with 999 repetitions. Finally, the parameters having a significant effect ($p<0.05$ or very close) and an interpretable representation in the axes system of the first BCA were analysed.

Secondly, a FCA of the neperian logarithm of the abundance of the species + 1 with three axes was performed. This FCA was next used, along with the same treatments as in the BCA, to produce a CCA with three axes.

Thirdly, a FCA in fuzzy coding with the maximum number of axes was elaborated. The characteristics used for this analysis were the proportions of individuals of each the trophic categories, the repartition of the trophic categories among the biomass, the proportion of individuals of each size category, the proportion of individuals of each breeding period, the proportions of individuals of each length of life cycle and the proportion of individuals of each reproductive strategy. The contribution of each of those characteristics to the composition of the first two axes was then determined. Finally, the position of the same parameters as in the PCA in the axes system of the FCA in fuzzy coding was represented, and the analyzed parameters were chosen in the same way as for the PCA (BCA and Monte-Carlo tests). For the sake of concision, the results of the fuzzy coding FCA will not be presented for the analysis on only the pitfalls of early June 2021.

Effect of emergence traps

To check the effect of the emergence traps, paired t-tests were realised on the mean biomass of captured individuals, the total number of caught individuals and the proportions of big, small, granivorous and generalist predator individuals according to the trap type. The data used for the tests were the individuals caught in the pitfalls of one plot at one date compared with the individuals caught in the emergence traps of the same plot at the same sampling date. The outliers were spotted using a Grubbs's test and a visual inspection, and then removed. The homoscedasticity was verified using a Bartlett's test. All the tests were realized with an *a priori* assumption: the mean individual mass, the total number of catches, the proportion of big species and the proportion of generalist predators were supposed to be higher in pitfall traps. The proportion of small species and of granivorous ones were supposed to be higher in emergence traps.

Results

A total of 22 027 carabids were identified, and 18 410 (4998 from early June 2020, 6187 from late June 2020 and 7225 from 2021) of them were used for the analyses.

For the PCAs and fuzzy FCAs, only the most informative graphs are displayed here. The graphs showing the position of the other parameters in the axes systems used can be found in the appendix.

Dry mass

The table 5 summarizes the mean mass and the associated sd of each weighed species.

Table 5 : Mean mass and sd of the weighed species

	Species	**Mean mass(g)**	**sd**
1	Agonum dorsale	0.0037470588	1.208865e-03
2	Agonum muelleri	0.0051291667	1.035659e-03
3	Amara sp.	0.0076866667	3.383968e-03
4	Asaphidion gr. flavipes	0.0009700000	3.093003e-04
5	Bembidion lampros	0.0008333333	2.516611e-04
6	Bembidion obtusum	0.0004300000	1.159502e-04
7	Bembidion properans	0.0010100000	2.846050e-04
8	Bembidion quadrimaculatum	0.0002800000	1.898420e-03
9	Bembidion tetracolum	0.0024500000	4.123106e-04
10	Clivina fossor	0.0032500000	7.427427e-04
11	Harpalus affinis	0.0148527778	3.180879e-03
12	Harpalus rufipes	0.0283789474	4.736686e-03
13	Microlestes maurus	0.0005625000	1.505941e-04
14	Microlestes minutulus	0.0002250000	8.864053e-05
15	Nebria brevicollis	0.0155870968	6.139476e-03
16	Nebria salina	0.0129416667	6.100814e-03
17	Notiophilus biguttatus	0.0017285714	4.990467e-04
18	Pterostichus cupreus	0.0222800000	5.156252e-03
19	Pterostichus melanarius	0.0373024390	1.027802e-02
20	Trechus gr. quadristriatus	0.0007500000	2.718251e-04

Among the eight species whose dry mass was compared in heavily plowed soil and slightly plowed soil, only *Nebria salina* showed a significant effect of plowing on body mass, the individuals sampled in slightly tilled soil being significantly heavier (0.0167±0.0067g) than the ones sampled in heavily tilled soil (0.0097±0.0032g) (lmer, Chi² test, p = 0.0015). The mass of these individuals is depicted on figure 10.

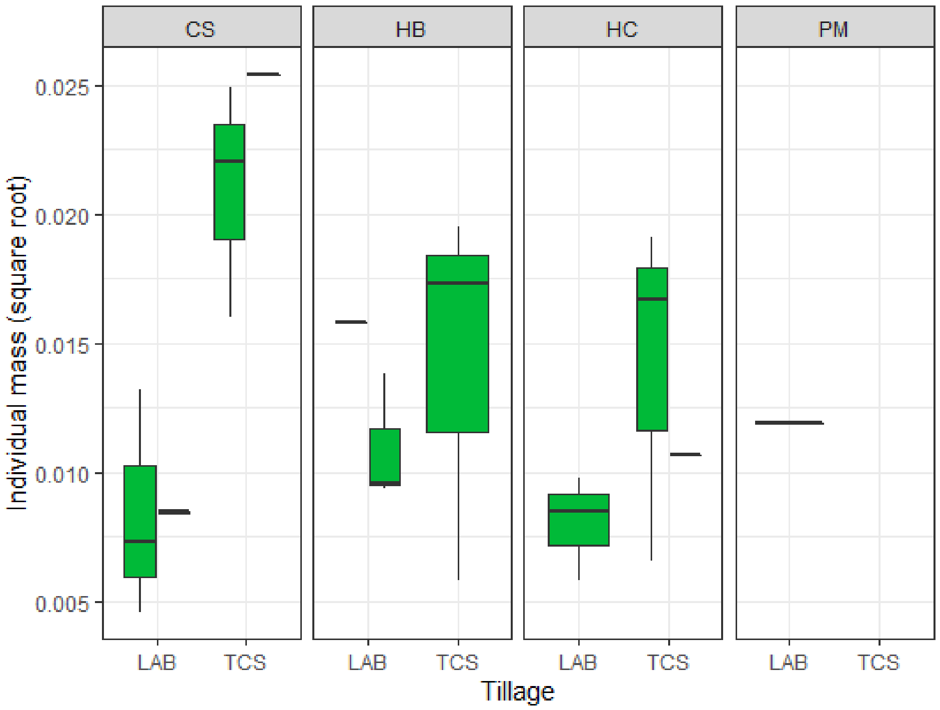


Figure 10 : Square root of the individual dry mass of Nebria salina according to the tillage. LAB = Intensive tillage; TCS = Superficial tillage. The green boxplots represent the individuals that were sampled in May 2021 (n = 20). The horizontal bars outside of the green boxplots represent individuals that were sampled in June 2020 (n = 2) or 2021 (n = 4)

2020 – Early June

PCA

The first three axes of the PCA represented respectively 42.35, 24.93 and 15.81% of the inertia, leading to a total of 83.09% of the inertia represented. The correlations of the community characteristics with the plane formed by axes 1 and 2 is shown in figure 11.

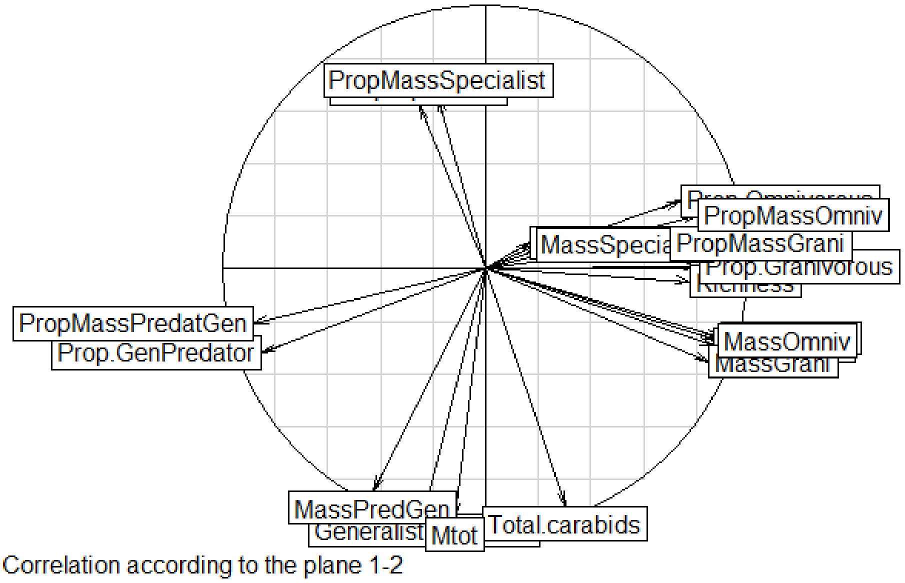


Figure 11 : Correlations of the community characteristics with the plane formed by the first two axes of the PCA for early June 2020. Mtot = Total dry biomass; MassPredGen = Total dry biomass of generalist predators; MassGrani = Total dry biomass of granivorous; MassOmniv = Total dry biomass of omnivorous; MassSpecialist = Total dry biomass of specialist predators of springtails; Prop.GenPredator = Individual proportion of generalist predators; Prop.Granivorous = Individual

proportion of granivorous; Prop.Omnivorous = Individual proportion of omnivorous; Prop.Specialist = Individual proportion of specialist predators of springtails; ; PropMassPredatGen = Massic proportion of generalist predators; PropMassGrani = Massic proportion of granivorous; Prop.MassOmniv = Massic proportion of omnivorous; PropMassSpecialist = Massic proportion of specialist predators of springtails

The table 6 shows the part of variability represented in each BCA.

*Table 6 : Part of inertia represented in the BCA using the listed parameter as factor and p-value of the associated Monte-Carlo test (999 repetitions) for the PCA of early June 2020. Significant results at the p<0.05 level are indicated by **

Factor	Part of inertia (%)	p-value of Monte-Carlo test (999 repetitions)
Site	79.37	**0.001***
Modality	19.30	**0.032***
Tillage	37.53	0.130
Crop	56.42	**0.002***
Region	25.28	0.052
Tillage simplified	12.50	0.270
Sowing period	30.53	**0.001***

The figures 12, 13 and 14 respectively show the position of the modality, the region and the sowing period in the plane formed by the first two axes of the PCA.

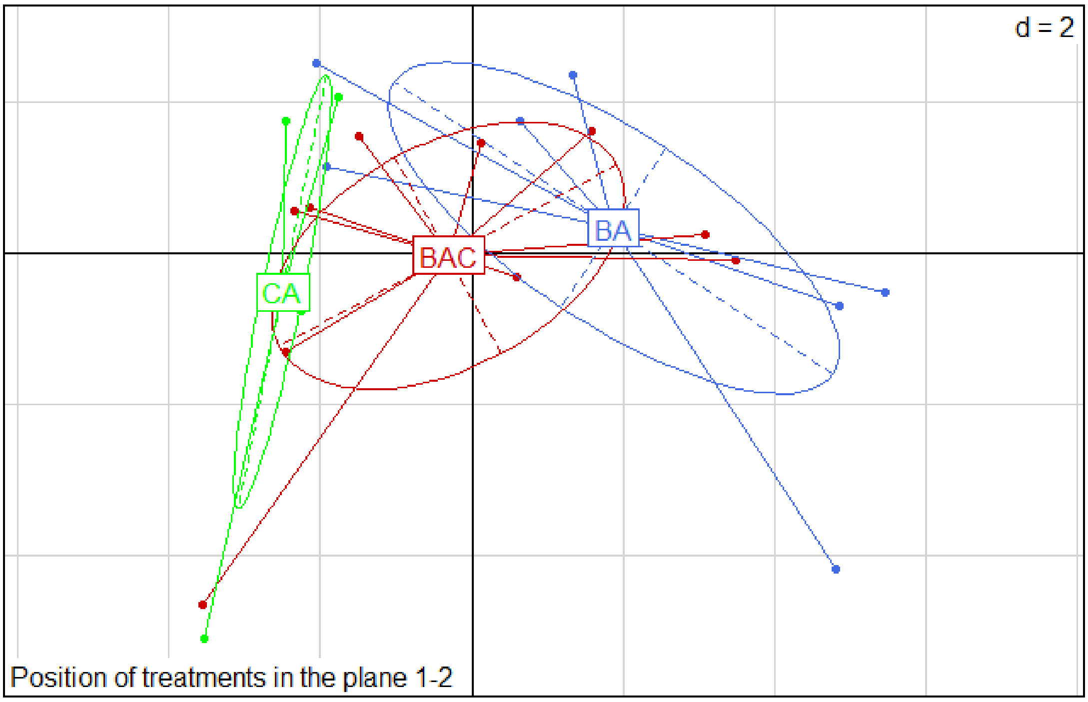


Figure 12 : Position of the modality in the plane formed by the first two axes of the PCA for early June 2020

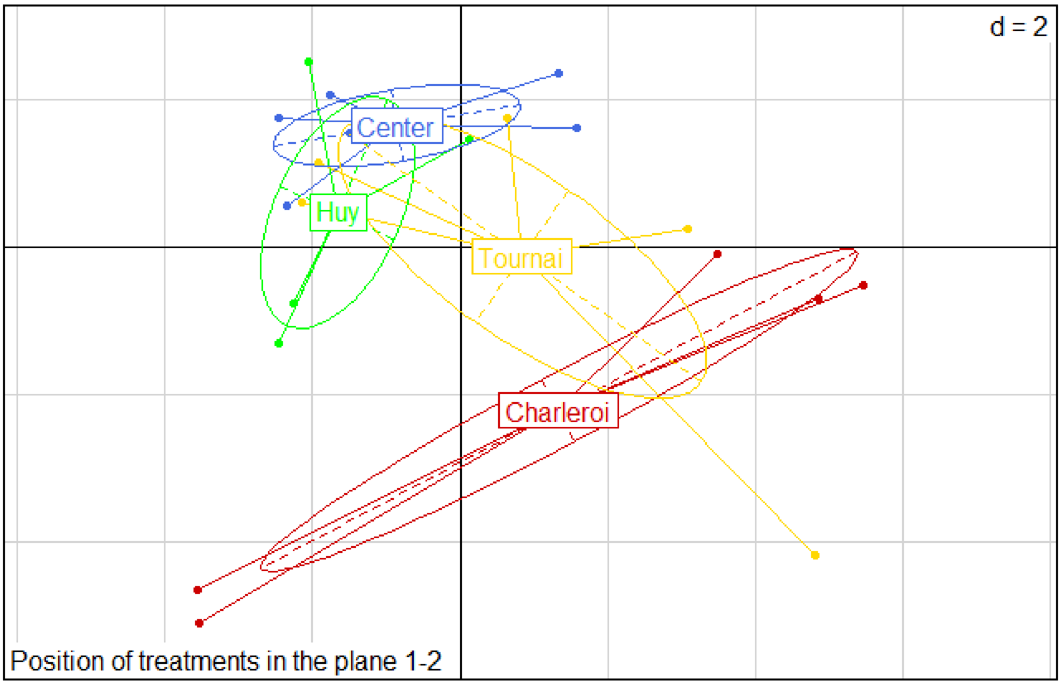


Figure 13 : Position of the region in the plane formed by the first two axes of the PCA for early June 2020

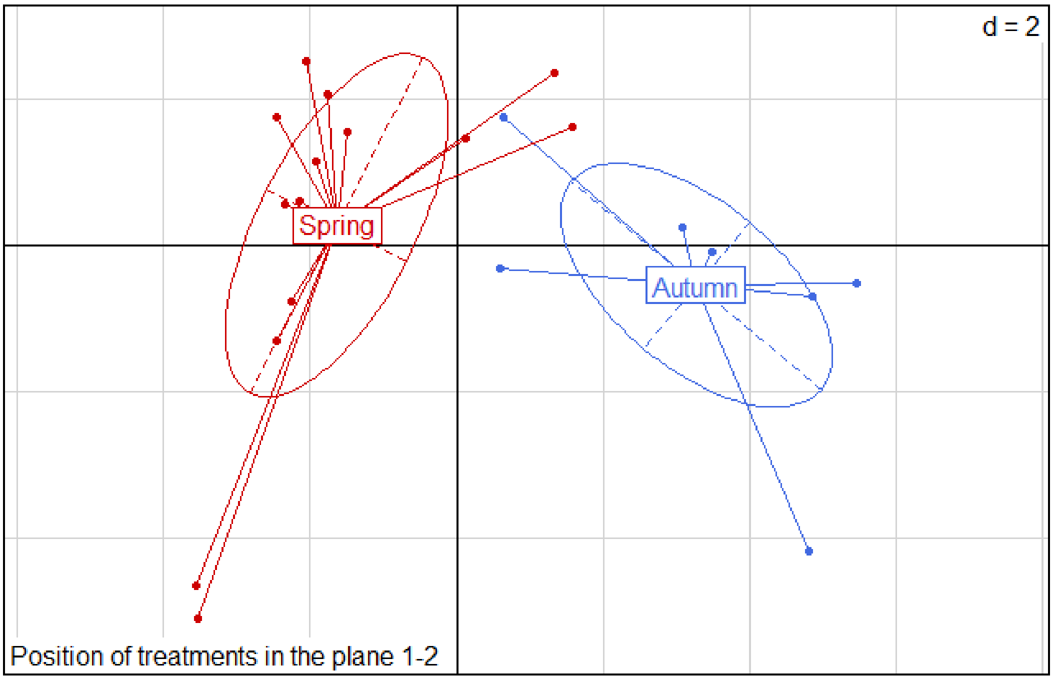


Figure 14 : Position of the sowing period in the plane formed by the first two axes of the PCA for early June 2020

FCA

The first three axes of the FCA represented respectively 21.67, 16.66 and 11.18% of the inertia, leading to a total of 49.49% of the inertia represented on these axes.

The figure 15 represents the position of the species on this axes system.

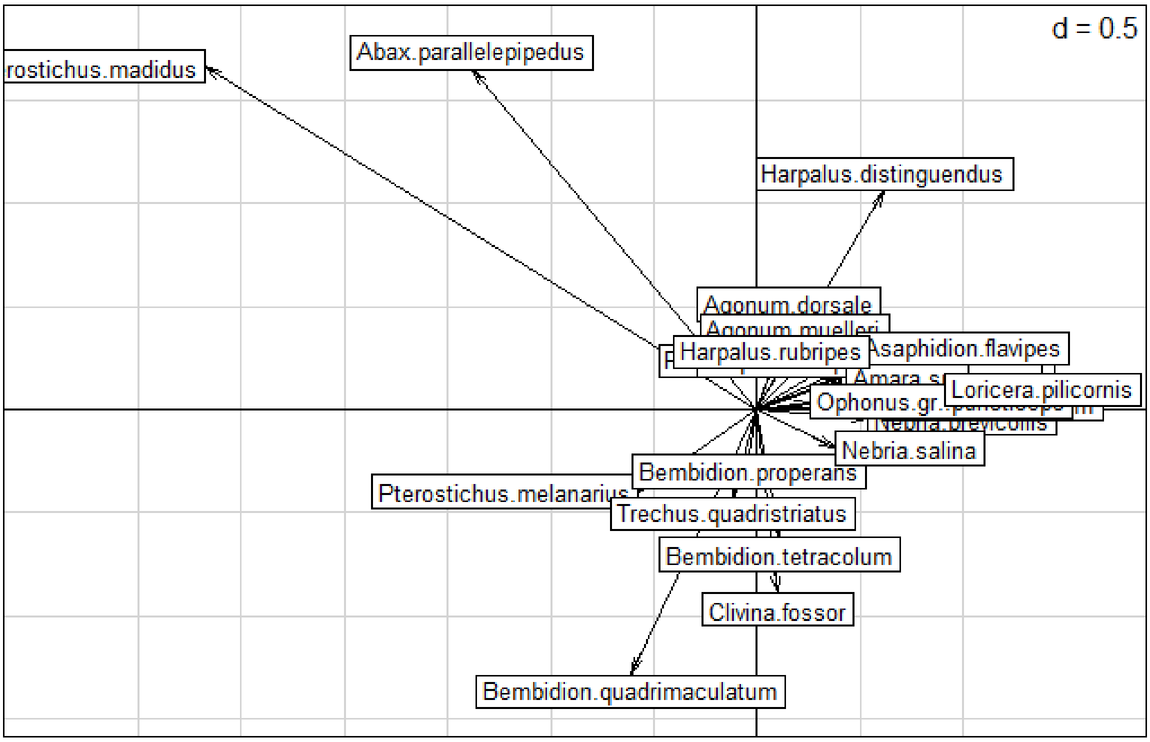


Figure 15 : Position of the species in the axes system of the FCA for early June 2020.
Species on the upper left corner: Pterostichus madidus

CCA

96.3% of the FCA inertia was represented on the CCA, 51.13% of which on the first three axes. The figure 16 represents the correlations of the treatments with the CCA axes system, and the figure 17 shows the position of the species in the same axes system.

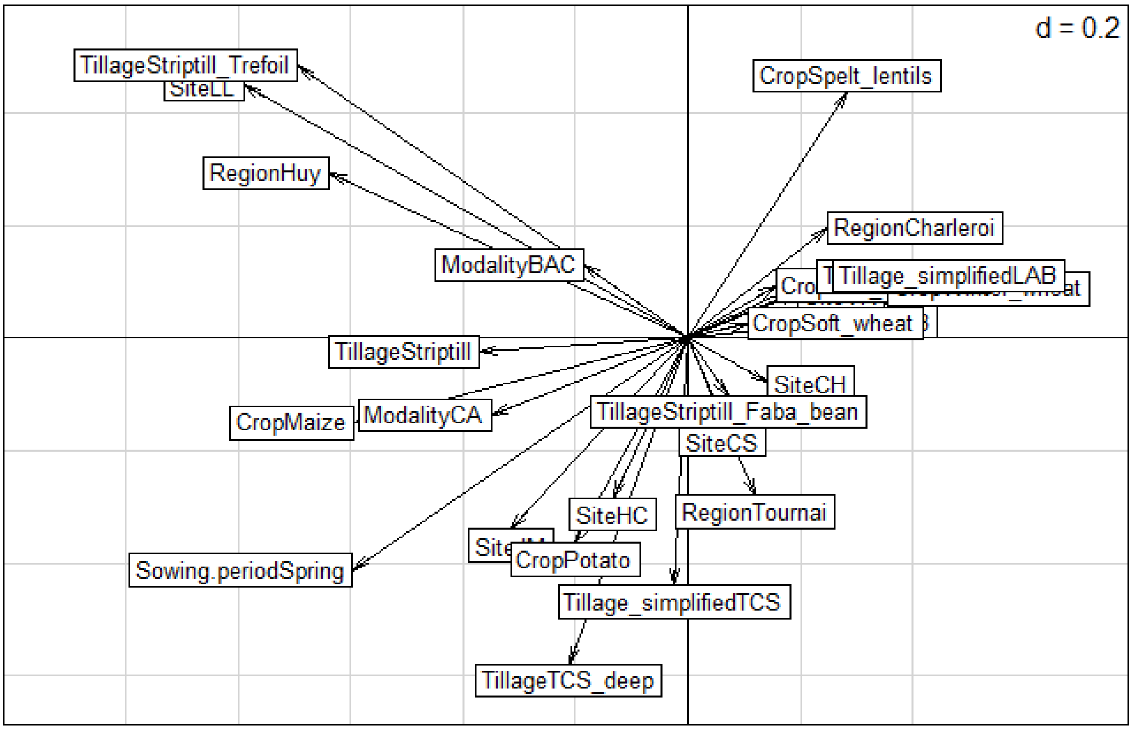


Figure 16 : Correlations of the treatments with the axes system of the CCA for early June 2020

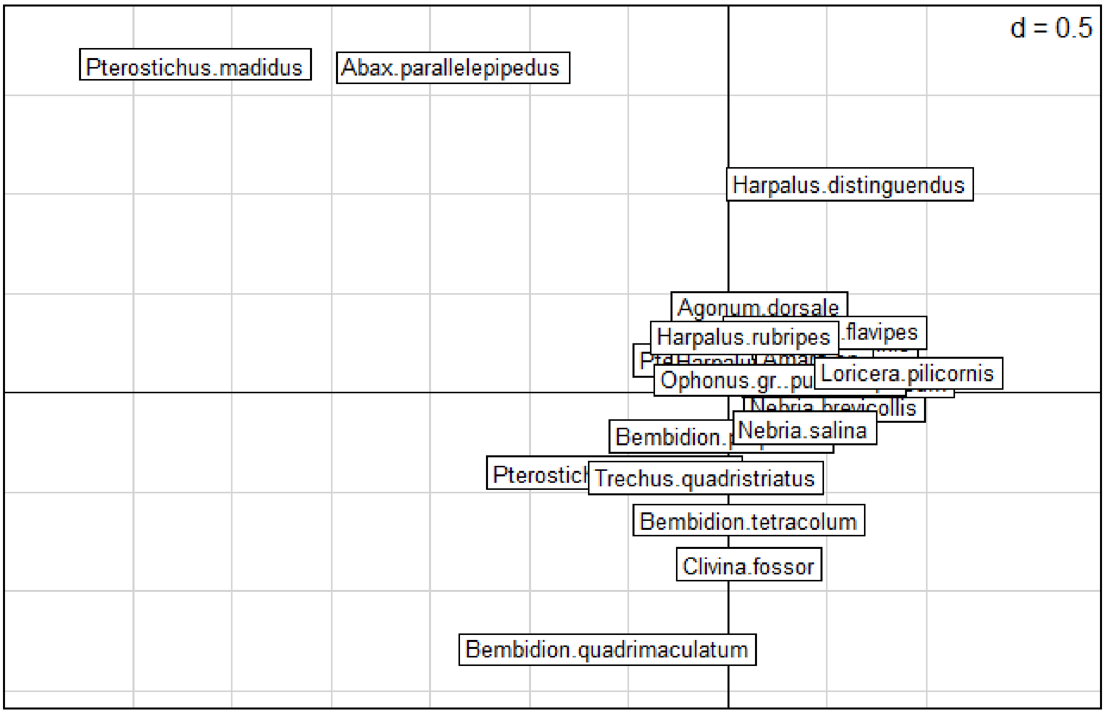


Figure 17 : Position of the species in the axes system of the CCA for early June 2020

Fuzzy FCA

The first two axes represented respectively 65.56 and 20.03% of the inertia, leading to a total of 85.59% of inertia represented. The figures 18 and 19 show the contribution of the traits to the first and second axis, respectively.

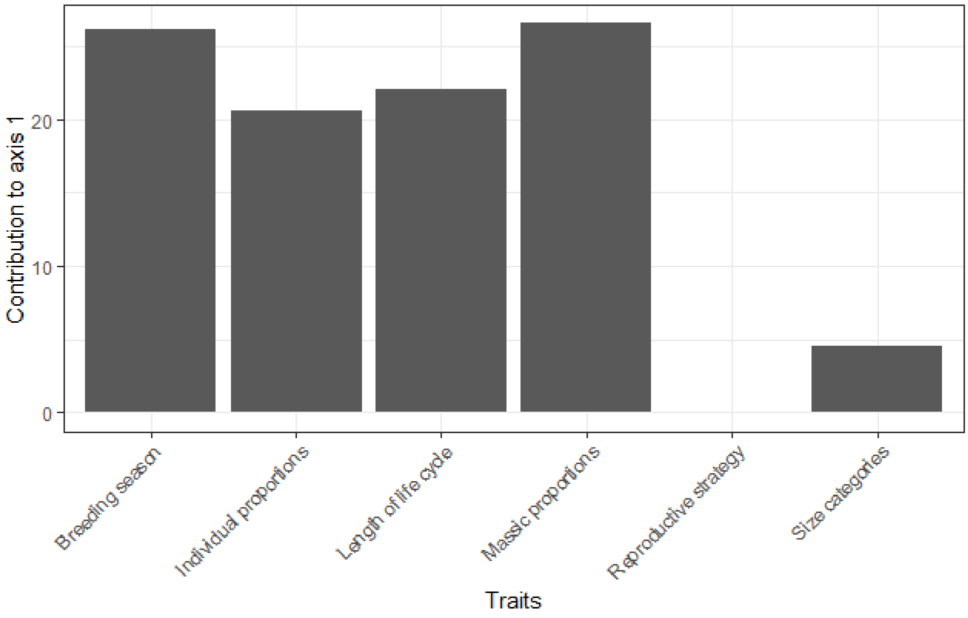


Figure 18 : Contribution of the carabid traits to the first axis of the fuzzy FCA for early June 2020

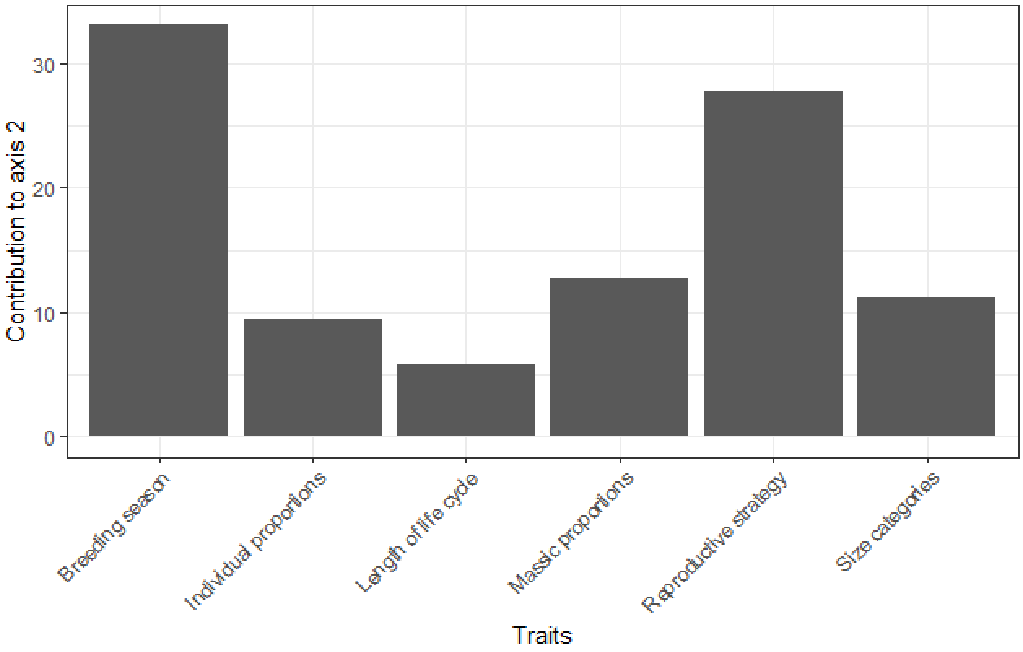


Figure 19 : Contribution of the carabid traits to the second axis of the fuzzy FCA for early June 2020

The table 7 shows the part of variability explained in each BCA.

*Table 7 : Part of inertia represented in the BCA using the listed parameter as factor and p-value of the associated Monte-Carlo test (999 repetitions) for the fuzzy FCA of early June 2020. Significant results at the p<0.05 level are indicated by **

Factor	Part of inertia (%)	p-value of Monte-Carlo test (999 repetitions)
Site	89.85	**0.001***
Modality	15.88	0.138
Tillage	58.01	**0.004***
Crop	56.51	**0.007***
Region	9.44	0.750
Tillage simplified	12.50	**0.024***
Sowing period	21.37	**0.009***

The figure 20 shows the correlations of the community characteristics with the axe system of the fuzzy FCA. The figures 21, 22 and 23 respectively show the position of the site, the tillage and the sowing period in the plane formed by the first two axes of the fuzzy FCA.

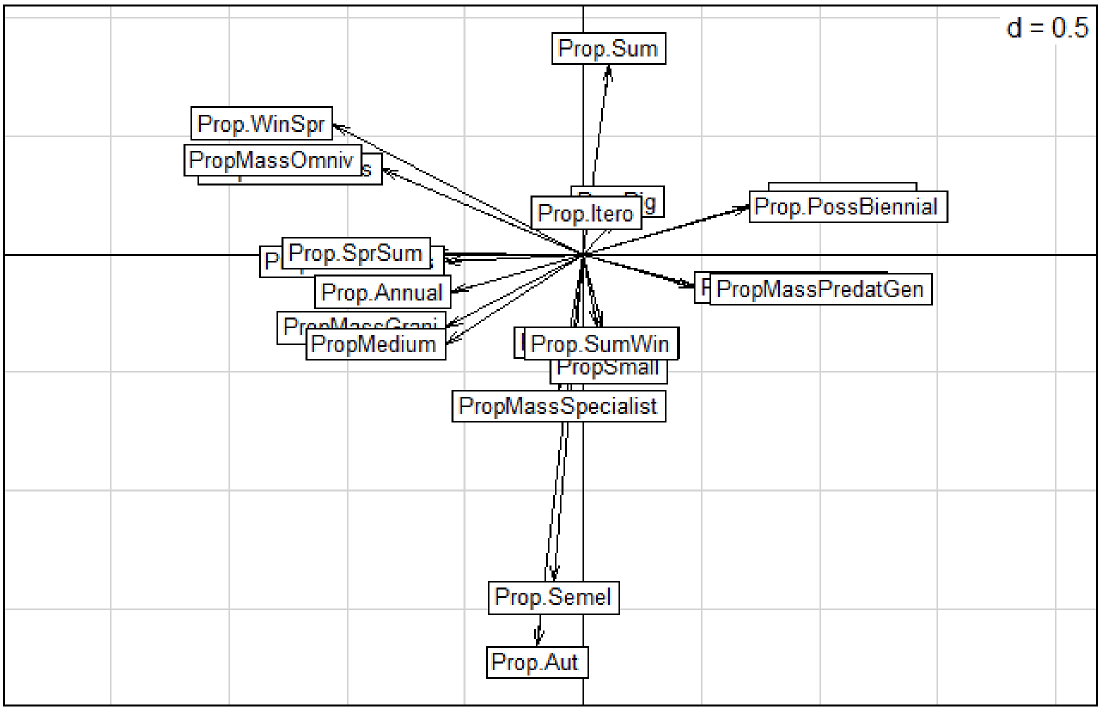


Figure 20 : Correlations of the community characteristics with the plane formed by the first two axes of the fuzzy FCA for early June 2020. Prop.SprSum = Individual proportion of spring-summer breeders; Prop.Sum = Individual proportion of summer breeders; Prop.SumAut = Individual proportion of summer-autumn breeders; Prop.Aut = Individual proportion of autumn breeders; Prop.SumWin = Individual proportion of summer-winter breeders; Prop.WinSpr = Individual proportion of winter-spring breeders; Prop.Itero = Individual proportion of iteroparous species; Prop.Semel = Individual proportion of semelparous species; Prop.PossBiennial = Individual proportion of species that can display a biennial life cycle; Prop.Anuual = Individual proportion of species that always display an annual life cycle. For other abbreviations, see figure 11. Behind Prop.PossBiennial : Prop.SumAut; behind PropMassOmniv : Prop.Omnivorous; behind PropMassPredatGen: Prop.GeneralistPredator; behind Prop.SumWin: Prop.Specialists; behind Prop.SprSum: Prop.Granivorous

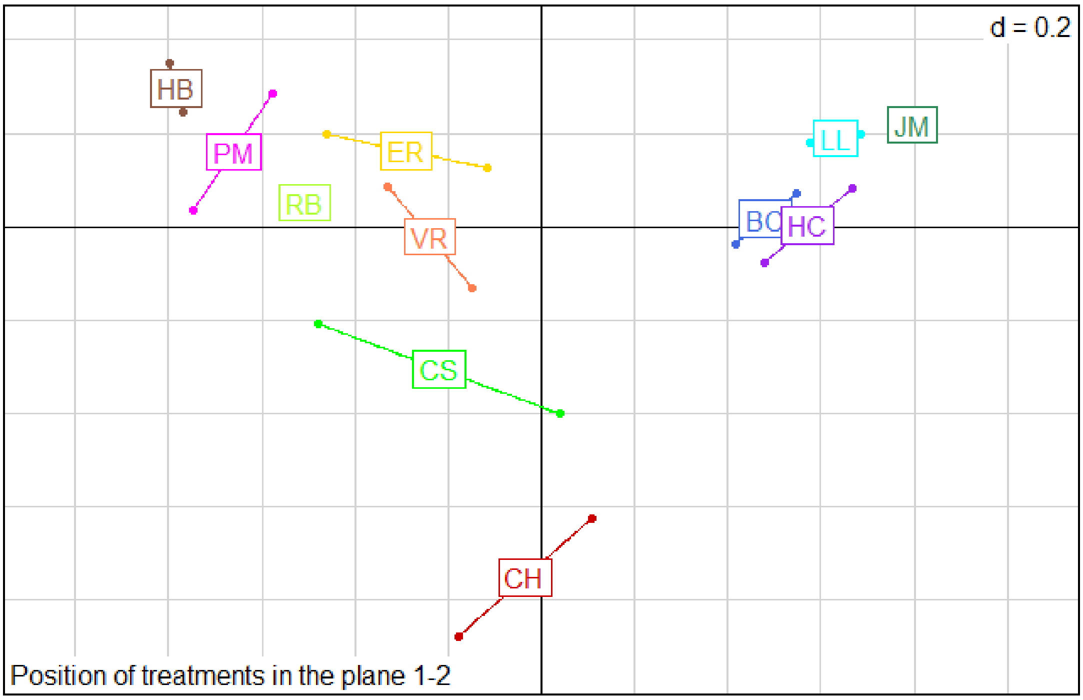


Figure 21 : Position of the site in the plane formed by the first two axes of the fuzzy FCA for early June 2020

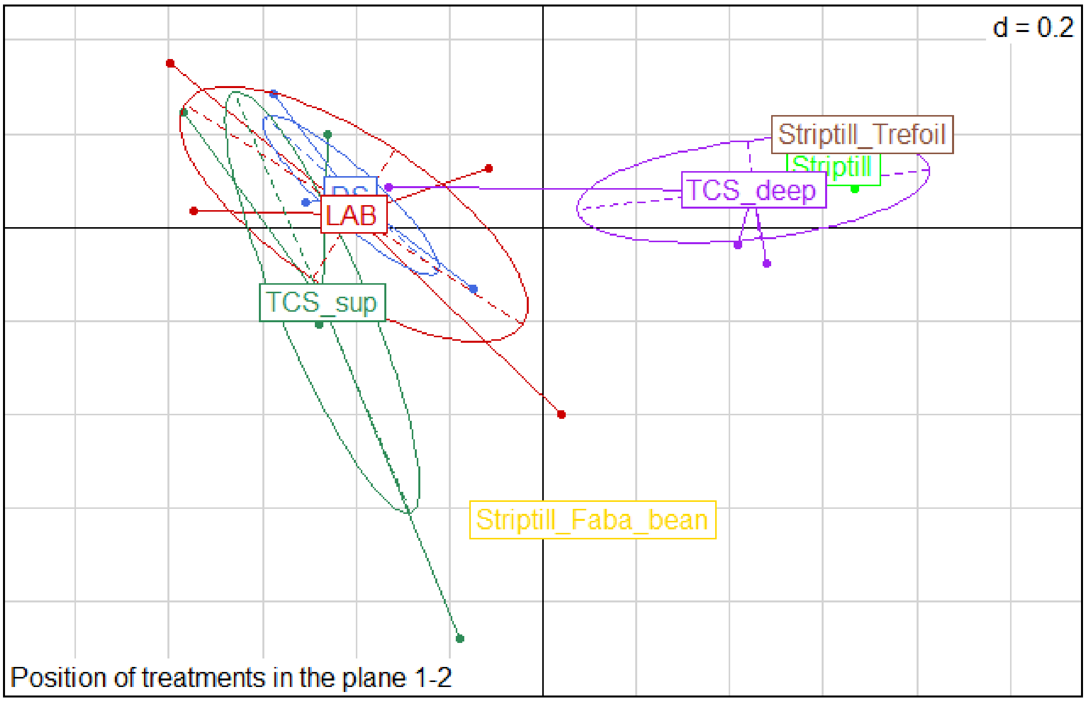


Figure 22 : Position of the types of tillage in the plane formed by the first two axes of the fuzzy FCA for early June 2020. LAB = Deep ploughing; TCS_sup = Superficial TCS

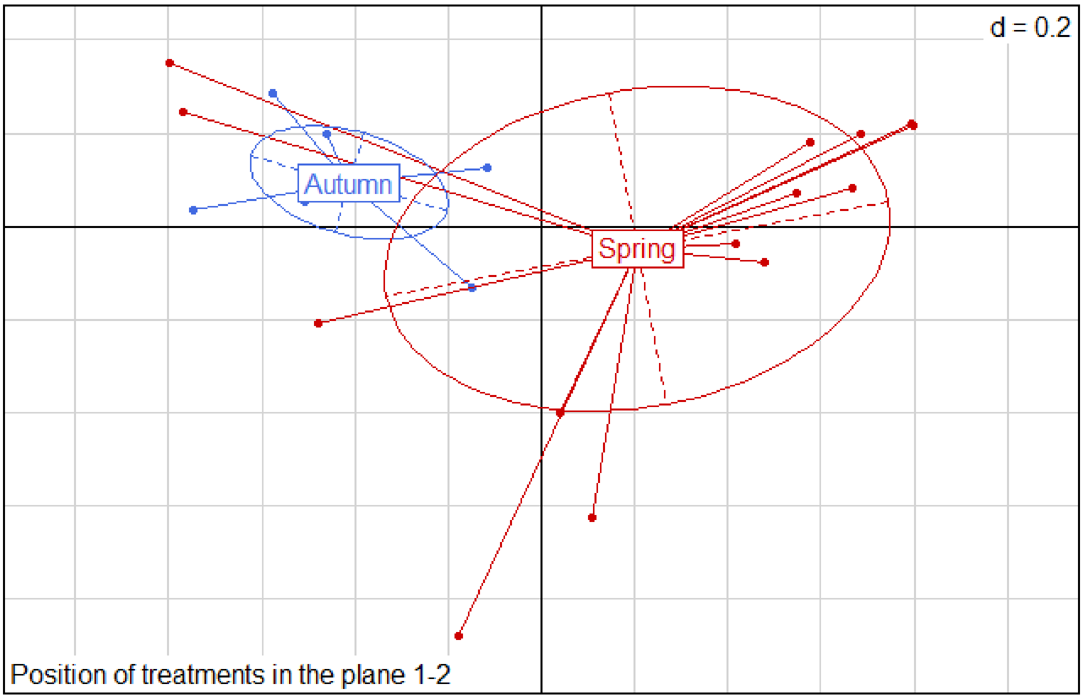


Figure 23 : Position of the sowing periods in the plane formed by the first two axes of the fuzzy FCA for early June 2020

2020 – Late June

PCA

The first three axes of the PCA represented respectively 37.73, 23.60 and 17.76% of the inertia, leading to a total of 79.09% of the inertia represented. The correlation of the community characteristics with the plane formed by axes 1 and 2 is shown in figure 24.

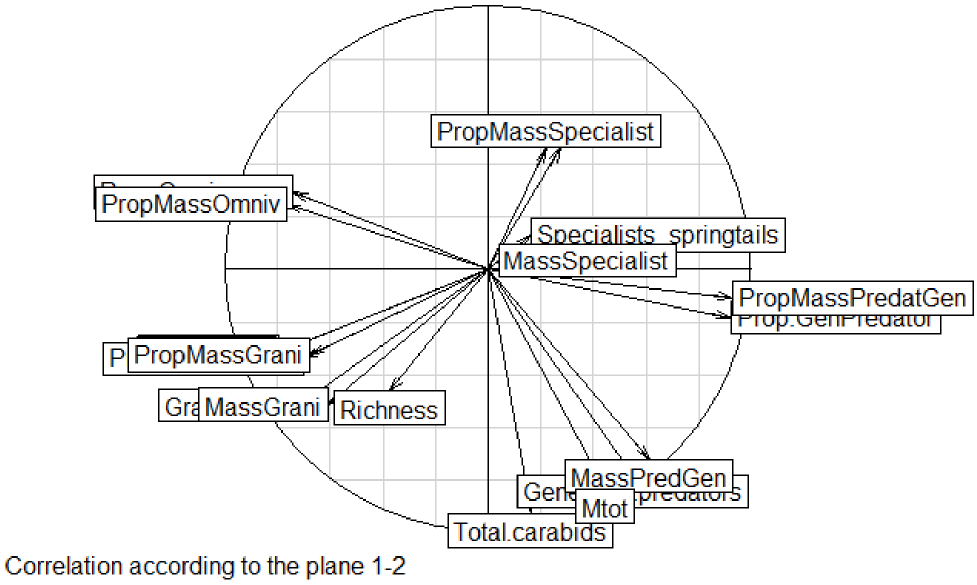


Figure 24 : Correlations of the community characteristics with the plane formed by the first two axes of the PCA for late June 2020. For abbreviations, see figure 11

The table 8 shows the part of variability explained in each BCA.

*Table 8 : Part of inertia represented in the BCA using the listed parameter as factor and p-value of the associated Monte-Carlo test (999 repetitions) for the PCA of late June 2020. Significant results at the p<0.05 level are indicated by **

Factor	Part of inertia (%)	p-value of Monte-Carlo test (999 repetitions)
Site	77.45	**0.001***
Modality	19.25	**0.025***
Tillage	34.19	0.25
Crop	48.21	**0.011***
Region	22.68	0.058
Tillage simplified	10.77	0.376
Sowing period	16.43	**0.005***

The figures 25, 26 and 27 respectively show the position of the modality, the region and the sowing period in the plane formed by the first two axes of the PCA.

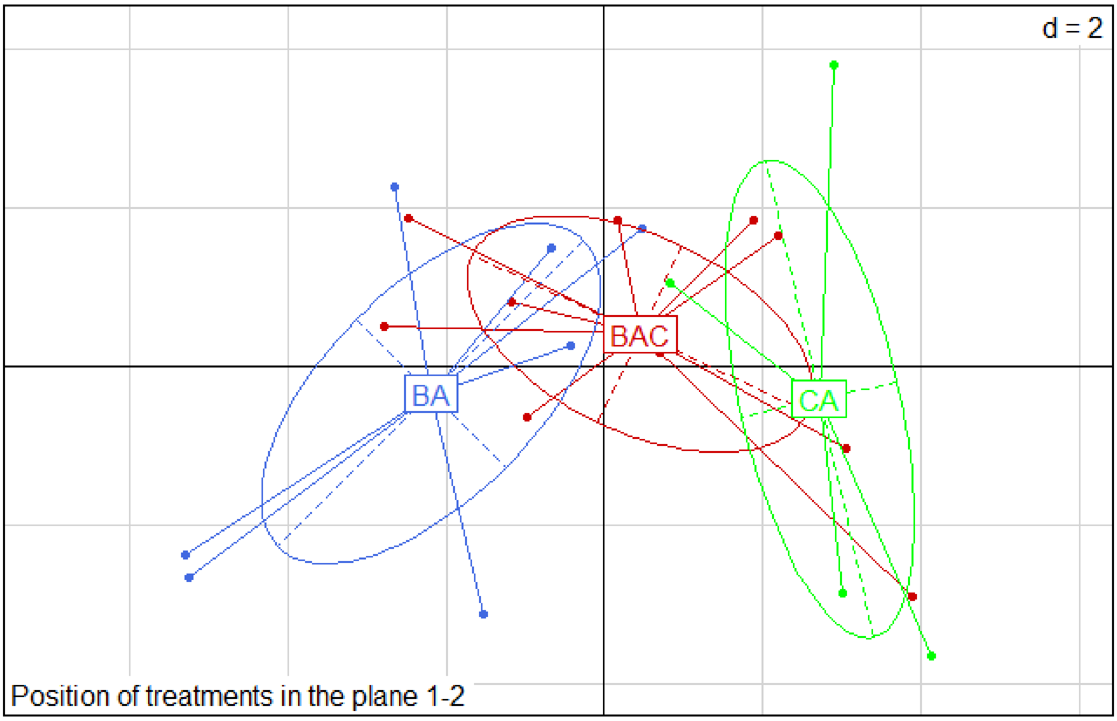


Figure 25 : Position of the modality in the plane formed by the first two axes of the PCA for late June 2020

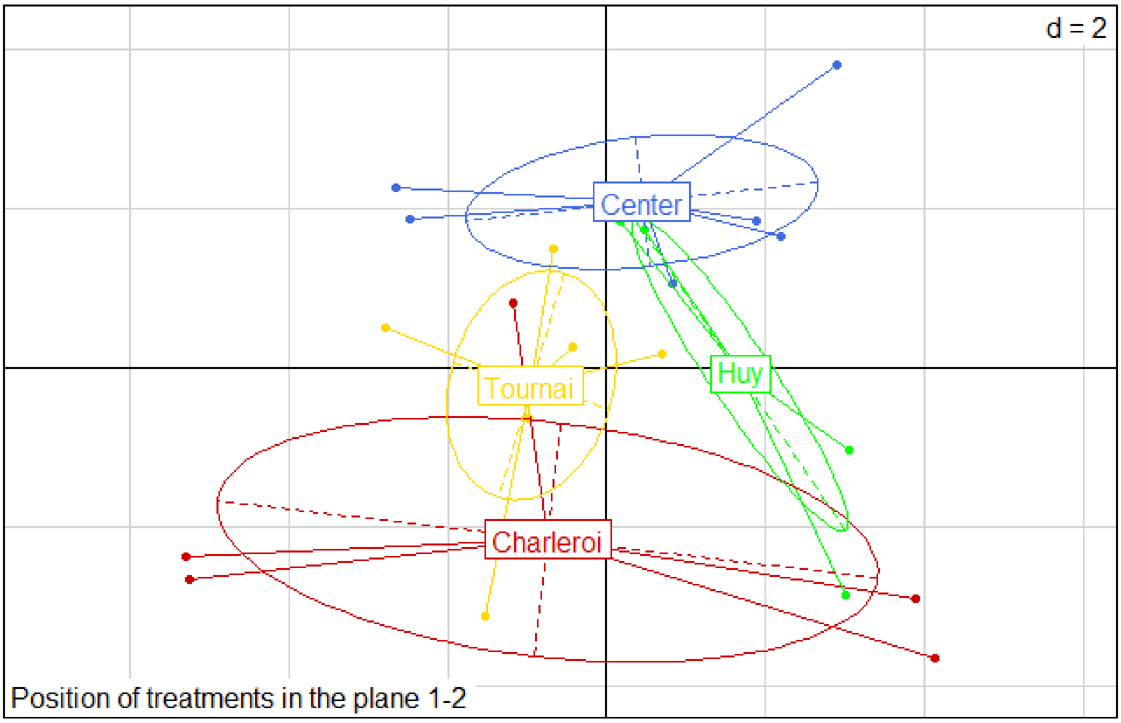


Figure 26 : Position of the region in the plane formed by the first two axes of the PCA for late June 2020

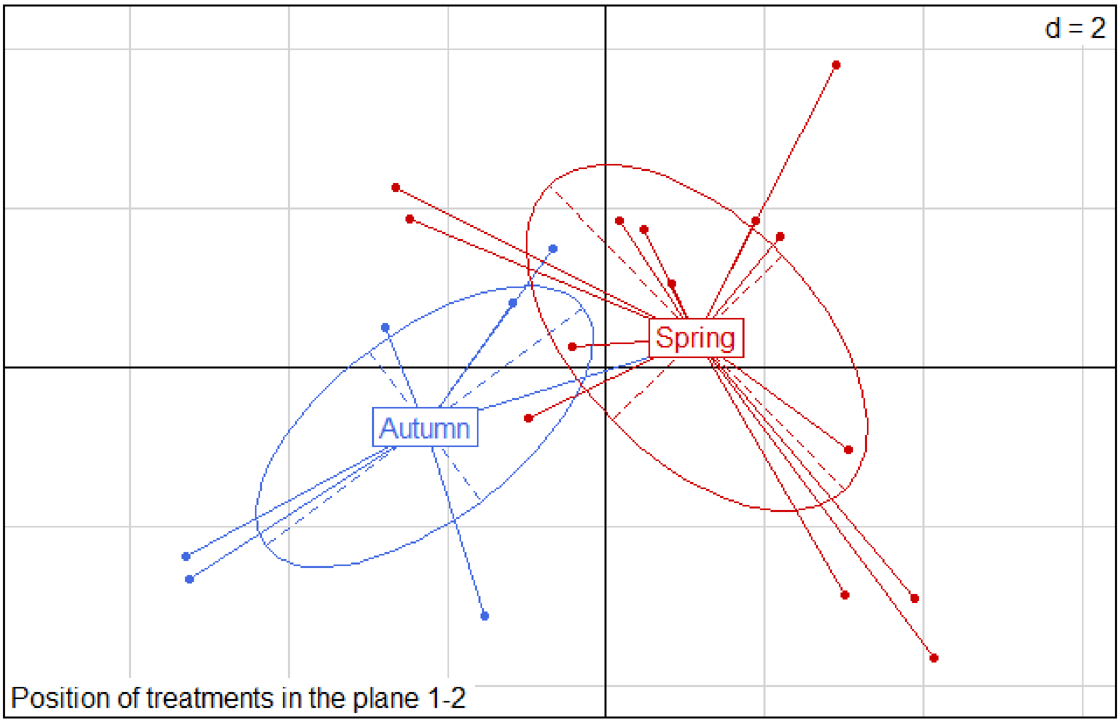


Figure 27 : Position of the sowing period in the plane formed by the first two axes of the PCA for late June 2020

FCA

The first three axes of the FCA represented respectively 22.20, 16.09 and 11.92% of the inertia, leading to a total of 50.21% of the inertia represented on these axes. The figure 28 represents the position of the species on this axes system.

