Global Ecology and Conservation 55 (2024) e03223

Contents lists available at ScienceDirect

Global Ecology and Conservation

journal homepage: www.elsevier.com/locate/gecco

Original research article

Conservation agriculture compared to conventional tillage improves the trade-off between ground-dwelling arthropod trophic groups for natural pest regulation in cotton cropping systems

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A R T I C L E I N F O

Keywords:
Conservation agriculture
Conventional tillage
Macrofauna
Ground-dwelling arthropods
Agroecological cotton farming
Cropping systems

A B S T R A C T

Conservation agriculture is an innovative approach based on minimal soil disturbance, soil cover with crop residues, and crop rotation, which increases the biodiversity of soil macrofauna thus contributing to nutrient cycling and soil aggregation. In addition, macrofaunal abundance may play a role at regulating insect pest populations. The study aims to predict the effects of soil management practices (conventional tillage and conservation agriculture) on the abundance of soil macrofauna and herbivore predation in cotton (*Gossypium hirsutum* L.) based cropping systems. We conducted a field experiment with a randomized complete block comprising two treatments, Conventional Tillage (CT) and Conservation Agriculture (CA), and six replications in a cotton-maize rotation system from 2020 to 2023. Soil monoliths and pitfall traps were installed in both treatments to collect ground-dwelling arthropods, to analyse the influence of soil management practices on their abundance, their trophic groups, and the rate of pest predation by generalist predators. Pest predation rates were assessed using artificial caterpillars made from plasticine. The results showed significant positive effects of soil management practices on herbivory rate, herbivore abundance, predator abundance, omnivore-predator abundance and pest predation rate. The average herbivory rate was 9.8 % in the conservation agriculture plots and 11.6 % in the conventional tillage plots. Overall, the predation rate was 58.9 % in the conservation agriculture plots and 21.8 % in the conventional tillage plots. The abundance of predators and of omnivore-predators were significantly higher in conservation agriculture than in

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https://doi.org/10.1016/j.gecco.2024.e03223
Received 15 May 2024; Received in revised form 17 August 2024; Accepted 25 September 2024
Available online 26 September 2024

conventional tillage. These findings suggest that conservation agriculture practices improve soil macrofauna and pest regulation, with potential benefits on soil quality and sustainability in cotton cropping systems.

1. Introduction

Cotton production often involves the extensive use of chemicals such as insecticides and herbicides, leading to significant environmental pollution and loss of biodiversity (Kiliç et al. 2020), as well as intensive tillage generating soil physical and biological disturbance (Yemadje et al., 2022). Conventional tillage increases short-term soil porosity, facilitates air exchange between soil particles and contributes to good initial root development, but buries most crop residues in the soil and leaves the soil surface bare and unprotected (Tavares and Tessier, 2009). Tilled soils tend to warm more quickly than those that are less disturbed and covered by crop and/or cover crop biomass (Subbulakshmi et al., 2009). This leads to changes in the structure of the food web of soil organisms, including changes in the structure and function of the soil microbial community (Mathew et al., 2012). This is particularly the case for the biochemical process dominated by bacteria, which increases the rate of carbon and nitrogen mineralization, and leads to the loss of nutrients and soil organic matter (Zikeli et al., 2013). Tillage can not only mechanically stress the soil structure, but also damage the habitat of soil microorganisms (Hartmann and Six, 2023). In addition, intensive tillage practices can increase the nitrate leaching from the soil and increase the potential for greenhouse gas emissions. Conventional tillage combined with occasional straw burning accelerates soil erosion, depletes soil organic carbon (SOC) and increases soil compaction.