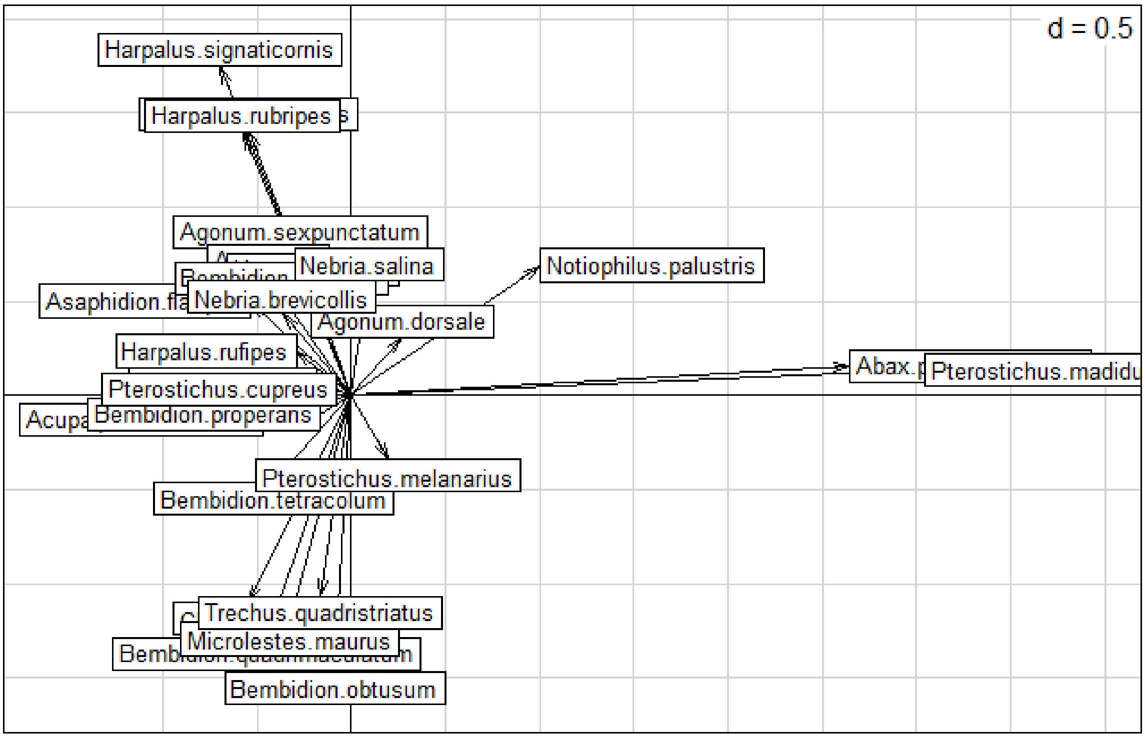


Figure 28 : Position of the species in the axes system of the FCA for late June 2020.
Species on the extreme right: Pterostichus madidus

CCA

90.44% of the FCA inertia was represented on the CCA, 53.63% of which on the first three axes. The figure 29 represents the correlations of the treatments with the CCA axes system, and the figure 30 shows the position of the species in the same axes system.

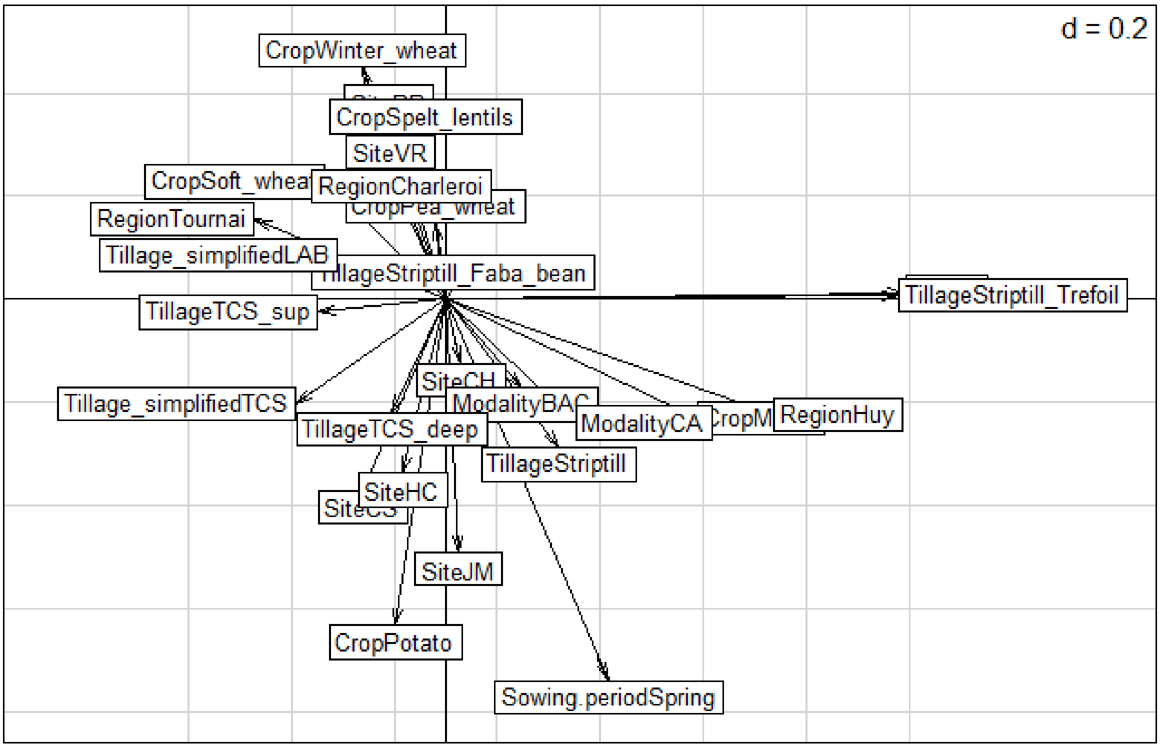


Figure 29 : Correlations of the treatments with the axes system of the CCA for late June 2020. Behind TillageStriptill_Trefoil: SiteLL

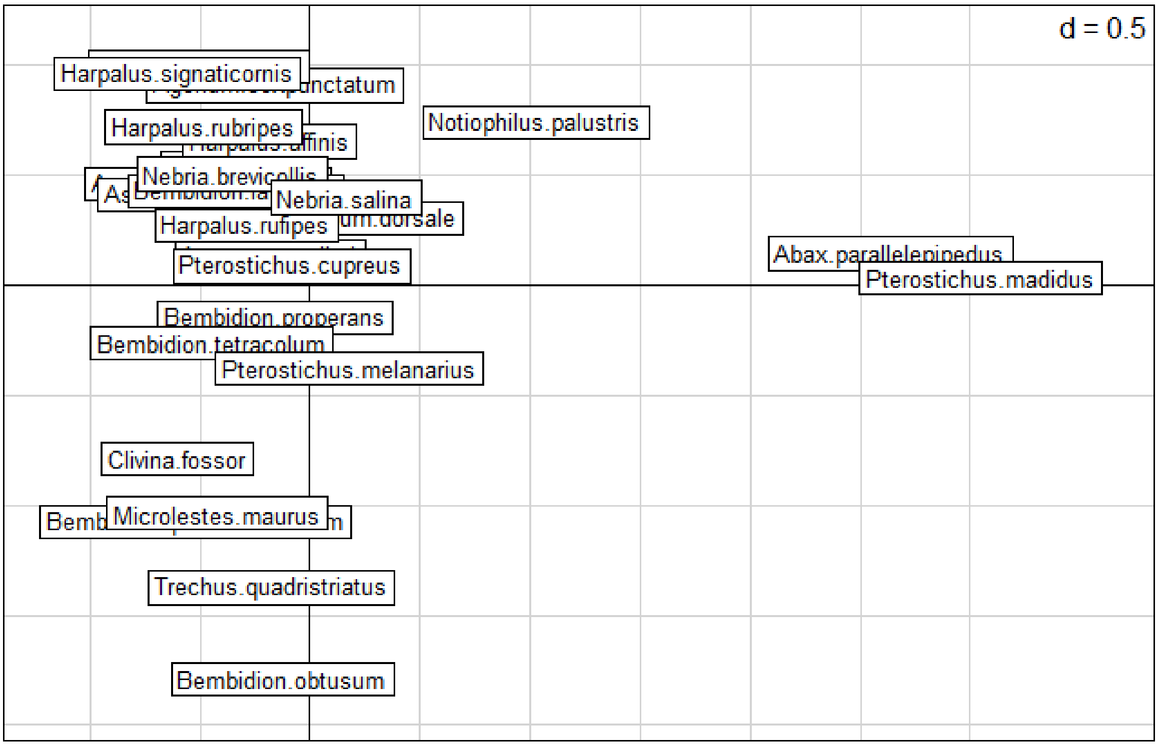


Figure 30 : Position of the species in the axes system of the CCA for late June 2020

Fuzzy FCA

The first two axes represented respectively 57.70 and 13.99% of the inertia, leading to a total of 71.69% of inertia represented. The figures 31 and 32 show the contribution of the traits to the first and second axis, respectively.

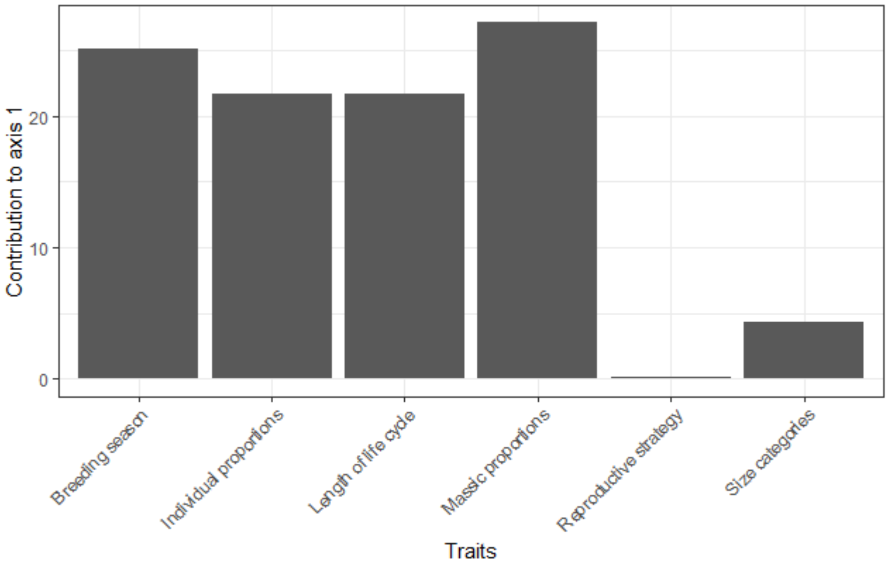


Figure 31 : Contribution of the carabid traits to the first axis of the fuzzy FCA for late June 2020

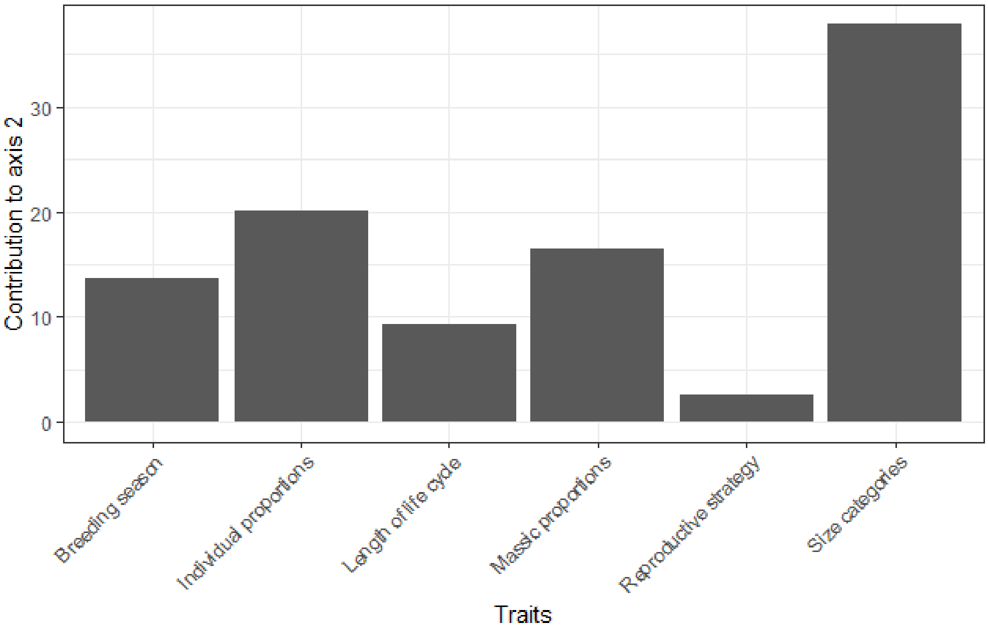


Figure 32 : Contribution of the carabid traits to the second axis of the fuzzy FCA for late June 2020

The table 9 shows the part of variability explained in each BCA.

*Table 9 : Part of inertia represented in the BCA using the listed parameter as factor and p-value of the associated Monte-Carlo test (999 repetitions) for the fuzzy FCA of late June 2020. Significant results at the p<0.05 level are indicated by **

Factor	Part of inertia (%)	p-value of Monte-Carlo test (999 repetitions)

Site	83.7	**0.001***
Modality	22.11	**0.037***
Tillage	50.97	**0.014***
Crop	54.48	**0.006***
Region	12.02	0.631
Tillage simplified	18.99	0.075
Sowing period	12.32	0.073

The figure 33 shows the correlations of the community characteristics with the axes system of the fuzzy FCA. The figures 34, 35 and 36 respectively show the position of the modality, the tillage and the sowing period in the plane formed by the first two axes of the fuzzy FCA.

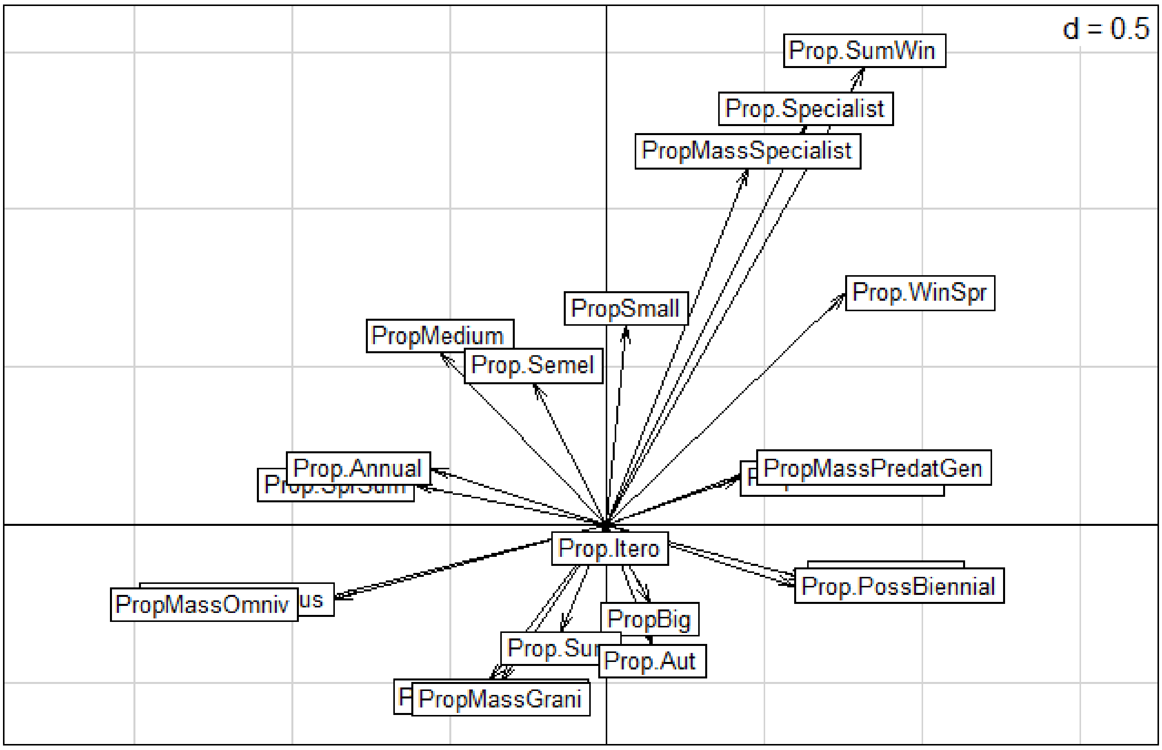


Figure 33 : Correlations of the community characteristics with the plane formed by the first two axes of the fuzzy FCA for late June 2020. For abbreviations, see Figures 11 and 20. Behind Prop.PossBiennial: Prop.SumAut; behind PropMassOmniv: Prop.Omnivorous; behind PropMassGrani: Prop.Granivorous; behind PropMassPredatGen: Prop.GenPredator

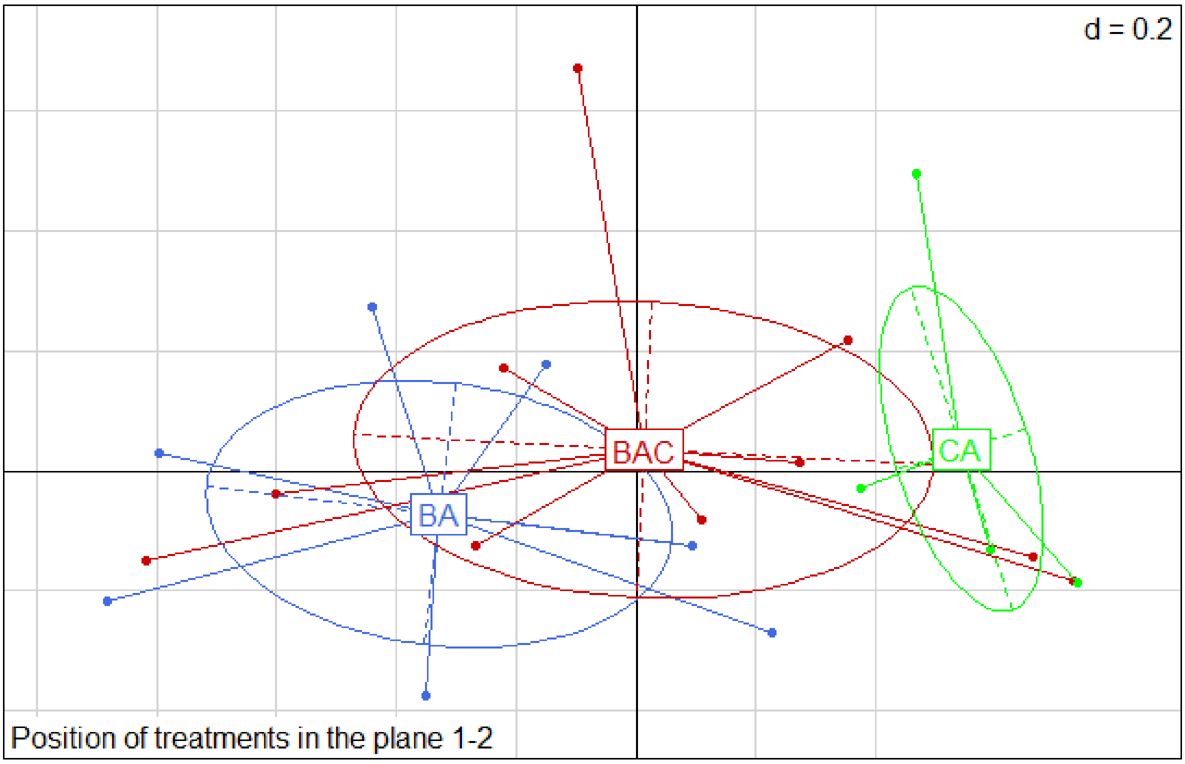


Figure 34 : Position of the modality in the plane formed by the first two axes of the fuzzy FCA for late June 2020

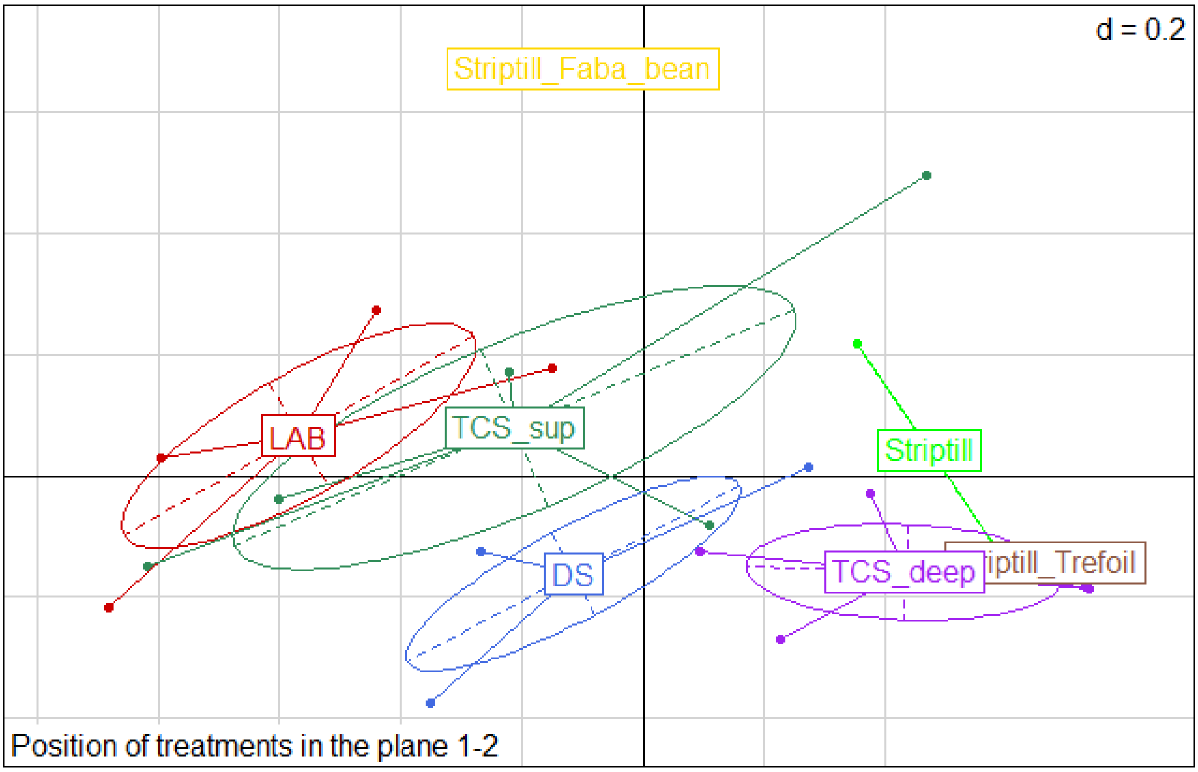


Figure 35 : Position of the tillage in the plane formed by the first two axes of the fuzzy FCA. For abbreviations, see Figure 22

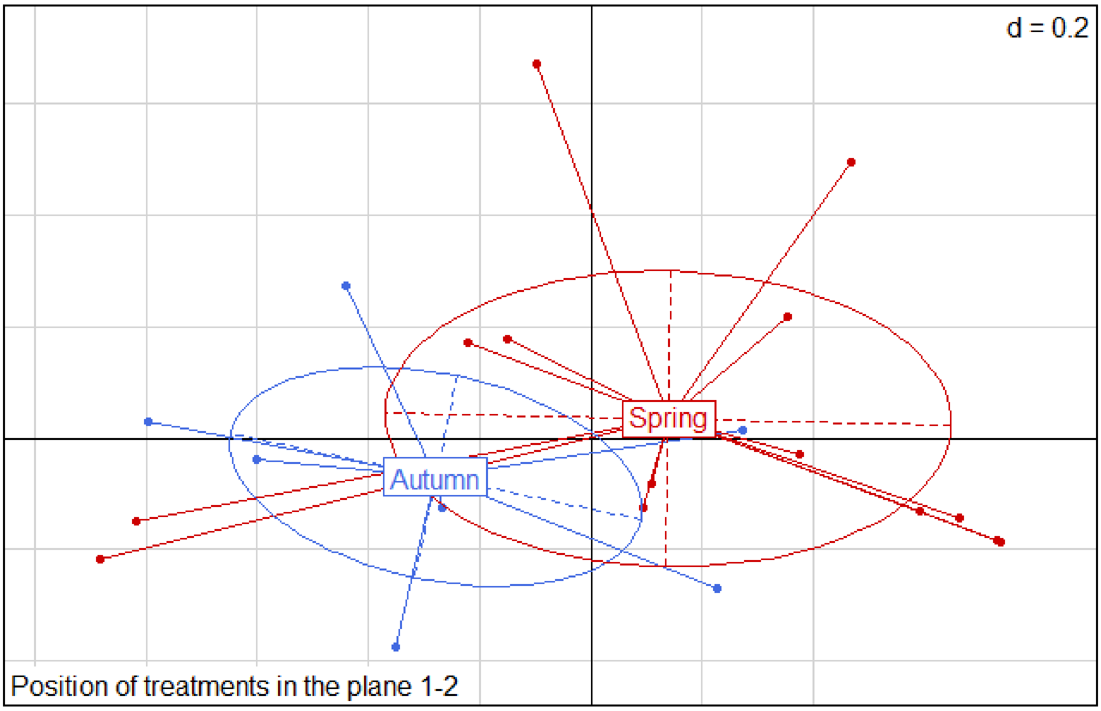


Figure 36 : Position of the sowing period in the plane formed by the first two axes of the PCA for late June 2020

2021 - Global

PCA

The first three axes of the PCA represented respectively 32.18, 18.25 and 16.07% of the inertia, leading to a total of 66.51% of the inertia represented. The correlation of the community characteristics with the plane formed by axes 1 and 2 is shown in figure 37, and the one with the plane formed by axes 2 and 3 in figure 38.

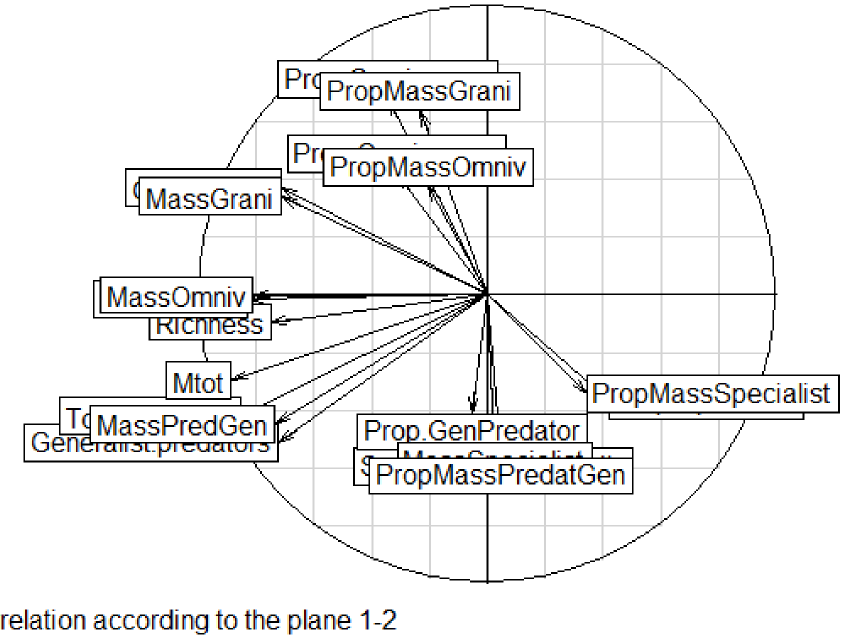


Figure 37 : Correlations of the community characteristics with the plane formed by the first two axes of the PCA for 2021. For abbreviations, see Figure 11

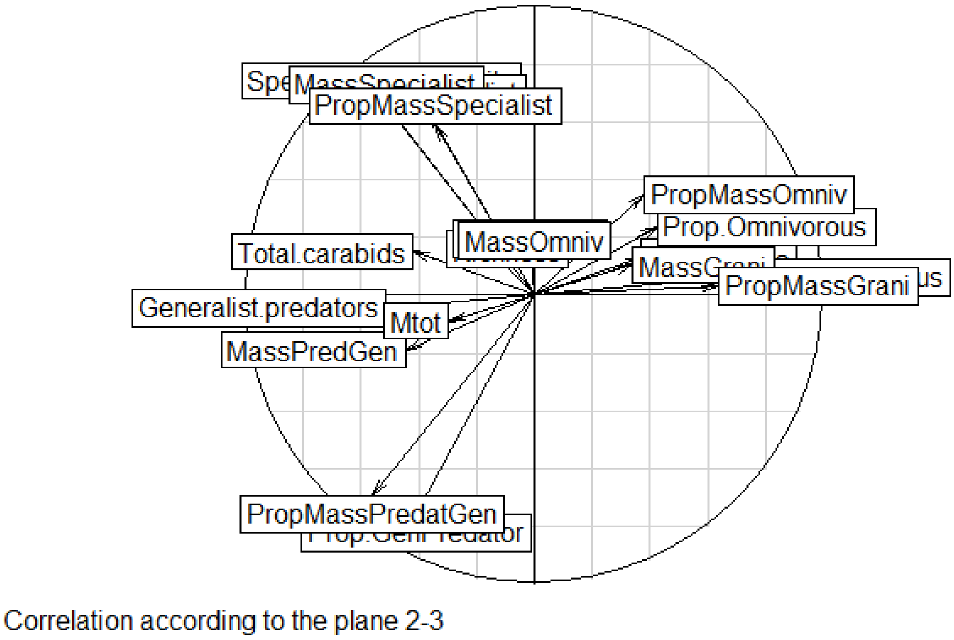


Figure 38 : Correlations of the community characteristics with the plane formed by the second and third axes of the PCA for 2021. For abbreviations, see Figure 11

The table 10 shows the part of variability represented in each BCA.

*Table 10 : Part of inertia represented in the BCA using the listed parameter as factor and p-value of the associated Monte-Carlo test (999 repetitions) for the PCA of 2021. Significant results at the p<0.05 level are indicated by **

Factor	Part of inertia (%)	p-value of Monte-Carlo test (999 repetitions)
Site	22.88	**0.001***
Modality	3.86	**0.001***
Tillage	4.49	**0.024***
Crop	19.28	**0.002***
Region	9.93	**0.001***
Tillage simplified	1.94	**0.036***
Sowing period	3.45	**0.001***
Date	11.54	**0.001***
Trap type	6.42	**0.001***

The figures 39 shows the position of the trap type in the plane formed by the first two axes of the PCA.

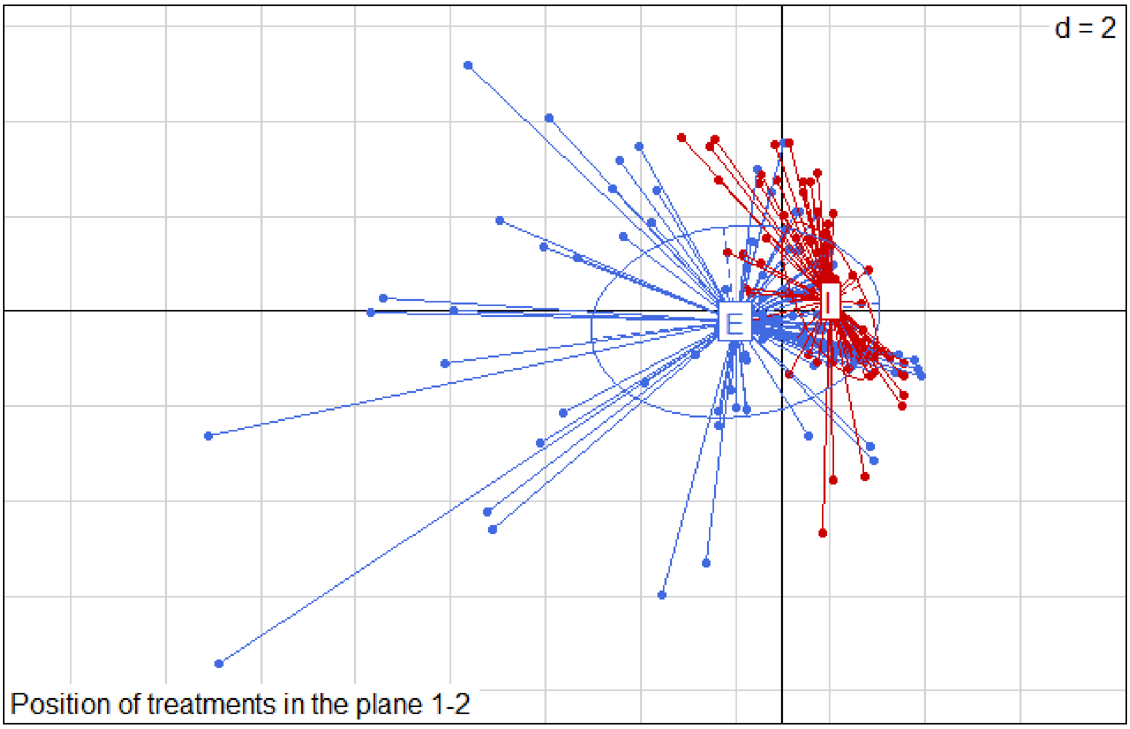


Figure 39 : Position of the trap type in the plane formed by the first two axes of the PCA for 2021. E=Exterior pitfall trap (thus pitfall trap); I = Interior pitfall trap (thus emergence trap)

The figures 40, 41 and 42, as for them, display the position of the modality, the sowing period and the simplified tillage in the plane formed by the second and the third axis of the BCA.

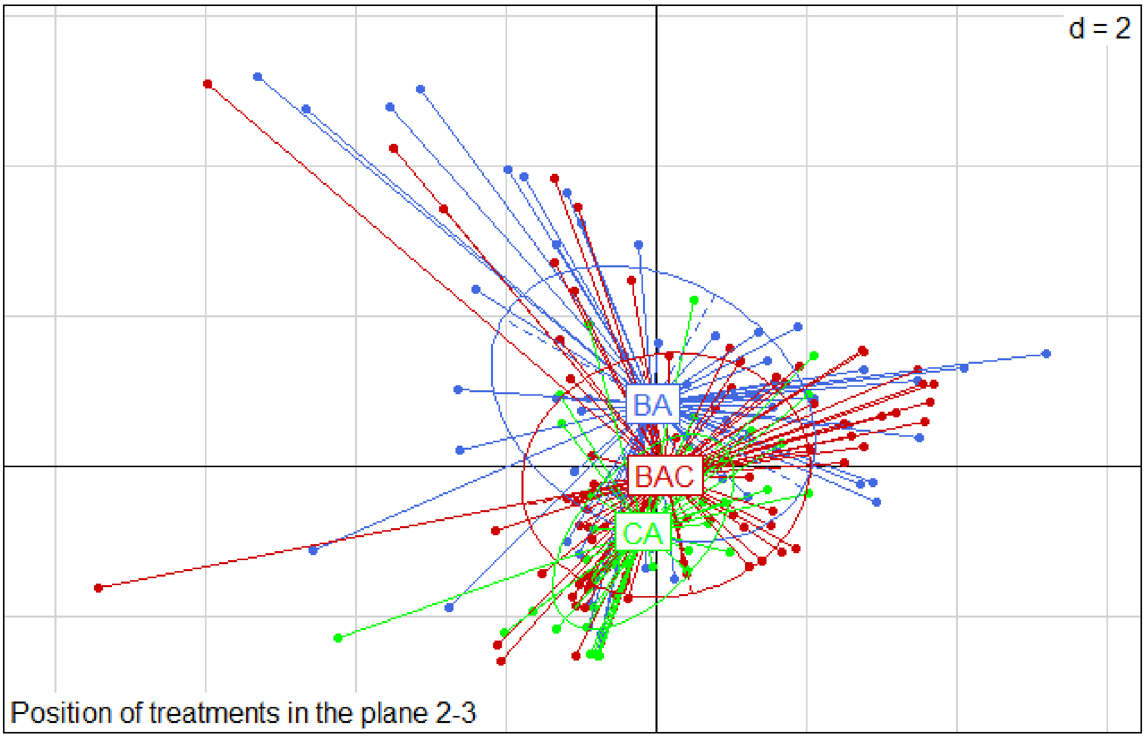


Figure 40 : Position of the modality in the plane formed by the second and third axes of the PCA for 2021

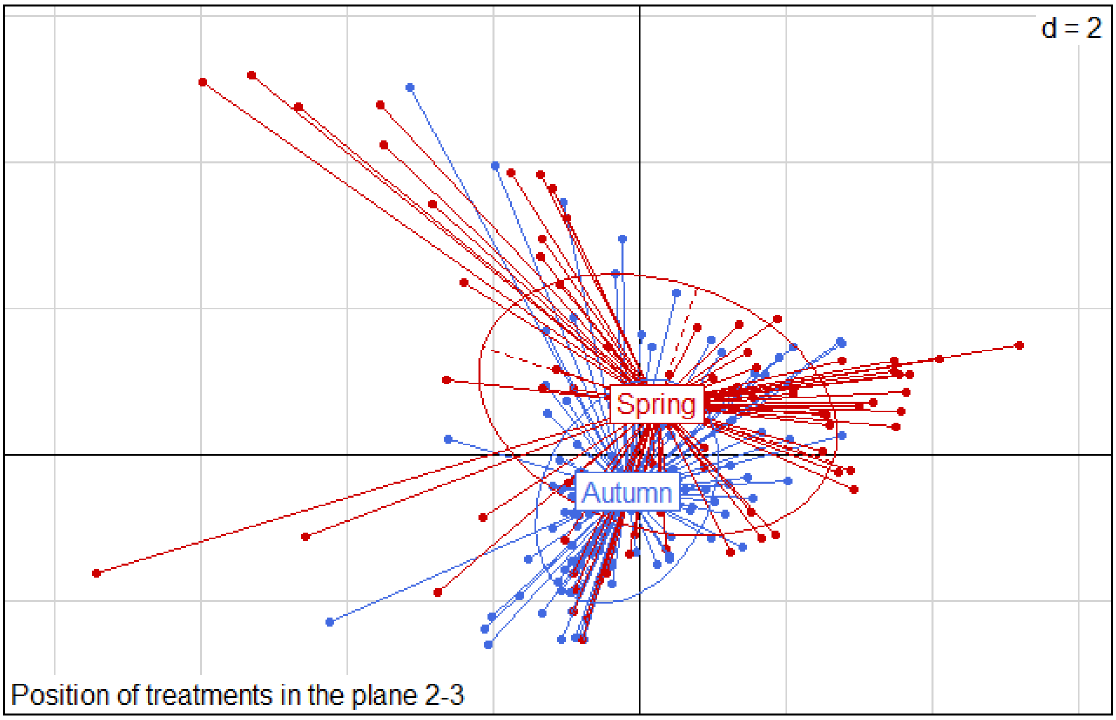


Figure 41 : Position of the sowing period in the plane formed by the second and third axes of the PCA for 2021

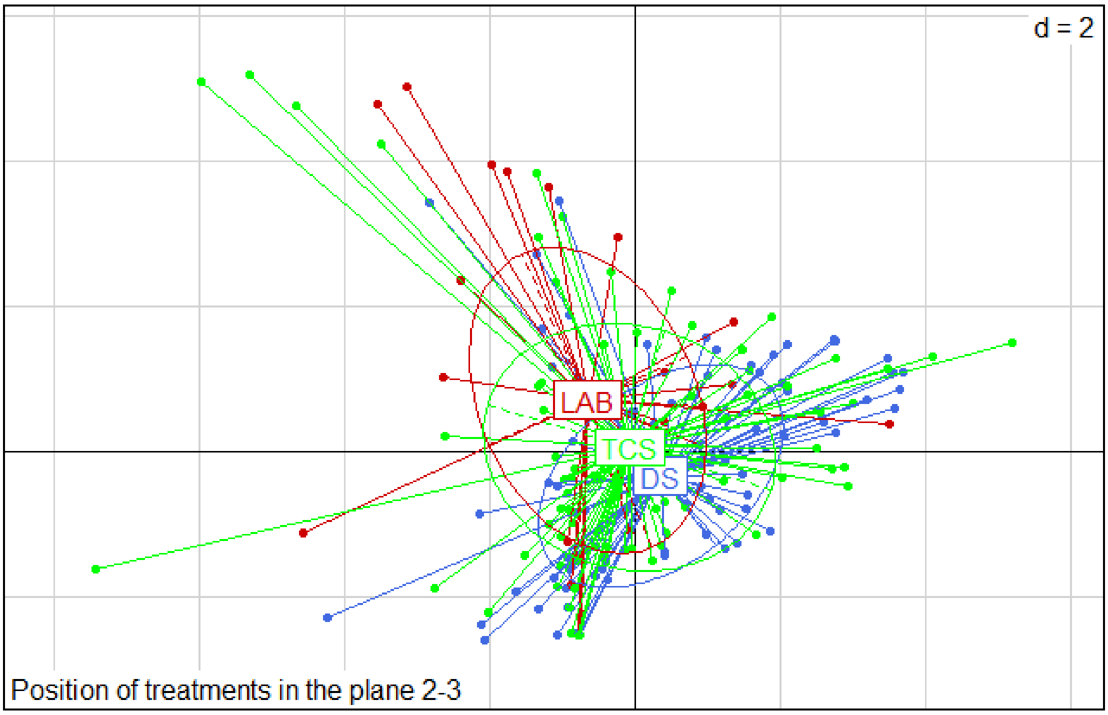


Figure 42 : Position of the simplified tillage in the plane formed by the second and third axes of the PCA for 2021. For abbreviations, see Figure 22

FCA

The first three axes of the FCA represented respectively 12.08, 9.00 and 7.41% of the inertia, leading to a total of 28.49% of the inertia represented on these axes.

The figure 43 represents the position of the species on this axes system.

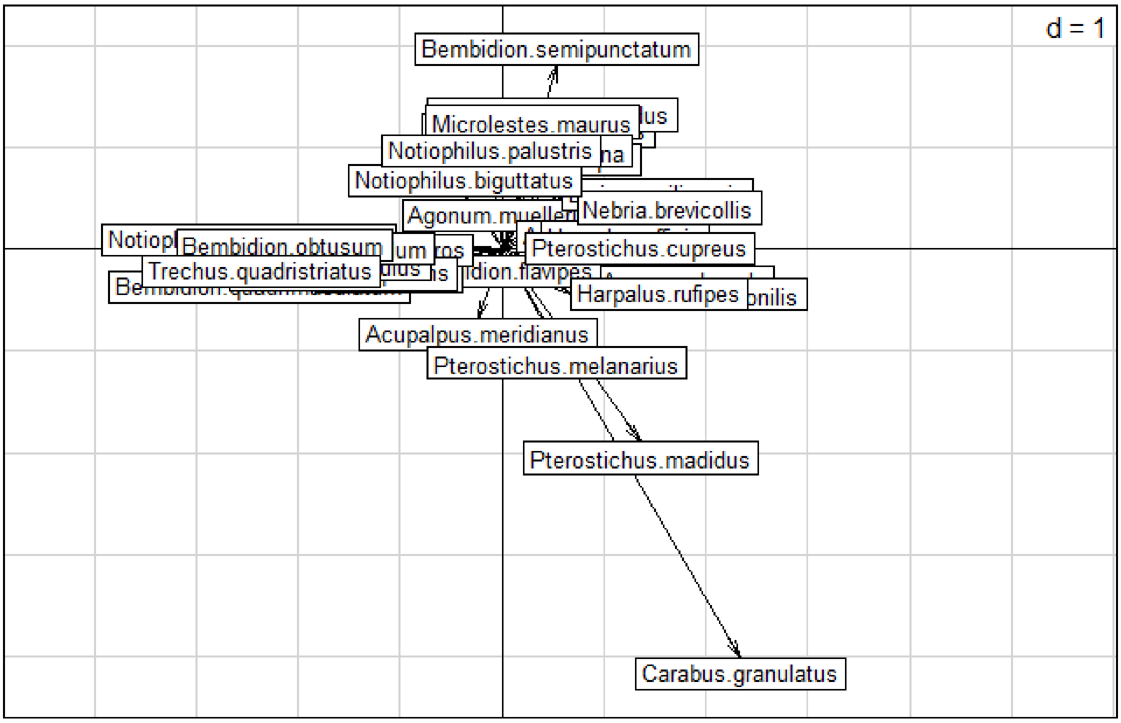


Figure 43 : Position of the species in the axes system of the FCA for 2021

CCA

40.11% of the FCA inertia was represented on the CCA, 54.68% of which on the first three axes. The figure 44 represents the correlations of the treatments with the CCA axes system, and the figure 45 shows the position of the species in the same axes system.

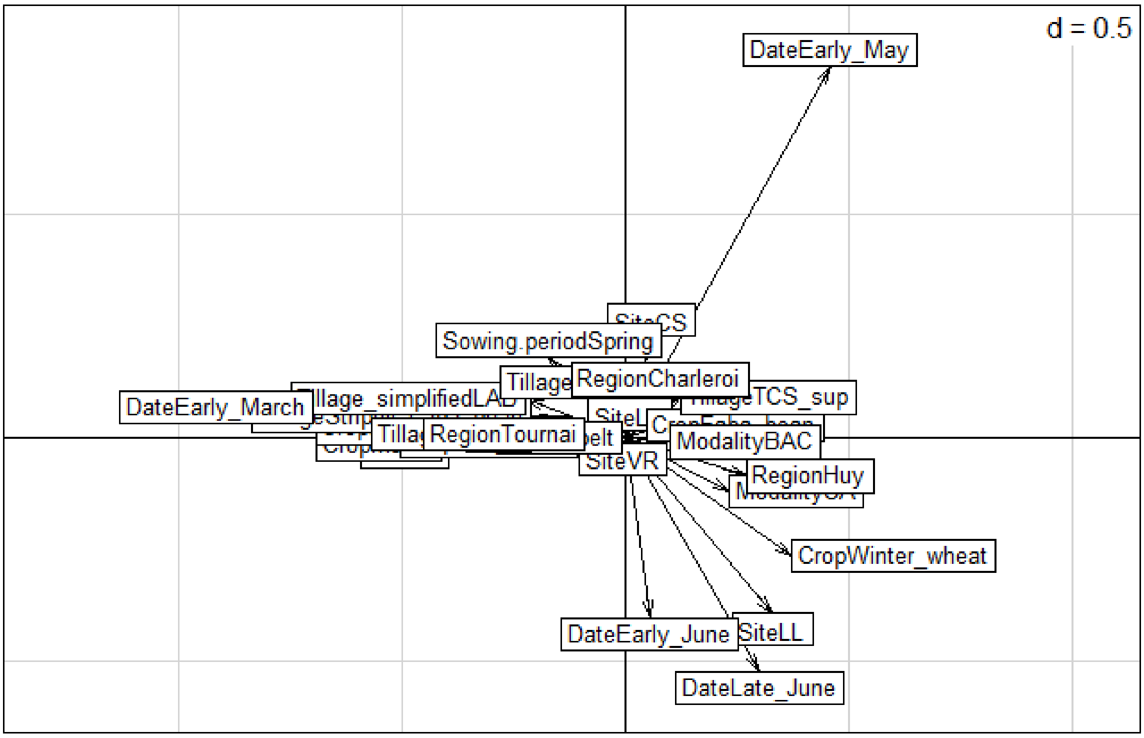


Figure 44 : Correlations of the treatments with the axes system of the CCA for 2021

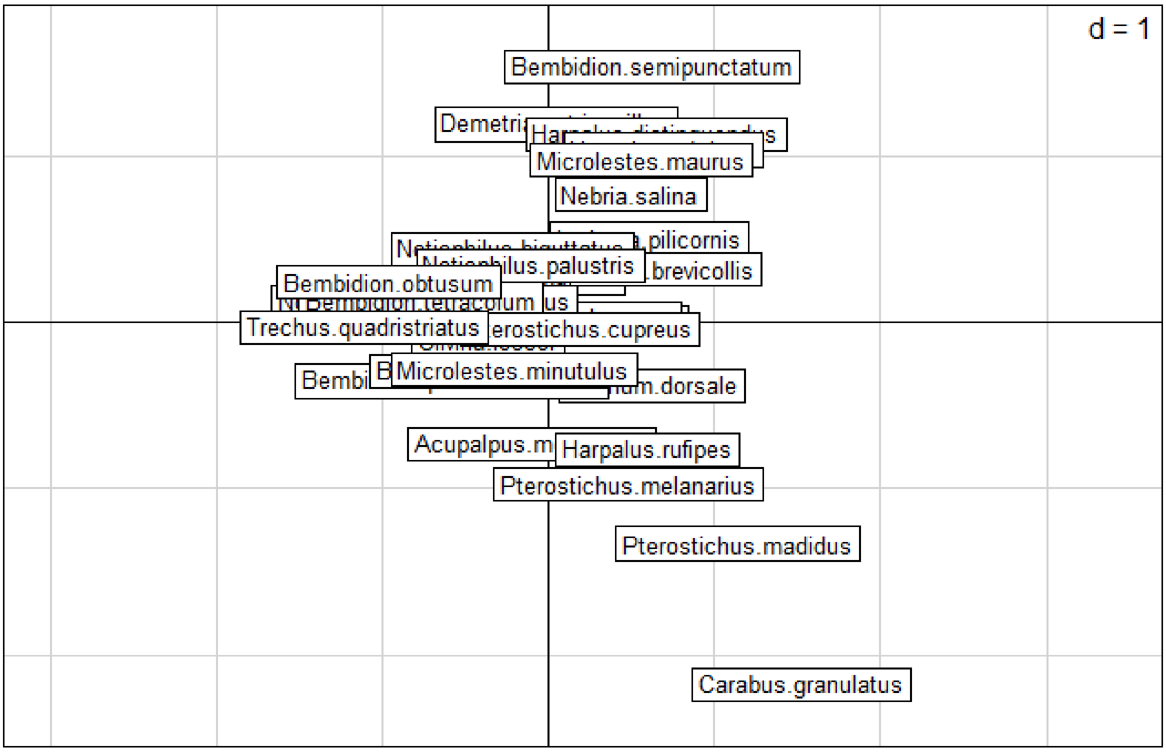


Figure 45 : Position of the species in the axes system of the CCA for 2021

Fuzzy FCA

The first two axes represented respectively 30.15 and 17.69% of the inertia, leading to a total of 47.84% of inertia represented. The figures 46 and 47 show the contribution of the traits to the first and second axis, respectively.

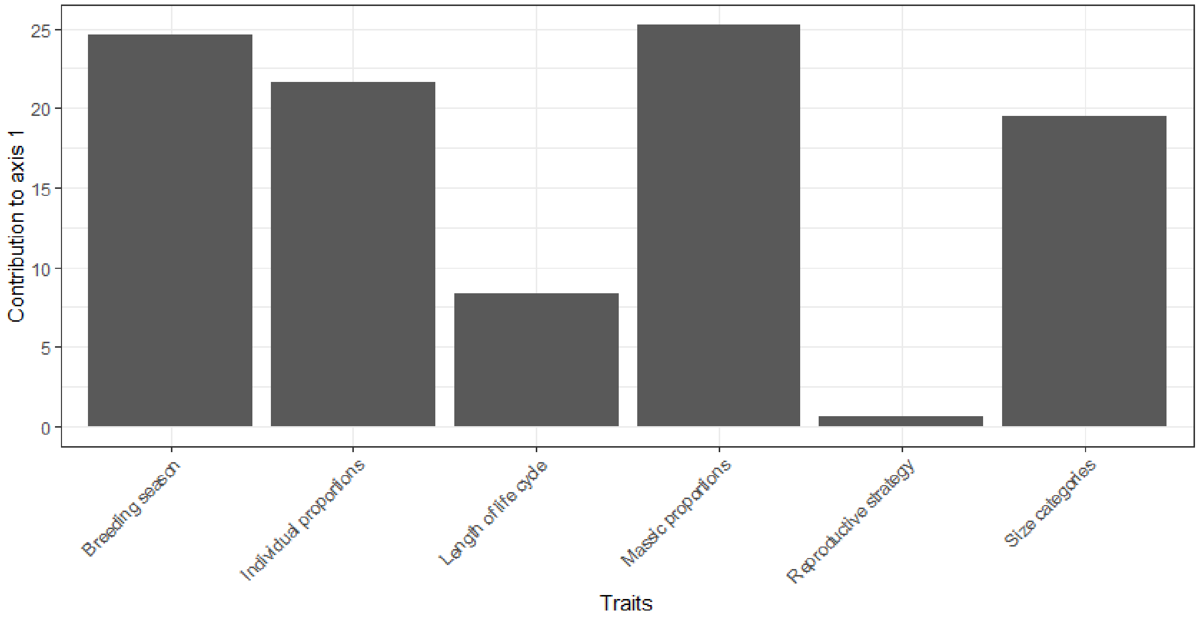


Figure 46 : Contribution of the carabid traits to the first axis of the fuzzy FCA for 2021

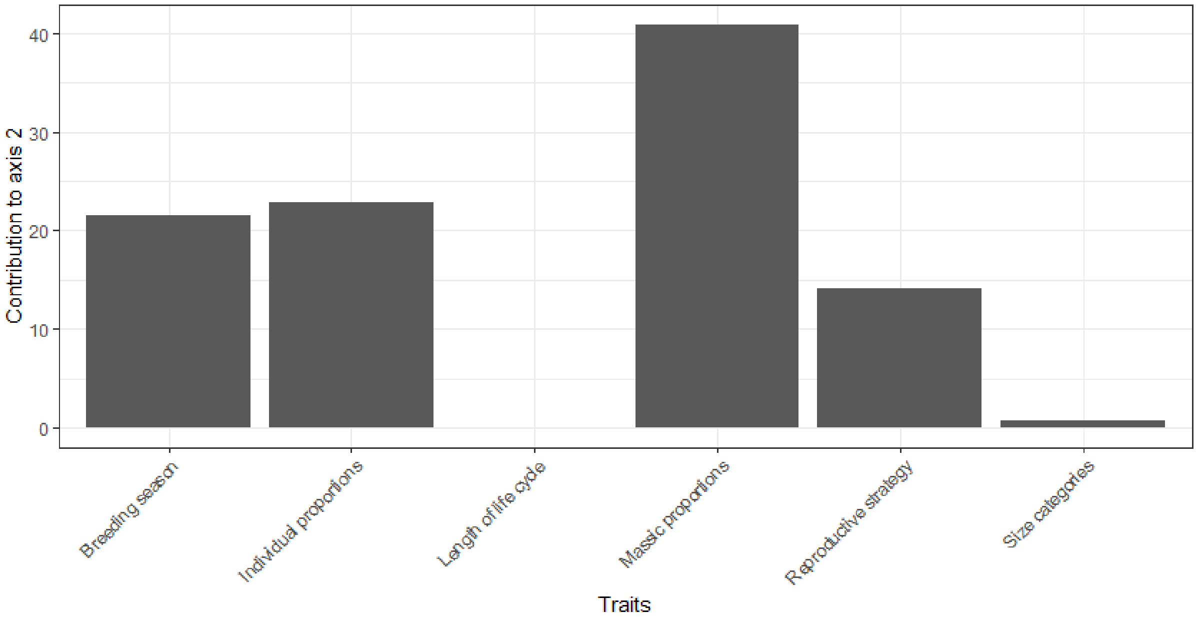


Figure 47 : Contribution of the carabid traits to the second axis of the fuzzy FCA for 2021

The table 11 shows the part of variability explained in each BCA.

*Table 11 : Part of inertia represented in the BCA using the listed parameter as factor and p-value of the associated Monte-Carlo test (999 repetitions) for the fuzzy FCA of 2021. Significant results at the p<0.05 level are indicated by **

Factor	Part of inertia (%)	p-value of Monte-Carlo test (999 repetitions)
Site	20.08	**0.001***
Modality	2.56	**0.001***
Tillage	5.95	**0.001***
Crop	17.11	**0.001***
Region	6.22	**0.001***
Tillage simplified	2.01	**0.029***
Sowing period	2.59	**0.001***
Date	23.38	**0.001***
Trap type	1.16	**0.032***

The figure 48 shows the correlations of the community characteristics with the axes system of the fuzzy FCA. The figures 49, 50 and 51 respectively show the position of the sampling date, the sowing period and the modality in the plane formed by the first two axes of the fuzzy FCA.

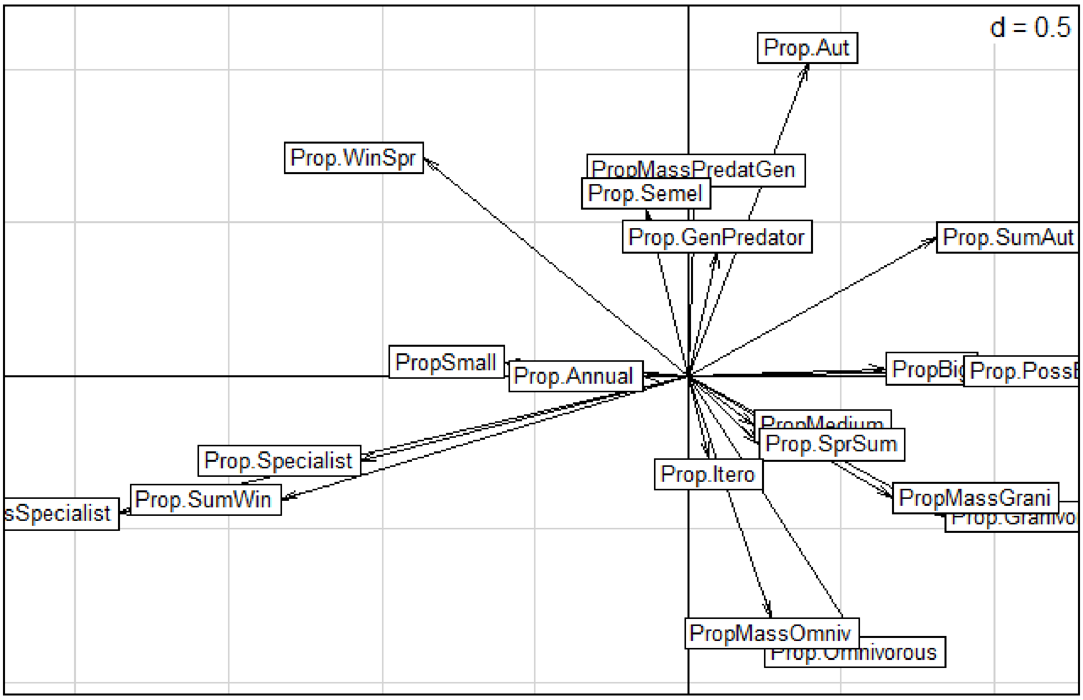


Figure 48 : Correlations of the community characteristics with the plane formed by the first two axes of the fuzzy FCA for 2021. For abbreviations, see Figures 11 and 20. Characteristic at the extreme left of the figure: PropMassSpecialist. Characteristics at the extreme right of the figure: Prop.PossBiennial and Prop.Granivorous

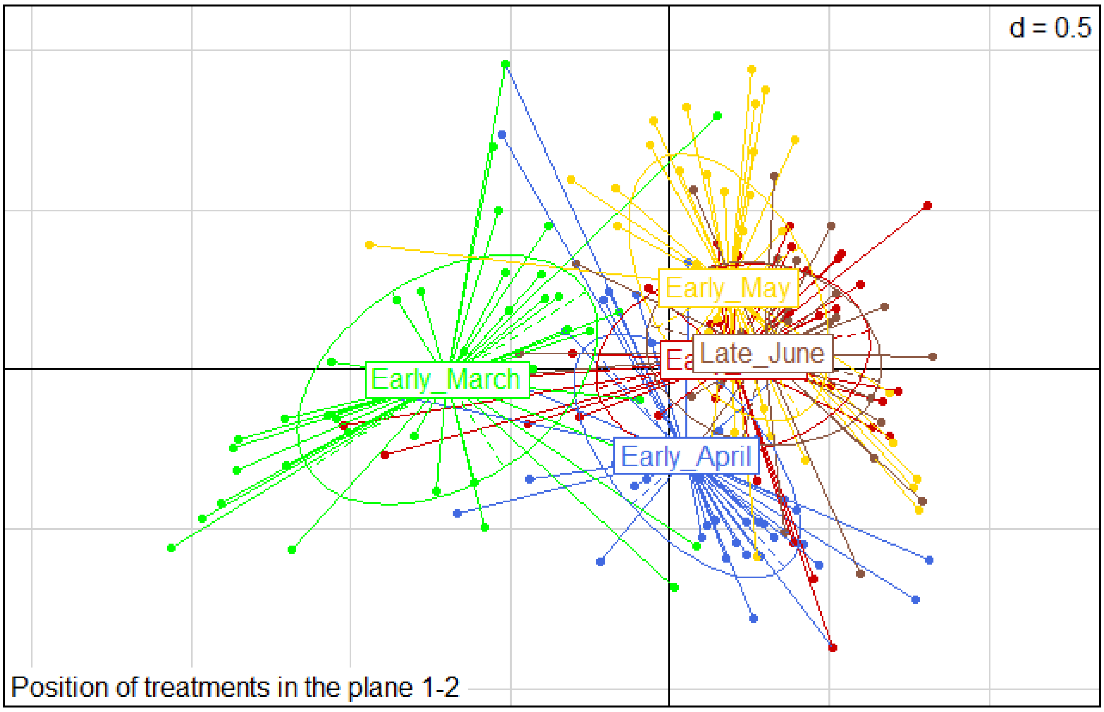


Figure 49 : Position of the sampling date in the plane formed by the first two axes of the fuzzy FCA for 2021

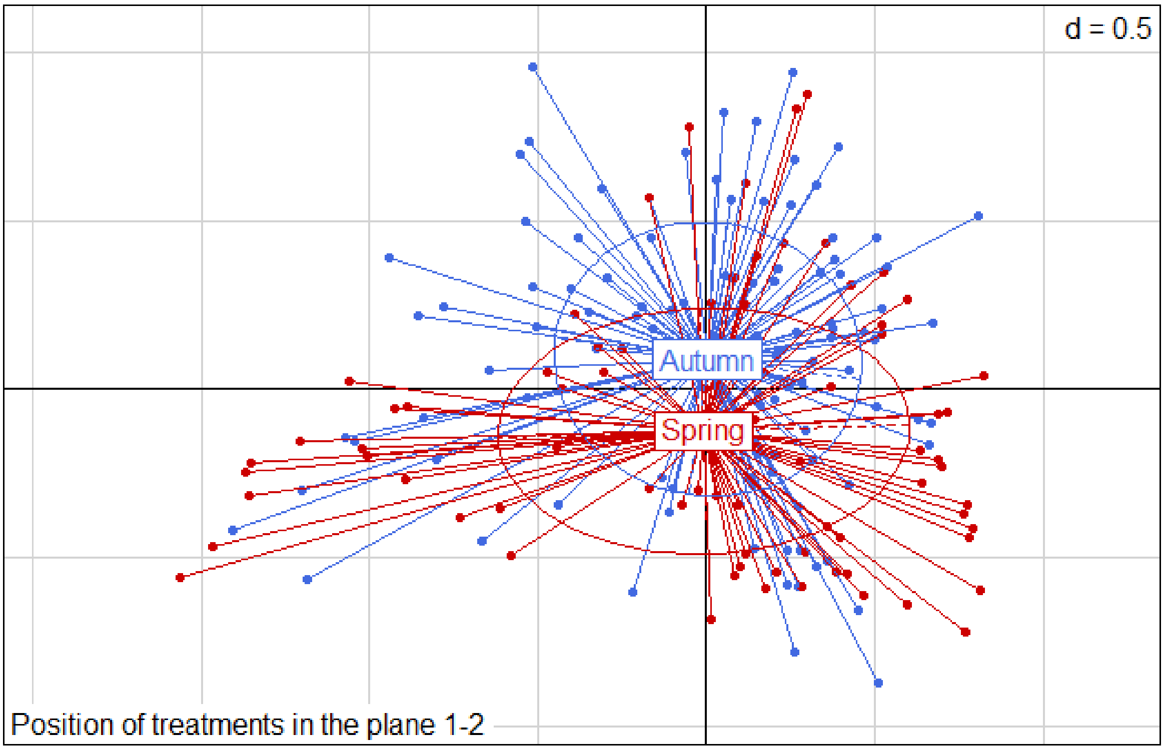


Figure 50 : Position of the sowing period in the plane formed by the first two axes of the fuzzy FCA for 2021

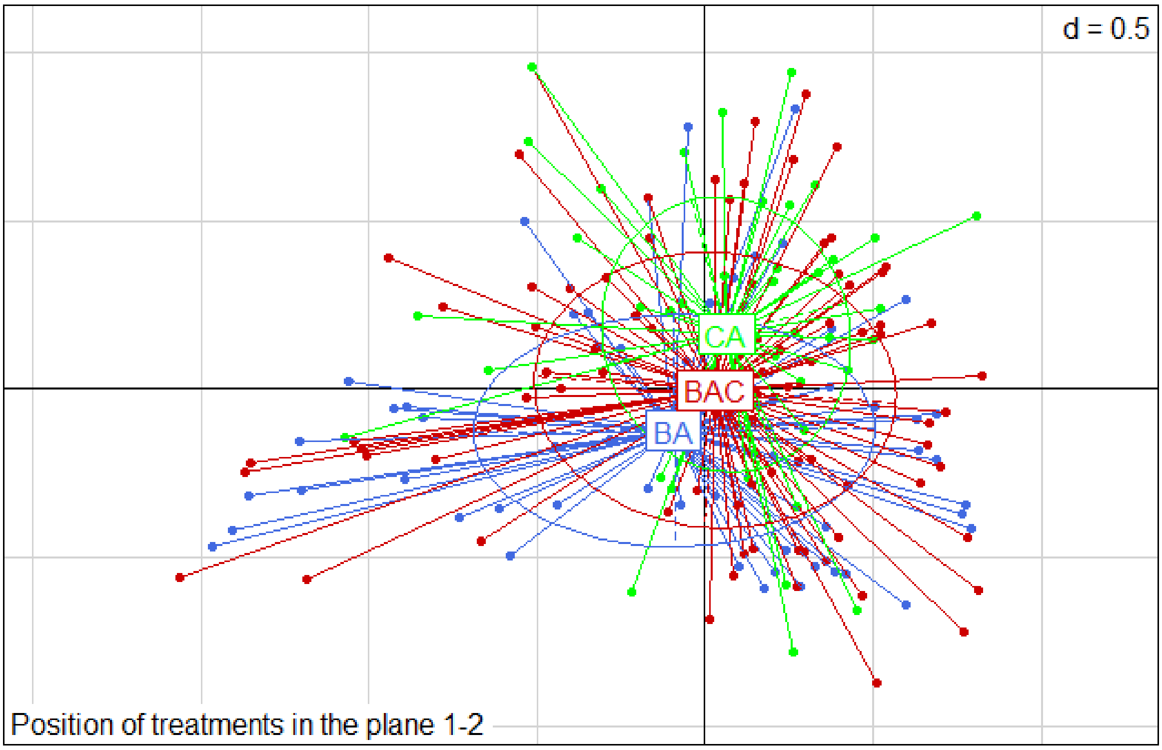


Figure 51 : Position of the modality in the plane formed by the first two axes of the fuzzy FCA for 2021

2021 – Early June and pitfall traps only

PCA

The first three axes of the PCA represented respectively 34.46, 26.30 and 18.02% of the inertia, leading to a total of 78.78% of the inertia represented. The correlation of the community characteristics with the plane formed by axes 1 and 3 is shown in figure 52.

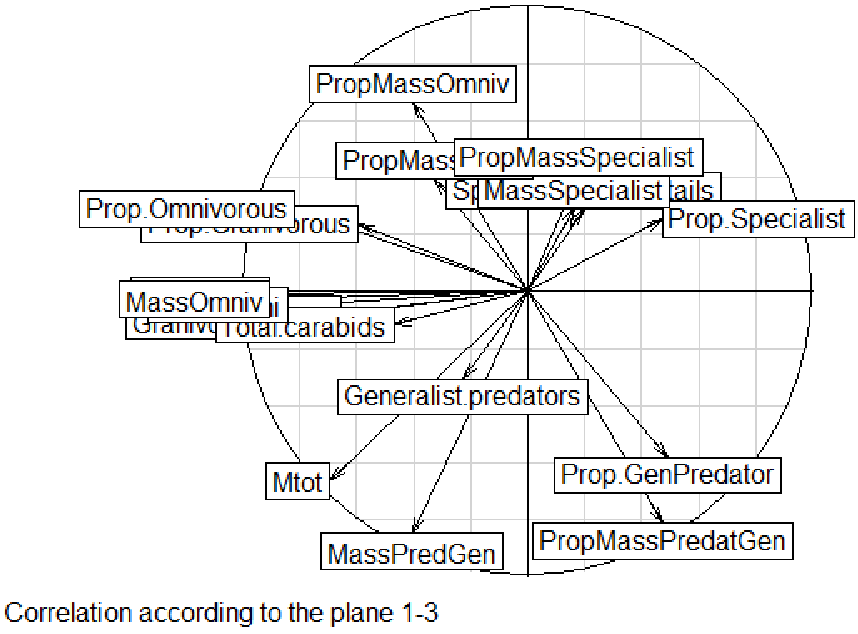


Figure 52 : Correlations of the community characteristics with the plane formed by the first and third axes of the PCA for early June 2021. For abbreviations, see Figure 11

The table 12 shows the part of variability represented in each BCA.

*Table 12 : Part of inertia represented in the BCA using the listed parameter as factor and p-value of the associated Monte-Carlo test (999 repetitions) for the PCA of early June 2021 (Pitfalls only) . Significant results at the p<0.05 level are indicated by **

Factor	Part of inertia (%)	p-value of Monte-Carlo test (999 repetitions)
Site	83.49	**0.001***
Modality	17.80	**0.046***
Tillage	16.87	0.760
Crop	62.87	**0.001***
Region	40.81	**0.001***
Tillage simplified	9.20	0.558
Sowing period	11.38	**0.047***

The figures 53, 54, 55 and 56 respectively show the position of the modality, the region, the sowing period and the crop in the plane formed by the first two axes of the PCA.

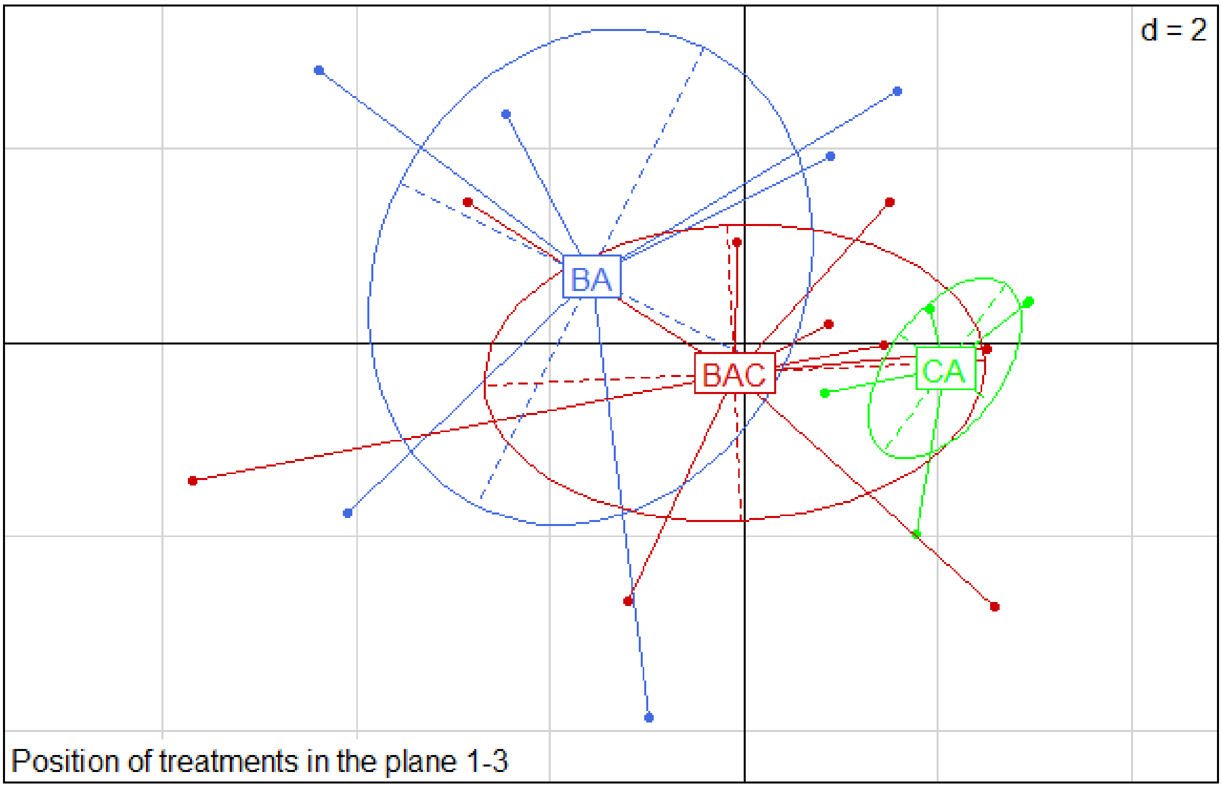


Figure 53 : Position of the modality in the plane formed by the first and third axes of the PCA for early June 2021 (pitfalls only)

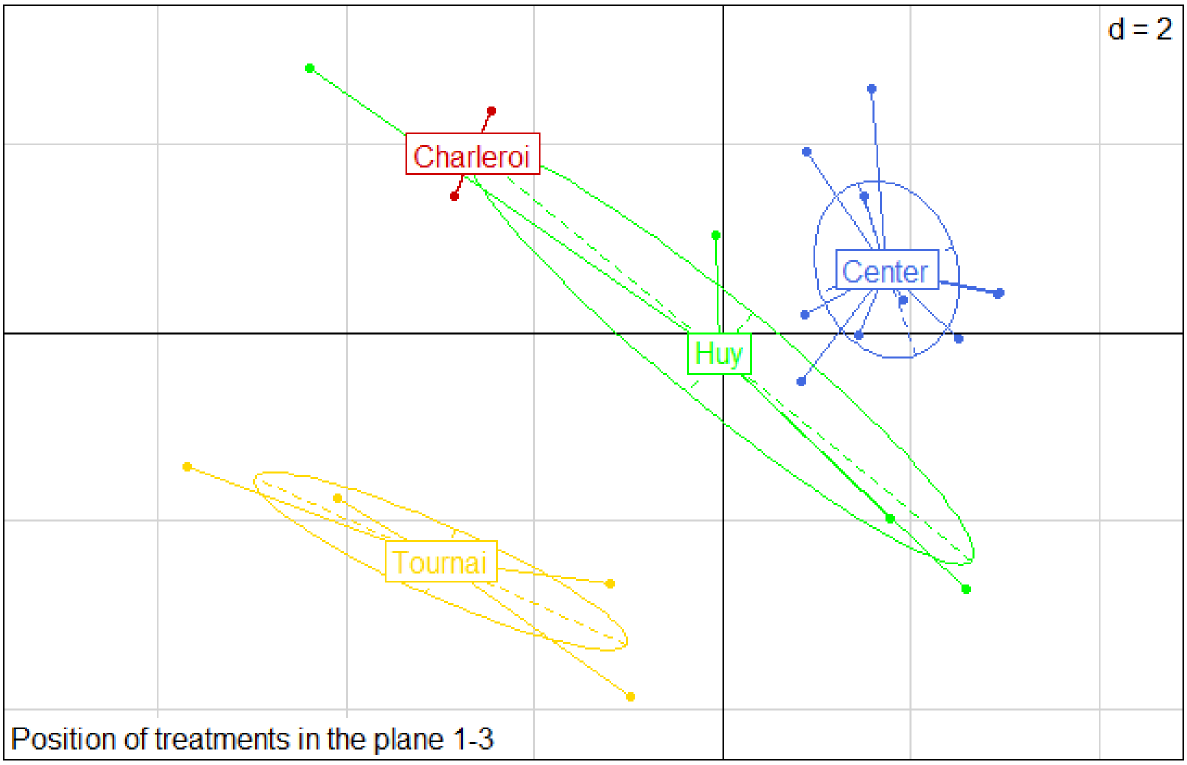


Figure 54 : Position of the region in the plane formed by the first and third axes of the PCA for early June 2021 (pitfalls only)

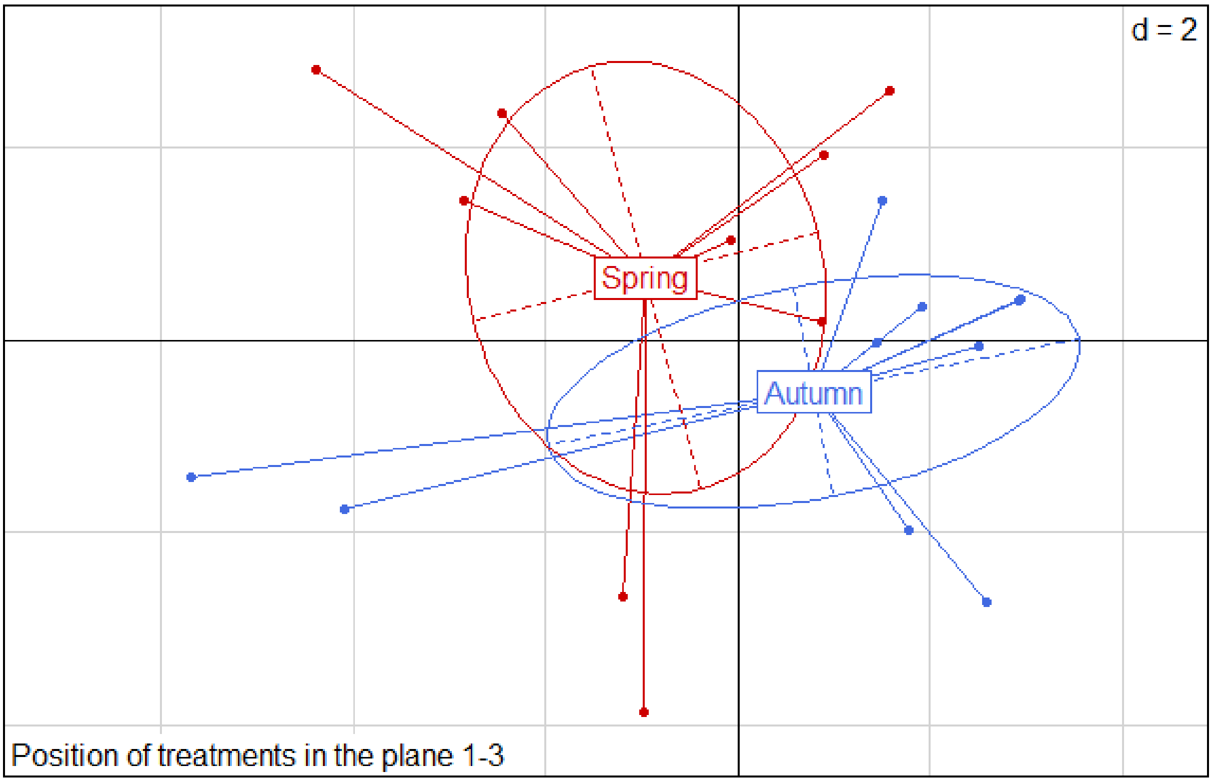


Figure 55 : Position of the sowing period in the plane formed by the first and third axes of the PCA for early June 2021 (pitfalls only)

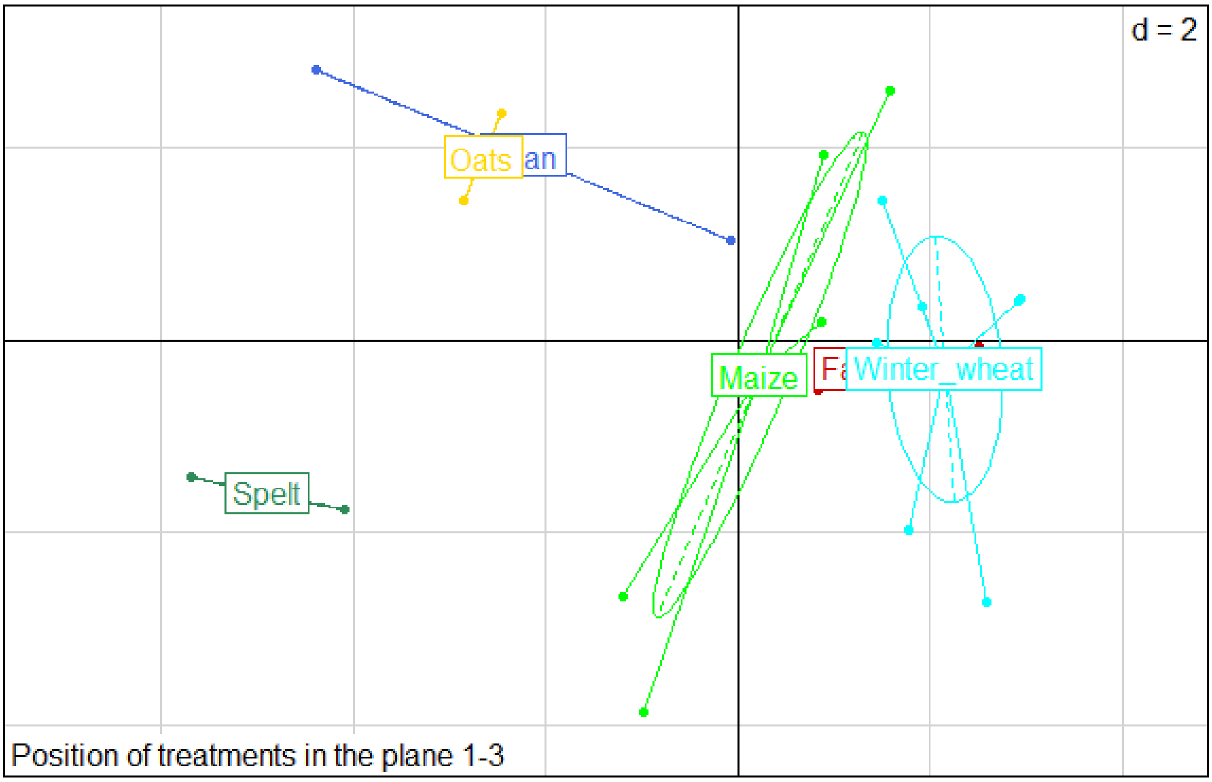


Figure 56 : Position of the crop in the plane formed by the first and third axes of the PCA for early June 2021 (pitfalls only)

FCA

The first three axes of the FCA represented respectively 29.73, 18.54 and 12.90% of the inertia, leading to a total of 61.16% of the inertia represented on these axes.

The figure 57 represents the position of the species on this axes system.

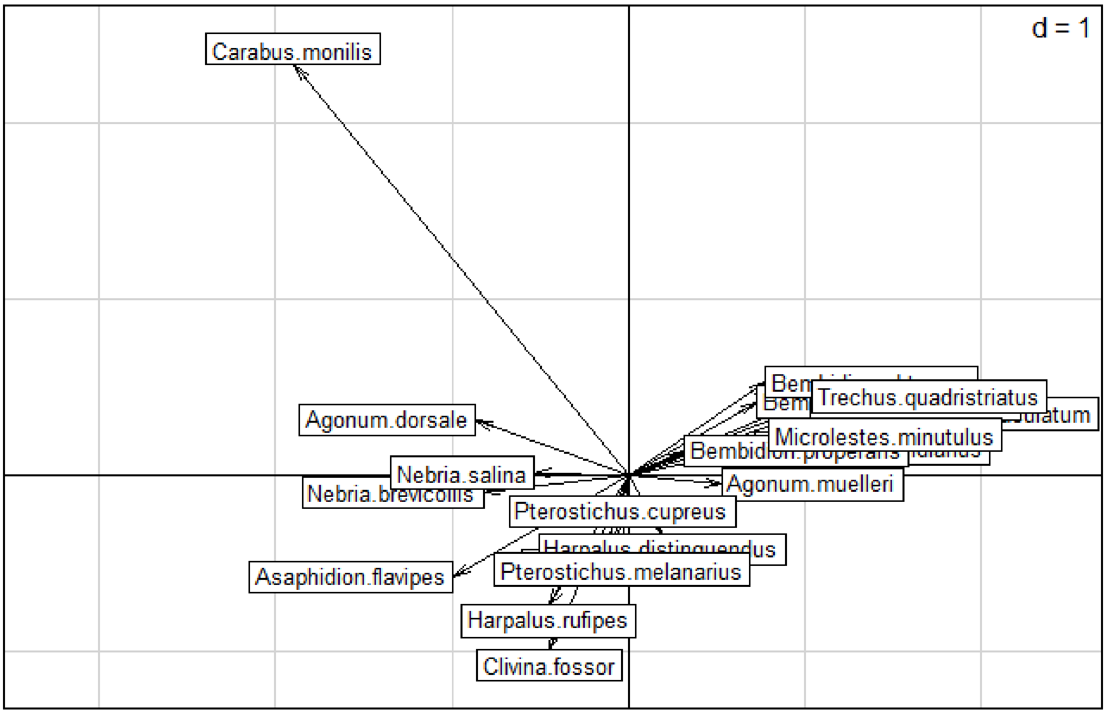


Figure 57 : Position of the species in the axes system of the FCA for early June 2021 (pitfalls only)

CCA

91.31% of the FCA inertia was represented on the CCA, 64.81% of which on the first three axes. The figure 58 represents the correlations of the treatments with the CCA axes system, and the figure 59 shows the position of the species in the same axes system.

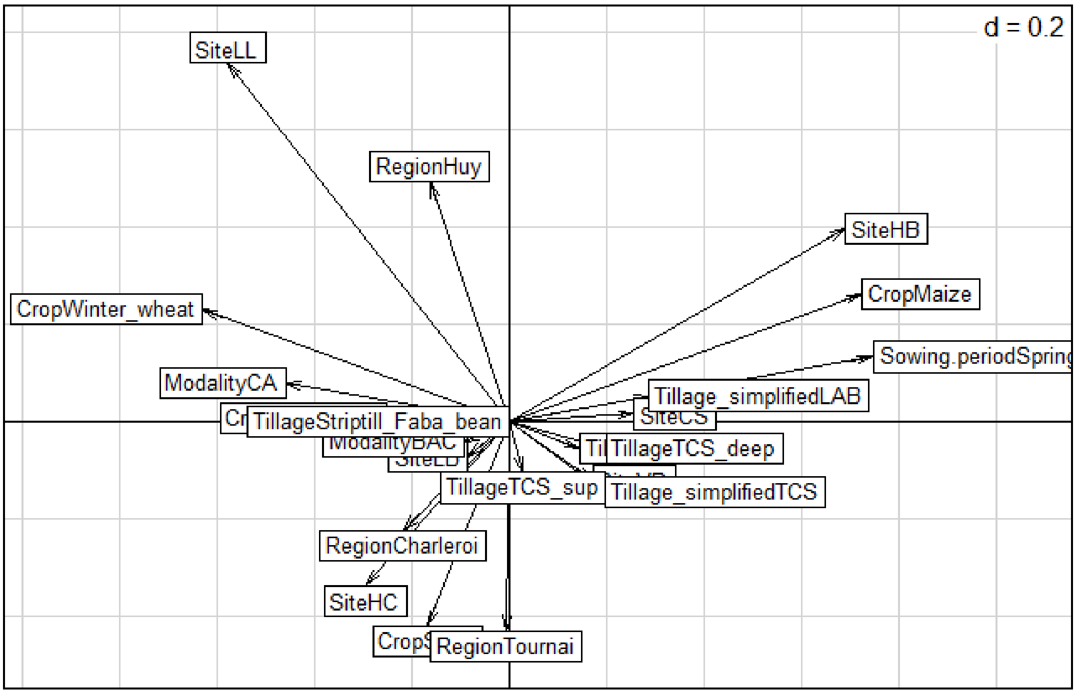


Figure 58 : Correlations of the treatments with the axes system of the CCA for early June 2021 (pitfalls only)

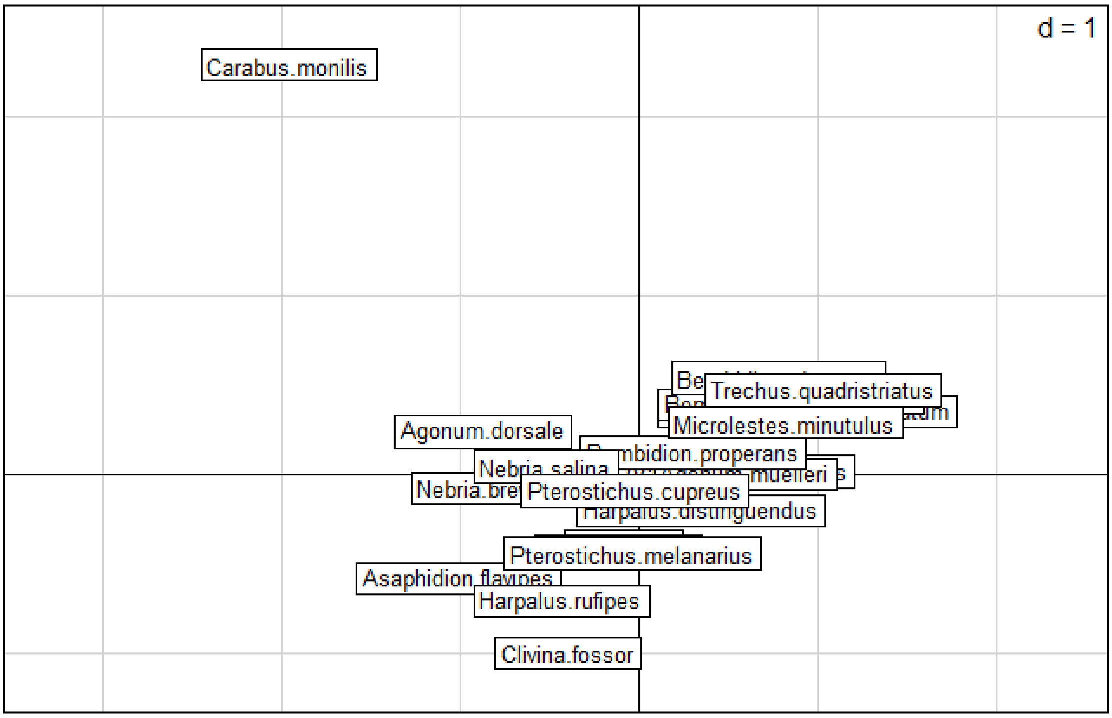


Figure 59 : Position of the species in the axes system of the CCA for early June 2021 (pitfalls only)

Effects of emergence traps

The table 13 displays the p-values of the paired t-tests on the trap type for each sampling date and each parameter tested. The *a priori* hypothesis of each parameter is indicated in brackets.

*Table 13 : p-values of the tests (paired t.tests with a priori hypotheses) on the effect of the trap type on the tested parameters for each sampling period, and proportion of significative (p<0.05) results. Pit = Pitfall trap; Em = Emergence trap. Significant results at the p<0.05 level are indicated by **

Sampling date	Mean individual mass(g) (Pit > Em)	Number of individuals (Pit > Em)	Proportion of small individuals (Pit < Em)	Proportion of big individuals (Pit > Em)	Proportion of granivorous (Pit < Em)	Proportion of generalist predators (Pit > Em)
Early March	0.286	**0.010***	0.092	0.195	NA (too few catches)	0.915
Early April	**0.002***	**$1.99*10^{-6}$***	0.289	0.110	0.553	0.9969
Early May	**$6.87*10^{-6}$***	**$2.48*10^{-6}$***	**0.001***	**$2*10^{-4}$***	0.104	0.377
Early June	**0.023***	**$6.61*10^{-5}$***	0.229	**0.004***	0.961	0.120
Late June	**0.003***	**$6*10^{-4}$***	**0.033***	**0.0215***	0.661	0.061
Proportion of significant ($p < 0.05$) results	4/5	5/5	2/5	3/5	0/4	0/5

The figures 60 to 65 show, for early June, the comparison between the pitfall and the emergence trap regarding, respectively, the mean individual mass, the number of individuals, the proportion of small individuals, the proportion of big ones, the proportion of granivorous ones and of generalist predators. The graphs referring to the other sampling periods can be found in the appendix.

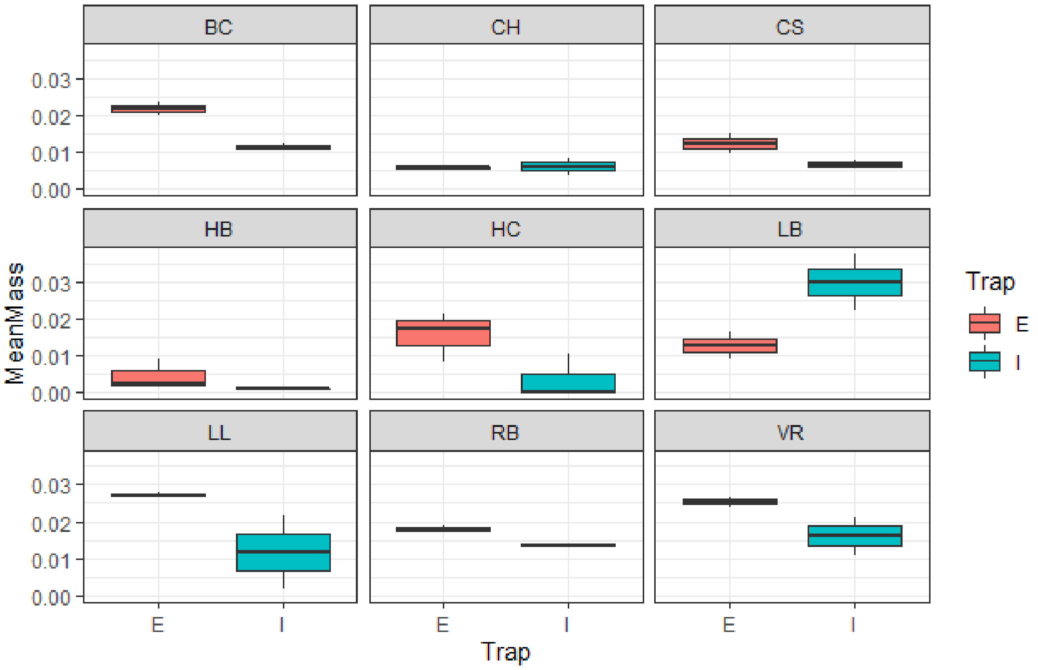


Figure 60 : Mean individual mass of the carabids caught in exterior pitfall traps (E), thus pitfall traps, and interior pitfall traps (I), thus emergence traps, in early June 2021

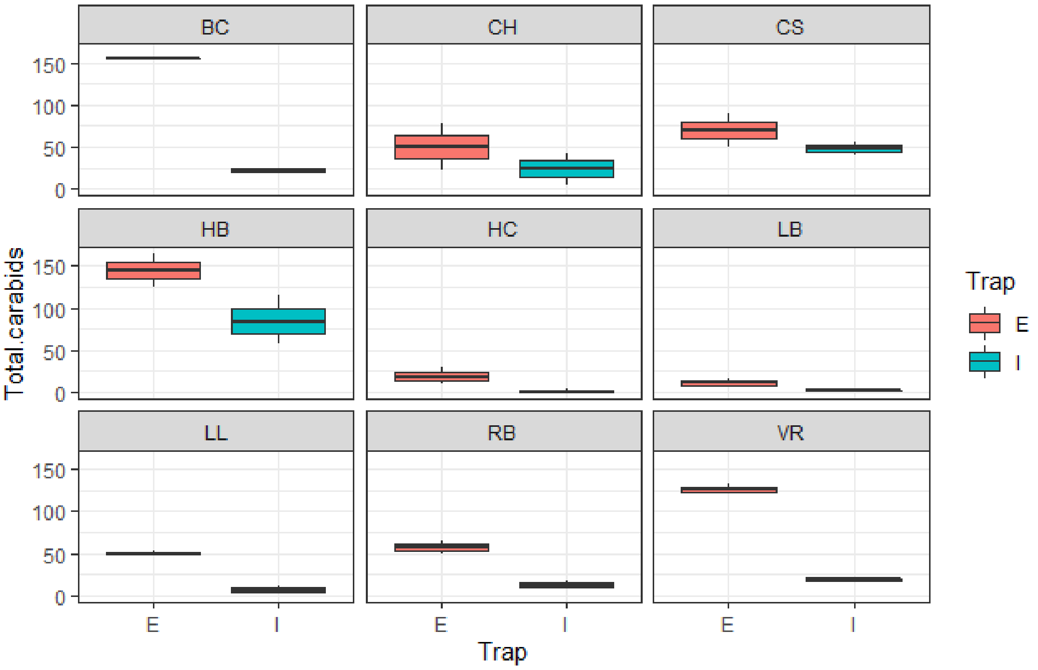


Figure 61 : Total number of carabids caught in exterior pitfall traps (E), thus pitfall traps, and interior pitfall traps (I), thus emergence traps, in early June 2021

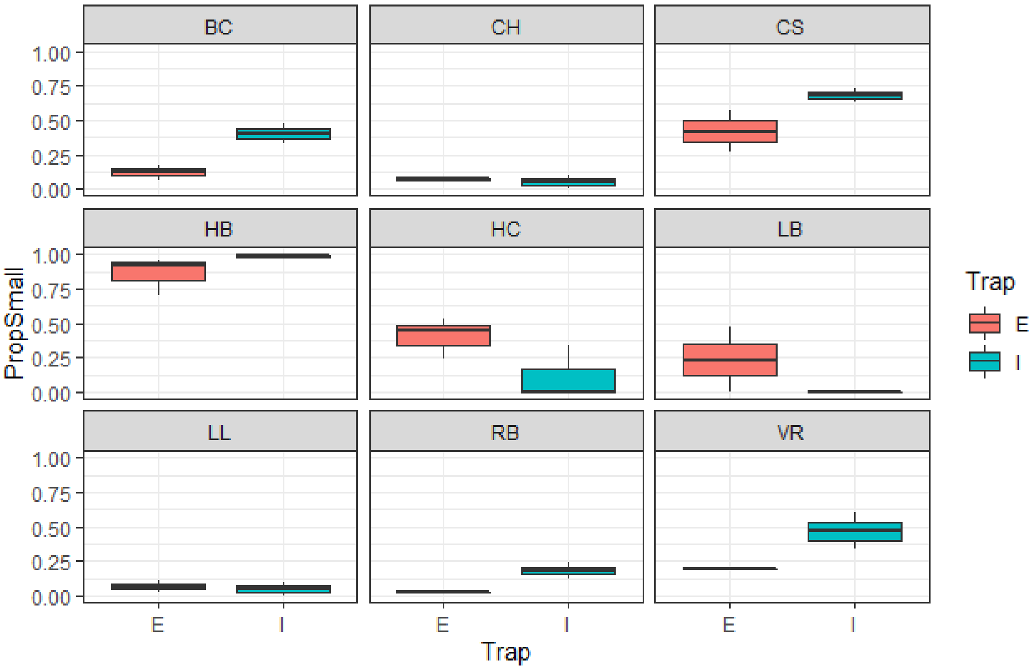


Figure 62 : Proportion of small individuals caught in exterior pitfall traps (E), thus pitfall traps, and interior pitfall traps (I), thus emergence traps, in early June 2021

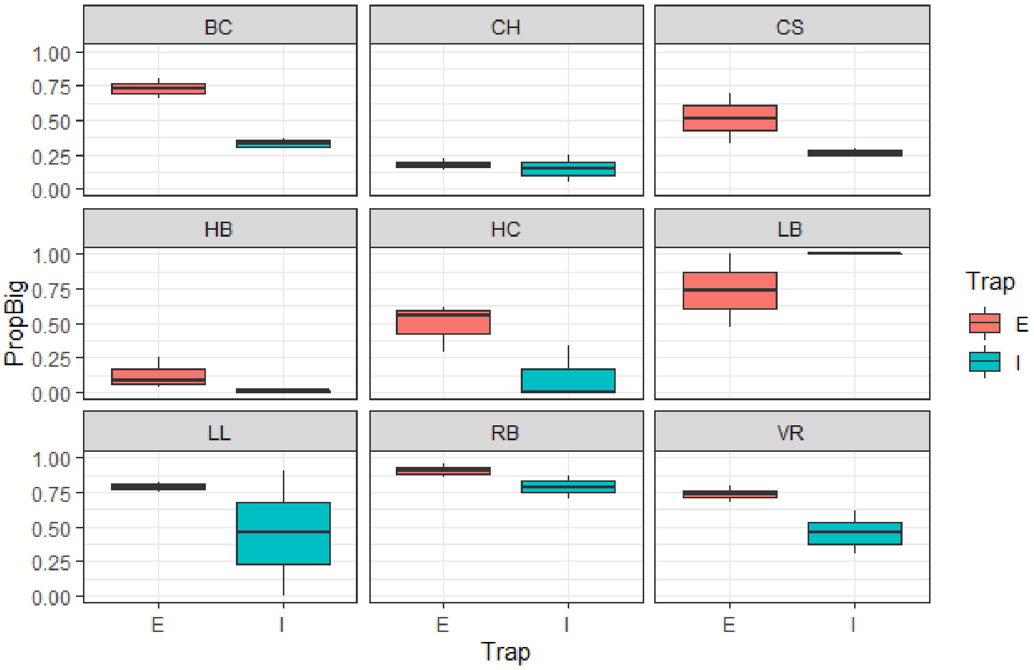


Figure 63 : Proportion of big individuals caught in exterior pitfall traps (E), thus pitfall traps, and interior pitfall traps (I), thus emergence traps, in early June 2021

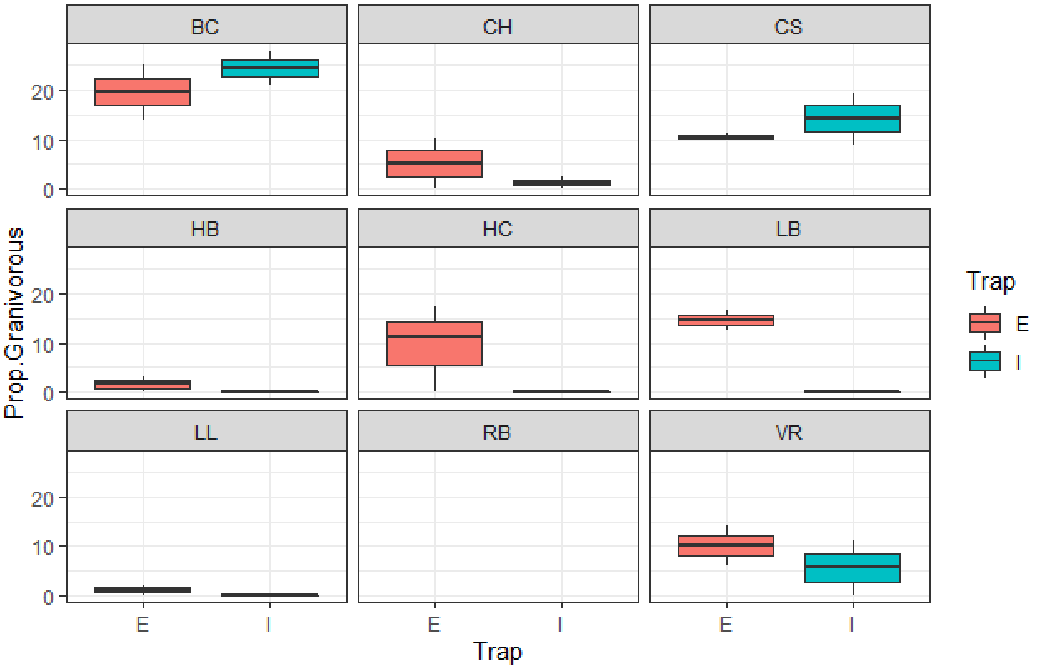


Figure 64 : Proportion of granivorous caught in exterior pitfall traps (E), thus pitfall traps, and interior pitfall traps (I), thus emergence traps, in early June 2021

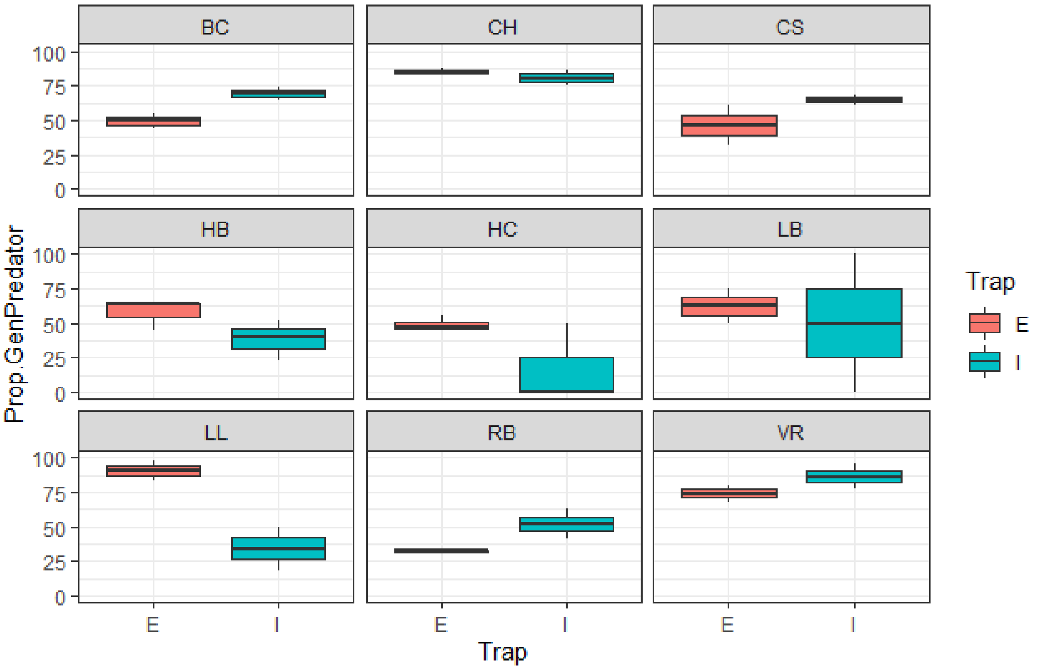


Figure 65 : Proportion of generalist predators individuals caught in exterior pitfall traps (E), thus pitfall traps, and interior pitfall traps (I), thus emergence traps, in early June 2021

Discussion

Dry mass

Even though Carabidae are extremely well studied, the huge majority of the studies focus on the population or community level. Thus, measuring traits like body mass at the individual scale seems like an interesting and more innovative methodology. Individual body mass is a useful approach when considering different succession stages of an ecosystem (Gobbi, 2014). In this case, we can consider the heavily tilled soil as one state of the system, and the less tilled one as another state. Since species with higher biomass are usually more sensitive to environmental perturbations (Kotze and O'Hara, 2003; Hatten *et al.*, 2007, Rusch *et al.*, 2013), we supposed that the same pattern could apply at the individual level, i.e., individuals with higher mass should be found in less perturbed (slightly tilled) plots. This could be due, for example, to the lower habitat complexity in conventionally tilled fields (because of the removal of the vegetation). Indeed, less complex habitats might lead to less prey availability, with a direct effect on individual biomass. Simpler habitats can also affect the behaviour of the beetles, because a lower vegetation cover implies less shelters (Kromp, 1999; O'Sullivan and Gormally, 2002; Langellotto and Denno, 2004) and thus potentially less time foraging and more time hiding.