Conservation agriculture practices have been proposed as a means to maintain structure stability, improve soil moisture, reduce soil erosion and improve soil health through promoting SOC storage (Cárceles-Rodríguez et al., 2022; Francaviglia et al., 2023) and microbial community diversity and activity (Holland, 2004; Wang et al., 2020; Zhang et al., 2018; El Mujtar et al., 2019). Conservation agriculture involves crop rotation, permanent soil cover with crop residues and possibly cover crops, and no or minimal tillage. Crop rotation is widely used in Benin, alternating the cultivation of cotton with other complementary crops such as maize and soybean (Lv et al., 2023; Acevedo-Siaca and Goldsmith, 2020). This strategy helps prevent depletion of specific soil nutrients and reduces pressure from cotton-specific pests. Permanently covering the soil with residues from previous crops creates a protective barrier that limits erosion, improves soil structure and conserves moisture. This creates more favourable conditions for soil biodiversity, particularly for sensitive soil-dwelling arthropods.

Soil macrofauna play an essential role in the physical, chemical and biological properties of the soil, which improves soil quality and plant productivity in agroecosystems (Blanchart et al., 2006). Soil macrofauna communities are partially responsible for organic matter decomposition. Organic matter ingested by macrofauna is fragmented and digested under the action of enzymes before being released to microorganisms for complete decomposition. Soil macrofauna improve through bioturbation the physicochemical properties of soils such as aeration, energy, water availability. They are soil engineers that feed on the litter and organic residues on the soil surface. In this way, it indirectly stimulates the activity of the macrofauna and ensures the presence of a very active cellulolytic microflora (Velásquez et al., 2012). Furthermore, the soil macrofauna are themselves a source of nitrogen that can be mobilized when they die. Soil macrofauna regulates the activity, abundance of microorganisms, the transformation and recycling of organic matter and nutrients and the stabilization of the soil structure (Vasconcellos et al., 2013).

In the specific context of cotton production in Benin, where pest pressure is high, conservation agriculture may offer additional benefits. In addition to the positive effects on nutrient cycling and soil aggregation, the enhanced microfauna communities associated with conservation agriculture may contribute to regulate the population and activity of pest insects. It has been postulated that conservation agriculture practices focused on crop diversification promote the presence of natural predators of pests, thus contributing to biological control of insect populations (Brévault et al., 2007, Silvie et al., 2024). The relevant trophic groups for this are generalist predators and omnivo-predators (Brainard et al., 2016; Paudel et al., 2020). However, this effect has been only rarely proven in cotton-based cropping systems in Benin, and the impact of an increased macrofaunal abundance on predation levels, and hence their effectiveness in pest regulation, needs to be further demonstrated in this context. Moreover, recent insect pest outbreaks in conservation agriculture in North-Western India suggest that mulching may also benefit certain ground-dwelling pests, and thus a better understanding of the relationship between tillage practices, crop residue mulches, and pest population dynamics is needed (Jasrotia et al., 2023).

We hypothesize that conservation agriculture will increase the abundance of ground-dwelling beneficial arthropods, increase the rate of herbivore predation and reduce herbivory on cotton. Our study aims to compare the effects of conventional tillage and conservation agriculture on the abundance of soil macrofauna, herbivory and herbivore predation in cotton cropping systems. We analyzed arthropod abundance using traps installed in a field experiment comparing these two soil management practices for cotton production at two sites of Benin.

2. Material and methods

2.1. Study sites

The Permanent Experimental Centers (CPE) of Soaodou (10°29 N, 1°98E, 425 m), located in the northern zone of Benin, and of Savalou (7°90 N, 1°92 E, 300 m), located in the central zone of the country, served as bases for the experiments. These sites have been carefully selected to represent different pedoclimatic contexts, thus providing a solid basis for a comprehensive and representative study. The Soaodou CPE is located in the north of the country, a region characterized by a Sudano-Sahelian climate, with a single rainy season and an average annual rainfall of around 1200 mm.