Nebria salina was heavier in slightly tilled soil than in heavily tilled ones, which is consistent with our hypothesis. However, this result can be criticized in four different ways. Firstly, *N. salina* was the only species to display this pattern, even though we tested it for eight ones. Secondly, this difference of biomass, even if it was statistically significant, was of a relatively low magnitude (only 7mg). It seems therefore unsure that this phenomenon, although it exists, has a strong biological consequence on predation rates for example. Thirdly, only 24 individuals (13 from heavily tilled soil and 11 for the slightly tilled one) were weighed, which might be too few to draw solid conclusions. This third critic can underline the main problem of individuals measurements: they are extremely time consuming compared with larger scale (typically community) analyses. The low number of weighing we made could also have masked an effect of tillage on the individual biomass of the other species. Fourthly, carabids are very mobile (Delacre, 2019) and plots belonging to the same farmer, but being ploughed differently, are very close (only a few meters). Thus, it is possible that a carabid sampled in a LAB plot has spent his entire life in the adjacent plot, where tillage is lower, and had just dispersed onto the LAB plot, or vice-versa. Weighed individuals might then not be representative of the conditions they are supposed to have lived in.

It is therefore hard to affirm that tillage either has or does not have a real impact on individual traits such as biomass. Nevertheless, the result we obtained for *N. salina* seem interesting and larger scale studies, implying more weighed beetles and more separated plots, could be very useful to better understand the hypothetical effect tillage has on individual biomass.

2020 samplings

Before any comments on the results regarding the 2020 samplings, it is worth remembering that, for each sampling zone (containing three pitfall traps), we only analyzed the trap that seemed to have caught the highest number of carabids (thus only one trap per sampling zone). We chose this methodology to both reduce the time needed for identifications and make sure we would still have enough carabids to make our analyses. The problem with this method is that in some sampling zones, we had a homogeneous repartition of carabids among the three traps (thus we identified roughly one third of the carabids of the sampling zone) while, in other zones, one or two trap had caught much less insects, which led us to identify more than one third of the carabids of the sampling zone. A less biased approach would have been to count the carabids caught in the sampling zone and identify precisely one third of them (chosen randomly). However, since the main goal of our approach was to save time, it would not have made sense. Furthermore, it was relatively rare that the three traps caught very different numbers of beetles, except when there had apparently been a problem with one of them (for example, when the trap was completely empty), which would have led us to discard the trap anyway. Thus, we are not too worried about that potential bias regarding the 2020 samplings.

However, we should be cautious when making comparisons with 2021, because there was only one pitfall trap (besides the emergence trap) per sampling zone. Thus, if less beetles were caught in 2021 compared with 2020, it might be partly due to the methodology. However, since a lot of parameters were very different between 2020 and 2021 (for example the climate or the crop on the same field) we do not think that this variation had a strong impact. Nevertheless, we can not reject this possibility.

The first thing that appears while looking at the result is the huge part of inertia explained by the BCAs based on the site (77.45 to 89.85%), which is the only parameter that was always significant, regardless of the analysis performed. This can partly be explained by the very variable landscape context the sites are in. Indeed, some sites like the field owned by LL are surrounded by forests, others like the one managed by CH are shrouded in a vast number of other fields, and some others like the one belonging to HB are very close to important roads. Since landscape and edge effects are well known to strongly influence carabid communities (Roschewitz *et al.*, 2005; Puech *et al.*, 2015; Tamburini *et al.*, 2016; Aguilera *et al.*, 2021; Carbonne *et al.*, 2021; Fischer *et al.*, 2021), it is not surprising that such a high portion of the variation is explained by the site.

Furthermore, it is important to remember that the fields are managed by different farmers, and that the BA and CA plots corresponded to plots were the farmer applied his usual techniques. Hence, it is very likely that the actual treatments (pesticides, tillage, fertilization) were different among the same type of plots from different farmers. Even though BA is associated with legal specifications (see *Introduction*), it is not sufficient to suppose that all BA plots were treated the same way. Indeed, the use of non-synthetic pesticides, for example, is allowed in BA. Thus, some plots might have been treated with such pesticides, while others were not, or with different ones, which could of course have strongly influenced the carabid community composition (Puech *et al.*, 2014). Regarding CA, there are not even clear and universal regulations or protocols, so what we just discussed about BA is even more applicable to CA. It is enough to simply look at the variety of tillage types that were realised in CA plots (Striptill, deep TCS, superficial TCS) to realize that, even though reduced tillage is a characteristic of CA, tillage types were far from uniform in CA plots. Only the BAC plots, where recommendations from the CRA-W were followed, should be relatively standardised (still, the same remark regarding tillage types applies).

Finally, one must realise that the site is a very integrative parameter, including not only landscape context and the farmer’s usual practices, but also the crop (which is a very important parameter for carabids as well (Bohan *et al.*, 2011; Eyre *et al.*, 2012)) and several non-measured features that might influence the carabid community: for example, the climate (Eyre *et al.*, 2016; El-Danasouri *et al.*, 2017), the natural abundance of other organisms like alternative preys (Prasad and Snyder, 2006) or the fertilization and the associated soil chemistry (Aguilera *et al.*, 2021). For all of those reasons, it seems normal that the site is the predominant parameter explaining communities composition structures.

Another clear and interesting result can be deduced regarding the position of the modalities on the PCAs and fuzzy FCAs. Globally, BA seemed to hold a greater proportion of granivorous and omnivorous (G&O) individuals, while CA seemed to host a larger proportion of generalist predators. BAC, as for it, appeared as an intermediary position between BA and CA. Interestingly, the distribution of the modalities on the axes system almost exclusively occurred on the first axis, and both the total number of individuals and the total biomass are mainly correlated with the second axis. Therefore, it does not seem like the modality had a net effect on the abundance of carabids, but rather an effect on the relative proportions of the trophic categories.

The beneficials of BA for G&O species is a well-known and documented phenomenon (Döring and Kromp, 2003; Eyre *et al.*, 2012; Rusch *et al.*, 2013; Diekötter *et al.*, 2016). We can hypothesize that the use of herbicides in CA plots reduced vegetation cover more efficiently than the mechanical weeding more often made in BA. This would have resulted in greater vegetation cover in BA than in CA, which in turn provides more food for G&O species Vegetation may also have complexified the habitat, providing more shelters (Harrisson and Gallandt, 2012; Roubinet *et al.*, 2017).
This explanation is a bit paradoxical because one of the requirements of CA is a permanent vegetation cover. However, it does not guarantee an important one (30% is enough), thus it is still possible that the cover in BA would be more important than the one in CA. Alternatively, direct mortality of G&O species because of pesticides is possible, but information regarding the toxicity of those chemicals on carabids is lacking (Holland and Luff, 2000). Actually, the reasons of the overall higher abundance and richness of carabids in BA compared to conventional agriculture remain largely unknown (Irmler, 2018).

The higher proportion of predatory carabids in CA might seem trickier to explain. Indeed, a commonly accepted idea is that larger species are more vulnerable to perturbations, especially ploughing (Holland and Reynolds, 2003; Kotze and O'Hara, 2003; Hatten *et al.*, 2007, Kennedy *et al.*, 2013; Rusch *et al.*, 2013), even though this is still subject to debates (e.g., Eyre *et al.*, 2013). Since the most abundant predator (and, more generally, species) we found in this study was *Pterostichus melanarius*, a very large beetle (only outsized, in this study, by *Abax parallelepipedus*, *Carabus monilis* and *Carabus granulatus*, three forest species (du Bus de Warnaffe and Lebrun, 2004; Roger *et al.*, 2012) that are also generalist predators), it would seem like this pattern is respected, especially since the sensitivity of this species to tillage is documented (Fadl *et al.*, 1996; Hatten *et al.*, 2007; Shearin *et al*, 2007; Eyre *et al.*, 2013), even though there are exceptions in the literature (Baguette and Hance, 1997). However, there were also small generalist predators (mainly *Bembidion properans* but also *Bembidion lampros* and *Bembidion quadrimaculatum*) and a large granivorous (*Harpalus rufipes*). Thus, size of the species alone does not seem to explain the pattern. It should be noted, however, that *H. rufipes* has been shown to be more abundant in more disturbed fields (Eyre *et al.*, 2013), but the number of studies finding this result is too small to be sure of this particularity.

However, if we look at the number of individuals of each species captured, the abundance of *P. melanarius* compared to the other species is crushing. Indeed, a total of 5481 individuals were trapped, whereas we only identified 319 *B. properans,* which was the most common small generalist predator, and 914 *Agonum dorsale*, which was the second most common predator. Thus, the trends followed by generalist predators is probably mainly directed by *P. melanarius* alone. Therefore, the fact that smaller carabids should not be associated with less disturbing practices, like CA, is not a very pertinent claim.

The low density of small beetles can be simply explained by the fact that the traps used were pitfall traps, which are known to capture a higher proportion of largest carabids, because they are more active. However, another explanation could be intraguild predation. Indeed, it has been shown that several large species like *P. melanarius* can consume smaller carabids (Prasad and Snyder, 2004 and 2006; Rusch *et al.*, 2015; Perez-Alvarez *et al.*, 2021). Since the activity-density of *P. melanarius* is much higher than that of the other species, it is possible that it maintains small species like *Bembidion spp.* at small densities.

Important precisions should be brought regarding the diet of *P. melanarius*. In this study, we considered it as a generalist predator because it is described this way in most of the literature (Symondson *et al.*, 1996; Prasad and Snyder, 2004 and 2006; Roger *et al.*, 2012; Corfdir, 2020). Some studies are even based on the assumption that *P. melanarius* is a predator to compare the effect of tillage on predator *versus* granivorous species (Shearin *et al.*, 2007). Granivory by *P. melanarius*, is sometimes mentioned, but more as an anecdotical behaviour and not as a general habit, (Corfdir, 2020). However, a non-negligible number of authors considered *P. melanarius* as a true omnivorous species (Bohan *et* al, 2011; Trichard *et al.*, 2014; Kulkarni *et al.*, 2015; Carbonne *et al.*, 2020). Because of the high abundance of *P. melanarius,* the results would have probably been different if we considered it as an omnivorous species. The possibility of *P. melanarius* to help in the management of weeds should therefore not be ignored. Globally speaking, simplifications had to be made when attributing a diet to the species because of the complexity of the subject and the discrepancies in the literature. In this regard, Carbonnne *et al.* (2020) suggest clarifying the knowledge about the diet of carabids.

An alternative explanation would be that CA plots happened to have less vegetation cover than the BA ones, which would result in a decline of granivorous species and, to a lesser extent, omnivorous ones. The situation in CA plots would then favour predators (because of the lack of vegetation) of large size (because of the superficial tillage), typically *P. melanarius*. This would also explain why G&O species are less found in CA: they would lack food.

Claiming that BA crops had greater vegetative cover and more complex structures then CA is challenging, because no-till fields are often associated with higher vegetation cover and complexity, (Shearin *et al*, 2007) than conventionally managed ones. Complexity itself is often associated with a higher number of natural enemies (Langellotto and Denno, 2004; Trichard *et al.*, 2014; Gallé *et al.*, 2019). Nevertheless, it is also the case for BA fields (Weiner *et al.*, 2001; Roschewitz *et al.*, 2005; Navntoft *et al.*, 2006; Eyre *et al.*, 2012; Puech *et al.*, 2015). It would thus have been interesting to assess those parameters in our study.

An additional hypothesis regarding the diet of the species can also be formulated. Indeed, it has been shown that *Pterostichus melanarius* can use earthworms as an alternative prey (Symondson *et al.*, 2000). However, the effect of tillage on earthworms is extremely severe because of the combined effects of direct mortality and indirect factors such as habitat destruction (Roger-Estrade *et al.*, 2010). Therefore, it is possible that the earthworm populations were higher in the CA fields, where tillage was more superficial, and that those earthworms were used as alternative preys by generalist predators like *P. melanarius*, thus increasing the abundance of those beetles. Of course, similar reasonings can be processed for uncountable interactions of that kind, whether the plot is managed under CA or BA. Therefore, we can imagine that the reasons for the pattern we described are explained by some specific interactions like this one, rather than general rules, which underlines the complexity of the phenomenon.

It is also possible that inorganic fertilization has increased the density of *Pterostichus melanarius* (Kromp, 1999) in CA fields.

Yet another alternative would be that *P. melanarius* is simply more present in some CA fields because of non-controlled factors. Indeed, this species was extremely abundant in the field of JM, and because there were only four CA plots in 2020, it might have strongly influenced the results. Globally speaking, the fact that we only had four CA plots and a lot of non-measured parameters make any interpretation difficult because any source of unexplained variation can greatly affect the results. Of course, none of those explanations are mutually exclusive.

BAC showed an intermediate situation between BA and CA, thus a more homogeneous repartition of trophic categories in the community. This more varied community is likely beneficial for ecosystem services because both weeds and animal pests can potentially be regulated by carabids. A more diverse community is also more resilient after perturbations like pesticides spraying or ploughing (Gallé *et al.*, 2019). It might seem surprising, though, that there are not more carabids in BAC than in the other modalities. It could be explained by interspecific competition or intraguild competition, but a higher variety of trophic categories should rather limit both of those phenomena. A more logical explanation would be that, when the carabid density becomes high in BAC plots because of the suitable conditions, a net dispersion flow towards the other plots occur. This is especially likely, given the fact that the plots are relatively small compared to the field. The number of individuals that those plots can host, even when the conditions are optimal, is therefore probably a limiting factor.

A more trivial explanation that we can not reject is that the communities of the BAC plots are similar to the ones of the neighbouring plots, which is likely because the plots within the same field are very close to each other. Thus, since there are BAC plots next to BA ones and others next to CA ones, it would be logical that, in average, the communities of those plots appear as intermediate ones.

The region also seemed to affect the carabid community, although this factor is hard to differentiate from the sites themselves. Specifically, the Charleroi sites seemed to host more carabids, with an important variety in terms of proportions of generalist predators and G&O species. The Tournai sites hosted a greater proportion of G&O species, and a higher proportion of generalist predators was found in Huy and Center sites, with less carabids in Center sites. However, those patterns are very likely to be explained by the properties of some sites rather than global landscape or climatic contexts. Indeed, the higher number of carabids found in Charleroi sites can be strongly driven by the site owned by JM, where huge densities of *P. melanarius* were detected. The other two sites of Charleroi were BA fields, and thus probably contained a higher proportion of G&O species. Therefore, it is logical that a lot of variation appeared in Charleroi regarding the relative proportion of the trophic categories (more generalist predators in the JM handled site and more G&O in the other ones). The higher proportion of G&O species in Tournai is probably due to the fact that all the farmers of this region practiced BA. Higher proportions of generalist predators in Huy may be explained by the presence of forest species like *Abax parallelepipedus* and *Pterostichus madidus* in the field owned by LL, especially since there were only two sites in Huy. Finally, the smaller density of carabids in the Center fields is, once again, probably driven by some very poor sites like the one owned by CH which is close to an important road, or the one managed by HC.

This effect of the site itself is one of the few things that can be interpreted with the CCAs. Specifically, those analysis clearly show that *A. parallelepipedus* and *P. madidus* are distributed differently from the other species, and are strongly associated with the site owned by LL. Since this site is located nearby a forest and that both of those species are forest ones, this result is not surprising. A more interesting factor, however, is that the HC site was also close to forest, but the two above-mentioned species were not found there. Thus, the forest near to the LL field might be of higher quality, but our data are far from sufficient to affirm this hypothesis.

Besides this particularity, not much information could be interpreted from the CCAs, even though the representation of the FCAs's variation was excellent (>90%). This underlines the interest of traits-based approaches rather than "simple" specific compositions, as discussed by several authors (Rusch *et al.,* 2013 and 2015; Gallé *et al.*, 2019; Lami *et al.,* 2020; Fisher *et al.,* 2021).

The results regarding the tillage were very surprising: indeed, we can see that DS, supposed to be the less intensive type of tillage, was very close to the LAB tillage (especially in early June), supposed to be the most intensive one. Similarly, superficial TCS was closer to LAB than deep TCS was. This second part can, however, be explained by the fact that the sites containing a LAB plot always had deep TCS as the second plot. Carabids could then have moved from one plot to another, leading to a confusion of those types of tillage effects. The DS plots were not associated with LAB ones, but a similar explanation can still be given: all the DS plots, as well as the LAB ones, belonged to BA fields. Therefore, the effect of the modality might have surpassed the one of tillage, thus merging LAB and DS. This is however in contradiction with most of the literature, according to which tillage is of capital importance for carabids (see *Introduction*). This may be because the farmers in this study manage their fields with an agroecological approach, and thus even the LAB modality might not be disturbing enough to contrast with the modality. Some intensively managed, nor BA nor CA fields, are needed to confirm this hypothesis and, globally speaking, improve the quality of our results.

The positions of the Striptill + faba bean and Striptill + trefoil were not very relevant because they are represented by one single plot and, as we have already discussed, the site is a prime importance factor.

The site's effect followed the same global pattern as the modalities, with a cluster formed by most sites under BA management (HB, PM, ER, RB and VR) and another by most sites under CA management (LL, JM and BC). However, the position of the sites owned by CS (BA management), CH and HC (CA management) differed from that pattern. However, those deviations are probably of low importance, because those three sites were by far the poorest in terms of carabid abundance (CH: 80 carabids; CS: 119 carabids; HC: 256 carabids) compared to the other ones (always several hundreds, sometimes >1000 or even >2000). This further highlights the need for prudence when interpreting the data relative to CA fields: only four fields were used, one had the maximum density among the studied sites and two others had very weak densities.

In addition to those effects, the fuzzy FCAs show that proportionally more spring-summer breeders were found in BA, and more summer-autumn breeders were detected in CA. This could partly be because *P. melanarius*, the most found generalist predator, is a summer-autumn breeder, and that most of other species are spring-summer breeders. *H. rufipes*, however, is a summer-autumn breeder as well, but since it was less common than *Pterostichus melanarius*, and because a lot of common species found in BA like *Pterostichus cupreus* and *Harpalus affinis* are spring-summer breeders, the reasoning still makes sense. This pattern repeated in 2021.

The phenology of the carabids was also strongly related to the sowing period of the crop (spring crop or winter crop, sown in autumn). Indeed, the breeding season was a key component of the fuzzy FCA axes system (especially for early June). It appeared that spring-summer breeders were rather associated with winter crops, while summer-autumn breeders were mostly associated with spring crops. To summarize, species on the field are mostly species that breed at a different timing from the sowing period. It is indeed intuitive that spring-summer breeders could have faced difficulties while breeding and ovipositing during the sowing. However, for spring-summer breeders, the pupa, which is an extremely vulnerable stage (Lövei and Sunderland, 1996), is in the soil in autumn (Matalin, 2007), which would be problematic because it coincides with the sowing of winter crops. Furthermore, it is important to notice that the effect of crops from previous years could influence the result, especially for autumn breeders. And, most importantly, we are confronted in another experimental design flaw, in the sense that spring crops were cultivated on all the CA fields.

A more interesting way to use the phenology of carabids would be the hypothesis according to which spring breeders are less affected by tillage (regardless of its timing) because they are thermophilic and prefer open habitats (Holland and Reynolds, 2003; Hatten *et al.*, 2007). Autumn breeders are more hygrophilic and prefer closed habitats (Hatten *et al.*, 2007). However, this is in contradiction with the hypothesis we formulated regarding vegetation cover.

Finally, the length of life cycle and the reproductive strategy had a minor influence on the results. Species that were able to display biennial life cycles were more abundant in the CA fields; once again, since *Pterostichus melanarius* belongs to this category, it might have defined this trend by itself, even though *Harpalus affinis* and *H. rufipes* belongs to the same category. The importance of the reproductive strategy as component of the second axis in the early June analysis is probably mainly due to the relatively high proportion of *Nebria brevicollis* and, to a lesser extent, *Nebria salina* in the CH field. These two species are indeed among the few ones to display a semelparous strategy, but, once again, the extremely weak abundance of carabids in the CH field makes it difficult to conclude.

2021 samplings (global)

The first thing we can notice is a dramatic drop of the part of inertia explained by the site, that is now barely superior to 20%. Thus, the variability was much higher, probably partly because several samplings from different periods of the year were analyzed, and also because two different trap designs were used. It should be noted that the crop appeared as an important factor in the PCA and the sampling date as a very important factor (explaining more inertia than the site) in the fuzzy FCA. Globally speaking, all the parameters tested had a significant effect, even though explaining a small part of the inertia (often less than 10%). This highlights the complexity showed by the system as soon as we start working at slightly longer time scales and we vary the trap design. In addition, since the parts of variation explained by the parameters are relatively small, it is likely that other, non-controlled parameters, had a strong influence as well. The climatic hazards, for example, probably modified our results. Indeed, on the 636 we initially had for this year, we had to remove 91 ones, mainly because of flooding of the traps. We should therefore be cautious when interpreting those results.

The results from 2021 are globally less clear than those of 2020, probably mainly because of what we just discussed. However, interestingly, we can still detect a relatively similar pattern regarding the modality as we detected in 2020. Indeed, we can see that CA seems more associated with generalist predators than the other modalities, even though the JM-managed site (where a high density of *Pterostichus melanarius* was observed) was not used in 2021. The higher proportion of G&O species in BA, however, does not appear very clearly. Though, we can still see than more BA and BAC related points are placed to the right of the figure than CA related ones, so the proportion of G&O is probably higher in some BA and BAC plots than in CA ones, but not in all sites. The gradient is more oriented towards an increase in the proportion of specialist predators (predators of springtails) in BA plots. This seems intuitive because organic fertilization can promote springtails density, which is of course beneficial for specialist springtails predators (Birkhofer *et al.*, 2008). This increase in springtails density in BA pots is however uncertain (Eyre *et al.*, 2013; Roubinet *et al.*, 2017). Of course, our data cannot affirm that the springtails density was indeed greater in BA (and maybe BAC) plots, especially since other authors have suggested that conservation tillage could also enhance springtail abundance (Tamburini *et al.*, 2016). Still, we think it is an interesting hypothesis. Springtails are not pests, but bioindicators of soil quality (Ponge *et al.,* 2003) and can be used as an alternative food source for generalist predators (Tamburini *et al.*, 2016) even though they are less effective that specialist ones (Baulechner *et al.*, 2021). Their monitoring could thus be an interesting task to accomplish as well. However, since the monitoring of carabids is especially easy, we do not think it is a priority.

The reason why a lower proportion of specialist predators is observed in BAC than in BA might lie in intraguild competition. Indeed, as we have already discussed, species like *P. melanarius* can feed on smaller carabids. Since all caught specialist predators of springtails are small (<6mm), if the environment in BAC plots is more suitable for *P. melanarius* than the one from BA plots (which is possible, since we detected more generalist predators in BAC than in BA), the predation from *P. melanarius* against springtails specialists in BAC plots might reduce their density. A similar phenomenon could also possibly apply in CA fields.

Since the proportions of G&O species and of specialist predator ones are anticorrelated along the first axis of the PCA used, the higher abundance of specialist predators in BA might mask the effect on G&O. Indeed, we can distinguish two main clusters of points in the representation of BA, one towards specialist predators and the other towards G&O. Nevertheless, a non-negligible number of points do not follow this trend, indicating that the pattern we detected is subject to a lot of unexplained variation.

A more intuitive effect of simplified tillage than the one from 2020 appeared in this analysis. Indeed, here, we can see a gradient of relatively heavy ploughing (LAB) to more superficial tillage (DS) from upper left to bottom right. Specifically, it means that LAB plots shelter a higher proportion of specialist predators than the DS ones. Since specialist predators are small species, this is in adequation with the majority of the literature, according to which small species thrive better than larger ones in heavily ploughed soils (see above). However, no effect on the generalist predators or on the G&O appeared in this analysis.
The variation between TCS plots, for its part, was too important to draw any good conclusion. Nonetheless, it seemed to show intermediate results between LAB and DS, which would be expected, and is therefore encouraging.

The type of trap had a very clear effect, despite the tremendous variation of the data: emergence traps captured less carabids, a lower biomass of carabids and less generalist predators, which is probably directly linked to the lower number of carabids captured. Those effects were the ones we expected the most. Indeed, since the surface covered by the emergence trap is much lower than the one covered by the pitfall traps, and that a lot of carabid species are very mobile (Delacre, 2019), fewer carabids could, physically, enter in contact with the trap. This might seem like a trivial result, but it is important to ensure that the barrier is sufficiently impermeable to outside carabids before making any additional comparison between both trap types. The effect of the trap type will be discussed with more details in a following section.

The effect of sowing period was the opposite from the one of 2020. Spring-summer breeders were mostly associated with spring crops, while summer-autumn breeders where rather associated with winter crops, sown in autumn. But that does not mean that the whole pattern changed. Actually, the thing is that, in most fields were a winter crop was sown in 2020, a spring crop was sown in 2021 and vice-versa. The only two sites where it was not the case were the one owned by HB and the one owned by PM, and the latter stopped the experiment after the first sampling. Thus, it seems impossible to conclude anything in such a small period as two years, especially since we do not know the crops sown in 2019. To better assess the effect of the sowing period, we should have an experimental design in which agricultural works happen at the same time in the different fields, so that we can have representative before/after samplings in different fields. Organizing such a design is difficult, but might be worth taking into consideration, since the separation between summer-autumn breeders and spring-summer ones is an important parameter in all the fuzzy FCAs conducted. The interaction with the sowing period of the crop appears relatively clearly as well on most analyses.

The sampling period was a key parameter that explained a lot of inertia. We can clearly see that more small-sized, specialist, summer-winter breeder species were identified in early March. Actually, most of the identified carabids were *Trechus quadristriatus*, which fulfills all of these characteristics. It is also the only species of our dataset to breed from summer through winter.
In the April sampling, a higher proportion of medium and big-sized (the difference is hard to make because the medium size is not well represented in the axes system (5.32%)), G&O, spring-summer breeder species were identified. This corresponds best to species like *Pterostichus cupreus, Agonum muelleri* or *Harpalus affinis*. In May and June, a higher proportion of big-sized, generalist predators, summer-autumn breeder species were observed.

This mainly corresponds to *Pterostichus melanarius*, but also, to a lesser extent, to other large generalist predators like *Nebria brevicollis* or *Nebria salina*.
The main conclusion on this analysis based on sampling period is that the period of sampling can be adapted if some peculiar species are of special interest, regardless of other parameters. Indeed, most of the commonly sampled species seemed to be significatively proportionally more captured at certain periods, and the sampling period itself explains a lot of inertia. This, however, may be less applicable for small or medium-sized generalist predators like *Bembidion spp.*, *Loricera pilicornis* or *Agonum dorsale*. *Harpalus rufipes* and *H. rubripes* being the only granivorous summer-autumn breeders detected in this study, and *P. melanarius* being a summer-autumn breeder as well, the analyse does not give precise indications about the best sampling period for those species.

The length of life cycle and the reproductive strategy were not relevant parameters for this year. Since they were already not very informative for 2020, this is not a surprising result.

Comparison early June 2020 – early June 2021

The results between the two years were globally similar. As for 2020, the BCA related to the site explained a very high (>80%) of the variation, probably for the same reasons as we discussed earlier.

The effect of modalities on the relative proportions of the trophic categories was also quite similar: we observed a higher proportion of G&O species in BA, and a lower one in CA, that seemed to be associated with a higher proportion of generalist predators. However, the variability associated with CA plots was much lower than in 2020, probably because of the removal of the JM-managed field. Carabids also seemed less abundant in CA fields, probably for the same reason, and also because HC and LB-owned fields had an extremely weak abundance of carabids and were both CA fields.

The region was, once again, an important factor, but the same remarks about the sites themselves still apply. The situation in Charleroi in 2021 can not be compared to the one from 2020 because the field owned by JM was not part of the experiment in 2021, and PM stopped the experiment after only one sampling, which implies that there was only one site remaining in Charleroi from the second sampling on.
The fields in Tournai seemed to have the highest carabid biomass (probably because of the removal of the field owned by JM) and a higher proportion of G&O species, as in 2020, probably because all the fields in Tournai were BA ones.
The sites in Huy presented more variability than in 2020. It was probably because the LL field had a much higher density of carabids in 2020, thus leading the trend towards a higher proportion of generalist predators (the LL site is in a CA system while the other site is in a BA one). This drop of density in that field is strange. In fact, a careful examination of the data reveals a general crash of the number of identified *Pterostichus melanarius* and *Pterostichus madidus* from 2020 to 2021. This is probably simply due to the bad climatic conditions we had in 2021, but if this trend remains in the following years, the reason behind those drops should be investigated. As we discussed in the beginning of this section, the fact that we analyzed the trap that caught the highest number of carabids in 2020 might also have played a role.
The fields in the center were mostly associated with CA plot's characteristics because three out of these four fields were in a CA system.

The effect of the sowing period was less clear in 2021 than in 2020. The analysis taking the specific crop type into account revealed that spelt by itself was responsible for the confusion. We cannot explain this anomaly, but since spelt was only cultivated in one field, this effect might as well be due to uncontrolled factors. Once spelt is removed, we observe an opposite pattern compared to 2020: generalist predators were rather associated with winter crops, while G&O were so with spring crops. We can therefore conclude that the crop type did not, in this experiment, alter the carabid community composition. Instead, the key factor was likely the modality. As we have already mentioned, most of the farmers who sowed winter crops sowed spring crop in 2021, and vice versa. It did not change the usual pattern we observed, with more generalist predators in CA and more G&O in BA. If we want to assess the effect of crop, longer studies allowing to consider previous years crops might be helpful (Fadl *et al.*, 1996).

Finally, the CCA was relatively similar to the one of 2020, with the LL-owned site and the forest species associated. However, we can also see that most small species were clustered in the upper right part of the graph, the only notable exception being *Asaphidion flavipes*. The CCA indicates that this portion of the graph is associated with the site owned by HB, maize and spring crops. All those characteristics are associated with the BA modality (we can also see that those characteristics are anticorrelated with the CA modality along the fist axis). As we have already discussed, BA might be more suitable for small species because of the more frequent perturbations and the lower abundance of generalist predators such as *Pterostichus melanarius*, which might reduce intraguild predation. Furthermore, springtails density might be higher in BA, which is an advantage for species feeding on them. Since several small-sized species are also specialist predators of springtails, it is not surprising to see most of them clustered this way. This result appeared in 2021, but not in 2020, possibly because of the better trapping of those species in 2021 thanks to the emergence traps. It is disturbing, though, that the small specialist predator of springtails *A. flavipes* did not belong to that cluster. However, since this species was present in relatively low abundance compared to *Bembidion properans* or *Trechus quadristriatus*, this might simply be non-representative. Nevertheless, the same reasoning can be applied for several species that were present in the cluster, like *Bembidion lampros*, *Microlestes maurus* or *Microlestes minutulus*.

Overall, the fact that we have different sites and very different climatic conditions in 2020 and in 2021 makes any comparison very difficult. Nonetheless, the main trend (more generalist predators in CA and more G&O in BA) seems to be maintained.

Emergence traps

As detected in the multivariate analyses, we showed with paired t-tests that emergence traps captured less carabids, confirming our hypothesis. The paired t-tests brought out that the mean individual mass of a carabid was lower in the emergence trap than in the pitfall one, which means that the emergence traps captured a higher proportion of smaller species, in accordance with our hypothesis. This can not simply be due to a high amount of *Pterostichus melanarius* caught in the pitfall traps, because the effect was already visible since April, a period during which *P. melanarius* is extremely rare (Roger *et al.*, 2012). The only non-significant result concerned the March sampling, which was the poorest in term of abundance, so this sampling may be the less representative. This experiment is therefore another evidence of the pitfall trap bias towards larger species. This was further highlighted by subsequent tests, where we showed that the proportion of big (>9mm) individuals was lower in emergence traps in May and June. The non-significant results in the two preceding samplings may again be due to the too low number of active individuals in the field.

The results about the small (<5mm) species were more dispersed, with some samplings showing significant results and others not. It is possible that some small individuals have escaped from the trap thanks to growing vegetation, crawling through small soil irregularities allowing to pass under the barrier or, for some species, flying. Nonetheless, obtaining significant results concerning small carabids twice is already encouraging, given the number of traps that had to be discarded and, mostly, the clearly significant results regarding mean individual biomass.

However, our last hypothesis, assuming that predators are more active than granivorous and should therefore be proportionally more caught by pitfall traps, was never verified. Actually, we even sometimes obtained significant results that contradicted our hypothesis. It did not happen often enough, though, to validate the opposite hypothesis assuming that granivorous species are less captured by the emergence traps. Overall, the type of trap did not have any effect on the relative proportions of granivorous and generalist predators. This is consistent with the multivariate analyses, where we did not detect any pattern regarding those proportions.

It therefore appears that emergence traps have several advantages over the pitfall trap, the most obvious one being that those traps do not suffer from activity (and therefore individual mass) biases. This is probably because the small size of the surface they sample makes sure that all carabids that emerge from the trap will end up falling in the inside pitfall. In the same spirit, the standardization of emergence traps is easier, because we can suppose that their effectiveness does not depend on the inside pitfall characteristics (diameter, killing solution and matter), which is another problem of pitfall traps.

They might also be less affected by spillover of carabids from outside the site, for example forest species that could skew some analyses. Of course, the lack of this kind of information can also be problematic in studies trying to have a holistic picture of the events talking place in the field, including colonization from outside the field. Globally speaking, those traps may give a better picture of the situation inside the field and could help differentiate carabids that spend most of their life cycle on the field and those that just disperse onto the field during one season.

Finally, emergence traps captured less carabids. This could seem like a disadvantage at first glance, but it might be useful in some ways. Indeed, with pitfall trapping, a lot of carabids can be captured, sometimes several hundred in one trap. The identification can thus take a lot of time, even if carabids are easy to identify. Emergence traps might therefore be a solution to catch a smaller number of carabids without randomly rejecting some traps.

However, it might also be a disadvantage: Indeed, as we have seen in this discussion with the 2020 samples, traps that catch too few carabids may not be representative of the whole community. When using emergence trap, it is needed to make sure to use enough of them to avoid such problems.

But this leads us to the second disadvantage of emergence traps, the difficulties of establishment. Indeed, the barrier must be acquired or confectioned, placed on the field without disturbing the soil and stay on the same place for all the duration of the experiment.

This can be especially difficult to when collaborating with farmers since they may need to move the trap to accomplish some parts of their work like sowing or ploughing. The classic pitfall trap, on the other hand, is very easy to install on the field and does not (or much less) restrict agricultural works.

A third problem is the maintaining of the good working order of the device. Indeed, to prevent carabids from passing through the barrier, vegetation around and inside the trap should be maintained as low as possible. It is also important to make sure that there is no opening below the trap (the whole barrier must be in contact with the soil), which requires regular controls because the soil may slightly move according to precipitations for example. Finally, when switching the inside pitfall trap (thus taking a sample and renewing the cup2 for the next one), it is of course important to be cautious not to disturb the soil. This seems obvious, but practically, removing the inside pitfall from the soil can be quite challenging, especially in humid conditions. It is thus hard to remove without entering inside the surface and lean on the soil to dig the inside pitfall out.

As a conclusion, we can say that sampling through emergence traps probably gives a better estimation of the carabid community composition than pitfall traps and require less identifications. However, installing several traps per plot is needed to obtain enough carabids to make correct analyses. This installation and the maintenance that follows require a serious organization and efforts that must not be neglected.

Experimental design criticisms

As we have seen multiple times throughout this discussion, the experimental design suffered from a lot of flaws that we will briefly discuss. It should be underlined that this section does not aim to denigrate the work of the CRA-W, that must conciliate good design and practical feasibility. Rather, we will try to propose realistic solutions to deal with the most problematic features of the experimental design.

Firstly, the plots within the same field could be separated by a greater distance rather than being almost side by side. This way, the movements of carabids from one plot to the other one should be more limited, and we could have a better certitude that the carabids we associate to a plot are representative of the plot conditions.

Secondly, more standardized treatments should be applied. As much as possible, the same treatment should be associated to the same conditions. This implies, before anything else, a stricter definition of BA and CA, at least in the context of the ongoing study. Indeed, effects of specific agricultural practices like mulch can also alter the community composition (O’Neal *et al.*, 2005). However, since the CRA-W follows specific farmers, this suggestion is not really applicable to this structure.

Thirdly, the design needs to be more balanced. As much as possible, we should have similar numbers of replicates of each treatment, for example a more similar number of BA and CA systems. This also applies for other factors inside the sites, like the crop. The sowing period of the crop suffered heavily from this imbalance: in 2020, all the CA fields were sown with spring crops, and all those fields were sown with winter crops in 2021. It is therefore difficult to discriminate the effects of the crop, the year and the modality, even though all three of them are interesting factors.

Fourthly, more replicates are needed. There are simply too many types of tillage, crops and modalities compared to the number of fields. The removal of potential outliers (which are supposed to appear frequently in experiments with so much uncontrolled variation) is often difficult or impossible because it would remove one of the few observations of a treatment. And since all treatments have few replicates, it is not rare that a single field dictates a whole trend that might be due to other, non-controlled parameters. We have seen this case several times with the fields owned by JM and LL. And more generally speaking, this lack of replicates makes more complex analyses than the ones we made (e.g., modelling) unreliable.

Fifthly, the number of uncontrolled variables should be reduced. Vegetation cover or soil biochemistry, for example might be an important parameter that should be characterized and considered. Vegetation cover, especially, has been shown to be correlated with seed predation by invertebrates (Birthisel *et al.*, 2015). The surrounding landscape could also be analyzed and produce a variable appliable to each field, for example the occupation of the soil in a given radius.

Sixthly, the number of pitfall traps placed in 2020 should not be that important in future studies. We only analyzed one third of the traps from two sampling dates, and yet we obtained more carabids than in 2021, for which we analyzed more traps and five sampling periods. The number of carabids that still need to be identified to conclude the study of 2020 is probably unrealistically huge. In addition to the working time required to identify that many carabids, one might wonder if this intensive sampling has a consequence on demographic levels or raises ethical concerns.

Seventhly, since the goal of this study was to assess the ecosystem services provided by carabids, it would have been interesting to measure the impact that the results we found have on yield for example. Indeed, the fact that more or different carabids are found does not forcefully mean that there will be an impact on biological control (Kromp, 1999; Prasad and Snyder, 2006; Bohan *et al.*, 2011; Mabin *et al.*, 2020). For example, the effects of intraguild predation (Prasad and Snyder, 2004; Rusch *et al.*, 2015; Perez-Alvarez *et al.*, 2021) or alternative preys (Cardina *et al.*, 1996; Birthisel *et al.*, 2015; Carbonne *et al.*, 2020) might mitigate the biological control provided by carabids, and the impact on yield must therefore be known. Alternatively, monitoring other species like pests or springtails could also be a way to assess the impact of carabids on the agroecosystem.

Eighthly, controls (intensively, conventionally managed fields) might be useful to have more contrasting results. Indeed, BA, CA and BAC have common points, for example their frequent association with a more important vegetative cover than intensively managed fields. This acts as confounding factors while trying to establish the real effect those modalities have, and control fields could set a common baseline to facilitate the comparisons.

Conclusion

Most of the results are difficult to interpret because of the experimental design flaws and the high number of uncontrolled factors like climate. Nevertheless, despite those sources of confusion, we found a recurrent interesting pattern according to which G&O species prefer BA and generalist predators prefer CA. The community associated with BAC might appears more uniform, but it might also be due to dispersion from adjacent BA and CA plots.

We might therefore expect a better control of weeds in BA and a better control of animal pests in CA. But since the real impact that carabids have on the agroecosystem can not always be directly deduces by the community composition (Kromp, 1999; Prasad and Snyder, 2006; Bohan *et al.*, 2011; Mabin *et al.*, 2020), analyses including parameters such as yield or pest density need to be performed.

Those studies are of prime importance, because biological control of pests is a primordial concern in today’s agriculture, especially when trying to reduce pesticides. The interactions between carabids and the rest of the agroecosystem appear complex, and efforts needs to be made to improve our understanding.

Acknowledgements

First of all, I wish to thank my supervisor, Professor Thierry Hance, for his useful advice, feedbacks and help.

I would also like to thank my scientific advisors, Mr. Daniel Jamar, for his advice, the help he provided with the field work, as well as for the coordination of the project with the CRA-W. Mr. William Gyselynck accomplished the same tasks at the beginning of the project, and I would like to thank him as well.

I also thank Capucine Dutrieux, who worked in collaboration with me for the field work, the identifications and the weighings.

I wish to thank Mrs. Julie Pirson and Mr. Tom Philippe, technicians of the CRA-W, who helped us with the field work and put the insects in ethanol the two times we could not do so.

I thank Professor Hans Van Dyck, Mr. Kevin Tougeron and Professor Pierre Bertin who gracefully accepted to be part of the jury for this work.

I would like to thank Professor Andrei Matalin, who generously provided me a table summarizing the life cycles of the species identified during this work.

I finally thank the following members and ex-members of the ELIB for their benevolent help and friendly support during the project: Mr. Olivier Lebbe, Mr. Sebastien Demeter, Mr. Benoît Geelhand de Merxem, Mrs. Louise Ferrais, Mrs. Pauline Gardin, Mr. Ignace Murhububa Safari, Mrs. Mey Jerbi, Mr. Guillaume Le Goff and Mr. Christopher Pels. A special thank should be given to Mr. Benoît Geelhand de Merxem, who gave us precious advice regarding the functioning of the precision scales.

References

Aguilera, G. *et al.* (2021) 'Organic fertilisation enhances generalist predators and suppresses aphid growth in the absence of specialist predators', *Journal of Applied Ecology*, 58(7), pp. 1455–1465. doi:10.1111/1365-2664.13862.

Alcamo, J., Bennett, E.M. and Millennium Ecosystem Assessment (Program) (eds) (2003) *Ecosystems and human well-being: a framework for assessment*. Washington, DC: Island Press.

Andersen, J. (1995) 'A comparison of pitfall trapping and quadrat sampling of Carabidae (Coleoptera) on river banks', *Entomologica Fennica*, 6(2–3), pp. 65–77. doi:10.33338/ef.83842.

Anonymous (2006) *Focus: Agriculture de conservation, FAO*. Available at: http://www.fao.org/ag/fr/magazine/0110sp.htm (Accessed: 23 May 2021).

Anonymous (2018) *TEXTE consolidé: 32018R0848 — FR — 14.06.2018, EUR-Lex*. Available at: https://eur-lex.europa.eu/legal-content/FR/TXT/HTML/?uri=CELEX%3A02018R0848-20180614&from=EN&fbclid=IwAR070elTE0Z4v9bMSNc92RYMlOECo8gxmDhxnBGW9KFibGPM5eQrTfU-JpY (Accessed: 2 January 2022).

Anonymous (2020) *Walloon agriculture in figures 2020*. Liège: SPW Agriculture. Available at: https://agriculture.wallonie.be/documents/20182/21858/EN-2015.pdf/81e1d857-00be-4b39-b232-dff9c2374635 (Accessed: 29 May 2021).

Anonymous (2021) *FAOSTAT*. Available at: http://www.fao.org/faostat/en/#data/QC/visualize (Accessed: 29 May 2021).

Antier, C., Petel, T. and Baret, P. (2015) *Quelles agricultures en 2050 ?* UCLouvain. Available at: https://sytra.be/wp-content/uploads/2020/04/UCLouvain-QuellesAgriculturesEn2050-Print.pdf (Accessed: 29 May 2021).

Arthur, A.L. *et al.* (2021) 'Learnings from over a decade of increasing pesticide resistance in the redlegged earth mite, Halotydeus destructor (Tucker)', *Pest Management Science*, 77(6), pp. 3013–3024. doi:10.1002/ps.6340.

Baguette, M. and Hance, T. (1997) 'Carabid Beetles and Agricultural Practices: Influence of Soil Ploughing', *Biological Agriculture & Horticulture*, 15(1–4), pp. 185–190. doi:10.1080/01448765.1997.9755193.

Barrès, B. *et al.* (2016) 'Trends and Challenges in Pesticide Resistance Detection', *Trends in Plant Science*, 21(10), pp. 834–853. doi:10.1016/j.tplants.2016.06.006.

Baulechner, D., Jauker, F. and Wolters, V. (2021) 'Carabid adaptation to a collembolan diet: hunting efficiency and nutritional value', *Ecological Entomology*, n/a(n/a). doi:10.1111/een.13106.

Begg, G.S. *et al.* (2017) 'A functional overview of conservation biological control', *Crop Protection*, 97, pp. 145–158. doi:10.1016/j.cropro.2016.11.008.

Birkhofer, K., Wise, D.H. and Scheu, S. (2008) ‘Subsidy from the detrital food web, but not microhabitat complexity, affects the role of generalist predators in an aboveground herbivore food web’, *Oikos*, 117(4), pp. 494–500. doi:10.1111/j.0030-1299.2008.16361.x.

Birthisel, S.K. *et al.* (2015) ‘Habitat and Time Are More Important Predictors of Weed Seed Predation than Space on a Diversified Vegetable Farm in Maine, USA’, *Weed Science*, 63(4), pp. 916–927. doi:10.1614/WS-D-15-00057.1.

Blubaugh, C.K. and Kaplan, I. (2015) ‘Tillage compromises weed seed predator activity across developmental stages’, *Biological Control*, 81, pp. 76–82. doi:10.1016/j.biocontrol.2014.11.007.

den Boer, P.J. and den Boer-Daanje, W. (1990) ‘On life history tactics in carabid beetles: are there only spring- and autumn-breeders?’, in Stork, N.E. (ed.) *The role of ground beetles in ecological and environmental studies*. London: Intercept, pp. 247–258.

Boeraeve, F. (2019) ‘Agriculture bio de conservation: une solution pour restaurer les services écosystémiques ?’ *Workshop ‘Transition agroécologique’*. Available at: https://orbi.uliege.be/bitstream/2268/241792/1/Poster_4.pdf (Accessed: 28 December 2021).

Boetzl, F.A., Konle, A. and Krauss, J. (2020) ‘Aphid cards – Useful model for assessing predation rates or bias prone nonsense?’, *Journal of Applied Entomology*, 144(1–2), pp. 74–80. doi:10.1111/jen.12692.

Bohan, D.A. *et al.* (2000) ‘Spatial dynamics of predation by carabid beetles on slugs’, *Journal of Animal Ecology*, 69(3), pp. 367–379. doi:https://doi.org/10.1046/j.1365-2656.2000.00399.x.

Bohan, D.A. *et al.* (2011) ‘National-scale regulation of the weed seedbank by carabid predators: Carabid seed predation’, *Journal of Applied Ecology*, 48(4), pp. 888–898. doi:10.1111/j.1365-2664.2011.02008.x.

Bommarco, R., Kleijn, D. and Potts, S.G. (2013) ‘Ecological intensification: harnessing ecosystem services for food security’, *Trends in Ecology & Evolution*, 28(4), pp. 230–238. doi:10.1016/j.tree.2012.10.012.

Brandmayr, P., Ferrero, E. and Brandmayr, T.Z. (1980) ‘Larval Versus Imaginal Taxonomy and the Systematic Status of the Ground Beede Taxa Harpalus and Ophonus (Coleoptera: Carabidae: Harpalini)’, *Entomologia Generalis*, 6(2), pp. 335–353.

Brandmayr, T. and Brandmayr, P. (1975) ‘Biologia di Ophonus puncticeps Steph. Cenni sull fitofagia delle larve e loro etologia (Coleoptera, Carabidae)’, *Annali Facoltà di Scienze Agrarie di Torino*, 9.

Brust, G.E. and House, G.J. (1988) ‘Weed seed destruction by arthropods and rodents in low-input soybean agroecosystems’, *American Journal of Alternative Agriculture*, 3(1), pp. 19–25.

du Bus de Warnaffe, G. and Lebrun, P. (2004) ‘Effects of forest management on carabid beetles in Belgium: implications for biodiversity conservation’, *Biological Conservation*, 118(2), pp. 219–234. doi:10.1016/j.biocon.2003.08.015.

Carbonne, B. *et al.* (2020) 'The resilience of weed seedbank regulation by carabid beetles, at continental scales, to alternative prey', *Scientific Reports*, 10(1), pp. 1–14. doi:10.1038/s41598-020-76305-w.

Carbonne, B. *et al.* (2021) 'Direct and indirect effects of landscape and field management intensity on carabids through trophic resources and weeds', *Journal of Applied Ecology*, pp. 1365-2664.14043. doi:10.1111/1365-2664.14043.

Cárcamo, H.A. (1995) 'EFFECT OF TILLAGE ON GROUND BEETLES (COLEOPTERA: CARABIDAE): A FARM-SCALE STUDY IN CENTRAL ALBERTA', *The Canadian Entomologist*, 127(5), pp. 631–639. doi:10.4039/Ent127631-5.

Cardina, J. *et al.* (1996) 'Postdispersal Predation of Velvetleaf (Abutilon theophrasti) Seeds', *Weed Science*, 44(3), pp. 534–539. doi:10.1017/S0043174500094297.

Clapperton, M.J. (2003) 'Increasing soil biodiversity through conservation agriculture: Managing the soil as a habitat', in. *Proc. Second World Cong. on Conservation Agriculture: producing in harmony with nature*, Iguassu Falls, Parana-Brazil, pp. 136–144.

Clergue, B. *et al.* (2005) 'Biodiversity: function and assessment in agricultural areas. A review', *Agronomy for Sustainable Development*, 25(1), pp. 1–15. doi:10.1051/agro:2004049.

Cloyd, R.A. (2020) 'How Effective Is Conservation Biological Control in Regulating Insect Pest Populations in Organic Crop Production Systems?', *Insects*, 11(11), p. 744. doi:10.3390/insects11110744.

Coelho, S. (2009) 'European Pesticide Rules Promote Resistance, Researchers Warn', *Science*, 323(5913), pp. 450–450. doi:10.1126/science.323.5913.450.

Corfdir, V. (2020) *Guide pratique des insectes et autres invertébrés des champs*. 2e éd. Paris: Éditions France agricole (Agriproduction).

Delacre, E. (2019) 'ARENA » Les carabes: mieux connaître leur cycle de vie', *ARENA*. Available at: https://arena-auximore.fr/carabes-cycle-vie-pilotage-cultures/ (Accessed: 27 May 2021).

Desender, K. *et al.* (2010) 'Changes in the distribution of carabid beetles in Belgium revisited: Have we halted the diversity loss?', *Biological Conservation*, 143(6), pp. 1549–1557. doi:10.1016/j.biocon.2010.03.039.

Diekötter, T. *et al.* (2016) 'Organic farming affects the potential of a granivorous carabid beetle to control arable weeds at local and landscape scales', *Agricultural and Forest Entomology*, 18(2), pp. 167–173. doi:https://doi.org/10.1111/afe.12150.

Donovan, M. (2020) 'What is conservation agriculture?', *CIMMYT*, 23 January. Available at: https://www.cimmyt.org/news/what-is-conservation-agriculture/ (Accessed: 23 May 2021).