The soils of Soaodou are Fluvisols according to the World Reference Base classification (FAO, 2006). The average clay content is around 15 % with a carbon-nitrogen (C/N) ratio of 13:1 (Amonmide et al., 2019). Savalou is located in the central zone of Benin. It is a Sudano-Guinean climate with two distinct rainy seasons and an average annual rainfall of 1200 mm. The predominant soils in Savalou are also leached tropical ferruginous soils, but they have a lower clay content, around 7 %, with a C/N ratio of 9:1. These soils are partially compacted. This pedoclimatic diversity between the two study areas, from the north to the centre of Benin, provides an ideal situation to study the impact of different soil management practices on macrofauna under different conditions.

2.2. Experimental design

Conservation agriculture and the common, conventional practice in the study area were tested in a cotton-maize rotation system from 2020 to 2023. The experimental design was set up in 2020 with the aim of showing how conservation agriculture compared to conventional tillage could improve soil fertility and then crop performance. The plots were maintained under crop rotation with measurements of soil quality and crop performance until 2023 when the soil macrofauna was measured. At each site, the experimental design was a randomized complete block with two treatments (Conventional Tillage and Conservation Agriculture) and six replications (Fig. 1). Each elementary plot had an area of 26.9 m^2 and was separated from neighbouring plots by 2 m wide. Guazuncho 2 was the common cotton variety sown at both sites.

2.3. Cropping systems and soil management

Cotton-maize rotations are common practice in the cotton-based systems in Benin and were used in our study (Table 1). Conventional tillage (CT) consisted of shallow plouhging to a depth of 20 cm with a tiller equipment for soil inversion. In conventional tillage, maize was sown without any associated legumes. Soil management in conventional tillage took into account the specific characteristics of each site. In Soaodou, an area with high livestock potential, crop residues are grazed at the end of the rainy season. This practice was simulated in the conventional tillage by removing crop residues (maize and cotton) from the plots and then spreading of farmyard manure at a rate of 400 kg ha^{-1} before ploughing. In Savalou, cattle farming is not widely practiced, so there is no grazing of crop residues. In addition, because of the two rainy seasons, producers sow cowpea directly during the first growing rainy season and plough during the second rainy season, burying all the crop residues. Both practices were carried out under conventional tillage.

Conservation agriculture (CA) consisted of no tillage using a direct seeder, covering 85 % of the soil surface covered with a mulch of plant litter, and incorporating two legume cover crops, *Stylosanthes guianensis* and *Crotalaria retusa* grown as intercrops together with maize. Cotton was sown as a pure crop in both systems. In accordance with one of the principles of conservation agriculture, which is to

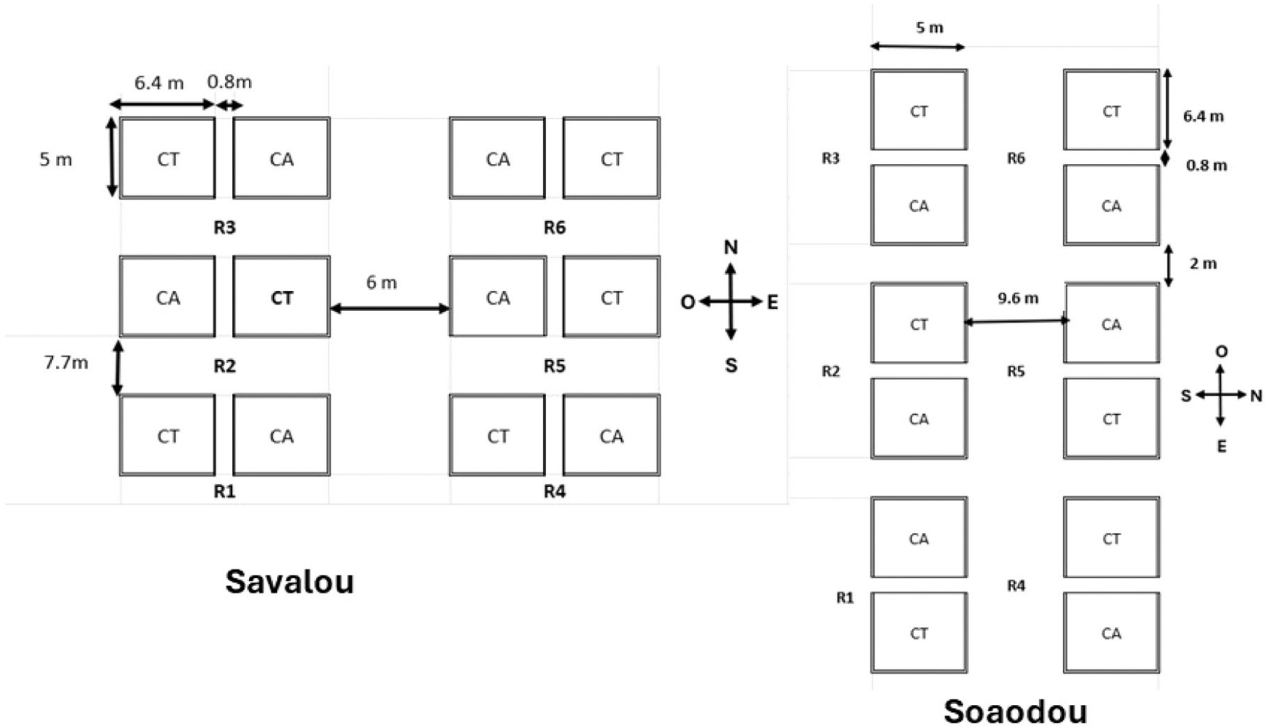

Fig. 1. Experimental design showing the two treatments (CT: Conventional Tillage and CA: Conservation Agriculture) and six replicates on the both sites Savalou and Soaodou.

Table 1
Characteristics of cropping systems.

Cropping systems	Sites	Tillage	Crop rotation	Crop diversification	Crop residues management	Observation
CT	Soaodou	+++	Maïze//cotton	0	Total export residues	Applying 400 kg. ha−1 of manure
	Savalou		Cowpea/maïze//cowpea/cotton	+	Burying residues at the time of ploughing	
CA	Soaodou	0	Maïze+C.r+S.g//cotton	++	Keeping on the soil surface	
	Savalou		Sorghum+C.j/maïze+C.r+S.g//S.g/cotton	+++		

//= Separates crops grown between years; /= Separates crops grown between from the same year; +++=high; ++=average; +=low; C.r= Crotalaria retusa; C.J= Crotalaria juncea; S. g= *Stylosanthes guianensis.* CT=Conventional Tillage; CA= Conservation Agriculture

keep the soil covered with crop residues, no grazing was allowed. In the year of cotton planting, the CA system benefits from the regenerative capacity of *Stylosanthes guianensis* which was associated with maize last year. In fact, the legume left on the plots resumes its growth during the first season in Savalou increasing biomass production and ensuring good soil cover. In the year of maize, sorghum combined in alternating with *Crotalaria juncea* is grown during the first season in Savalou to increase biomass inputs and provide a soil cover, prior to maize direct seeding. Cotton was sown as a pure crop in crop residues and the biomass produced by cover crops.

In 2023, cotton planting year, glyphosate 480 g/l was applied as total herbicide at a rate of 1080 g. ha^{-1} to control weeds and cover crop biomass before sowing cotton in the CA-based treatment. In both cropping systems, an application of selective cotton herbicide (Trifloxysulfuron- sodium 11 g/l) at a dose of 1 l/ha was applied to control weeds during the vegetative cycle. As for fertilization, NPKSB fertilizer formula 14–18–18–6–1 at a dose of 250 kg ha^{-1} was applied about two weeks after sowing, and urea with 46 % nitrogen at a dose of 50 kg ha^{-1} was applied at the beginning of flowering. On the conventional plots, weeding with a hoe and ridging was carried out at the same time as the urea application, to strengthen the plants. On the other hand, to ensure weed control, an average of 3 manual weeding operations are carried out on the conservation agriculture plots. To improve cotton pest management during the experiment, phyllophagous insects were controlled with Thalis 56/112 EC containing Emamectin benzoate and Acetamiprid.