Döring, T.F. and Kromp, B. (2003) 'Which carabid species benefit from organic agriculture?—a review of comparative studies in winter cereals from Germany and Switzerland', *Agriculture, Ecosystems & Environment*, 98(1), pp. 153–161. doi:10.1016/S0167-8809(03)00077-X.

Duflot, R. *et al.* (2022) ‘Farming intensity indirectly reduces crop yield through negative effects on agrobiodiversity and key ecological functions’, *Agriculture, Ecosystems & Environment*, 326, p. 107810. doi:10.1016/j.agee.2021.107810.

El-Danasoury, H. *et al.* (2017) ‘Predation by the carabid beetle *Harpalus rufipes* on the pest slug *Deroceras reticulatum* in the laboratory: *Harpalus rufipes* predation on *Deroceras reticulatum*’, *Annals of Applied Biology*, 170(2), pp. 251–262. doi:10.1111/aab.12337.

Epsky, N.D., Morrill, W.L. and Mankin, R.W. (2008) ‘Traps for Capturing Insects’, in Capinera, J.L. (ed.) *Encyclopedia of Entomology*. 2nd edn. Springer Netherlands, pp. 3887–3901.

Eyre, M. d. *et al.* (2012) ‘Ground beetle species (Carabidae, Coleoptera) activity and richness in relation to crop type, fertility management and crop protection in a farm management comparison trial’, *Annals of Applied Biology*, 161(2), pp. 169–179. doi:10.1111/j.1744-7348.2012.00562.x.

Eyre, M.D., Luff, M.L. and Leifert, C. (2013) ‘Crop, field boundary, productivity and disturbance influences on ground beetles (Coleoptera, Carabidae) in the agroecosystem’, *Agriculture, Ecosystems & Environment*, 165, pp. 60–67. doi:10.1016/j.agee.2012.12.009.

Eyre, M.D., McMillan, S.D. and Critchley, C.N.R. (2016) ‘Ground beetles (Coleoptera, Carabidae) as indicators of change and pattern in the agroecosystem: Longer surveys improve understanding’, *Ecological Indicators*, 68, pp. 82–88. doi:10.1016/j.ecolind.2015.11.009.

Fadl, A., Purvis, G. and Towey, K. (1996) ‘The effect of time of soil cultivation on the incidence of Pterostichus melanarius (Illig.) (Coleoptera: Carabidae) in arable land in Ireland’, 33, p. 8.

Fischer, C. *et al.* (2021) ‘Large carabids enhance weed seed removal in organic fields and in large-scale, but not small-scale agriculture’, *Landscape Ecology*, 36(2), pp. 427–438. doi:10.1007/s10980-020-01157-8.

Fleury, P., Chazoule, C. and Peigné, J. (2011) ‘Agriculture biologique et agriculture de conservation : ruptures et transversalités entre deux communautés de pratiques’, pp. 1–12.

Gaines, H.R. and Gratton, C. (2010) ‘Seed predation increases with ground beetle diversity in a Wisconsin (USA) potato agroecosystem’, *Agriculture, Ecosystems & Environment*, 137(3), pp. 329–336. doi:10.1016/j.agee.2010.03.003.

Gallé, R. *et al.* (2019) ‘Landscape configuration, organic management, and within-field position drive functional diversity of spiders and carabids’, *Journal of Applied Ecology*, 56(1), pp. 63–72. doi:10.1111/1365-2664.13257.

Gobbi, M. (2014) ‘Application of the mean individual biomass of ground beetles (Coleoptera: Carabidae) to assess the assemblage successions along areas of recent glacier retreats’, *European Journal of Entomology*, 111(4), pp. 537–541. doi:10.14411/eje.2014.071.

Gouix, N. and Brustel, H. (2012) ‘Emergence trap, a new method to survey Limoniscus violaceus (Coleoptera: Elateridae) from hollow trees’, *Biodiversity and Conservation*, 21(2), pp. 421–436. doi:10.1007/s10531-011-0190-1.

Gould, F., Brown, Z.S. and Kuzma, J. (2018) ‘Wicked evolution: Can we address the sociobiological dilemma of pesticide resistance?’, *Science*, 360(6390), pp. 728–732. doi:10.1126/science.aar3780.

de Graaff, M.-A. *et al.* (2019) ‘Chapter One - Effects of agricultural intensification on soil biodiversity and implications for ecosystem functioning: A meta-analysis’, in Sparks, D.L. (ed.) *Advances in Agronomy*. Academic Press, pp. 1–44. doi:10.1016/bs.agron.2019.01.001.

Hackston, M. (2013) ‘Family Carabidae. Key to genus after Lindroth (1974)’

Hance, T. (1987) ‘Predation impact of carabids at different population densities on Aphis fabae development in sugar beet’, *Pedobiologia (Jena)*, 30(4), pp. 251–262.

Hancock, M.H. and Legg, C.J. (2012) ‘Pitfall trapping bias and arthropod body mass’, *Insect Conservation and Diversity*, 5(4), pp. 312–318. doi:https://doi.org/10.1111/j.1752-4598.2011.00162.x.

Harrison, S. and Gallandt, E.R. (2012) ‘Behavioural Studies of Harpalus rufipes De Geer: an Important Weed Seed Predator in Northeastern US Agroecosystems’, *International Journal of Ecology*, 2012, p. e846546. doi:10.1155/2012/846546.

Hatten, T.D. *et al.* (2007) ‘Effects of Tillage on the Activity Density and Biological Diversity of Carabid Beetles in Spring and Winter Crops’, *Environmental Entomology*, 36(2), pp. 356–368. doi:10.1093/ee/36.2.356.

Holland, J. (2002) ‘Carabid beetles: their ecology, survival and use in agroecosystems’, in Holland, J.M. (ed.) *The Agroecology of Carabid Beetles*. Intercept, pp. 1–40.

Holland, J.M. and Luff, M.L. (2000) ‘The Effects of Agricultural Practices on Carabidae in Temperate Agroecosystems’, *Integrated Pest Management Reviews*, 5(2), pp. 109–129. doi:10.1023/A:1009619309424.

Holland, J.M. and Reynolds, C.J.M. (2003) ‘The impact of soil cultivation on arthropod (Coleoptera and Araneae) emergence on arable land’, *Pedobiologia*, 47(2), pp. 181–191. doi:10.1078/0031-4056-00181.

Honek, A. *et al.* (2007) ‘Size and taxonomic constraints determine the seed preferences of Carabidae (Coleoptera)’, *Basic and Applied Ecology*, 8(4), pp. 343–353. doi:10.1016/j.baae.2006.07.002.

Irmler, U. (2018) ‘Which carabid species (Coleoptera: Carabidae) profit from organic farming after a succession of 15 years?’, *Agriculture, Ecosystems & Environment*, 263, pp. 1–6. doi:10.1016/j.agee.2018.02.019.

Jeannel, R. (1941) *Faune de France Coléoptères carabiques*. 1st edn. Paris: Fédération française des sociétés de sciences naturelles (Faune de France).

Jowett, K. *et al.* (2021) ‘Above- and below-ground assessment of carabid community responses to crop type and tillage’, *Agricultural and Forest Entomology*, 23(1), pp. 1–12. doi:10.1111/afe.12397.

Kassam, A., Friedrich, T. and Derpsch, R. (2018) ‘Global spread of Conservation Agriculture’, *International Journal of Environmental Studies*, 76(1), pp. 29–51. doi:10.1080/00207233.2018.1494927.

Kennedy, T.F. *et al.* (2013) ‘A comparison of the effects of minimum-till and conventional-till methods, with and without straw incorporation, on slugs, slug damage, earthworms and carabid beetles in autumn-sown cereals’, *The Journal of Agricultural Science*, 151(5), pp. 605–629. doi:10.1017/S0021859612000706.

Kotze, D.J. *et al.* (2011) ‘Forty years of carabid beetle research in Europe – from taxonomy, biology, ecology and population studies to bioindication, habitat assessment and conservation’, *ZooKeys*, 100, pp. 55–148. doi:10.3897/zookeys.100.1523.

Kotze, D.J. and O’Hara, R.B. (2003) ‘Species decline—but why? Explanations of carabid beetle (Coleoptera, Carabidae) declines in Europe’, *Oecologia*, 135(1), pp. 138–148. doi:10.1007/s00442-002-1174-3.

Kromp, B. (1999) ‘Carabid beetles in sustainable agriculture: a review on pest control efficacy, cultivation impacts and enhancement’, *Agriculture, Ecosystems & Environment*, 74(1–3), pp. 187–228. doi:10.1016/S0167-8809(99)00037-7.

Kulkarni, S.S. *et al.* (2015) ‘Depth of Seed Burial and Gender Influence Weed Seed Predation by Three Species of Ground Beetle (Coleoptera: Carabidae)’, *Weed Science*, 63(4), pp. 910–915. doi:10.1614/WS-D-15-00080.1.

Lami, F. *et al.* (2020) ‘Seed predation intensity and stability in agro-ecosystems: Role of predator diversity and soil disturbance’, *Agriculture, Ecosystems & Environment*, 288, p. 106720. doi:10.1016/j.agee.2019.106720.

Landers, J.N. *et al.* (2021) ‘Next Steps for Conservation Agriculture’, *Agronomy*, 11(12), p. 2496. doi:10.3390/agronomy11122496.

Langellotto, G.A. and Denno, R.F. (2004) ‘Responses of invertebrate natural enemies to complex-structured habitats: a meta-analytical synthesis’, *Oecologia*, 139(1), pp. 1–10. doi:10.1007/s00442-004-1497-3.

Larsson, S.G. (1939) ‘Entwicklungstypen und Entwicklungszeiten der Danischen Carabiden’, *Entomologiske Meddedelelser*, 20, pp. 277–560.

Lescaudron, C. (2020) ‘ARENA » Une caméra pour les cartes de prédation’, *ARENA*. Available at: https://arena-auximore.fr/une-camera-pour-les-cartes-de-predation/ (Accessed: 20 January 2021).

Lindroth, C. (1974) *Coleoptera Carabidae*. 1st edn. London: Royal Entomological Society (Handbooks for the identification of british insects).

Lövei, G.L. and Sunderland, K.D. (1996) ‘Ecology and Behavior of Ground Beetles (Coleoptera: Carabidae)’, *Annual Review of Entomology*, 41(1), pp. 231–256. doi:10.1146/annurev.en.41.010196.001311.

Luff, M.L. (1975) ‘Some features influencing the efficiency of pitfall traps’, *Oecologia*, 19(4), pp. 345–357. doi:10.1007/BF00348110.

Ma, C.-S. *et al.* (2021) ‘Climate warming promotes pesticide resistance through expanding overwintering range of a global pest’, *Nature Communications*, 12(1), p. 5351. doi:10.1038/s41467-021-25505-7.

Mabin, M.D., Welty, C. and Gardiner, M.M. (2020) ‘Predator richness predicts pest suppression within organic and conventional summer squash (Cucurbita pepo L. Cucurbitales: Cucurbitaceae)’, *Agriculture, Ecosystems & Environment*, 287, p. 106689. doi:10.1016/j.agee.2019.106689.

Matalin, A.V. (2007) ‘Typology of life cycles of ground beetles (Coleoptera, Carabidae) in Western Palaearctic’, *Entomological Review*, 87(8), pp. 947–972. doi:10.1134/S0013873807080027.

Melander, L. (1914) ‘Can insects become resistant to sprays ?’, *Journal of Economic Entomology*, 15, pp. 167–173.

Melbourne, B.A. (1999) ‘Bias in the effect of habitat structure on pitfall traps: An experimental evaluation’, *Austral Ecology*, 24(3), pp. 228–239. doi:10.1046/j.1442-9993.1999.00967.x.

Menalled, F.D. *et al.* (2007) ‘Impact of agricultural management on carabid communities and weed seed predation’, *Agriculture, Ecosystems & Environment*, 118(1–4), pp. 49–54. doi:10.1016/j.agee.2006.04.011.

Navntoft, S., Esbjerg, P. and Riedel, W. (2006) ‘Effects of reduced pesticide dosages on carabids (Coleoptera: Carabidae) in winter wheat’, *Agricultural and Forest Entomology*, 8(1), pp. 57–62. doi:10.1111/j.1461-9555.2006.00282.x.

Néron, F. (2018) *Petit précis d’agriculture: de la politique à la technique le contexte de l’exploitation agricole, les productions végétales et animales, les différents types d’agriculture*. 3e éd. Paris: Éditions France agricole (Agriproduction).

Nichols, V. *et al.* (2015) ‘Weed dynamics and conservation agriculture principles: A review’, *Field Crops Research*, 183, pp. 56–68. doi:10.1016/j.fcr.2015.07.012.

Oerke, E.-C. (2006) ‘Crop losses to pests’, *The Journal of Agricultural Science*, 144(1), pp. 31–43. doi:10.1017/S0021859605005708.

O’Neal, M.E. *et al.* (2005) ‘Assessing Carabid Contribution to Ecosystem Services: Does It Matter If There Are More Beetles?’, *American Entomologist*, 51(4), pp. 231–233. doi:10.1093/ae/51.4.231.

O’Sullivan, C.M. and Gormally, M.J. (2002) ‘A Comparison of Ground Beetle (Carabidae: Coleoptera) Communities in an Organic and Conventional Potato Crop’, *Biological Agriculture & Horticulture*, 20(2), pp. 99–110. doi:10.1080/01448765.2002.9754954.

Peigné, J. *et al.* (2016) ‘How organic farmers practice conservation agriculture in Europe’, *Renewable Agriculture and Food Systems*, 31(1), pp. 72–85. doi:10.1017/S1742170514000477.

Pekár, S. (2002) ‘Differential effects of formaldehyde concentration and detergent on the catching efficiency of surface active arthropods by pitfall traps’, *Pedobiologia*, 46(6), pp. 539–547. doi:10.1078/0031-4056-00158.

Perez-Alvarez, R. *et al.* (2021) ‘Landscape composition mediates the relationship between predator body size and pest control’, *Ecological Applications*, 31(6). doi:10.1002/eap.2365.

Pierre, C. (2020) *Bio et agriculture de conservation sont-elles vraiment incompatibles ?*, *Aladin*. Available at: https://genie.aladin.farm/bio-et-agriculture-de-conservation-sont-elles-vraiment-incompatibles/ (Accessed: 23 May 2021).

Ponge, J.F. *et al.* (2003) ‘Collembolan communities as bioindicators of land use intensification’, *Soil Biology and Biochemistry*, 35(6), pp. 813–826. doi:10.1016/S0038-0717(03)00108-1.

Prasad, R.P. and Snyder, W.E. (2004) ‘Predator interference limits fly egg biological control by a guild of ground-active beetles’, *Biological Control*, 31(3), pp. 428–437. doi:10.1016/j.biocontrol.2004.07.005.

Prasad, R.P. and Snyder, W.E. (2006) ‘Polyphagy complicates conservation biological control that targets generalist predators: Polyphagy and biological control’, *Journal of Applied Ecology*, 43(2), pp. 343–352. doi:10.1111/j.1365-2664.2006.01129.x.

Puech, C. *et al.* (2014) ‘Organic vs. conventional farming dichotomy: Does it make sense for natural enemies?’, *Agriculture, Ecosystems & Environment*, 194, pp. 48–57. doi:10.1016/j.agee.2014.05.002.

Puech, C. *et al.* (2015) ‘Do farming practices affect natural enemies at the landscape scale?’, *Landscape Ecology*, 30(1), pp. 125–140. doi:10.1007/s10980-014-0103-2.

Resende, B.O. de *et al.* (2020) ‘Emergence trap for the collection of exuviae and adult of Odonata’, *Oecologia Australis*, 24(03), pp. 742–747. doi:10.4257/oeco.2020.2403.18.

Rivers, A. *et al.* (2016) ‘Conservation agriculture affects arthropod community composition in a rainfed maize–wheat system in central Mexico’, *Applied Soil Ecology*, 100, pp. 81–90. doi:10.1016/j.apsoil.2015.12.004.

Roger, J.L. *et al.* (2012) ‘Clé de détermination des Carabides. Paysages agricoles du Nord Ouest de la France.’

Roger-Estrade, J. *et al.* (2010) ‘Tillage and soil ecology: Partners for sustainable agriculture’, *Soil and Tillage Research*, 111(1), pp. 33–40. doi:10.1016/j.still.2010.08.010.

Roschewitz, I. *et al.* (2005) ‘The effects of landscape complexity on arable weed species diversity in organic and conventional farming’, *Journal of Applied Ecology*, 42(5), pp. 873–882. doi:10.1111/j.1365-2664.2005.01072.x.

Roubinet, E. *et al.* (2017) ‘Diet of generalist predators reflects effects of cropping period and farming system on extra- and intraguild prey’, *Ecological Applications*, 27(4), pp. 1167–1177. doi:10.1002/eap.1510.

Rowen, E.K. *et al.* (2020) ‘Is tillage beneficial or detrimental for insect and slug management? A meta-analysis’, *Agriculture, Ecosystems & Environment*, 294, p. 106849. doi:10.1016/j.agee.2020.106849.

Rusch, A. *et al.* (2013) ‘Response of ground beetle (Coleoptera, Carabidae) communities to changes in agricultural policies in Sweden over two decades’, *Agriculture, Ecosystems & Environment*, 176, pp. 63–69. doi:10.1016/j.agee.2013.05.014.

Rusch, A. *et al.* (2015) ‘Predator body sizes and habitat preferences predict predation rates in an agroecosystem’, *Basic and Applied Ecology*, 16(3), pp. 250–259. doi:10.1016/j.baae.2015.02.003.

Sasakawa, K., Ikeda, H. and Kubota, T. (2010) ‘Feeding ecology of granivorous carabid larvae: a stable isotope analysis’, *Journal of Applied Entomology*, 134(2), pp. 116–122. doi:10.1111/j.1439-0418.2009.01451.x.

Saska, P. (2008) ‘Composition of weed community determines carabid assemblage’, in Penev, L., Erwin, T., and Assmann, T. (eds) *Back to roots of back to the future. Towards a new synthesis amongst taxonomic, ecological and biogeographical approaches in carabidology*. Pensoft, Sofia, pp. 339–351.

Shearin, A.F., Reberg-Horton, S.C. and Gallandt, E.R. (2007) ‘Direct Effects of Tillage on the Activity Density of Ground Beetle (Coleoptera: Carabidae) Weed Seed Predators’, *Environmental Entomology*, 36(5), pp. 1140–1146. doi:10.1603/0046-225X(2007)36[1140:DEOTOT]2.0.CO;2.

Søgaard Jørgensen, P. *et al.* (2020) ‘Coevolutionary Governance of Antibiotic and Pesticide Resistance’, *Trends in Ecology & Evolution*, 35(6), pp. 484–494. doi:10.1016/j.tree.2020.01.011.

Sunderland, K.D. and Vickerman, G.P. (1980) ‘Aphid Feeding by Some Polyphagous Predators in Relation to Aphid Density in Cereal Fields’, *Journal of Applied Ecology*, 17(2), pp. 389–396. doi:10.2307/2402334.

Symondson, W.O.C. *et al.* (1996) ‘Effects of Cultivation Techniques and Methods of Straw Disposal on Predation by Pterostichus melanarius (Coleoptera: Carabidae) Upon Slugs (Gastropoda: Pulmonata) in an Arable Field’, *Journal of Applied Ecology*, 33(4), pp. 741–753. doi:10.2307/2404945.

Symondson, W.O.C. *et al.* (2000) ‘Do earthworms help to sustain the slug predator Pterostichus melanarius (Coleoptera: Carabidae) within crops? Investigations using monoclonal antibodies’, *Molecular Ecology*, 9(9), pp. 1279–1292. doi:10.1046/j.1365-294x.2000.01006.x.

Tamburini, G. *et al.* (2016) ‘Soil management shapes ecosystem service provision and trade-offs in agricultural landscapes’, *Proceedings of the Royal Society B: Biological Sciences*, 283(1837), p. 20161369. doi:10.1098/rspb.2016.1369.

Trichard, A. *et al.* (2014) ‘The spatio-temporal distribution of weed seed predation differs between conservation agriculture and conventional tillage’, *Agriculture, Ecosystems & Environment*, 188, pp. 40–47. doi:10.1016/j.agee.2014.01.031.

Tscharntke, T. *et al.* (2005) ‘Landscape perspectives on agricultural intensification and biodiversity – ecosystem service management’, *Ecology Letters*, 8(8), pp. 857–874. doi:10.1111/j.1461-0248.2005.00782.x.

Tuck, S.L. *et al.* (2014) ‘Land-use intensity and the effects of organic farming on biodiversity: a hierarchical meta-analysis’, *Journal of Applied Ecology*, 51(3), pp. 746–755. doi:10.1111/1365-2664.12219.

Ulyshen, M.D., Hanula, J.L. and Horn, S. (2005) ‘Using Malaise traps to sample ground beetles (Coleoptera: Carabidae)’, *The Canadian Entomologist*, 137(2), pp. 251–256. doi:10.4039/n04-035.

Venturini, T. (2006) ‘Les trous noirs de la révolution verte’, *Entropia - Décroissance et technique*, 3. Available at: https://hal.archives-ouvertes.fr/hal-02102597 (Accessed: 25 May 2021).

Vickerman, G.P. and Sunderland, K.D. (1977) ‘Some Effects of Dimethoate on Arthropods in Winter Wheat’, *The Journal of Applied Ecology*, 14(3), p. 767. doi:10.2307/2402808.

Weiner, J., Griepentrog, H.-W. and Kristensen, L. (2001) ‘Suppression of Weeds by Spring Wheat Triticum aestivum Increases with Crop Density and Spatial Uniformity’, *Journal of Applied Ecology*, 38(4), pp. 784–790.

Withers, P. *et al.* (2014) ‘Agriculture and Eutrophication: Where Do We Go from Here?’, *Sustainability*, 6(9), pp. 5853–5875. doi:10.3390/su6095853.

Yi, Z. *et al.* (2012) ‘A Comparison of Terrestrial Arthropod Sampling Methods’, *Journal of Resources and Ecology*, 3(2), pp. 174–182. doi:10.5814/j.issn.1674-764x.2012.02.010.

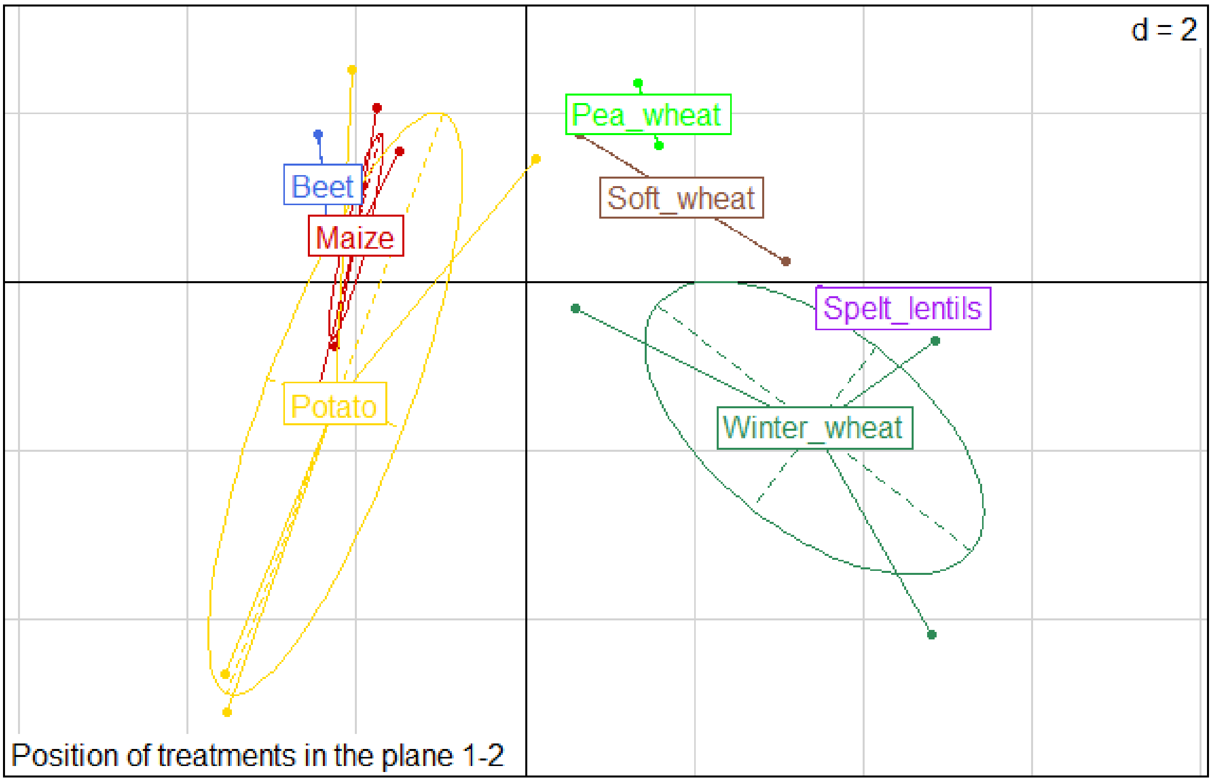
Zhang, W. *et al.* (2007) ‘Ecosystem services and dis-services to agriculture’, *Ecological Economics*, 64(2), pp. 253–260. doi:10.1016/j.ecolecon.2007.02.024.

Appendix

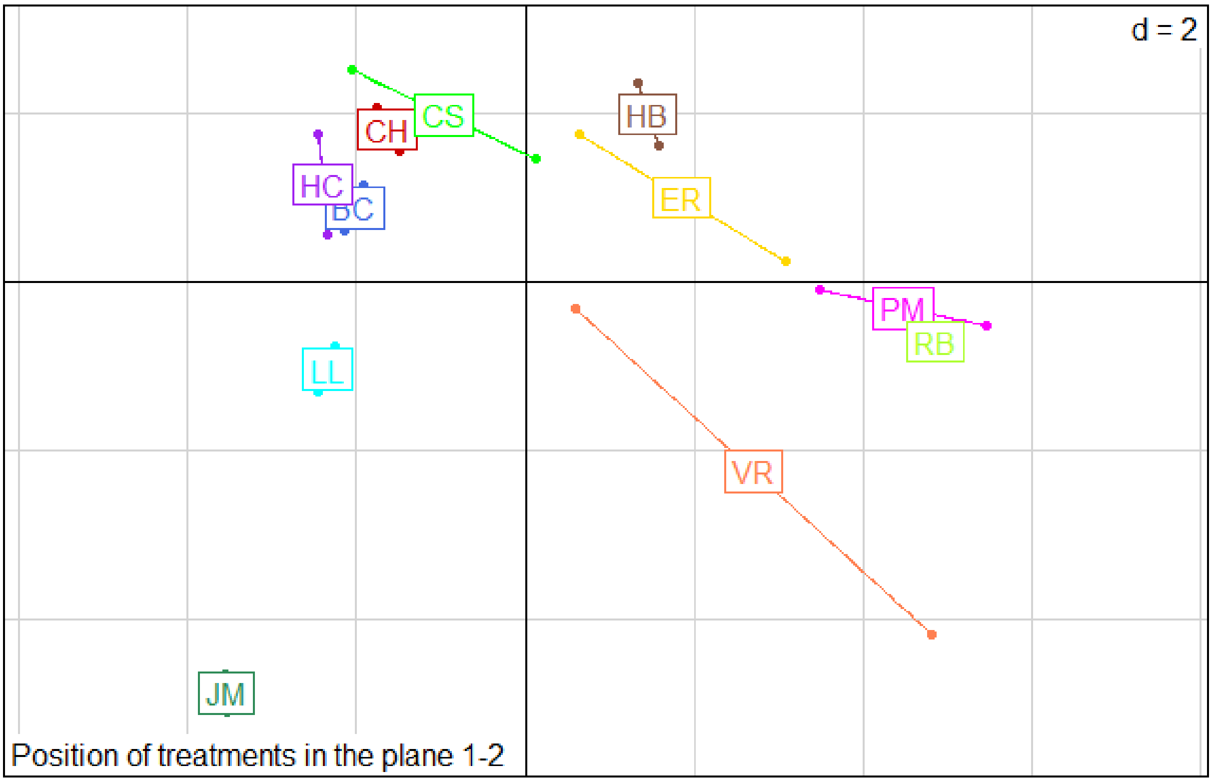
In each figure where it is depicted, LAB = Deep ploughing and TCS_sup = Superficial TCS

2020 – Early June

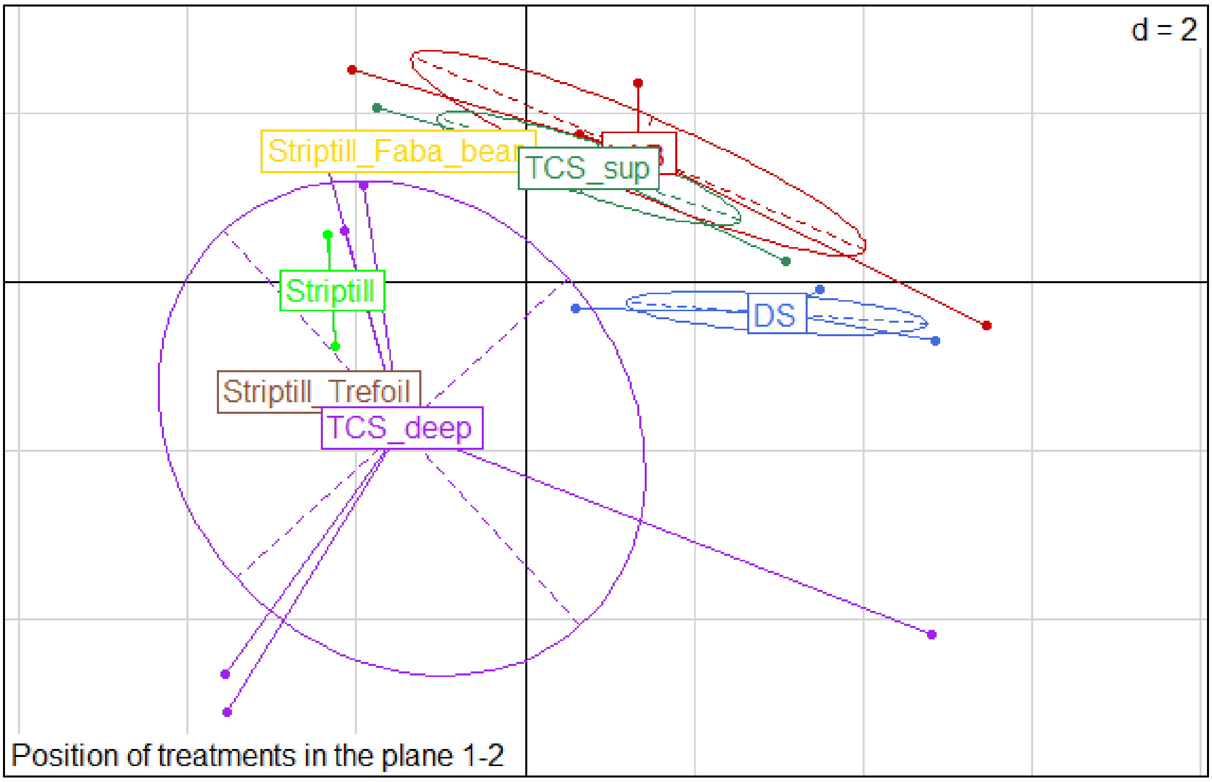
PCA



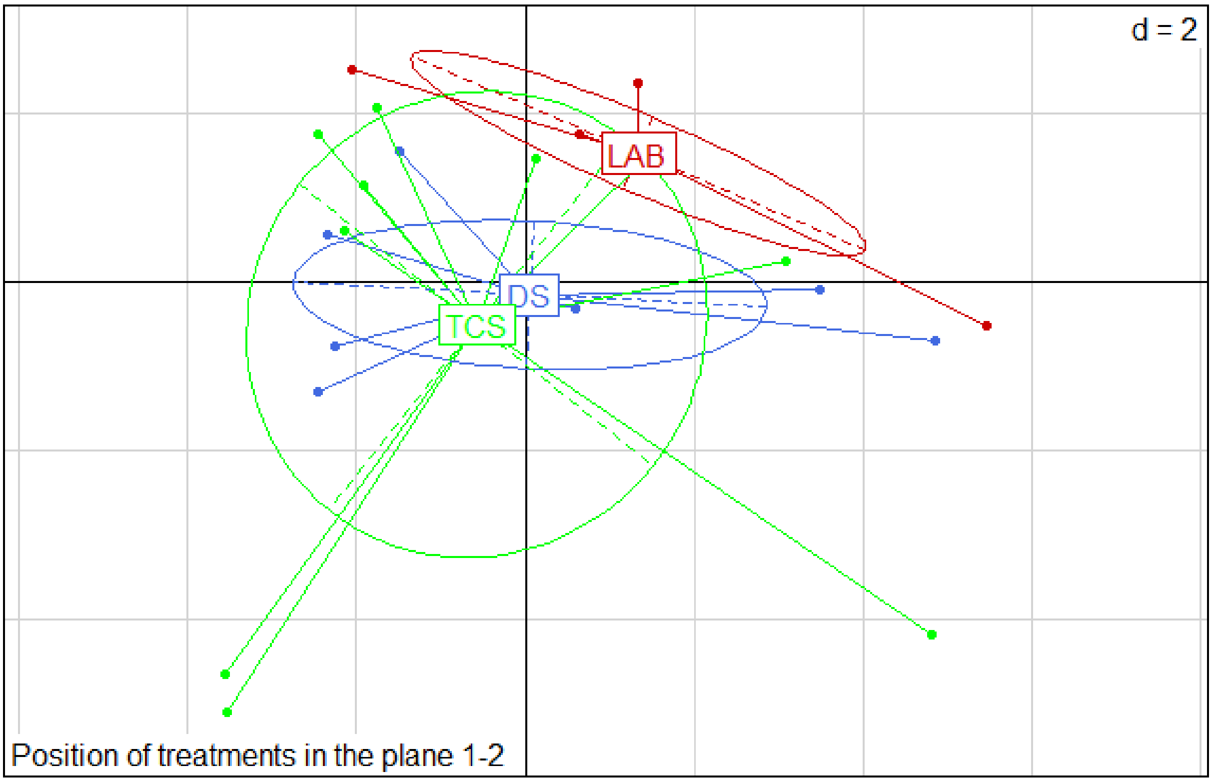
Appendix 1 : Position of the crop in in the plane formed by the first two axes of the PCA for early June 2020



Appendix 2 : Position of the site in in the plane formed by the first two axes of the PCA for early June 2020

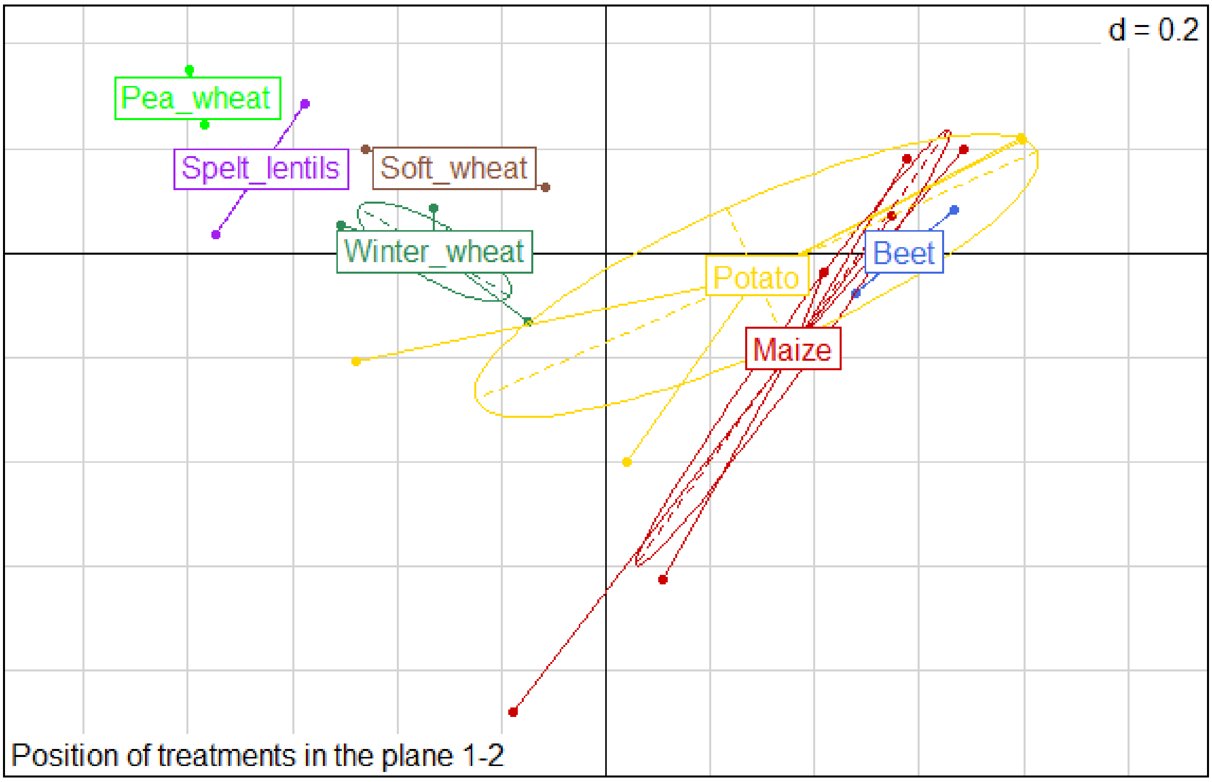


Appendix 3 : Position of the tillage in in the plane formed by the first two axes of the PCA for early June 2020

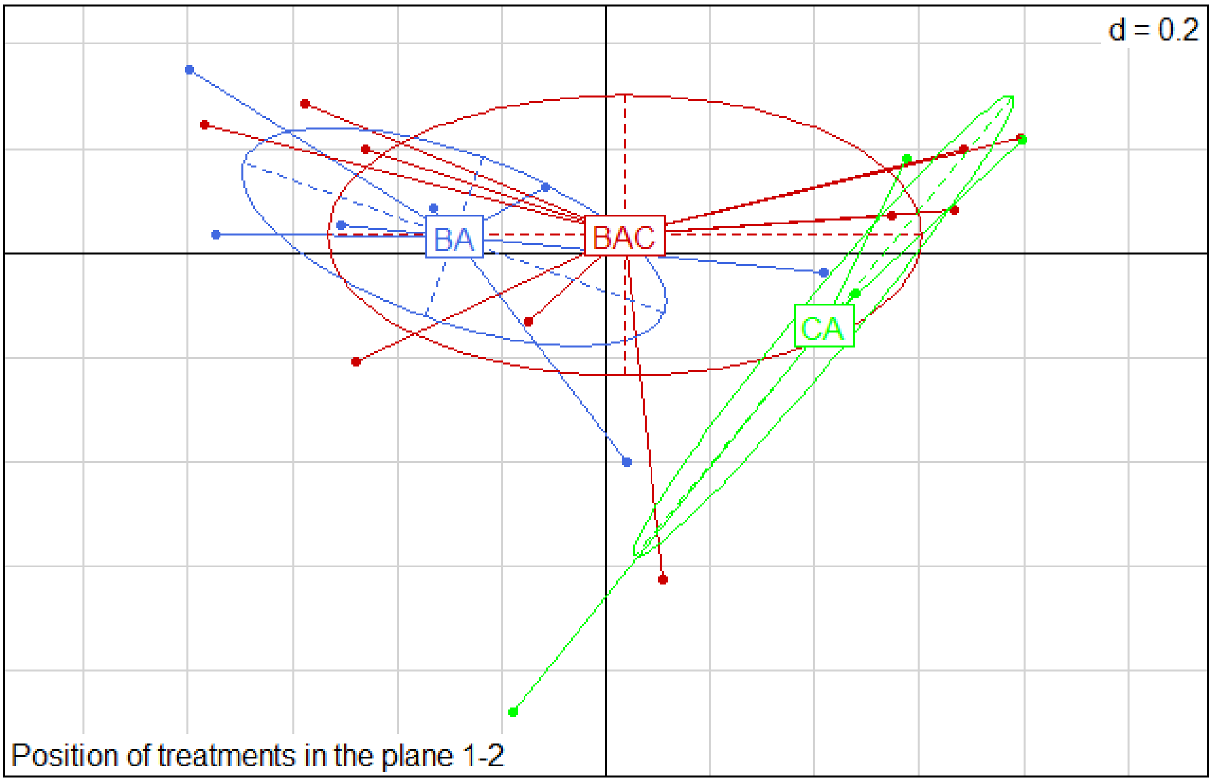


Appendix 4 : Position of the simplified tillage in in the plane formed by the first two axes of the PCA for early June 2020

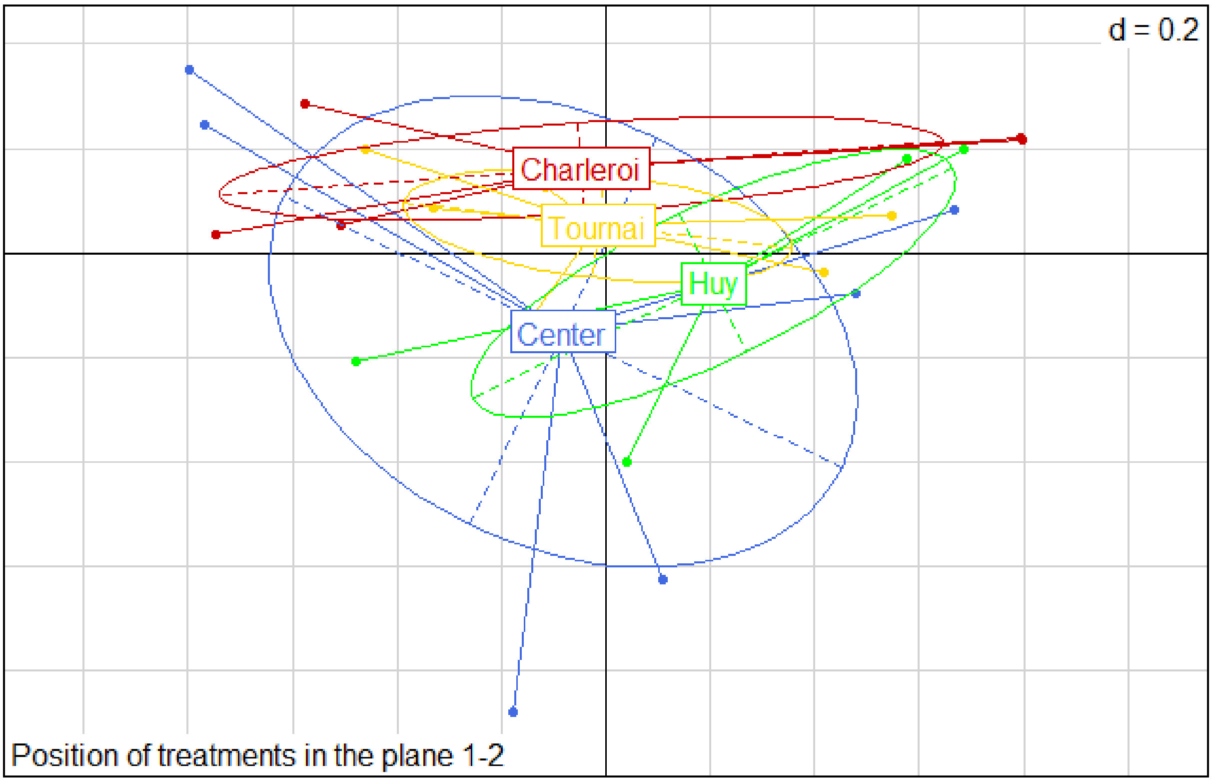
Fuzzy FCA



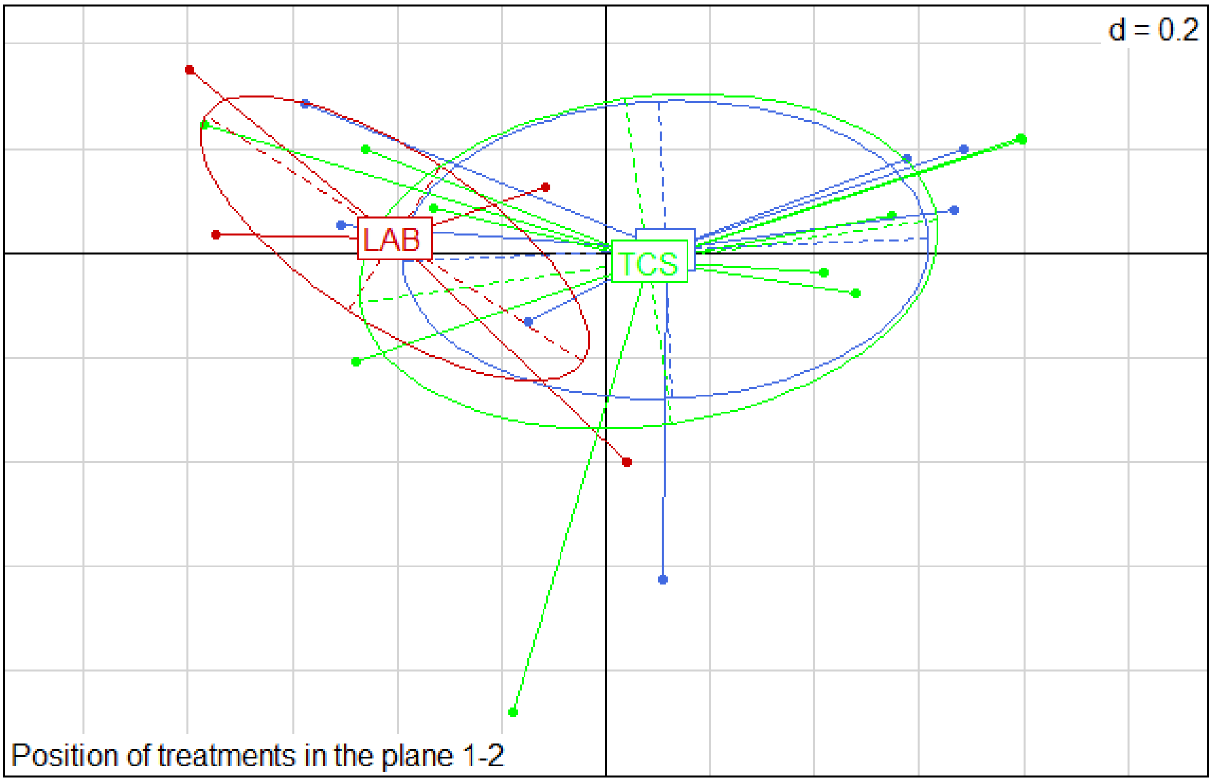
Appendix 5 : Position of the crop in in the plane formed by the first two axes of the fuzzy FCA for early June 2020



Appendix 6 : Position of the modality in in the plane formed by the first two axes of the fuzzy FCA for early June 2020



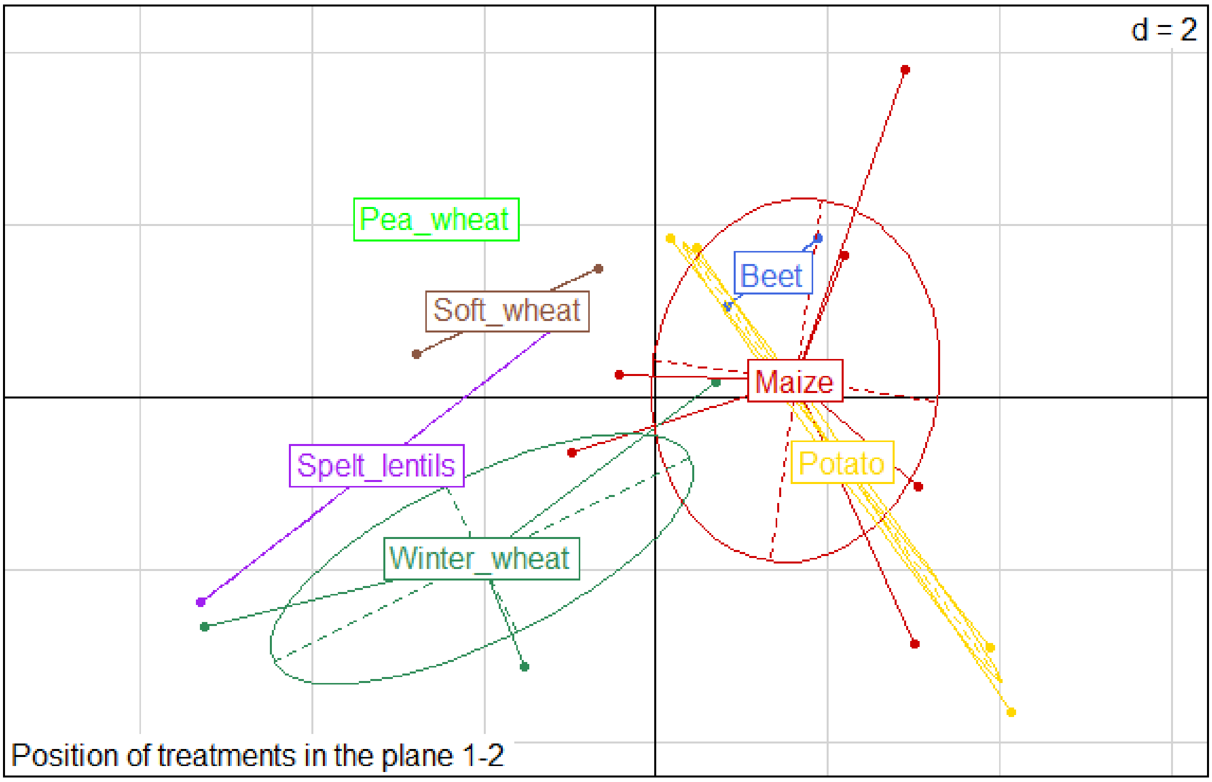
Appendix 7 : Position of the region in in the plane formed by the first two axes of the fuzzy FCA for early June 2020



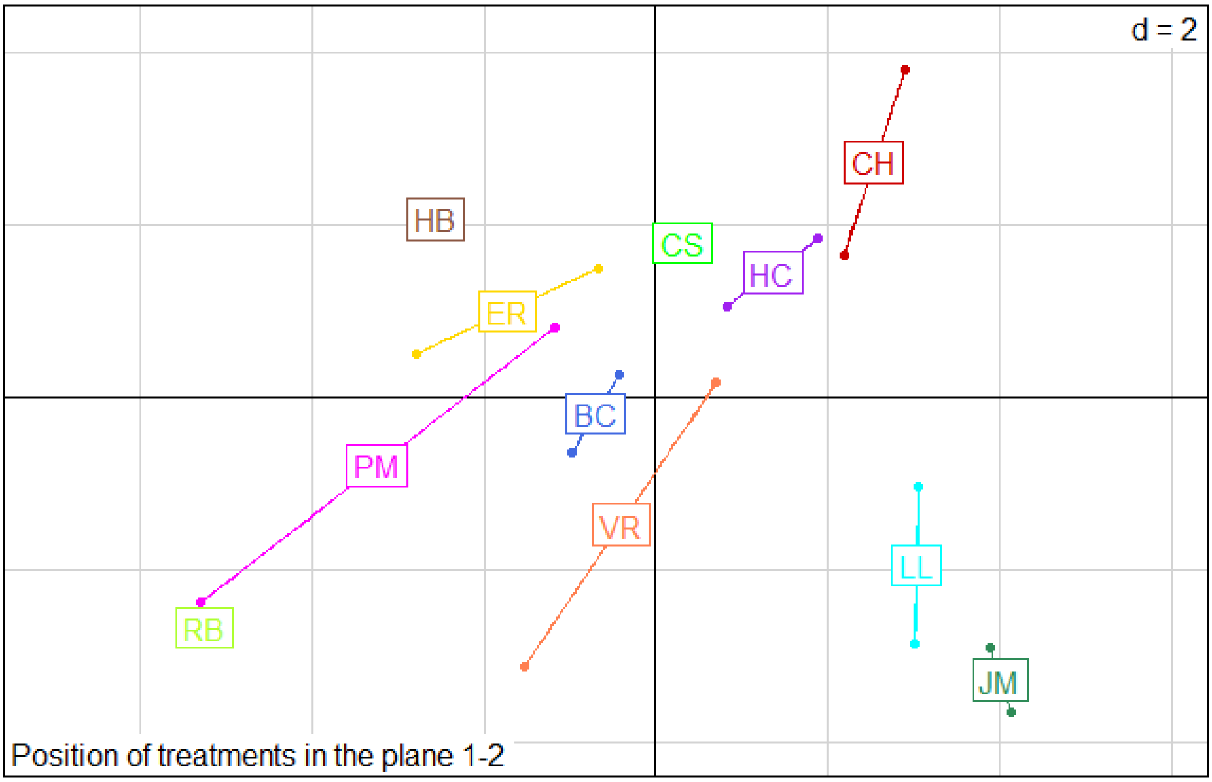
Appendix 8 : Position of the tillage in in the plane formed by the first two axes of the fuzzy FCA for early June 2020