2.4. Sampling methods

2.4.1. Sampling of the soil macrofauna

Our data collection protocol was designed to provide comprehensive information on the impact of soil management practices on soil macrofauna, as well as ecological interactions such as predation and herbivory. Data collection on the abundance and diversity of arthropods moving on the soil was carried out during the rainy season in 2023 using pitfall traps (Dassou et al., 2015). These traps consist of containers buried in the soil at ground level so as to be washed with the surface runoff. Insects and other arthropods moving on the ground fall into these traps and are thus captured. At each site, 12 pitfall traps (11 cm×14 cm x 14 cm) were placed in the 6 replicates of both treatments, CT (conventional tillage) and CA (conservation agriculture) for 48 hours before recording the arthropods captured. The traps were sampled twice, during the vegetative and flowering phases of the cotton plants. The abundance and diversity of arthropods found in the soil at a depth of 30 cm were assessed using the soil monoliths (Pauli et al., 2011). One monolith measuring 30 cm×30 cm x 30 cm was realized per plot in each of the two soil management treatments, with 12 monoliths per site. After digging the hole, the surface litter was quickly collected into a container in the form of a shower bucket. First, the top 10 centimeters of soil are dug out and the soil is placed in the container. Then, the same process is repeated for the 10–20 and 20–30 cm layers. For each shower bucket, we harvested the ground-dwelling arthropods visible to the naked eye by spreading a handful of soil on a flat table-top container. We then gently broke up the clods and lumps of soil with our fingers to extract any arthropods that might be hiding. This process was repeated until there was no soil left in the shower bucket and taking about 30 minutes per monolith. We then placed the ground-dwelling arthropods in an Eppendorf tube containing 75 % alcohol, with each bucket being labelled and specific to each monolith. The arthropods collected in the two types of traps (monoliths and pitfalls) were counted and identified at the entomology laboratory of the National School of Biosciences and Applied Biotechnologies of Benin using an insect identification key (Dassou et al., 2016).

2.4.2. Assessing herbivory rate

Herbivory damage was assessed by examining the leaf perforation index per perforated leaf (Azandémè-Hounmalon et al., 2023). Herbivory was assessed on 10 cotton plants that were the most attacked by insects in each of the plots of both soil management treatments. All perforated cotton leaves were scored using the leaf perforation index. The percentage of leaf herbivory was identified according to the following classification: 0 % = no hole on the leaf; 20 % = little damage (punctures and/or small holes); 40 % = moderate damage (a few larger holes) 60 % = severe damage (large holes and/or larger leaf edge areas eaten away); 80 % = very heavy damage (many larger holes and/or larger leaf edge areas eaten) and 100 % = total damage (leaves destroyed and non-functional).

2.4.3. Assessing predation rate

Predation was assessed using the sentinel prey method based on artificial caterpillars made from plasticine. The size of the caterpillars was 25 mm long and 5 mm wide (Low et al., 2014; Puliga et al., 2023). In each treatment, 2 artificial caterpillars were randomly placed on cotton plants, resulting in a total of 24 per site. The two artificial caterpillars used per plot were of different colours. One was yellow similar to the colour of natural caterpillars and easily visible to predators. The second was green, resembling the colour of the plants. These two colours were used to see if they could affect predation by generalist predators. After exposure, artificial caterpillars were collected, and marks made by generalist predators were identified. Predation was noted 24 hours after installation of the artificial caterpillar by determining the percentage of the part attacked by generalist predators. Bite marks were scored from 0 % to 100 % according to the area attacked by generalist predators. These measurements helped us understand how soil management practices influence interactions between herbivores and their predators.