2020 – Late June

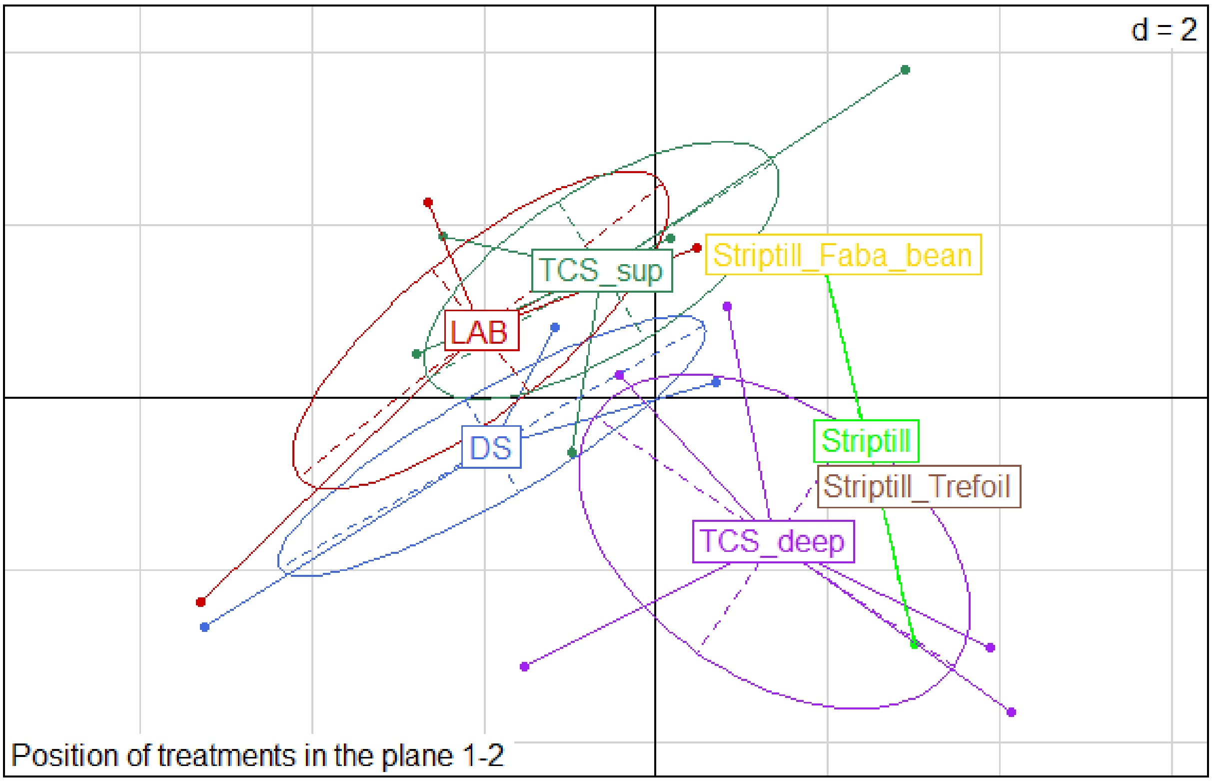
PCA



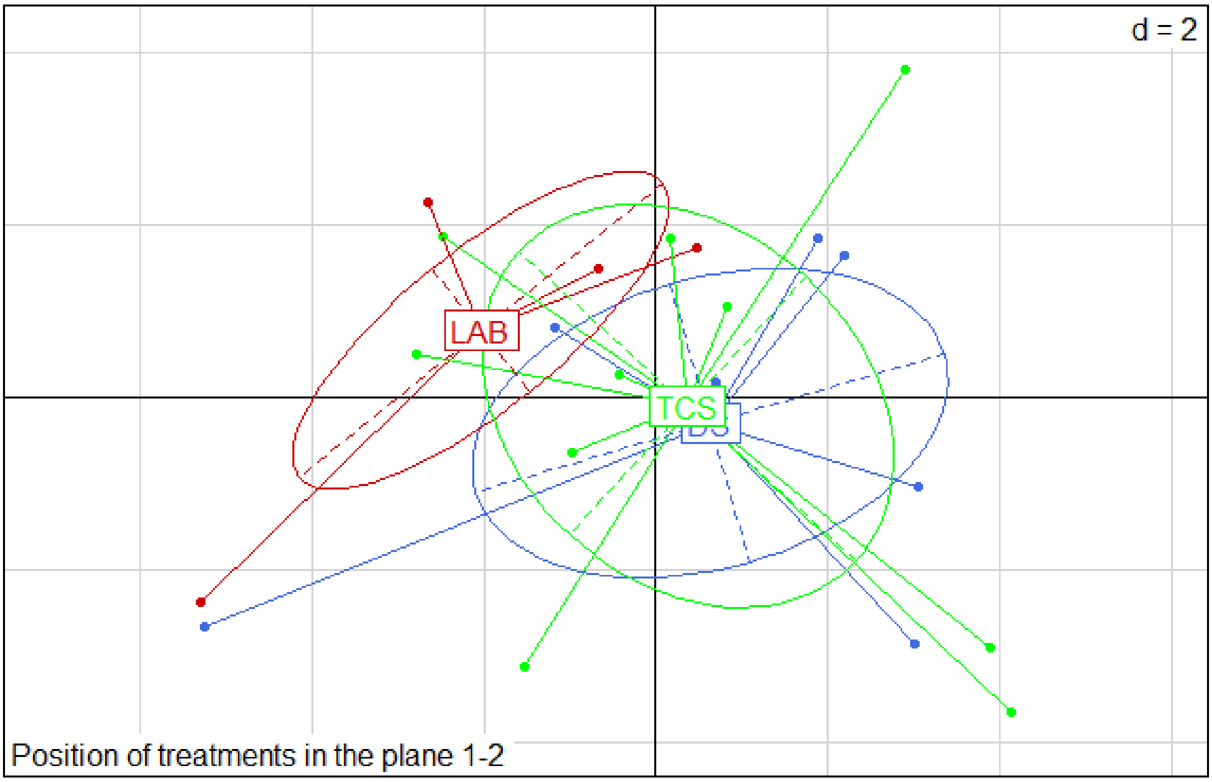
Appendix 9 : Position of the crop in in the plane formed by the first two axes of the PCA for late June 2020



Appendix 10 : Position of the site in in the plane formed by the first two axes of the PCA for late June 2020

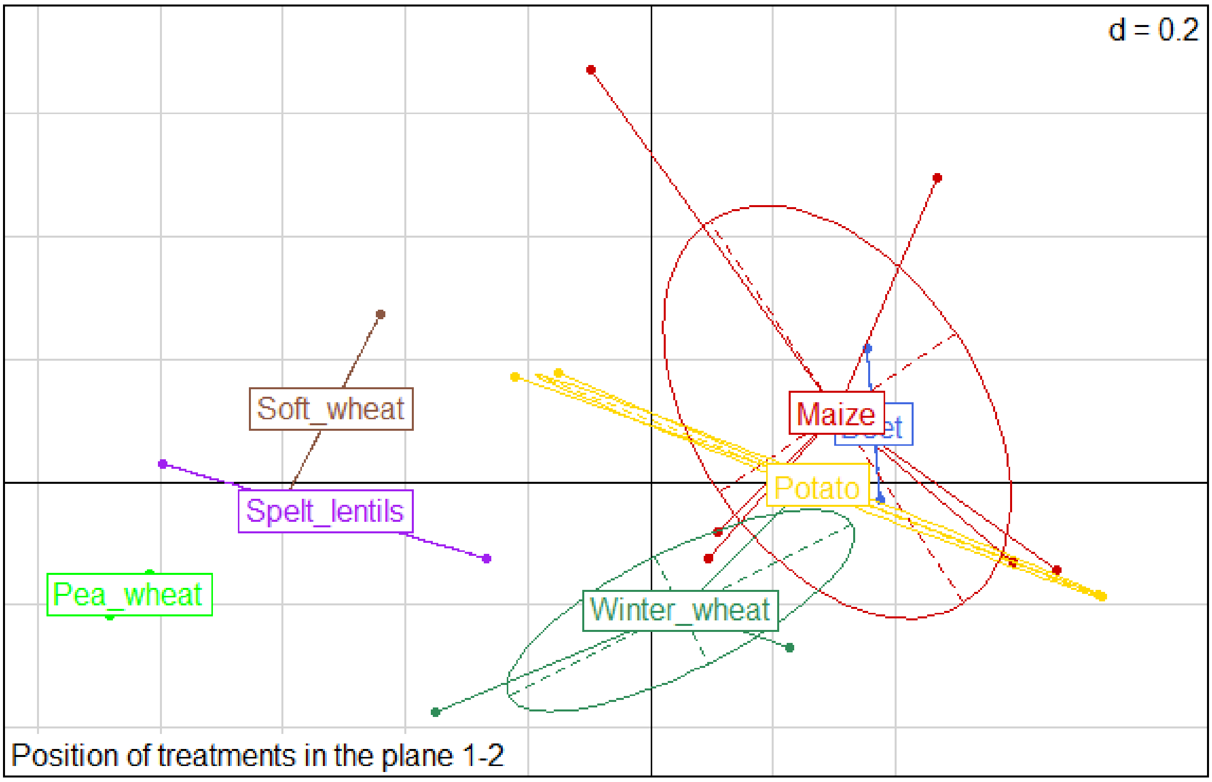


Appendix 11 : Position of the tillage in in the plane formed by the first two axes of the PCA for late June 2020

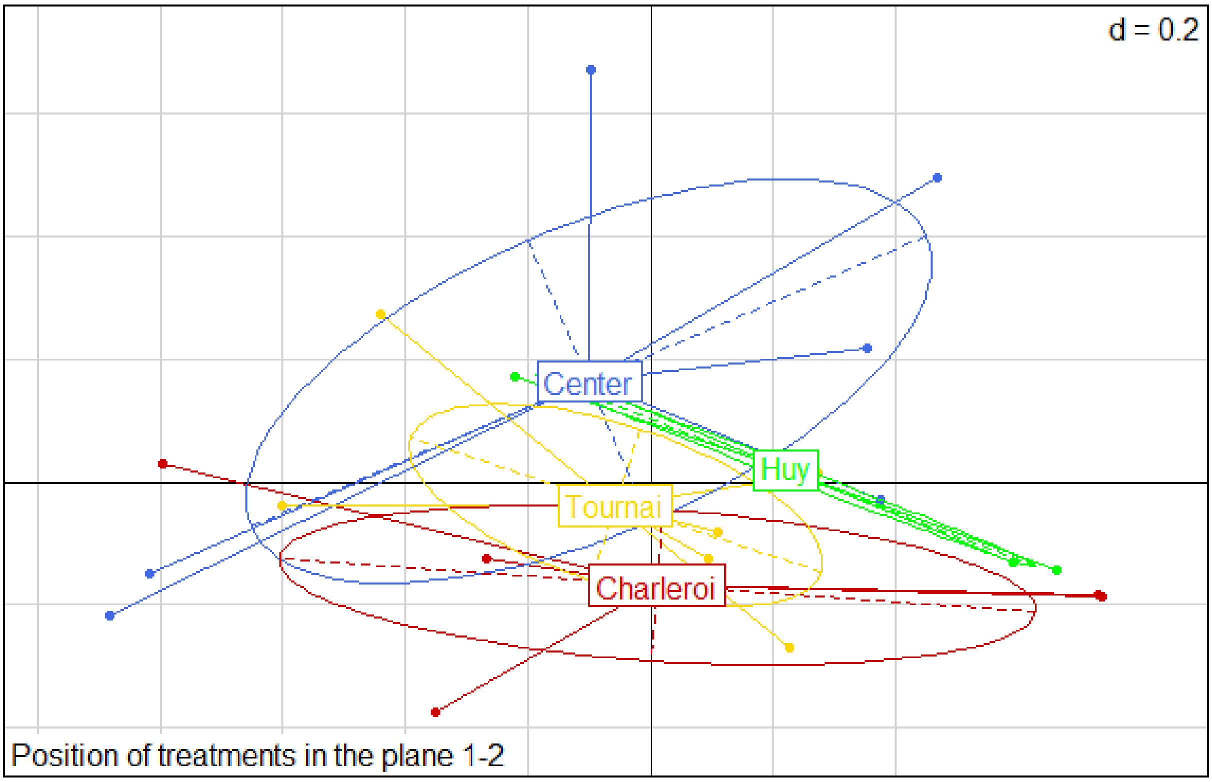


Appendix 12 : Position of the simplified tillage in in the plane formed by the first two axes of the PCA for late June 2020

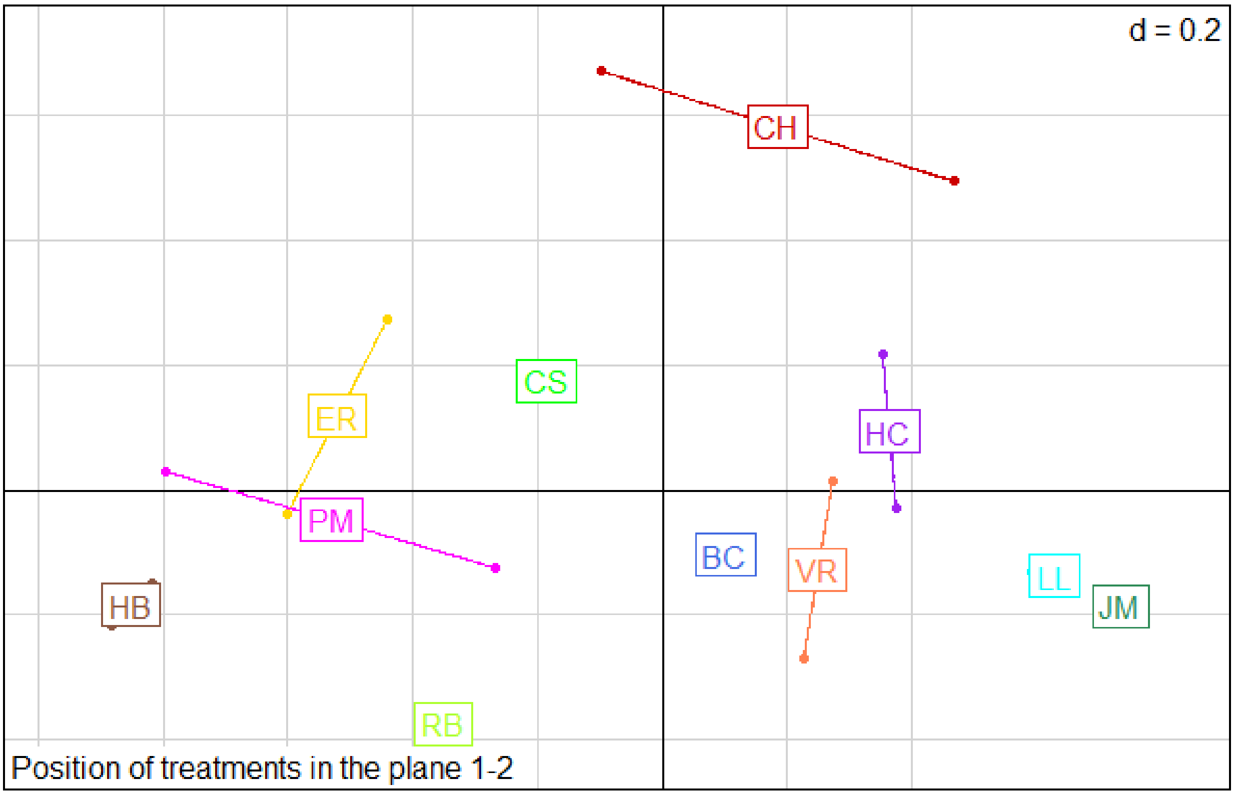
Fuzzy FCA



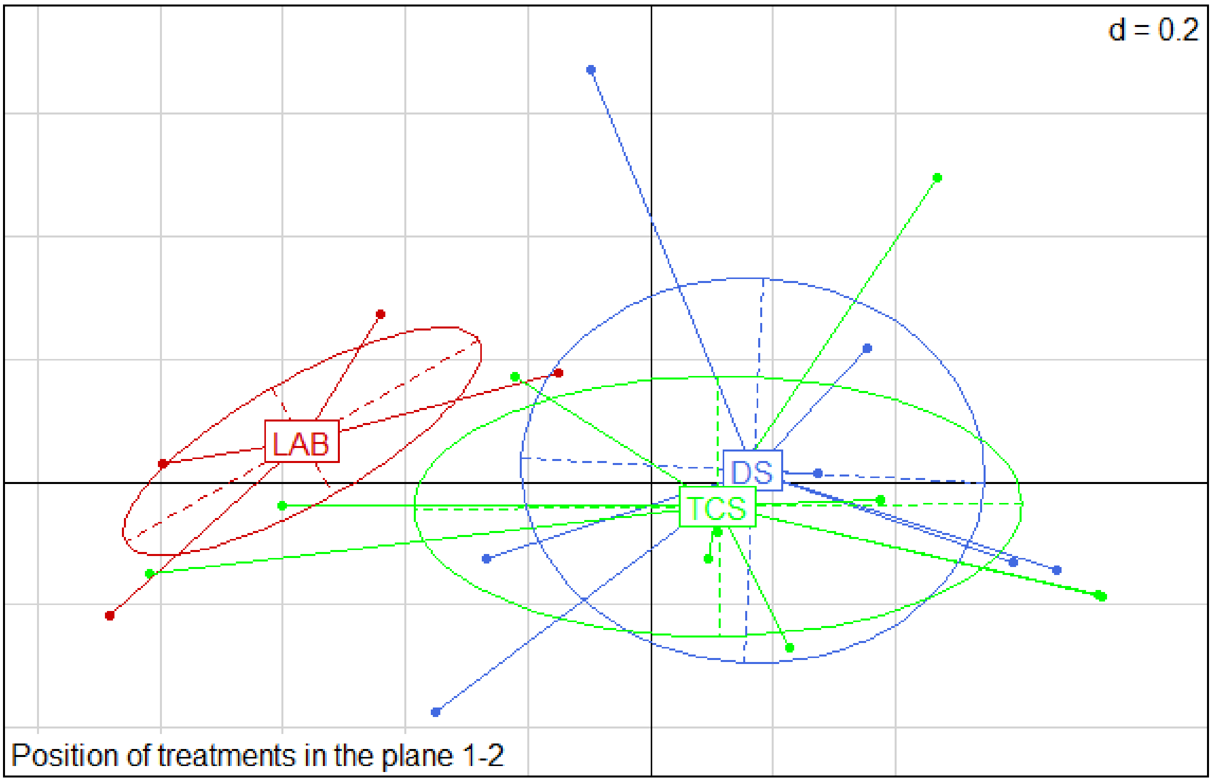
Appendix 13 : Position of the crop in in the plane formed by the first two axes of the fuzzy FCA for late June 2020



Appendix 14 : Position of the region in in the plane formed by the first two axes of the fuzzy FCA for late June 2020



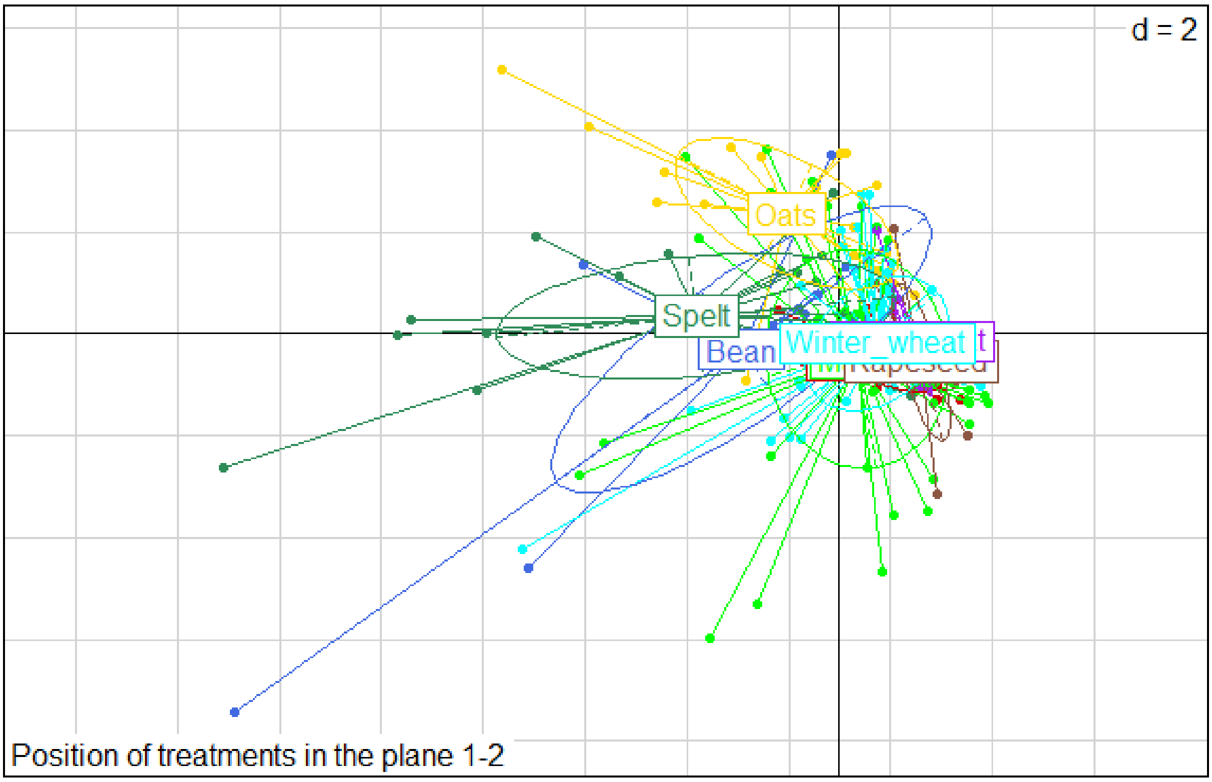
Appendix 15 : Position of the site in in the plane formed by the first two axes of the fuzzy FCA for late June 2020



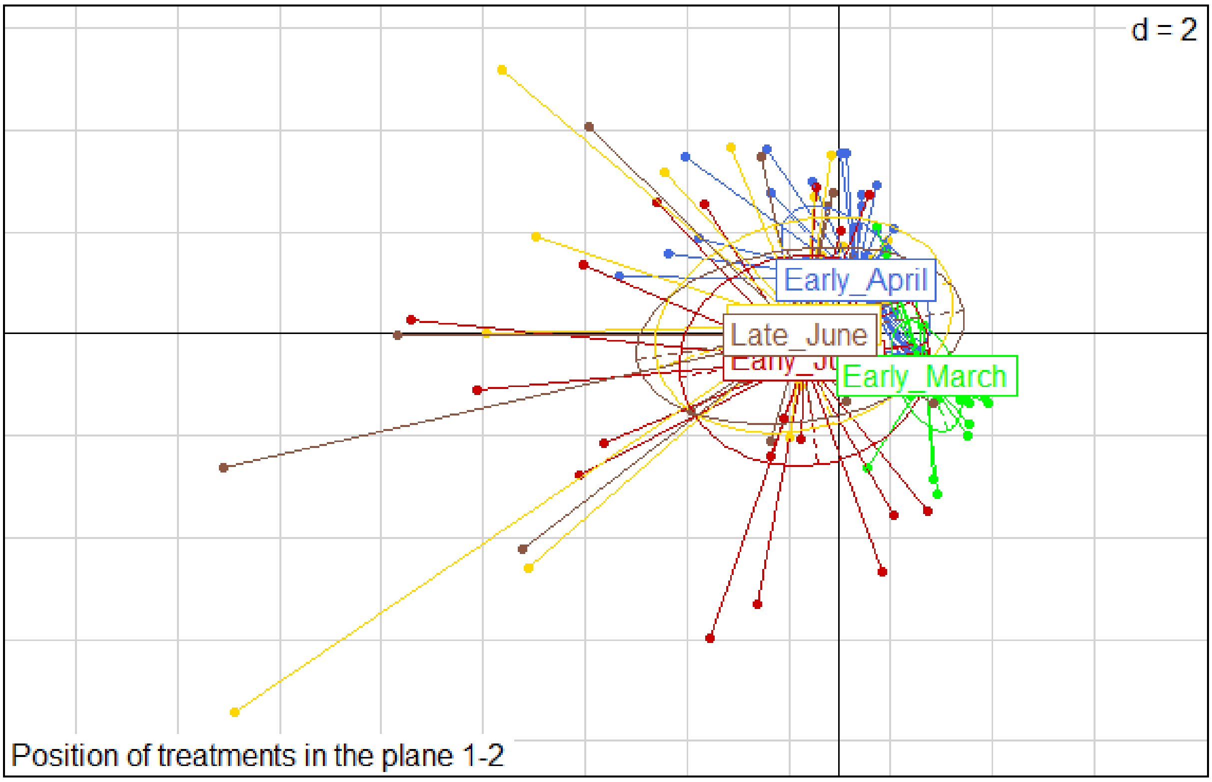
Appendix 16 : Position of the simplified tillage in in the plane formed by the first two axes of the fuzzy FCA for late June 2020

2021 – Global

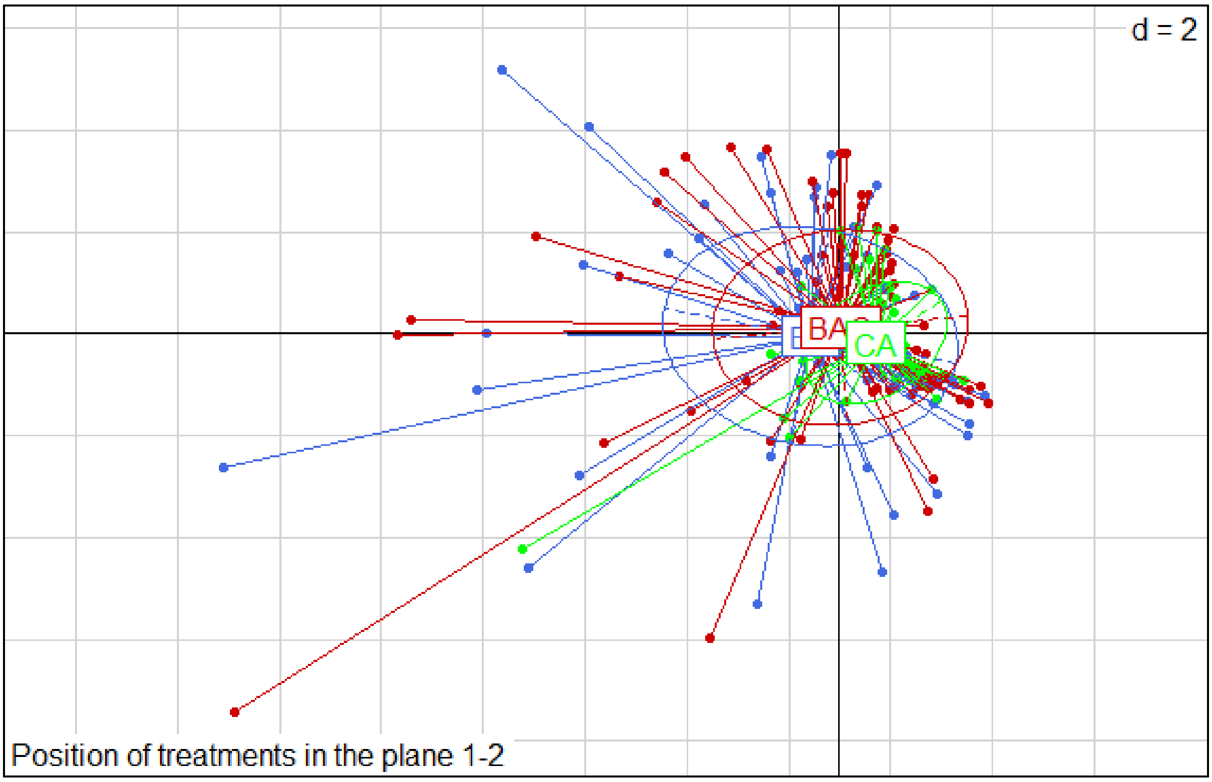
PCA



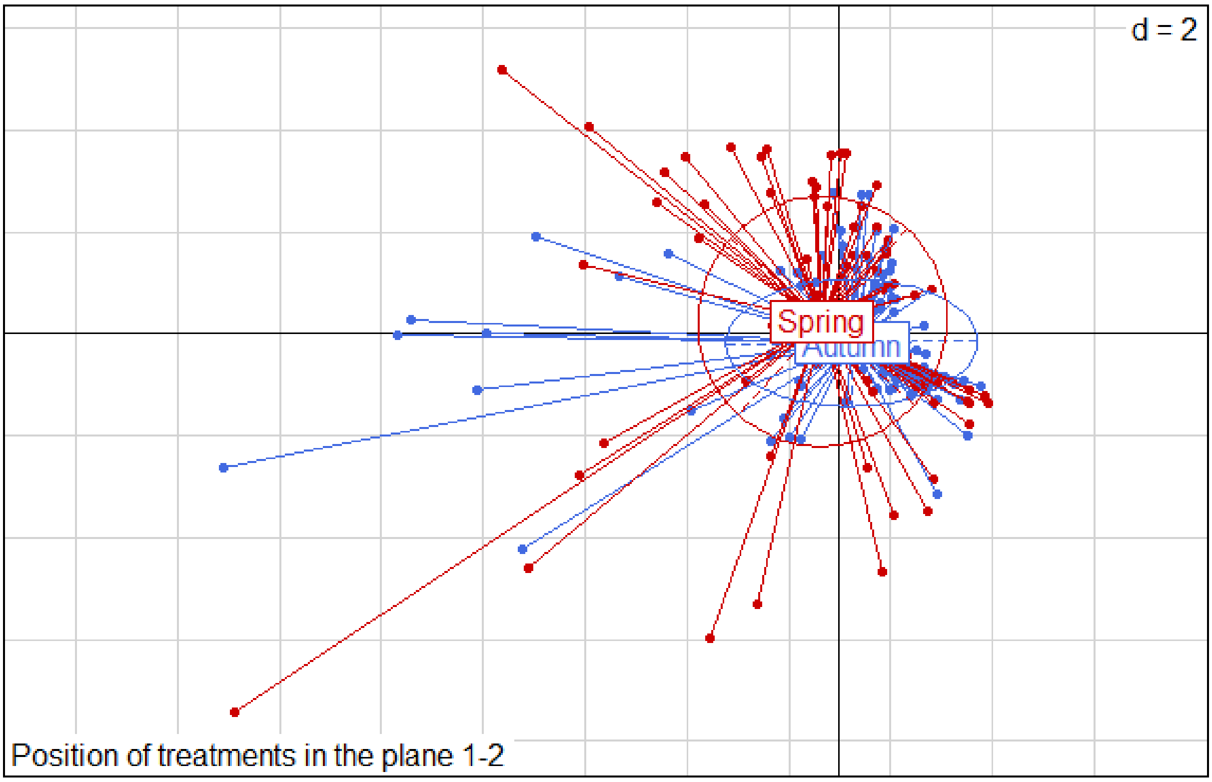
Appendix 17 : Position of the crop in in the plane formed by the first two axes of the PCA for 2021



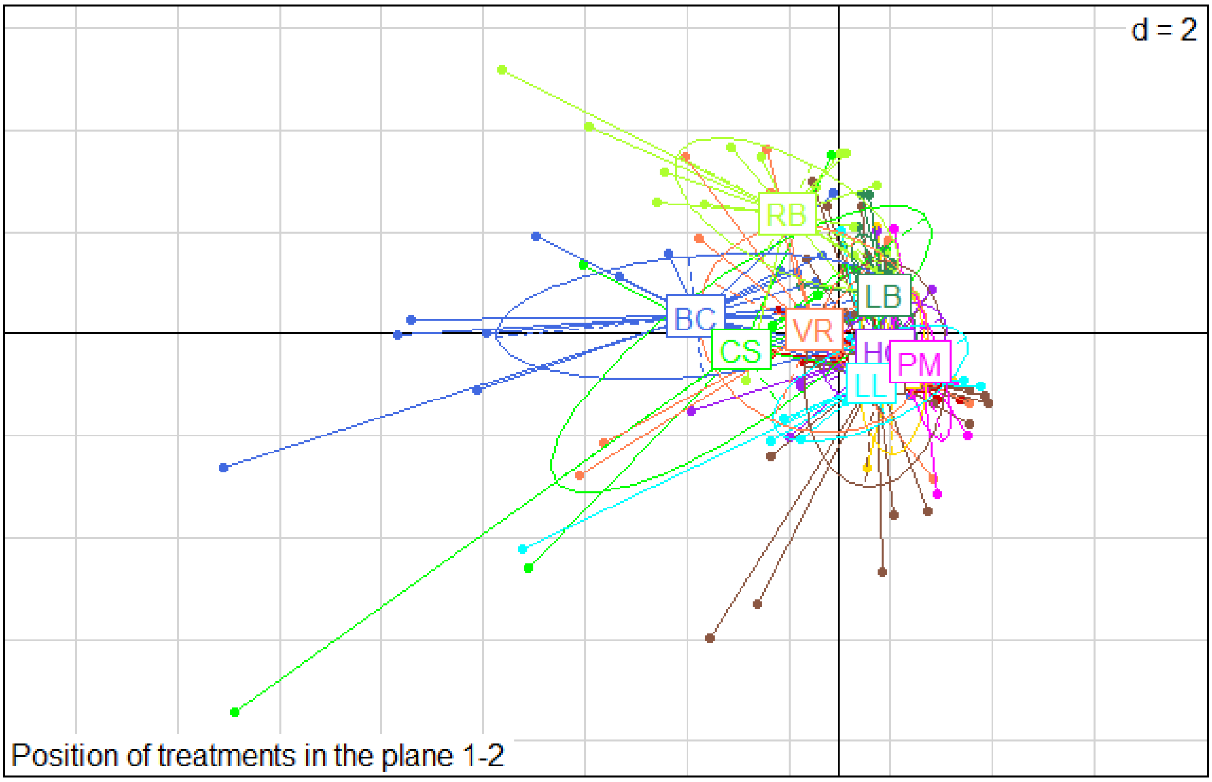
Appendix 18 : Position of the sampling date in in the plane formed by the first two axes of the PCA for 2021



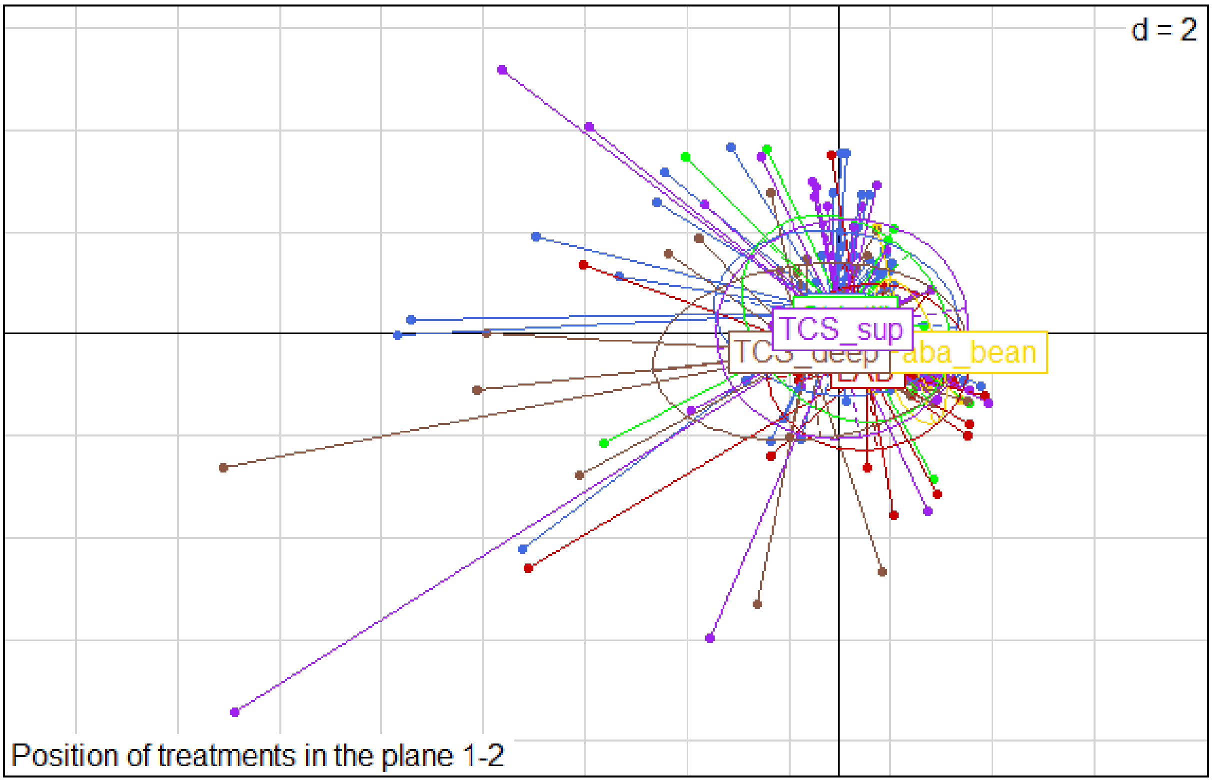
Appendix 19 : Position of the modality in in the plane formed by the first two axes of the PCA for 2021



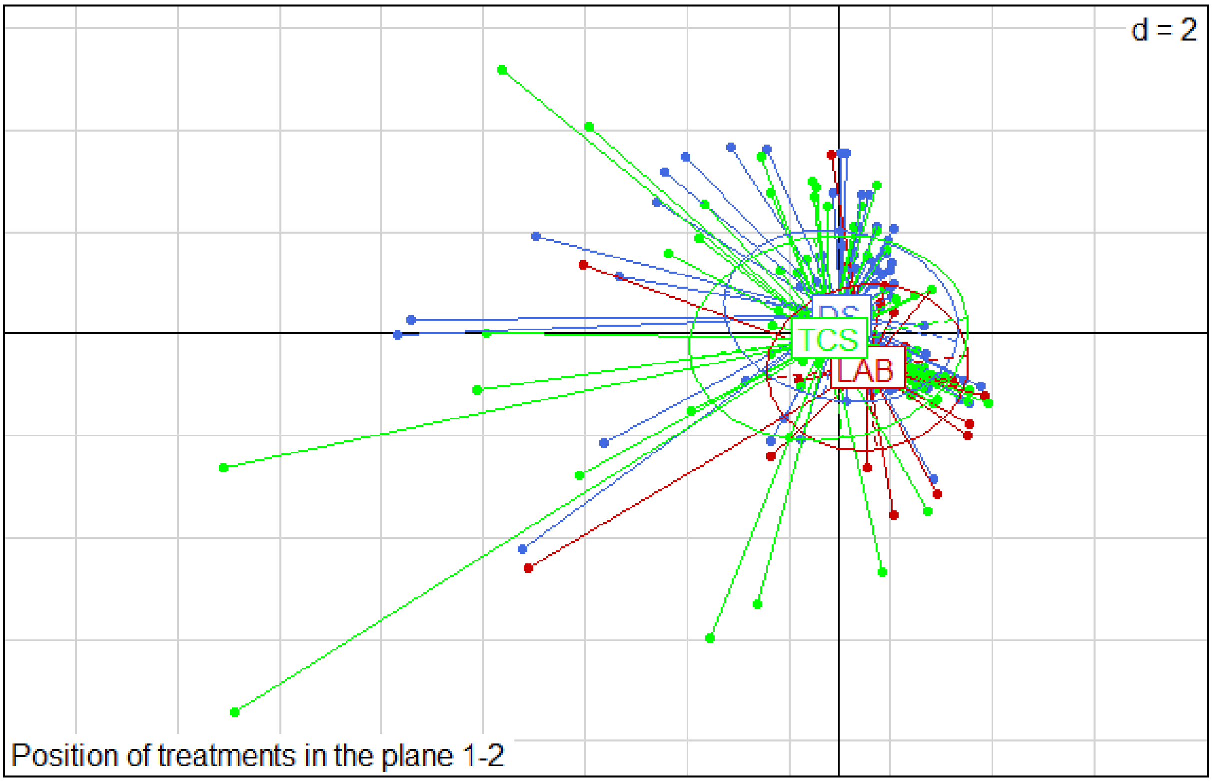
Appendix 20 : Position of the sowing period in in the plane formed by the first two axes of the PCA for 2021



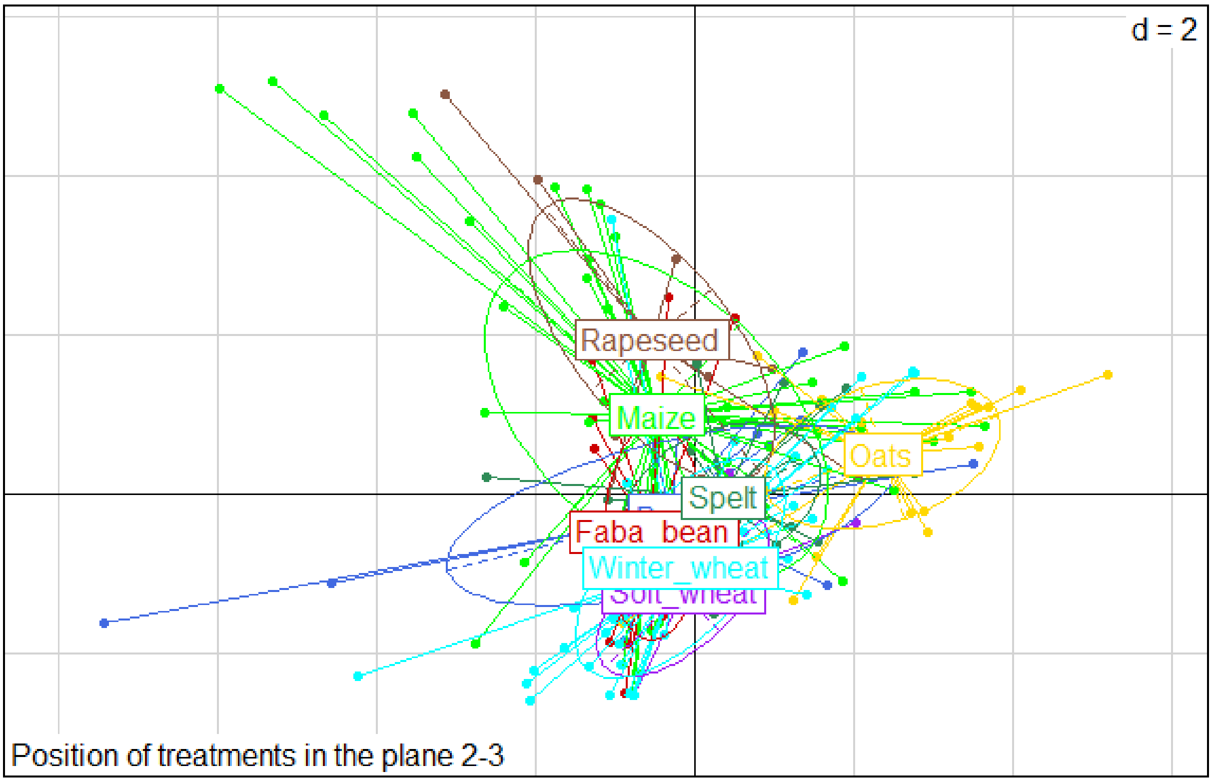
Appendix 21 : Position of the crop in in the site formed by the first two axes of the PCA for 2021



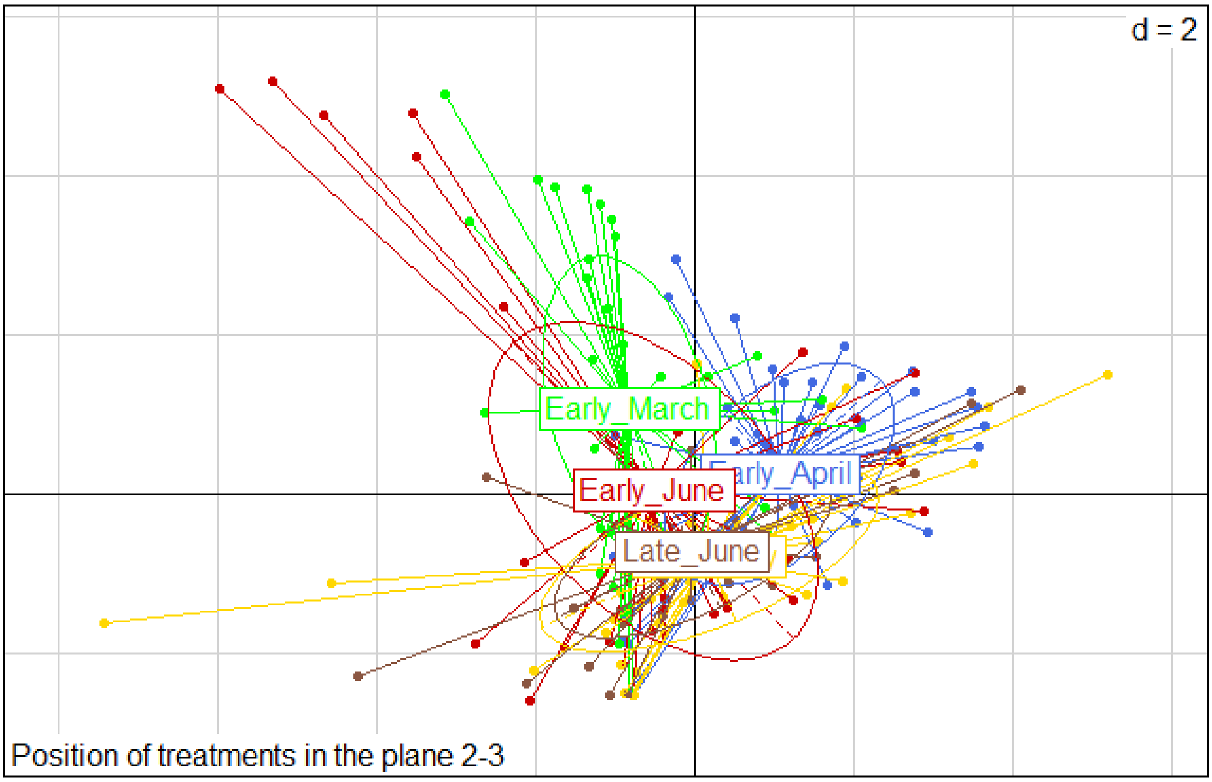
Appendix 22 : Position of the tillage in in the plane formed by the first two axes of the PCA for 2021



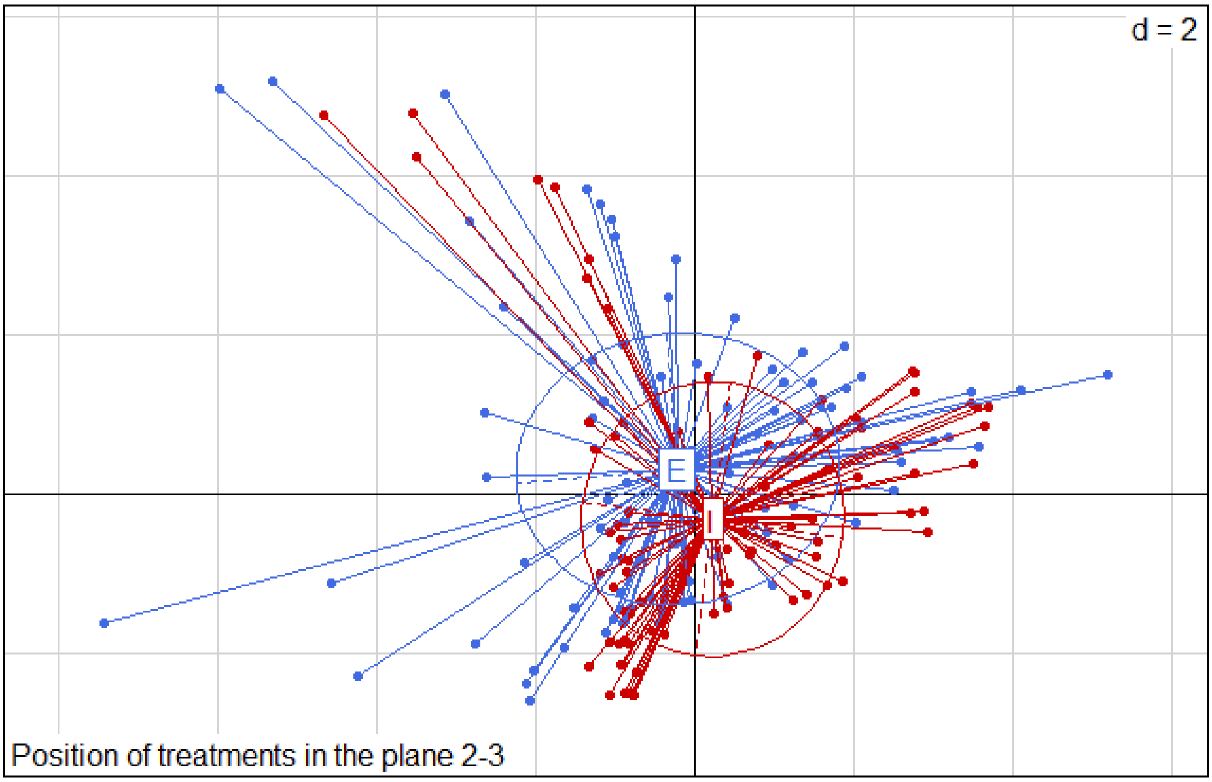
Appendix 23 : Position of the simplified tillage in in the plane formed by the first two axes of the PCA for 2021



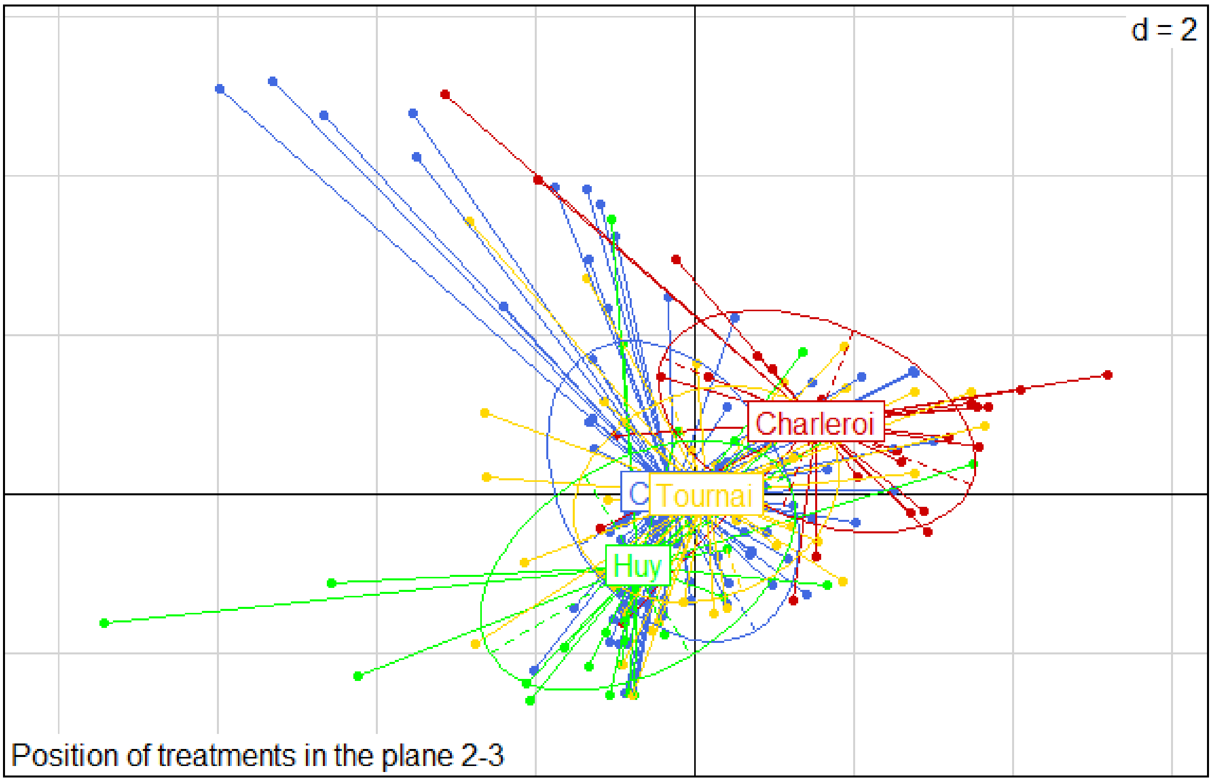
Appendix 24 : Position of the crop in in the plane formed by the second and third axes of the PCA for 2021



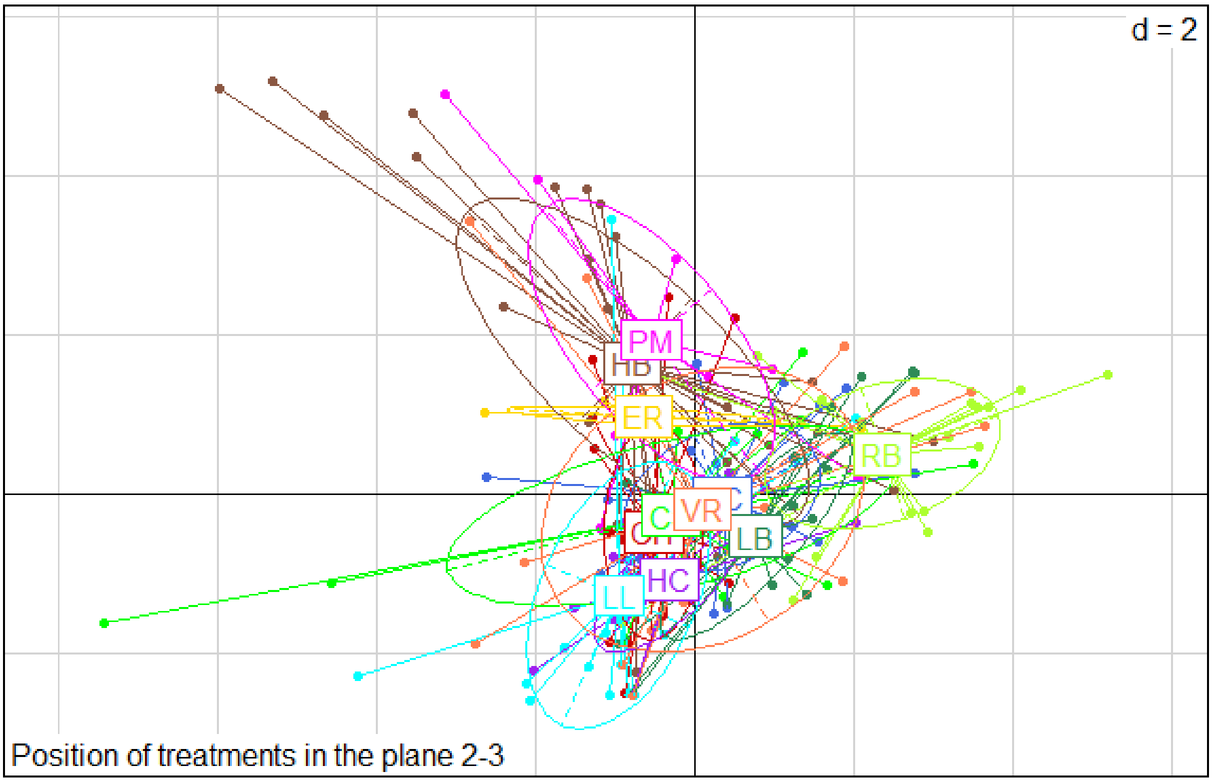
Appendix 25 : Position of sampling date crop in in the plane formed by the second and third axes of the PCA for 2021



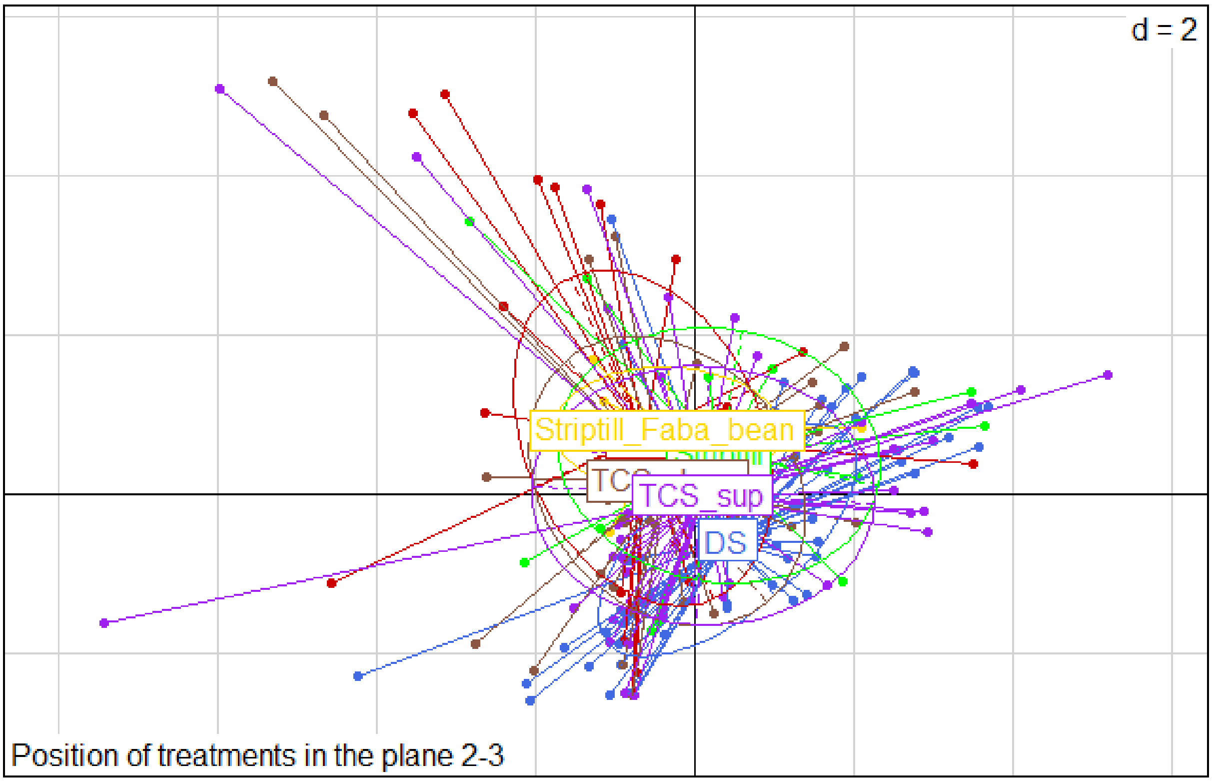
Appendix 26 : Position of the trap type in in the plane formed by the second and third axes of the PCA for 2021. E=Exterior pitfall trap (thus pitfall trap); I = Interior pitfall trap (thus emergence trap)



Appendix 27 : Position of the region in in the plane formed by the second and third axes of the PCA for 2021

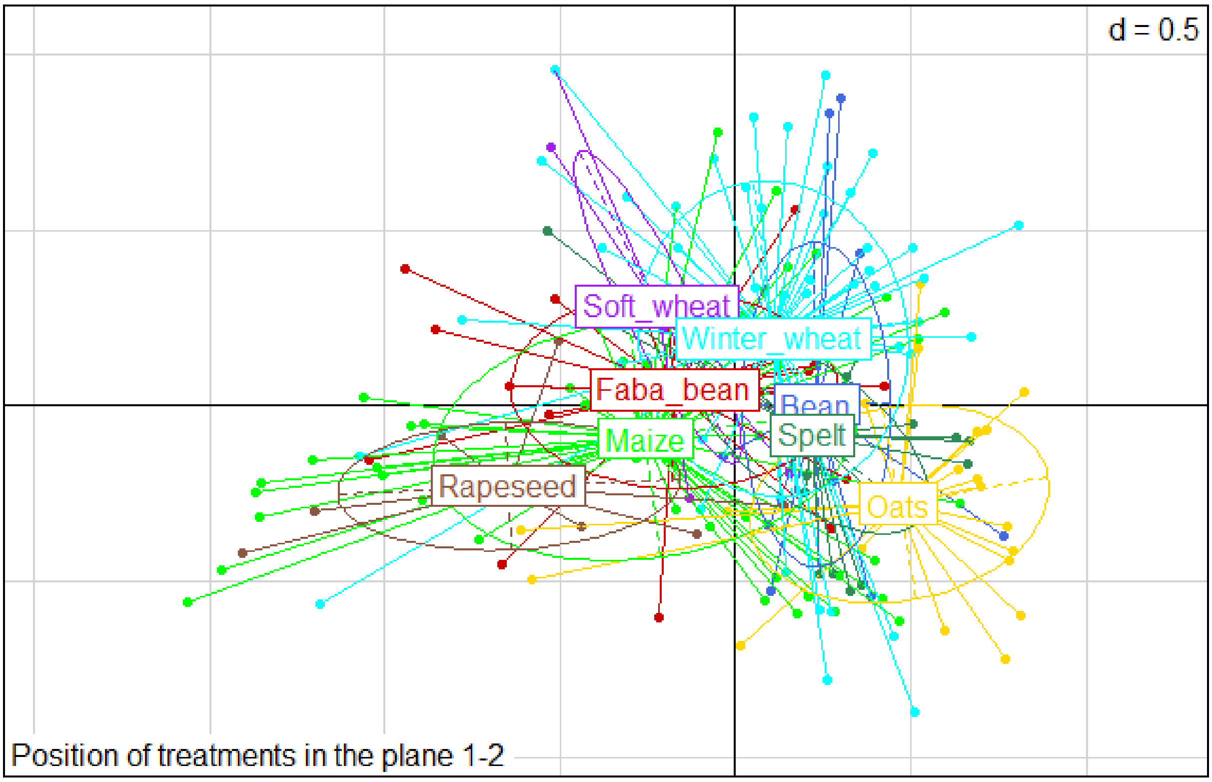


Appendix 28 : Position of the site in in the plane formed by the second and third axes of the PCA for 2021

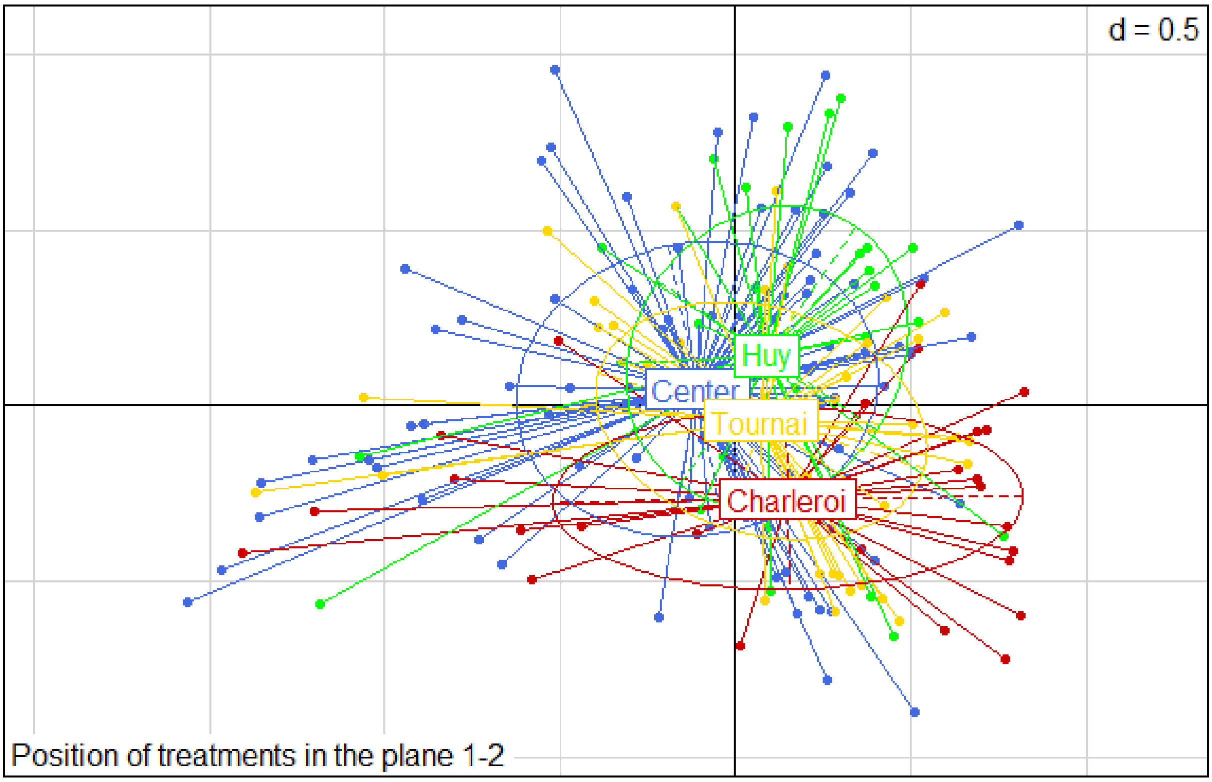


Appendix 29 : Position of the tillage in in the plane formed by the second and third axes of the PCA for 2021

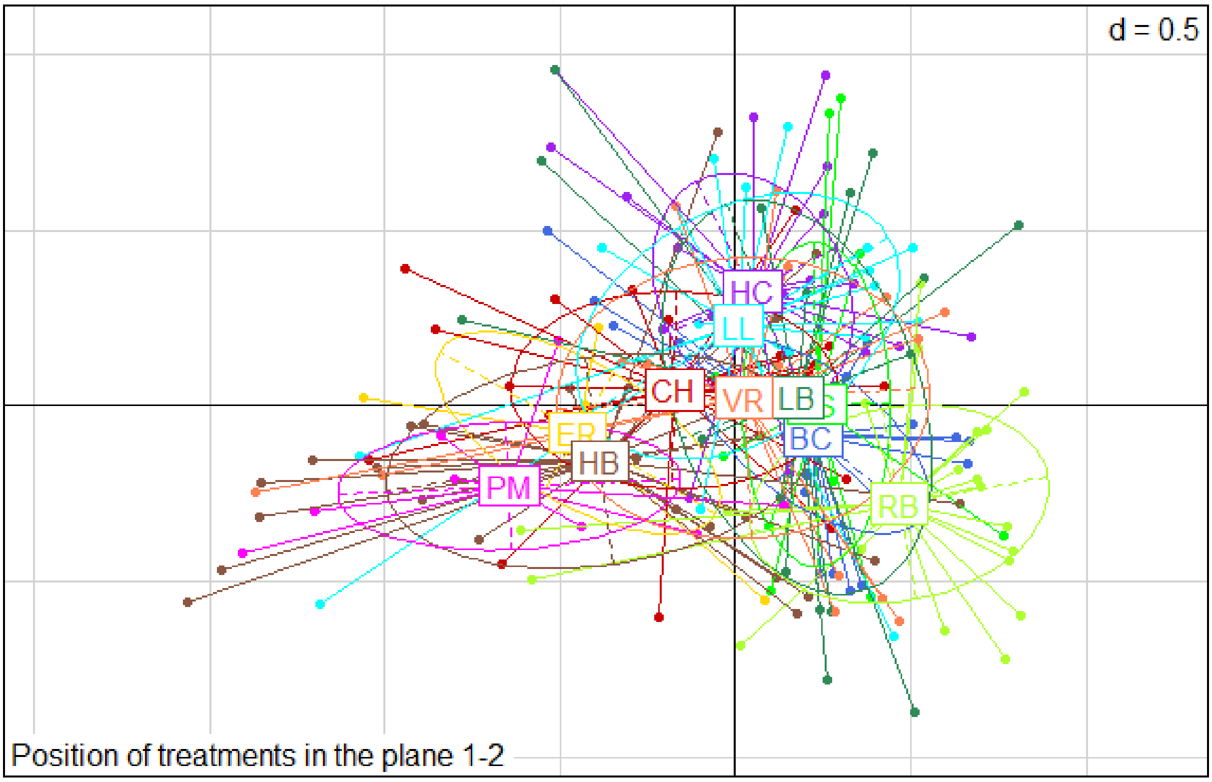
Fuzzy FCA



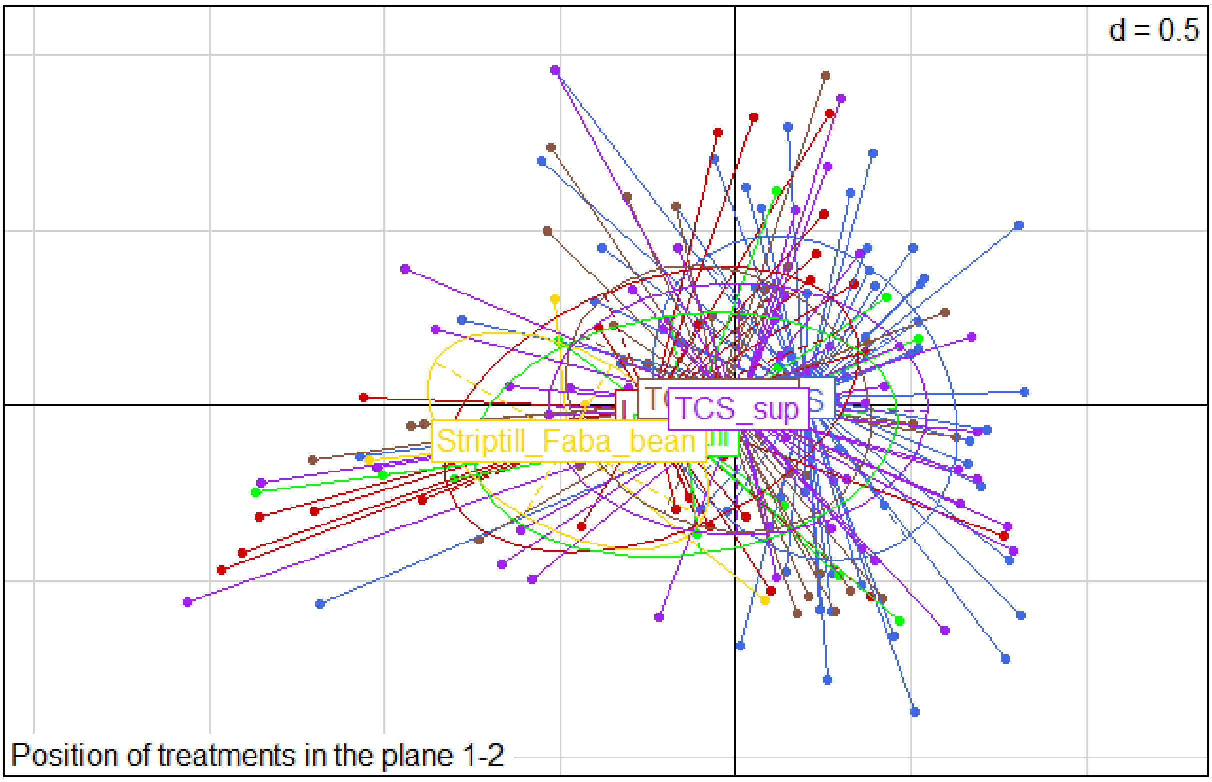
Appendix 30 : Position of the crop in in the plane formed by the first two axes of the fuzzy FCA for 2021



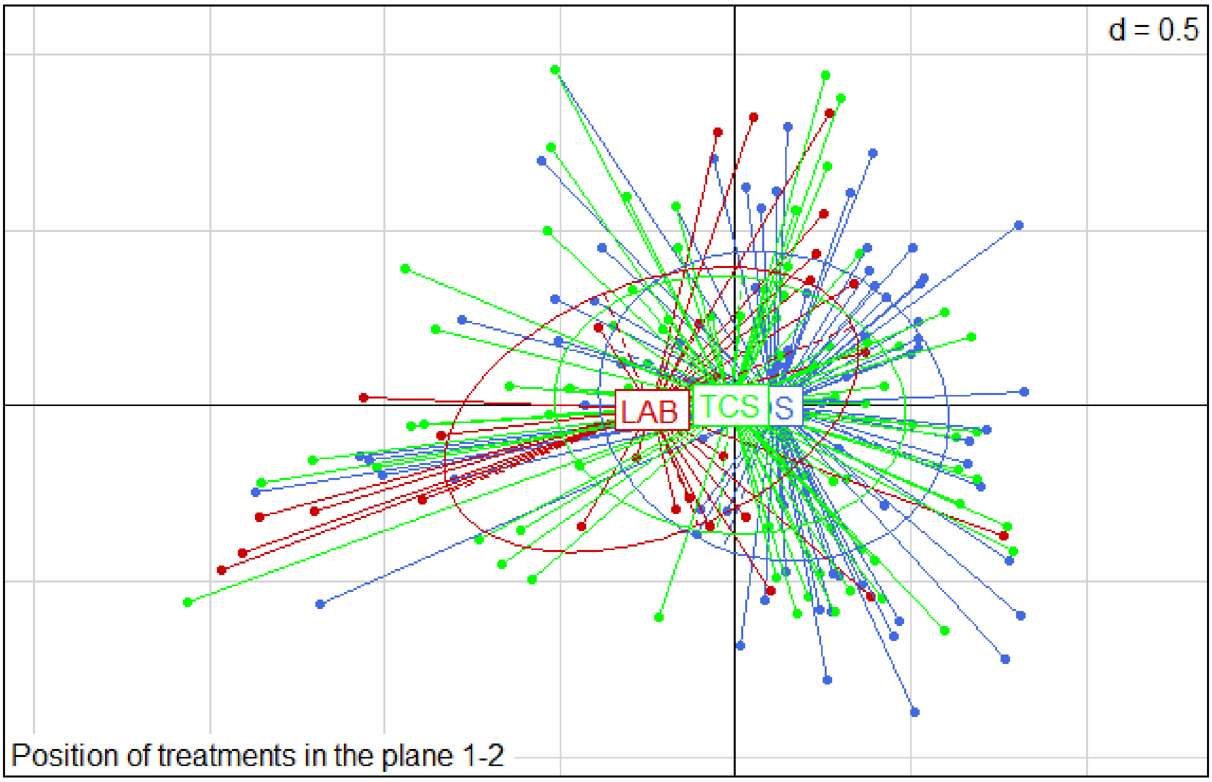
Appendix 31 : Position of the region in in the plane formed by the first two axes of the fuzzy FCA for 2021



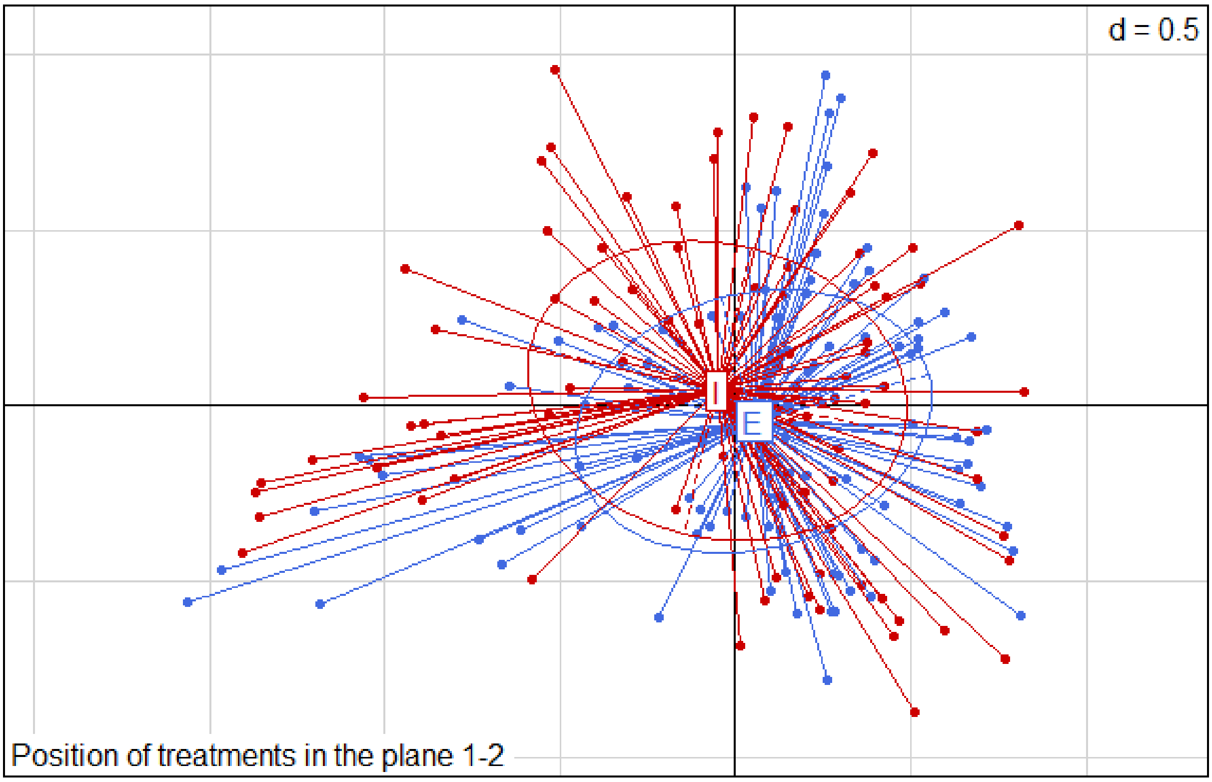
Appendix 32 : Position of the site in in the plane formed by the first two axes of the fuzzy FCA for 2021



Appendix 33 : Position of the tillage in in the plane formed by the first two axes of the fuzzy FCA for 2021



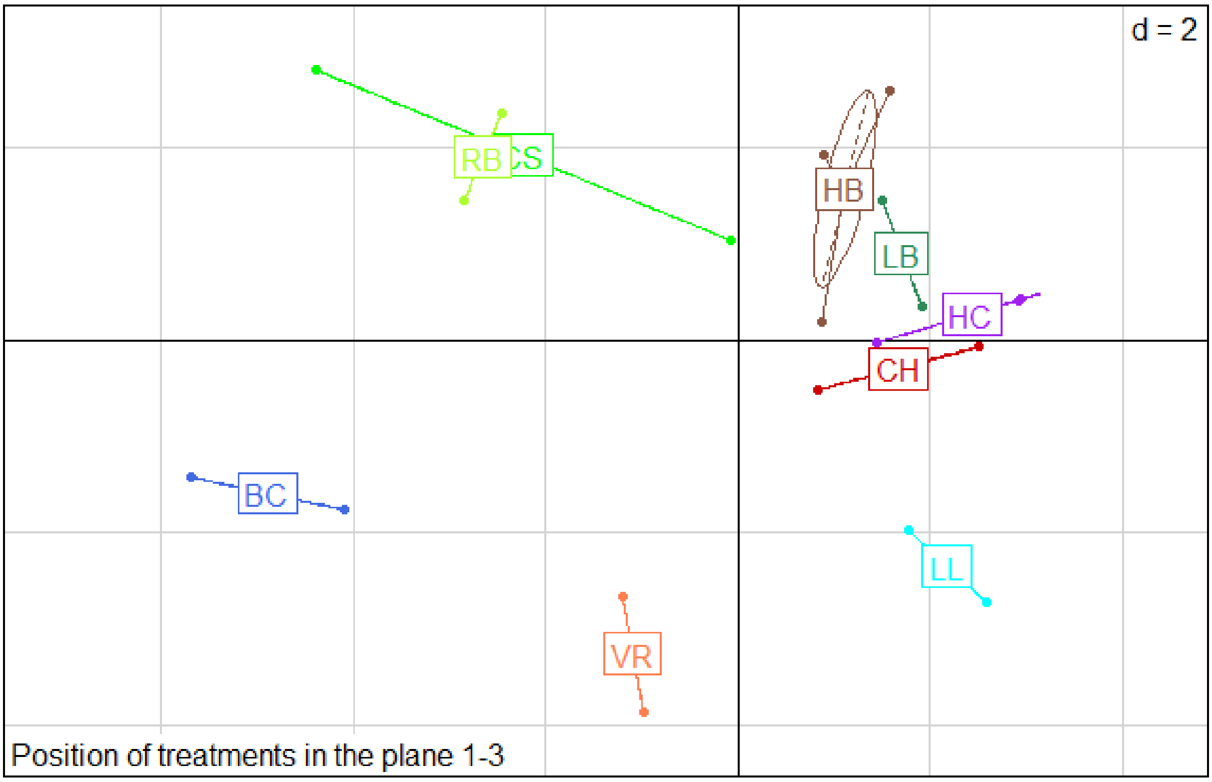
Appendix 34 : Position of the simplified tillage in in the plane formed by the first two axes of the fuzzy FCA for 2021



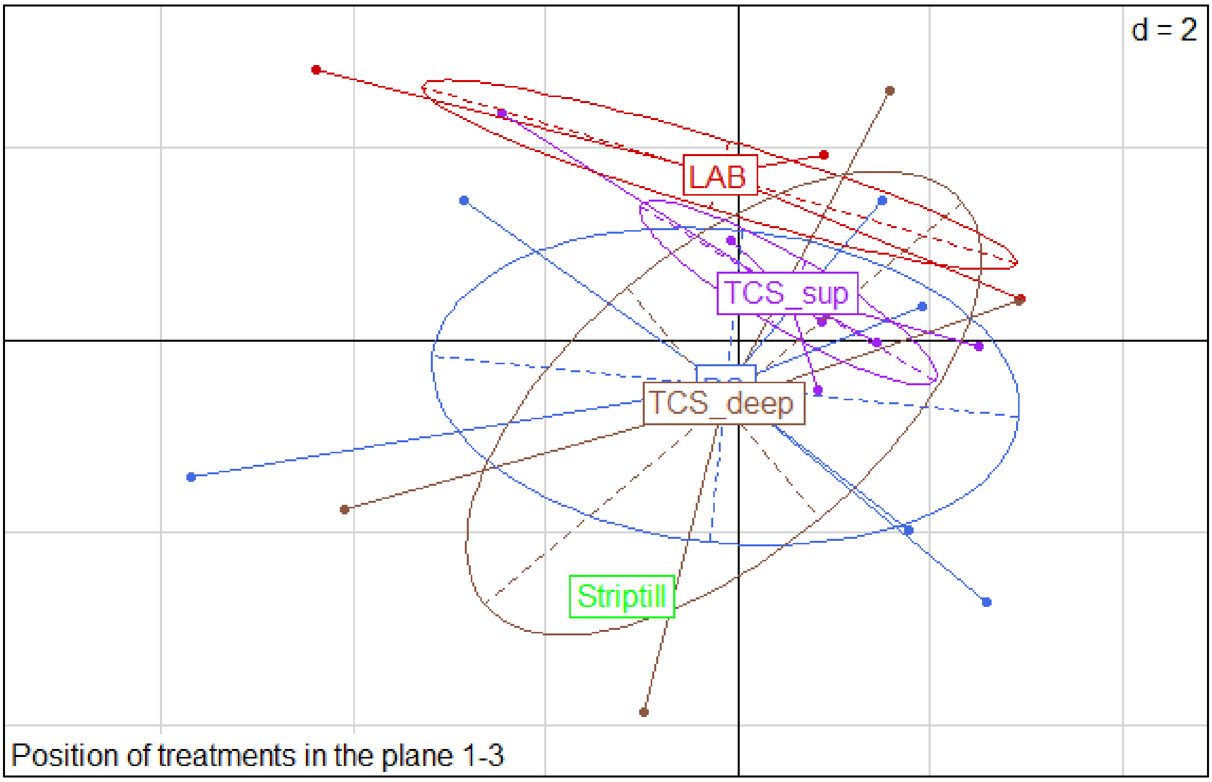
Appendix 35 : Position of the trap type in in the plane formed by the first two axes of the fuzzy FCA for 2021. E=Exterior pitfall trap (thus pitfall trap); I = Interior pitfall trap (thus emergence trap)

2020 – Early June

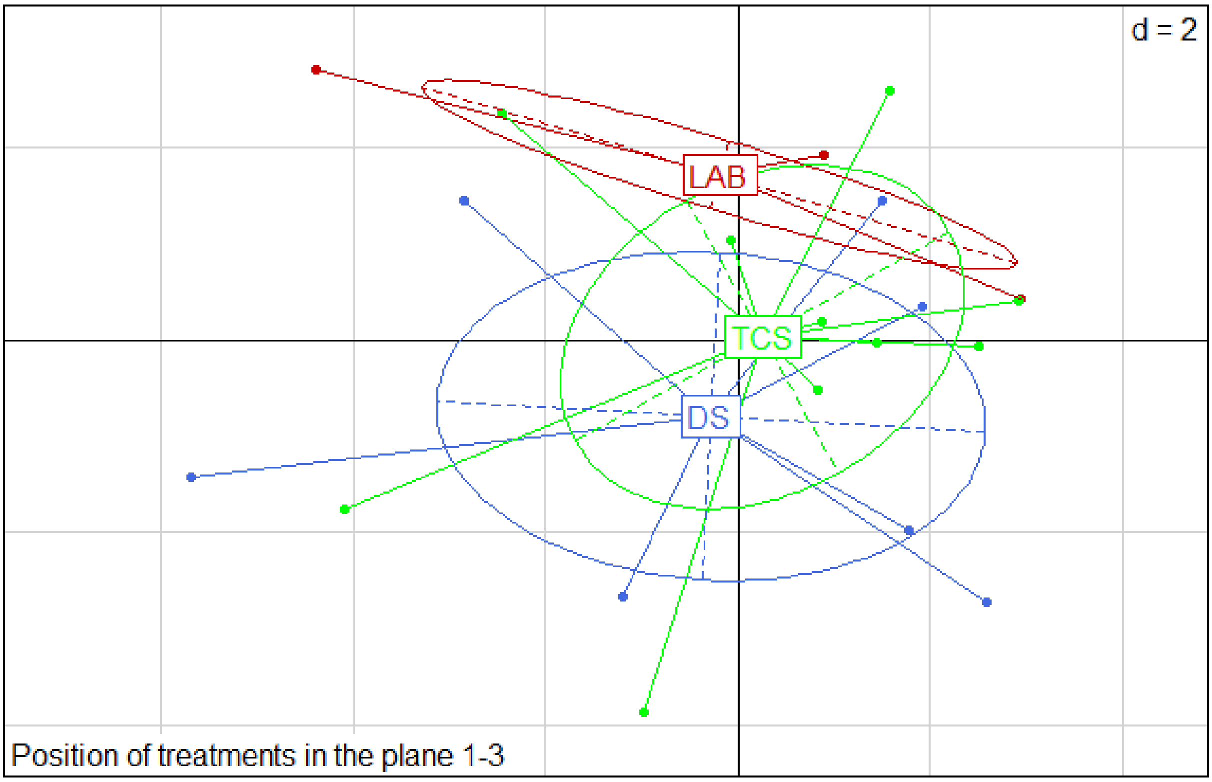
PCA



Appendix 36 : Position of the crop in in the plane formed by the first and third axes of the PCA for early June 2021 (pitfalls only)



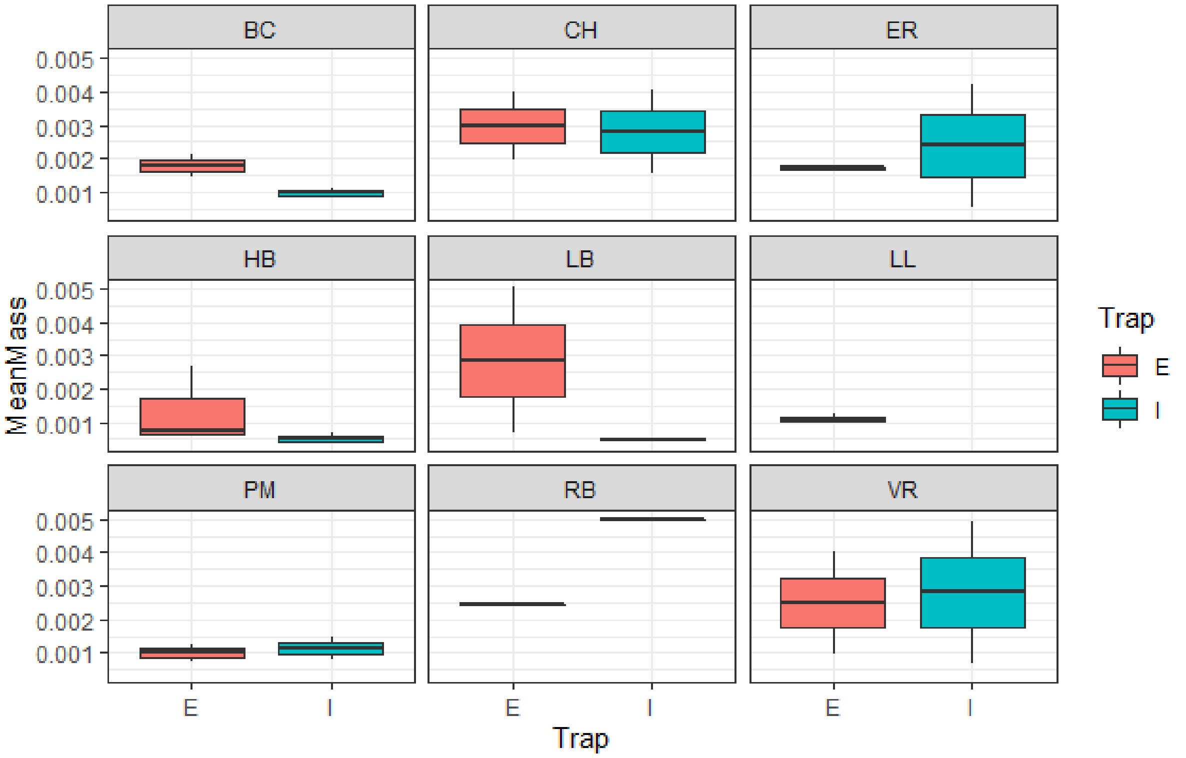
Appendix 37 : Position of the tillage in in the plane formed by the first and third axes of the PCA for early June 2021 (pitfalls only)



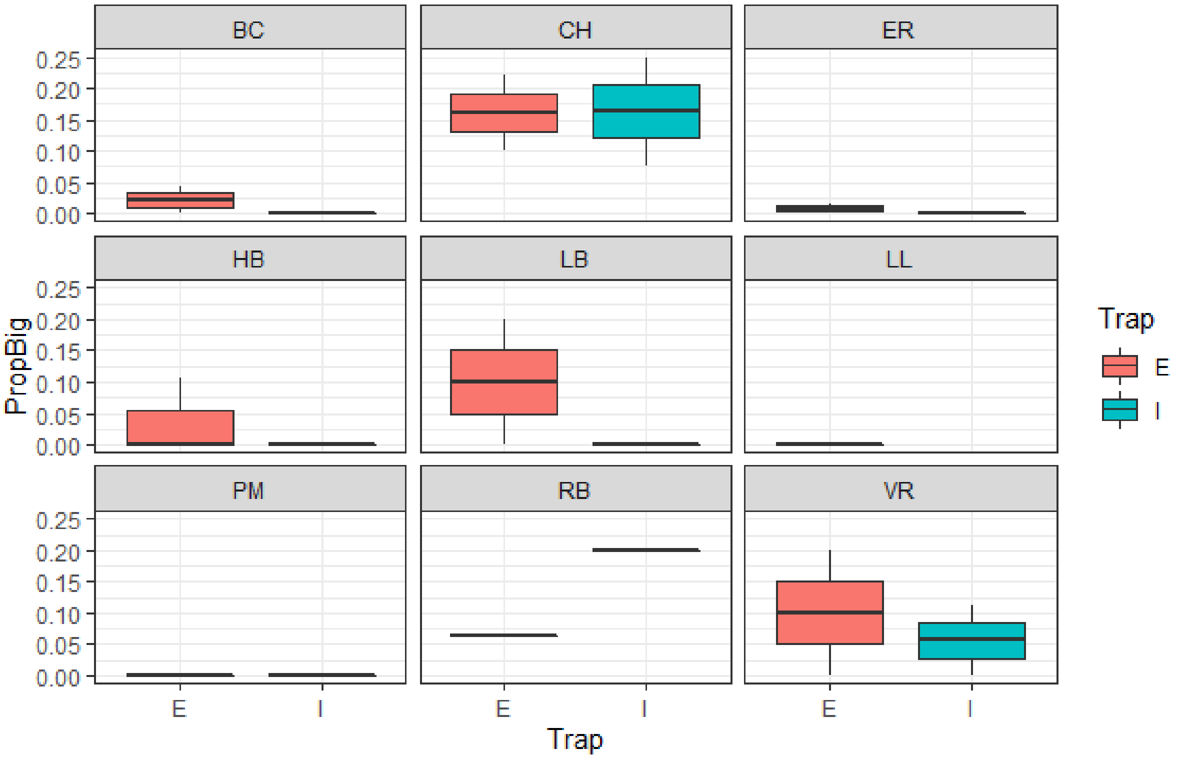
Appendix 38 : Position of the simplified tillage in in the plane formed by the first and third axes of the PCA for early June 2021 (pitfalls only)

Effects of emergence traps

Early March

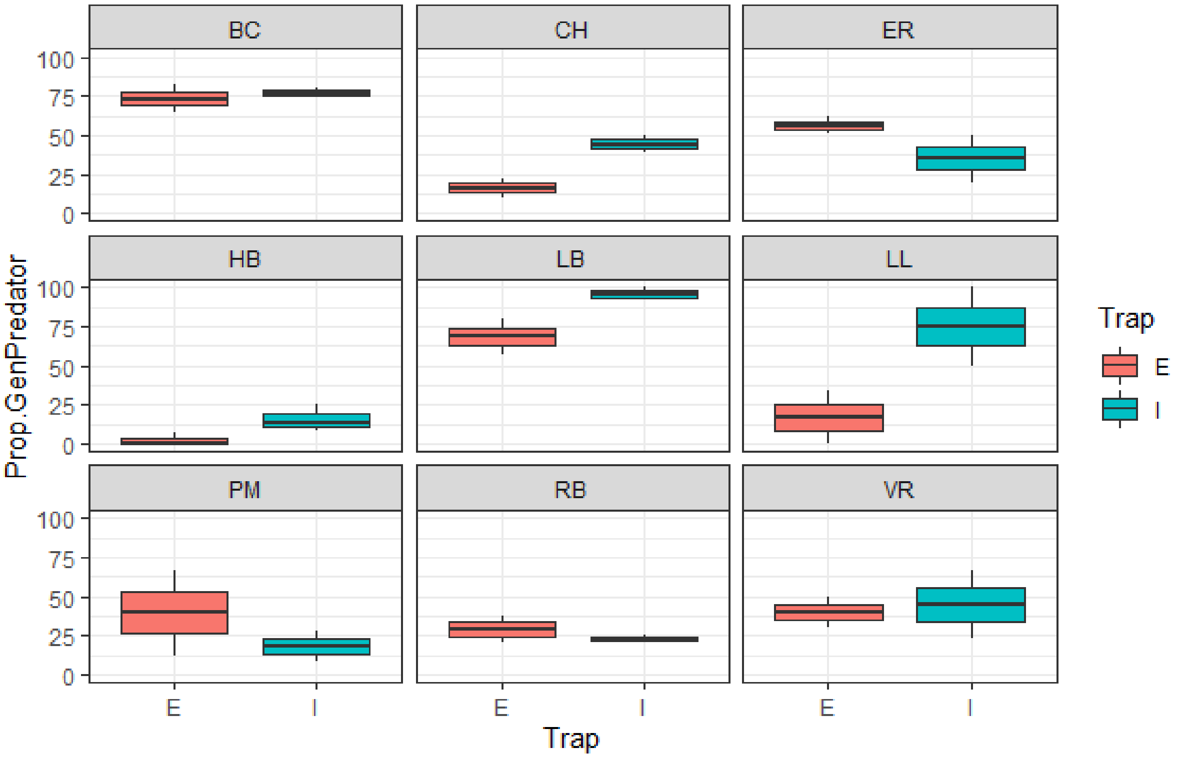


Appendix 39 : Mean individual mass of the carabids caught in exterior pitfall traps (E), thus pitfall traps, and interior pitfall traps (I), thus emergence traps, in early March 2021

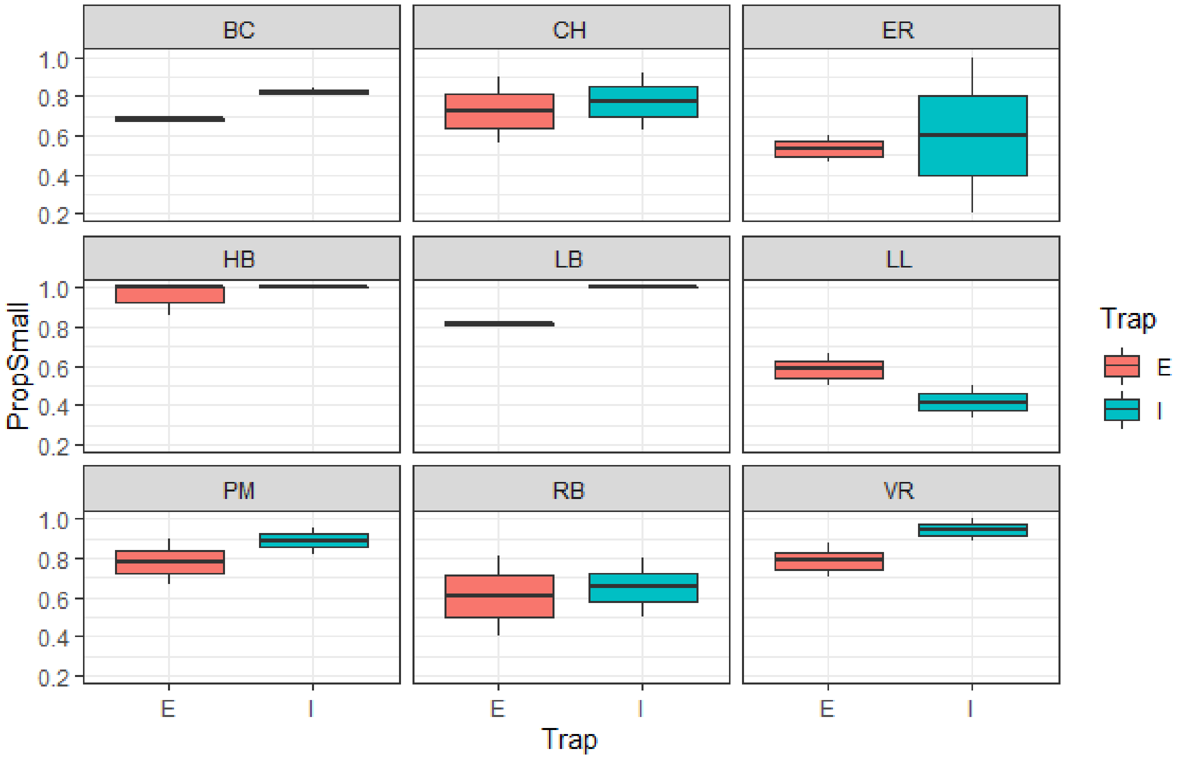


Appendix 40 : Proportion of big individuals caught in exterior pitfall traps (E), thus pitfall traps, and interior pitfall traps (I), thus emergence traps, in early March 2021

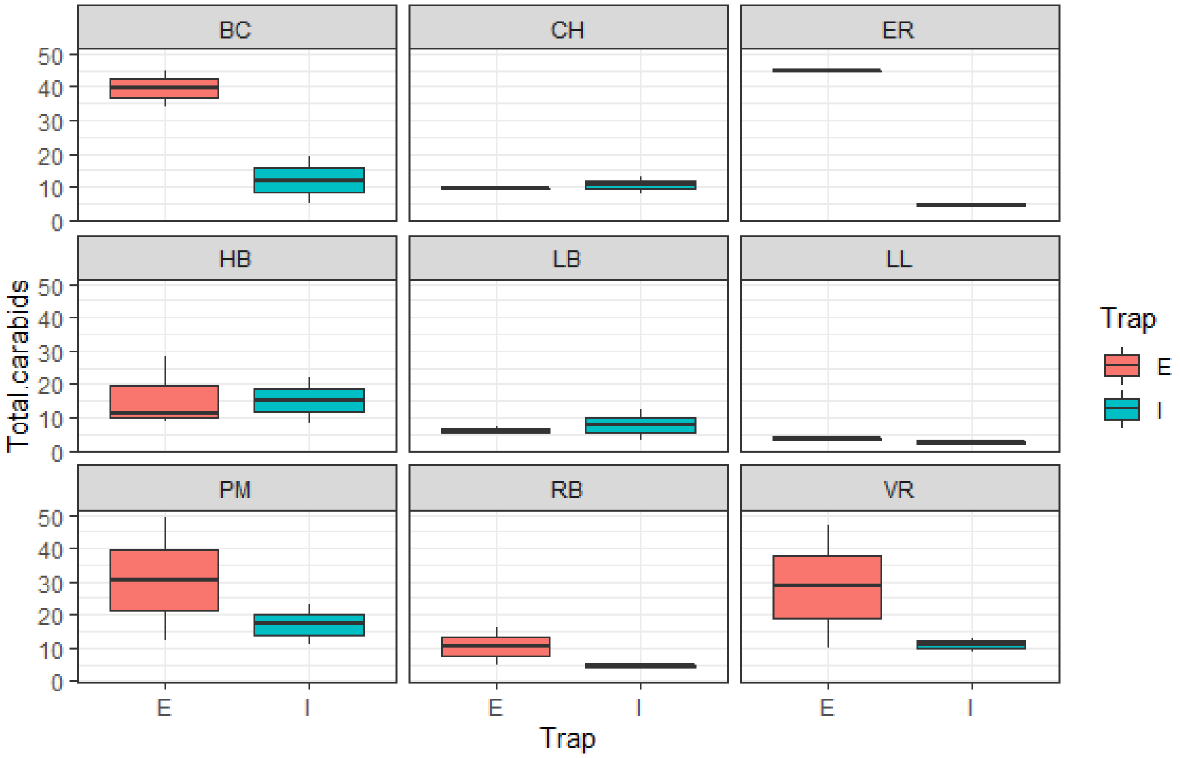
Appendix 41 : Proportion



Appendix 42 : Proportion of generalist predators caught in exterior pitfall traps (E), thus pitfall traps, and interior pitfall traps (I), thus emergence traps, in early March 2021

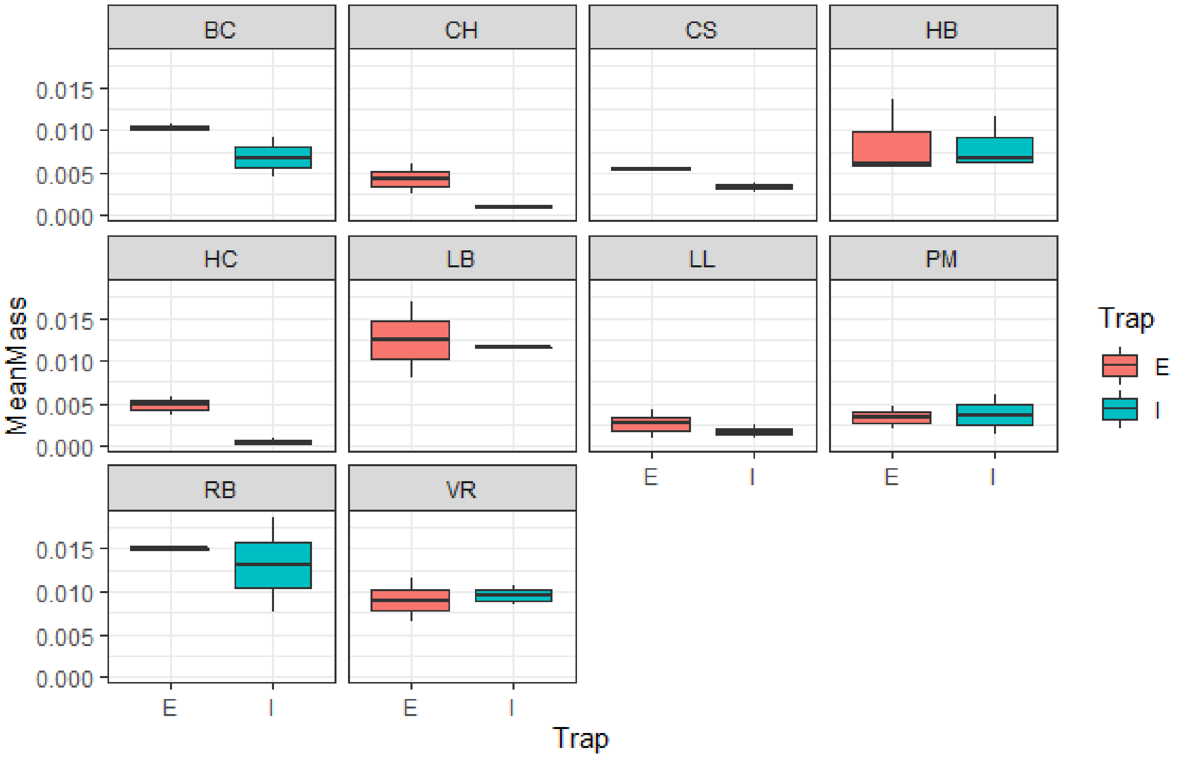


Appendix 43 : Proportion of small individuals caught in exterior pitfall traps (E), thus pitfall traps, and interior pitfall traps (I), thus emergence traps, in early March 2021

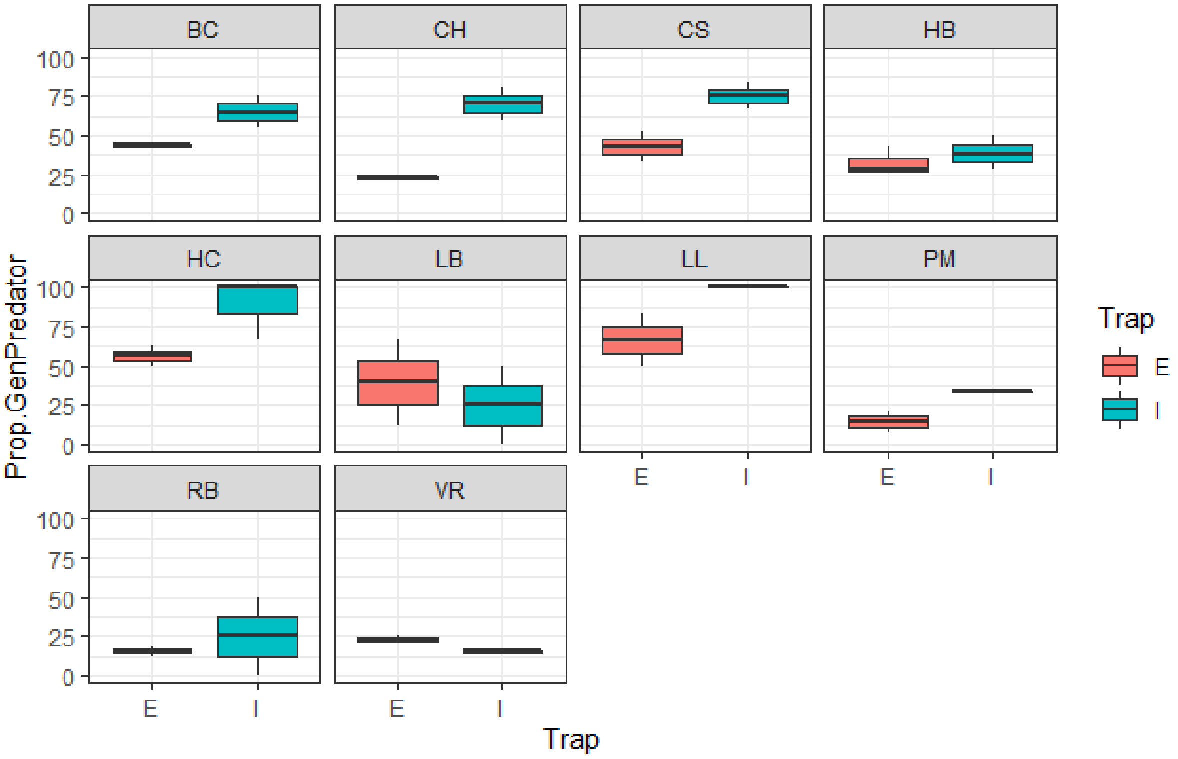


Appendix 44 : Total number of carabids caught in exterior pitfall traps (E), thus pitfall traps, and interior pitfall traps (I), thus emergence traps, in early March 2021

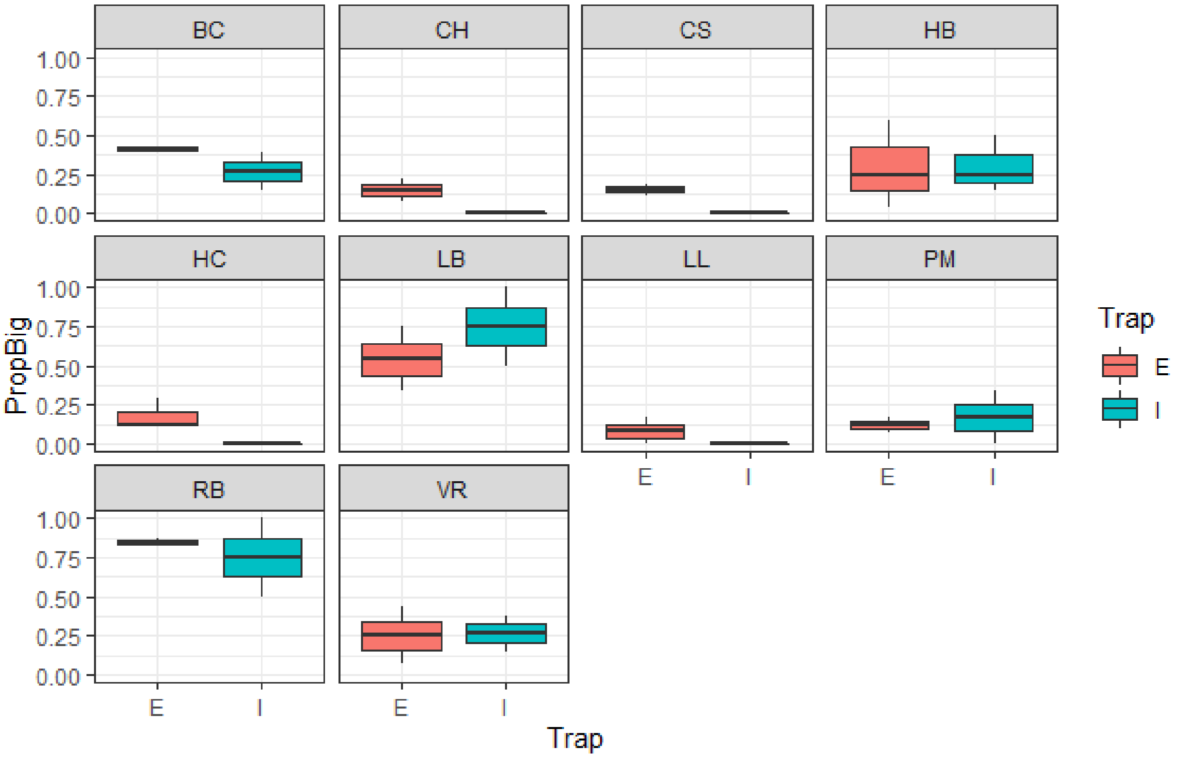
Early April



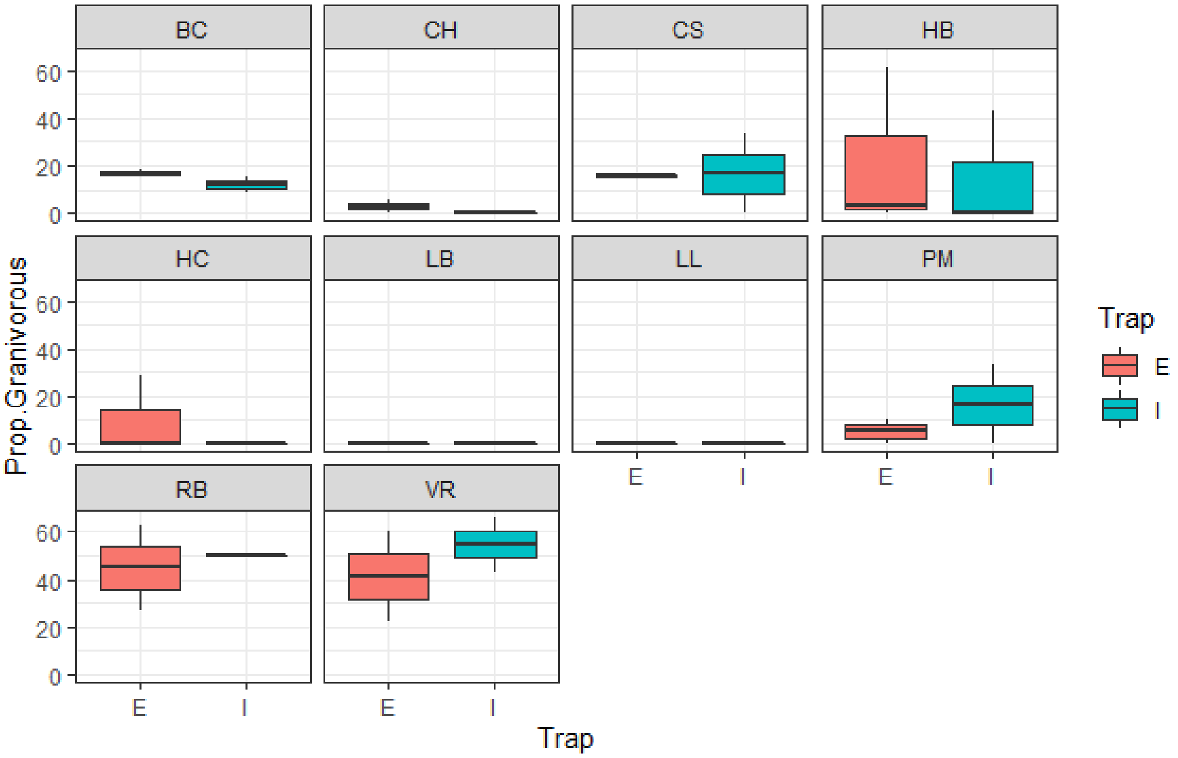
Appendix 45 : Mean individual mass of the carabids caught in exterior pitfall traps (E), thus pitfall traps, and interior pitfall traps (I), thus emergence traps, in early April 2021



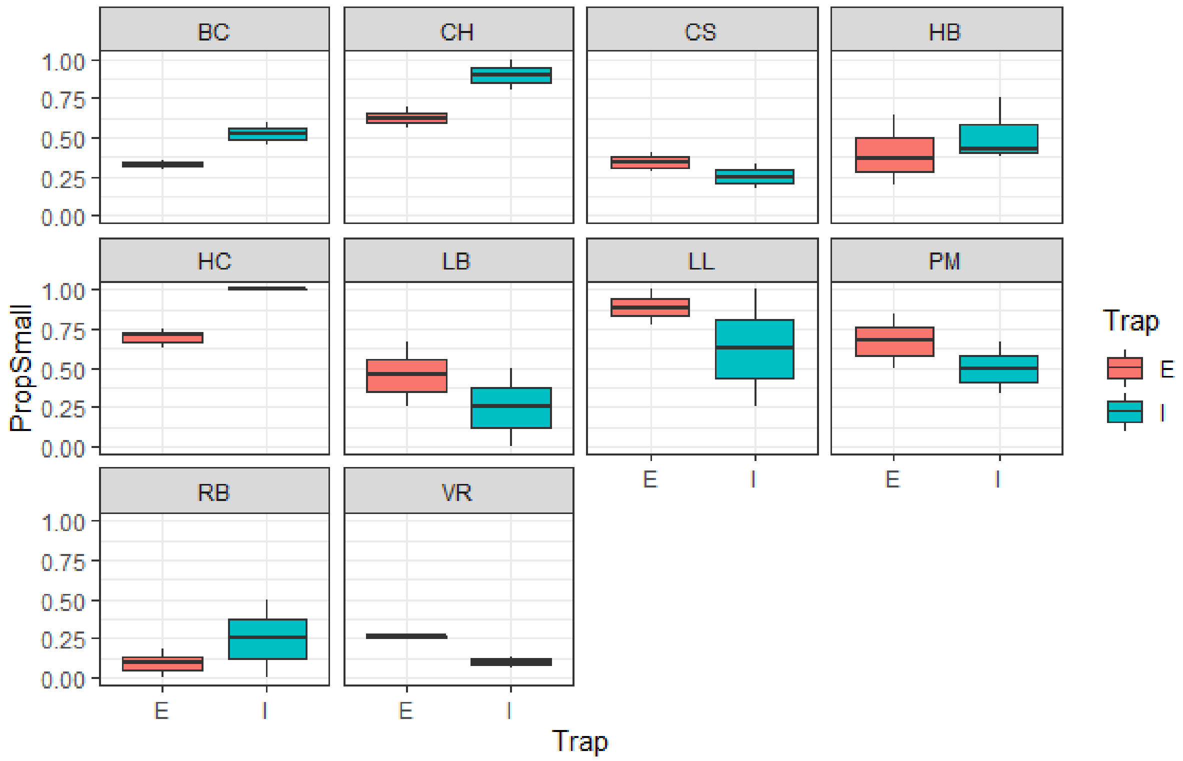
Appendix 46 : Proportion of generalist predators carabids caught in exterior pitfall traps (E), thus pitfall traps, and interior pitfall traps (I), thus emergence traps, in early April 2021



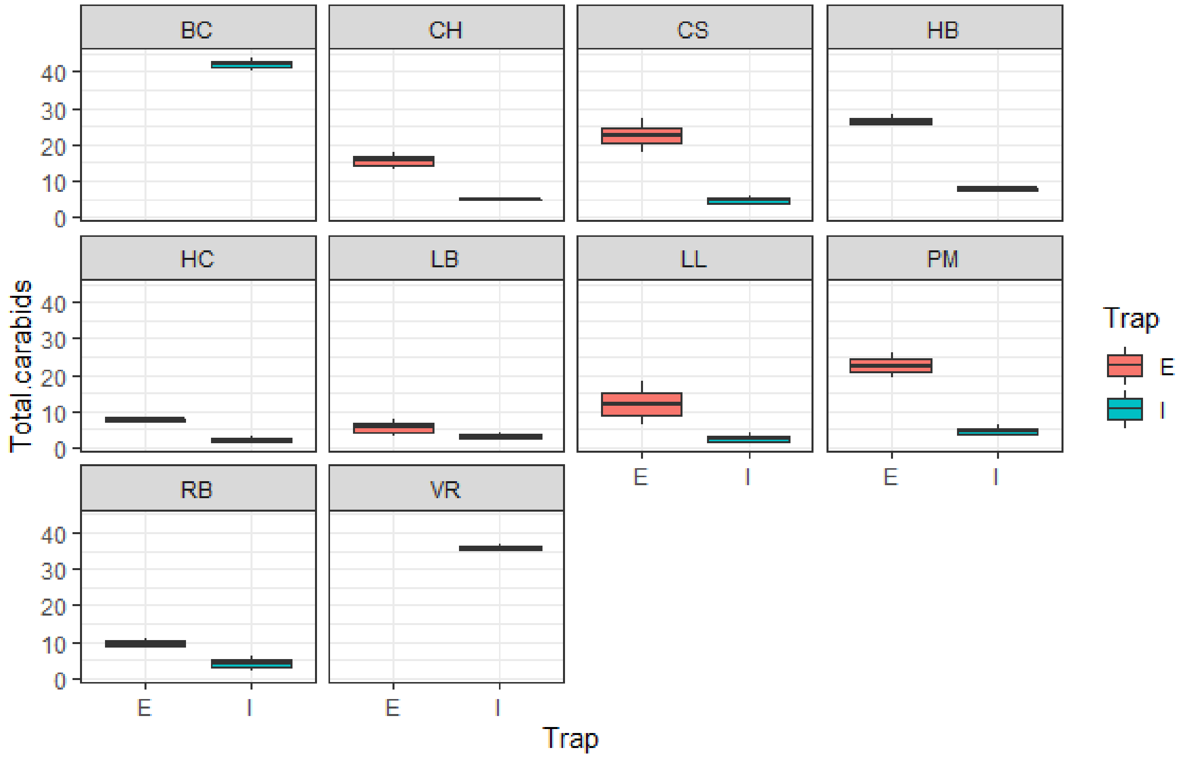
Appendix 47 : Proportion of big individuals caught in exterior pitfall traps (E), thus pitfall traps, and interior pitfall traps (I), thus emergence traps, in early April 2021



Appendix 48 : Proportion of granivorous caught in exterior pitfall traps (E), thus pitfall traps, and interior pitfall traps (I), thus emergence traps, in early April 2021

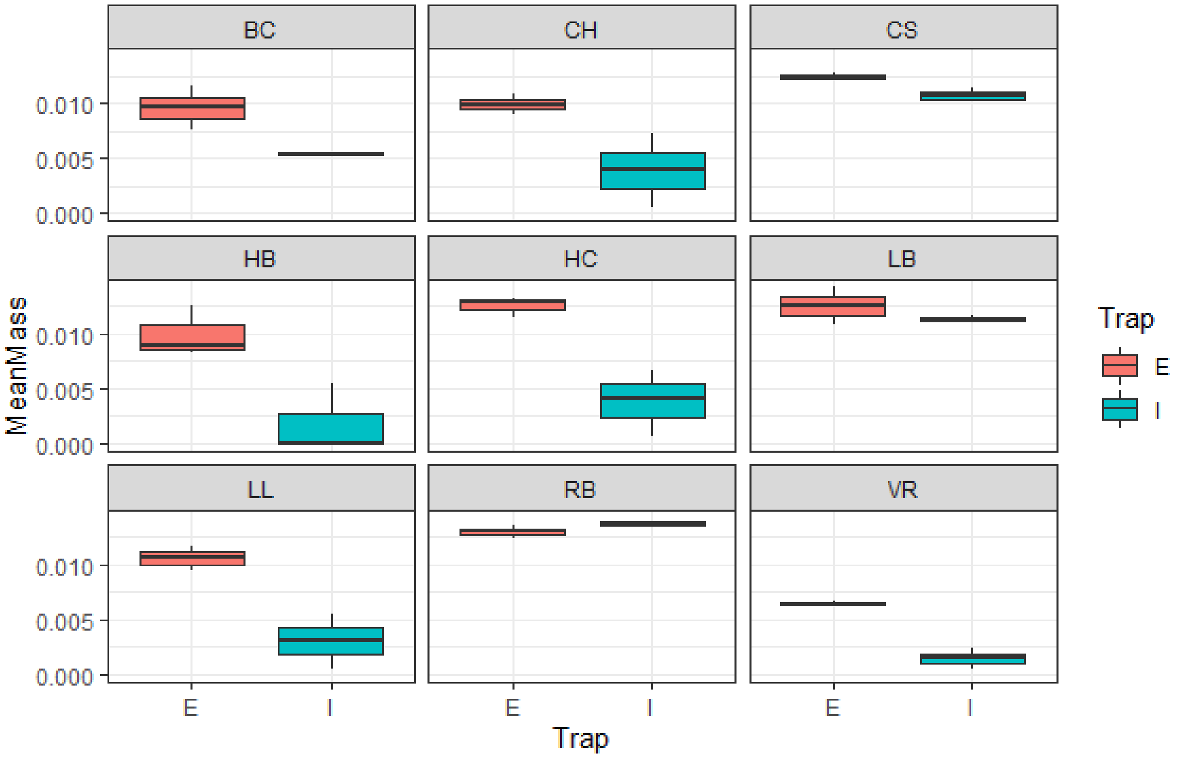


Appendix 49 : Proportion of small individuals caught in exterior pitfall traps (E), thus pitfall traps, and interior pitfall traps (I), thus emergence traps, in early April 2021

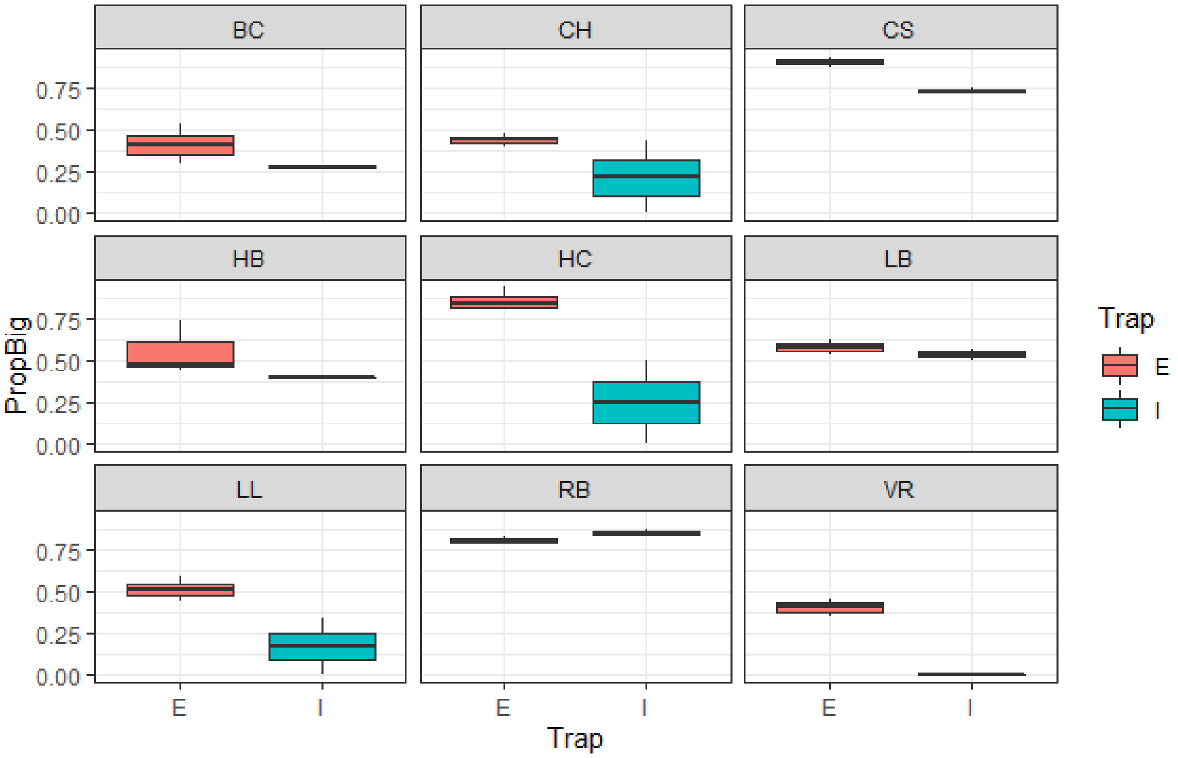


Appendix 50 : Total number of carabids caught in exterior pitfall traps (E), thus pitfall traps, and interior pitfall traps (I), thus emergence traps, in early April 2021

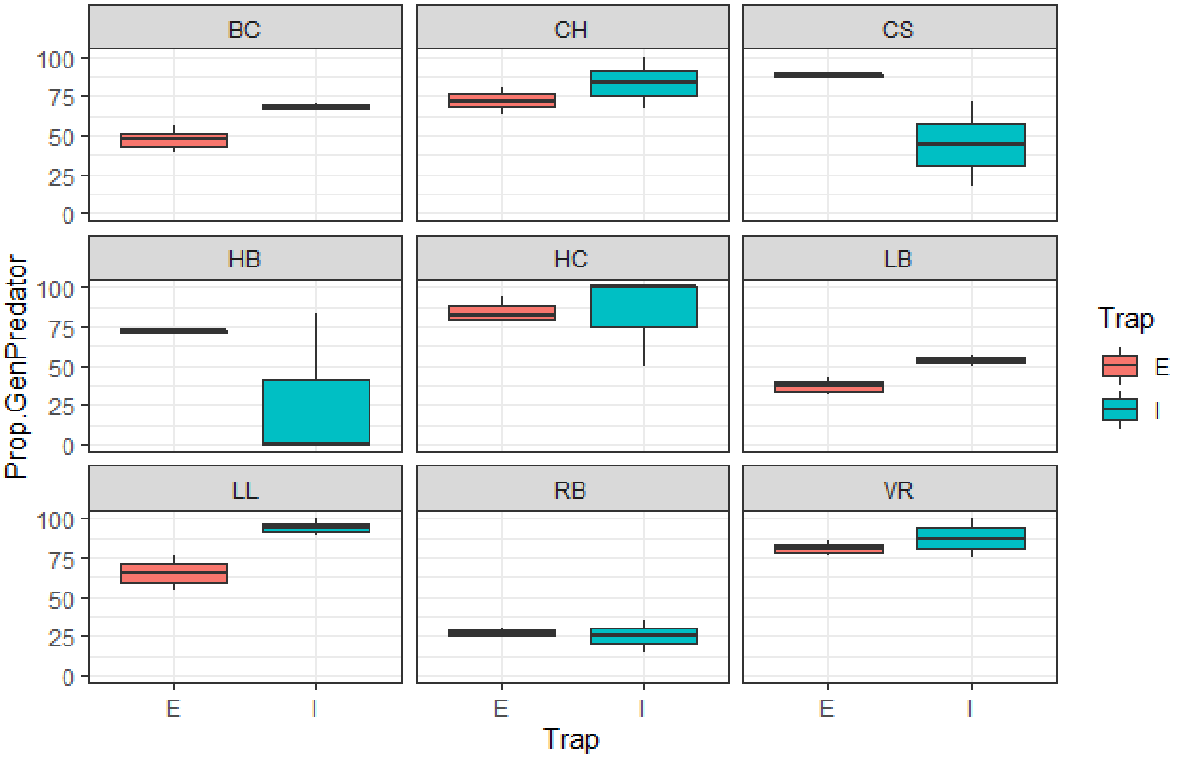
Early May



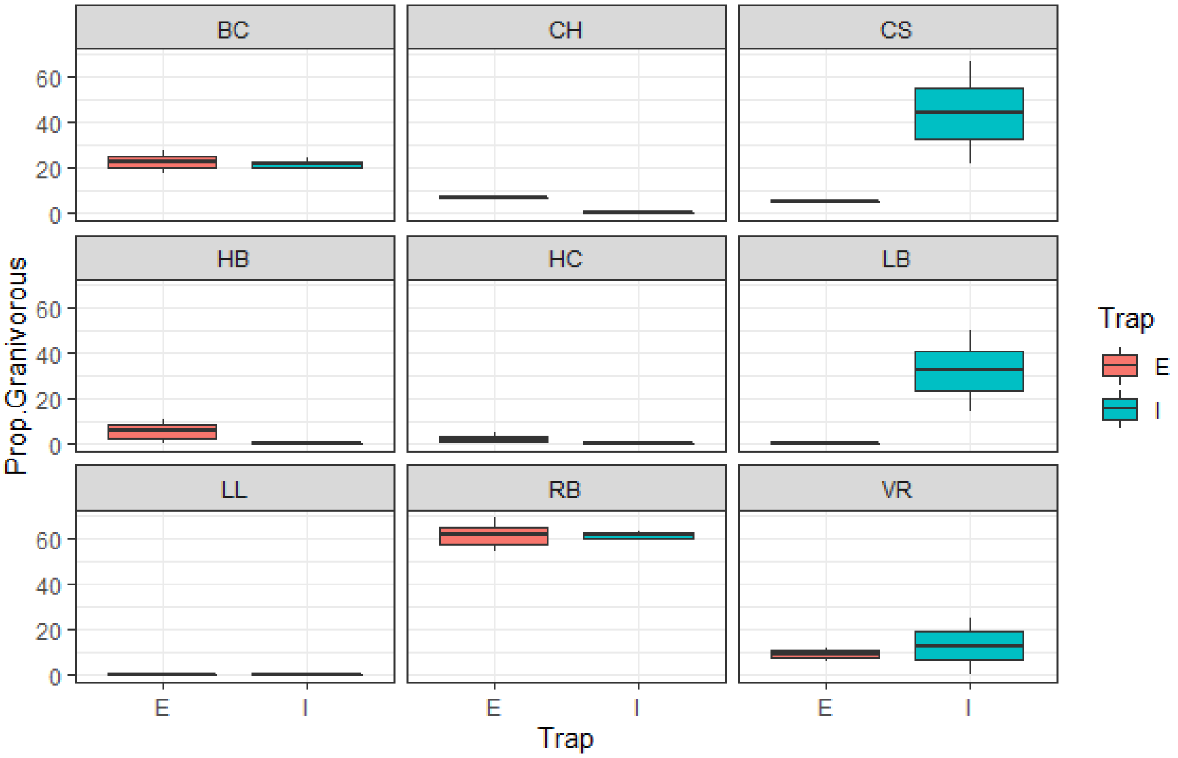
Appendix 51 : Mean individual mass of the carabids caught in exterior pitfall traps (E), thus pitfall traps, and interior pitfall traps (I), thus emergence traps, in early May 2021



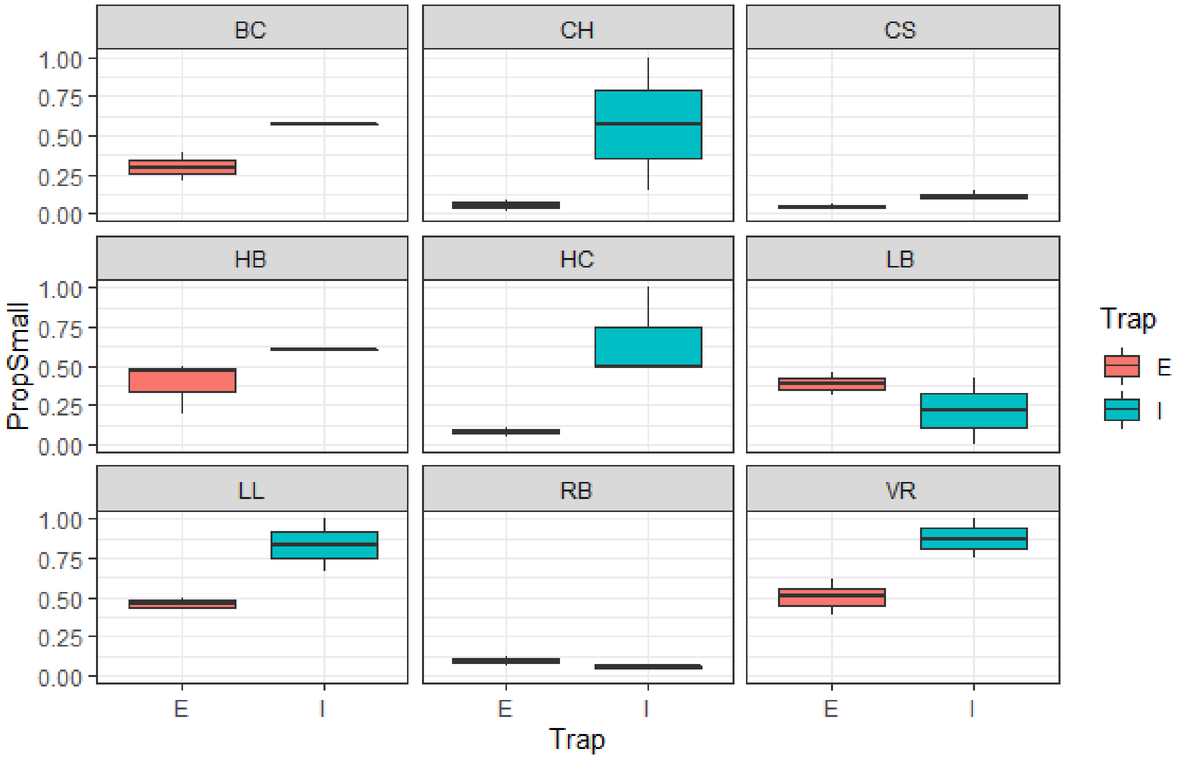
Appendix 52 : Proportion of big individuals caught in exterior pitfall traps (E), thus pitfall traps, and interior pitfall traps (I), thus emergence traps, in early May 2021



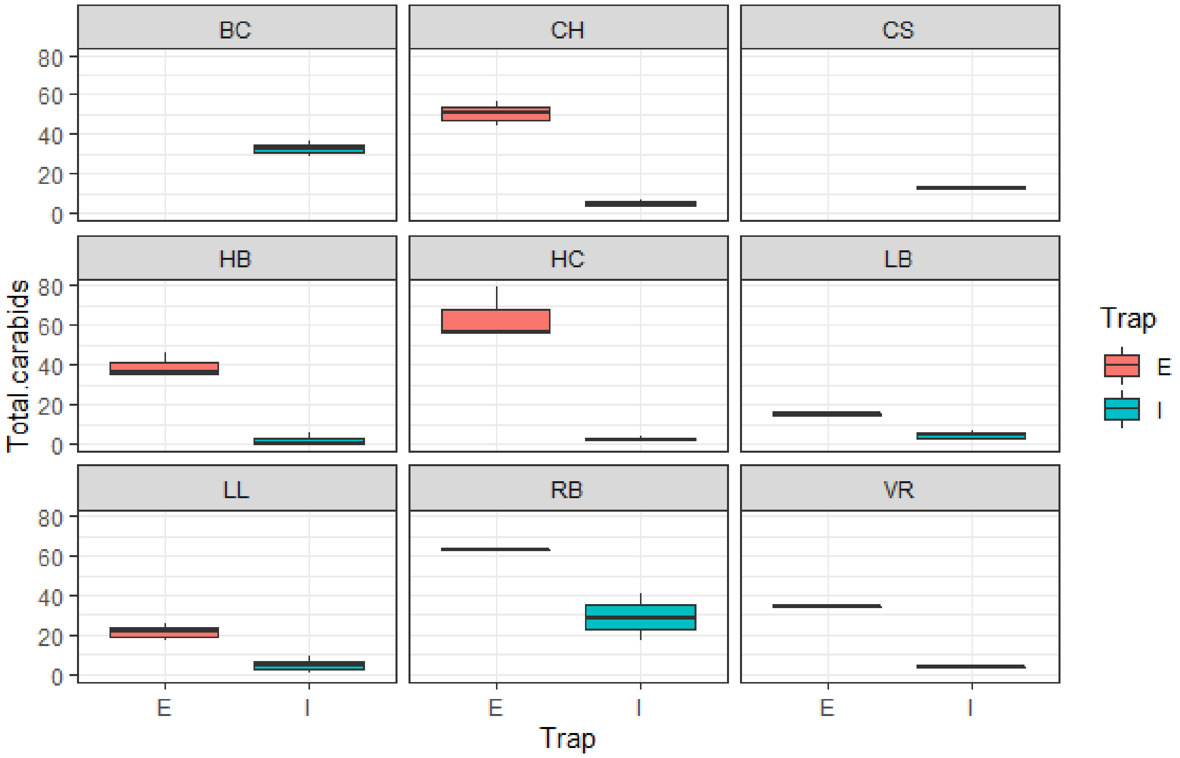
Appendix 53 : Proportion of generalist predators caught in exterior pitfall traps (E), thus pitfall traps, and interior pitfall traps (I), thus emergence traps, in early May 2021



Appendix 54 : Proportion of granivorous caught in exterior pitfall traps (E), thus pitfall traps, and interior pitfall traps (I), thus emergence traps, in early May 2021

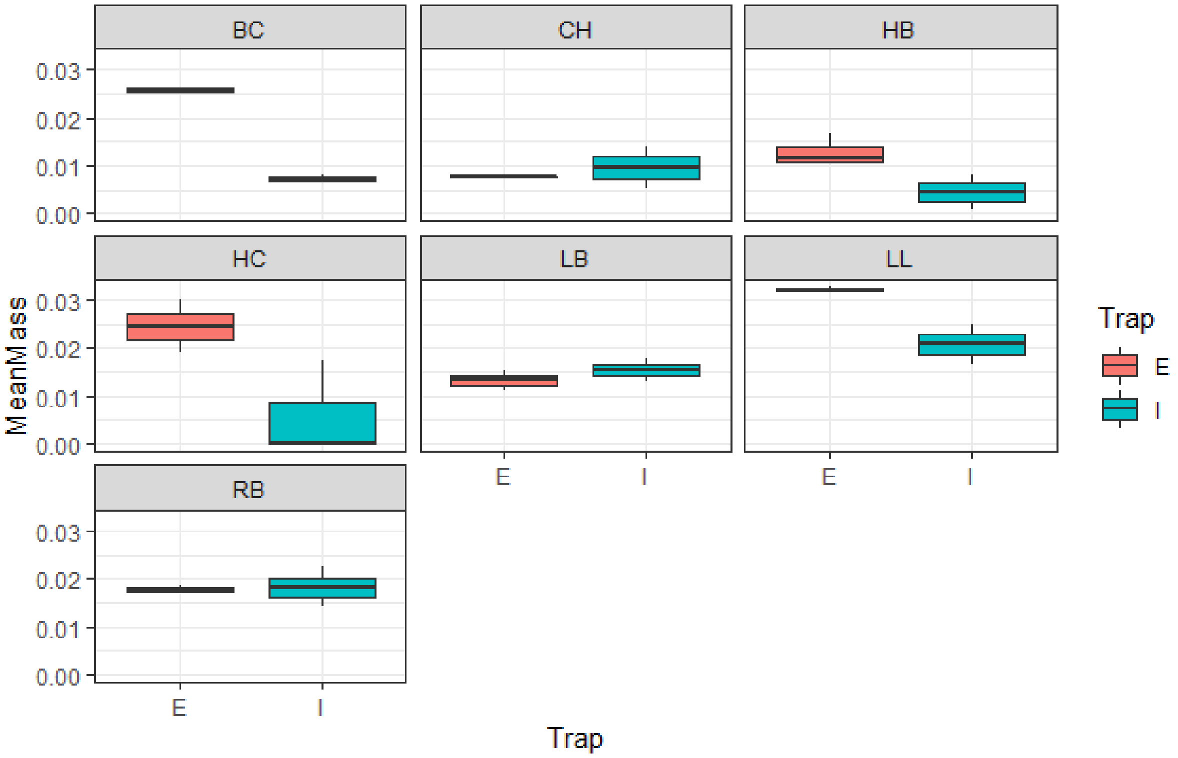


Appendix 55 : Proportion of small individuals caught in exterior pitfall traps (E), thus pitfall traps, and interior pitfall traps (I), thus emergence traps, in early May 2021

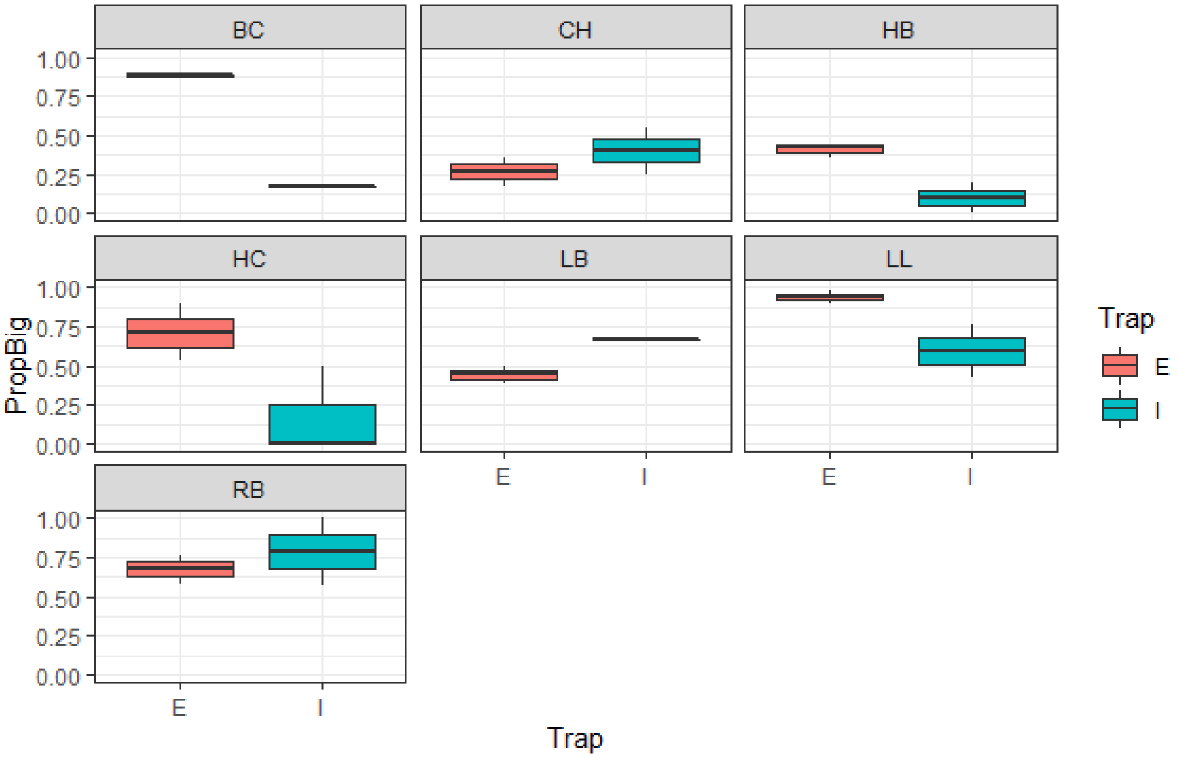


Appendix 56 : Total number of carabids caught in exterior pitfall traps (E), thus pitfall traps, and interior pitfall traps (I), thus emergence traps, in early May 2021

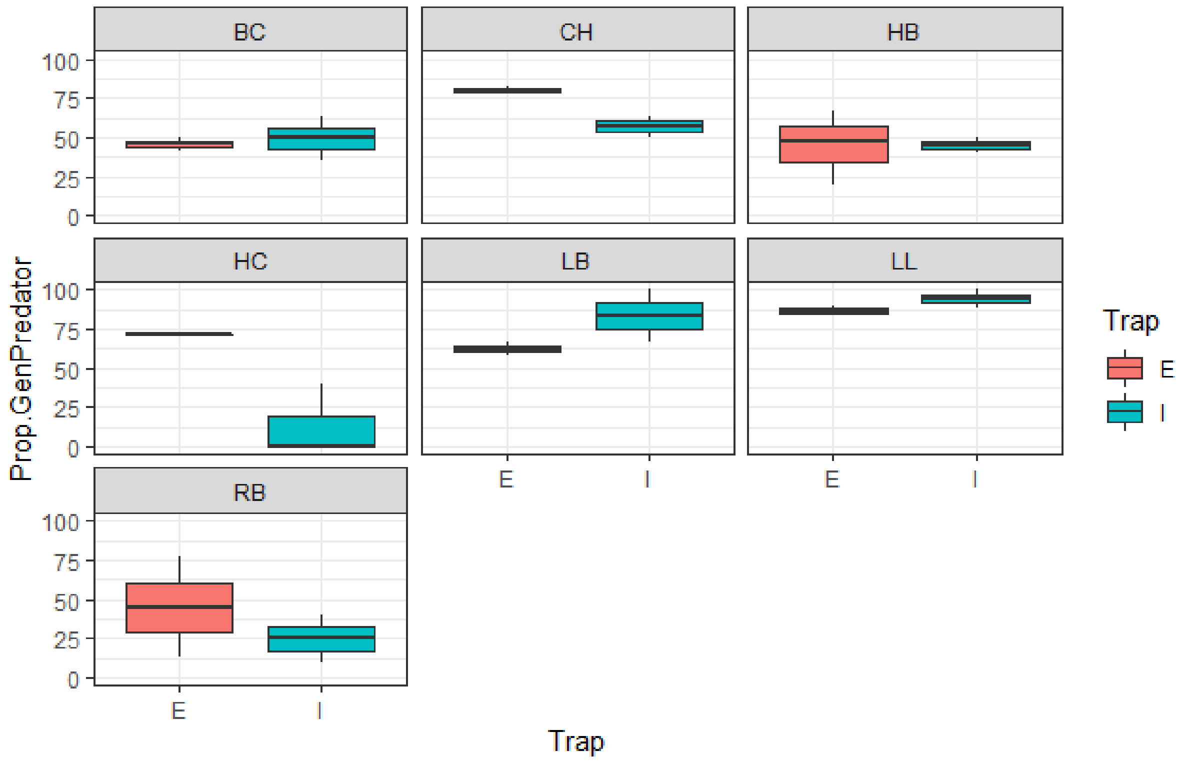
Late June



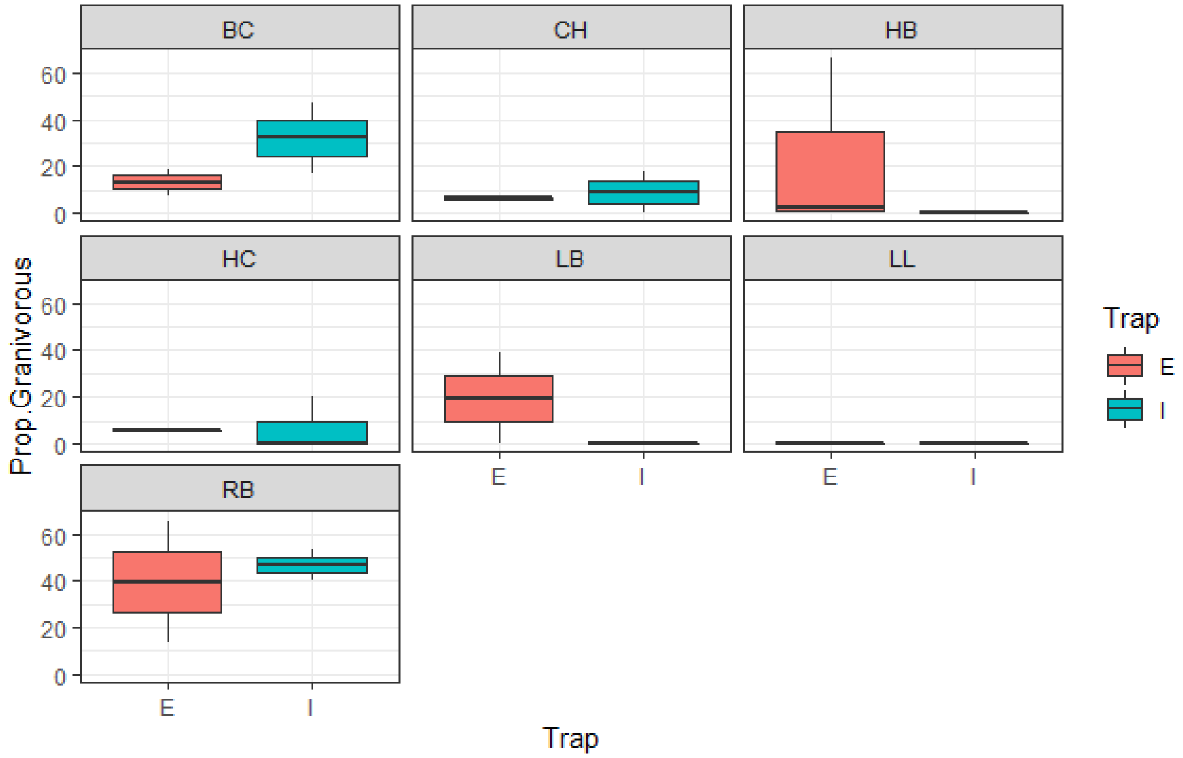
Appendix 57 : Mean individual mass of the carabids caught in exterior pitfall traps (E), thus pitfall traps, and interior pitfall traps (I), thus emergence traps, in late June 2021



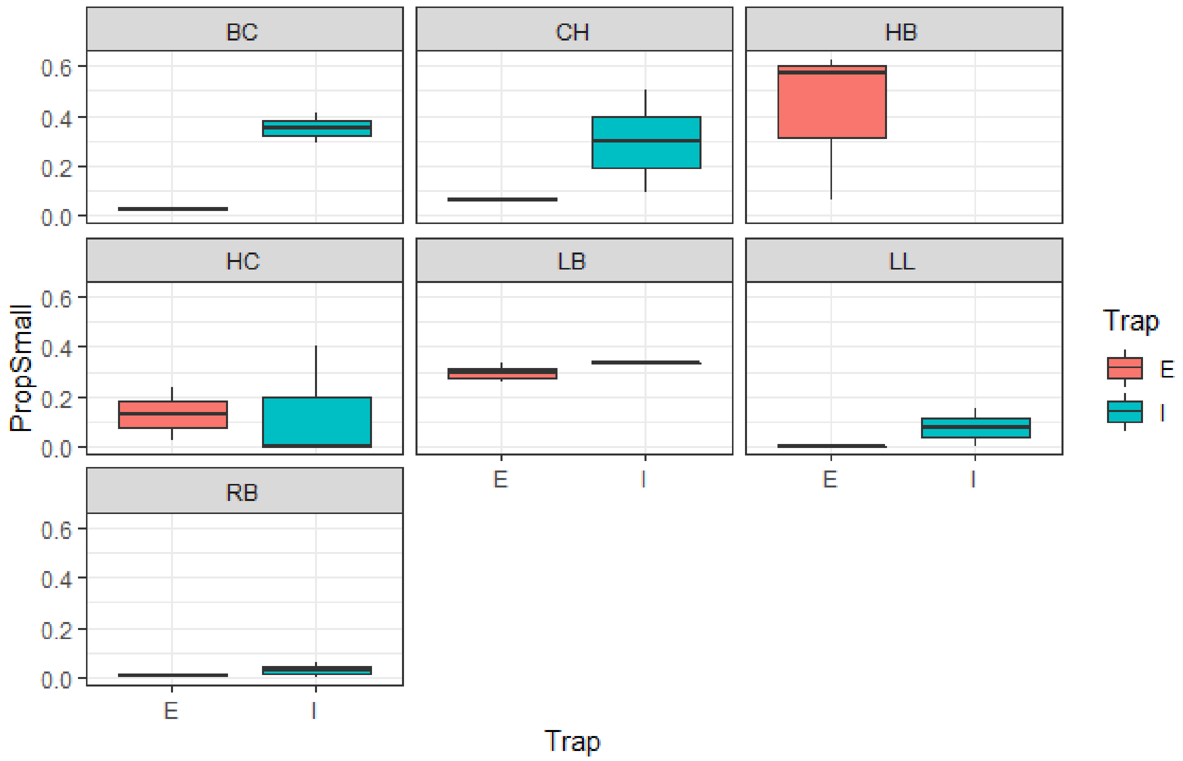
Appendix 58 : Proportion of big individuals caught in exterior pitfall traps (E), thus pitfall traps, and interior pitfall traps (I), thus emergence traps, in late June 2021



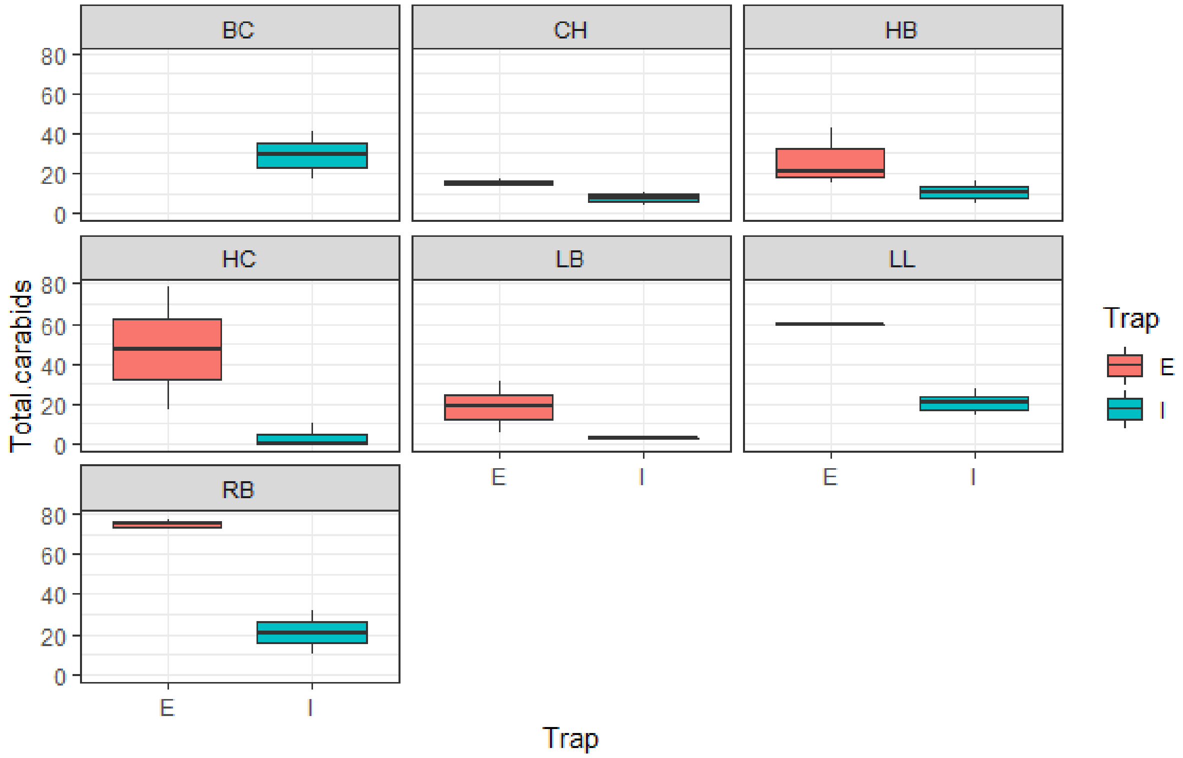
Appendix 59 : Proportion of generalist predators caught in exterior pitfall traps (E), thus pitfall traps, and interior pitfall traps (I), thus emergence traps, in late June 2021



Appendix 60 : Proportion of granivorous caught in exterior pitfall traps (E), thus pitfall traps, and interior pitfall traps (I), thus emergence traps, in late June 2021



Appendix 61 : Proportion of small individuals caught in exterior pitfall traps (E), thus pitfall traps, and interior pitfall traps (I), thus emergence traps, in late June 2021



Appendix 62 : Total number of carabids caught in exterior pitfall traps (E), thus pitfall traps, and interior pitfall traps (I), thus emergence traps, in late June 2021

UNIVERSITÉ CATHOLIQUE DE LOUVAIN
Faculté des sciences
Place des sciences, 2 bte L6.06.01, 1348 Louvain-la-Neuve, Belgique | **www.uclouvain.be/sc**