2.4.4. Data analyses

Data were analyzed using R software version 4.2 (R Core Team, 2017). Three types of statistical models were used to analyze the data collected. The first model was the Generalized linear mixed-effects models (GLMMs, Bolker et al., 2009) with a Poisson error and experimental site as a random effect to examine the effect of qualitative variables such as soil management practices, arthropod trophic groups and arthropod species on the abundances of arthropods collected. This model was used separately on the abundances of arthropods collected from monoliths and those collected from pitfall traps. The GLMMs were fitted by the Laplace approximation using the 'glmer' function in the 'lme4' package (Bates, 2011). The second model was Generalized linear models (GLMs) with binomial error to determine the effect of soil management practices on the predation rate and herbivory rate. GLMs with binomial error were also used to determine the influence of artificial caterpillar colors on predation rates. The Student *t*-test was used to compare the predation rate or the abundance of herbivores, predators, omnivore-predators between the two types of soil management practices. The relationships between soil management practices, herbivore abundance, herbivory rate and omnivore-predator abundance, on the one hand, and that between predator abundance and predation rate, on the other hand, were tested using a third model such as Structural Equation Modeling (SEM) with the piecewise SEM package (Lefcheck, 2016). We used marginal R^2 as an absolute value for the goodness of fit of the models (Nakagawa and Schielzeth, 2013).

3. Results

3.1. Variation in the abundance of arthropods collected from monoliths according to soil management practices, trophic groups, arthropod species and experimental sites

A total of 428 arthropods (including 221 from Soaodou and 207 from Savalou) were collected from the monoliths at the two experimental sites. Among the soil arthropods, the millipede species *Oxidus gracillis* of the family Paradoxosomatidae was the most abundant (67.75 % of the arthropod species collected from monoliths) followed by termites *Nasutitermes* sp. (22.42 % of the arthropod species collected from monoliths) and ants *Camponotus* sp. (6.75 % of the arthropod species collected from monoliths). The abundance of arthropods collected from soil monoliths varied significantly according to soil management practices, arthropod species, and arthropod trophic groups (Table 2). Arthropod abundance was higher in conservation agriculture soils than in conventional tillage soils at both experimental sites (Fig. 2A, Fig. 2B) but the Student t-test did not reveal significant effects neither at Savalou ($t = 0.25$; $Df = 13$; $P = 0.79$) nor at Soaodou ($t = 1.46$; $Df = 14$; $P = 0.16$). Predators ($t = 3.32$; $Df = 13$; $P < 0.00001$) and omnivore-predators ($t = 2.23$; $Df = 13$; $P < 0.02$) were most abundant in the conservation agriculture plots in Savalou, while herbivores were more abundant ($t = 4.55$; $Df = 13$; $P < 0.00001$) and omnivore-predators completely absent in the conventional tillage plots. In Soaodou, herbivores ($t = 6.25$; $Df = 14$; $P < 0.00001$) and predators ($t = 4.36$; $Df = 14$; $P < 0.00001$) were more abundant in conservation agriculture plots than conventional tillage plots (Fig. 2C, Fig. 2D).

Table 2
Influence of soil management practices, species and trophic groups on the abundances of arthropods collected in soil monoliths and in pitfall traps. Df: Degrees of freedom, AIC: Akaike's Information Criteria, δAIC: Relative Akaike's Information Criteria, logLik: log-likelihood values, χ2: Ki2, Pr (>Chisq): Probability values.

Variables	Df	AIC	δAIC	logLik	χ2	Pr(>Chisq)
	Abundances of arthropods collected from monoliths					
Soil management practices	1	280.42	−2.05	−132.21	4.04	0.04*
Arthropod trophic groups	1	315.62	−37.25	−149.81	39.24	<0.00001***
Arthropod species	3	346.46	−68.09	−130.19	74.08	<0.00001***
Experimental site						
	Abundances of arthropods collected from pitfall traps					
Soil management practices	1	1751.0	−45.8	−870.50	47.83	<0.00001***
Arthropod trophic groups	2	1866.0	−160,8	−928.98	164.78	<0.00001***
Arthropod species	3	1703.3	1.9	−846.64	164.67	<0.00001***
Experimental site	5	1703.3	−162.7	−846.64	164.67	<0.00001***

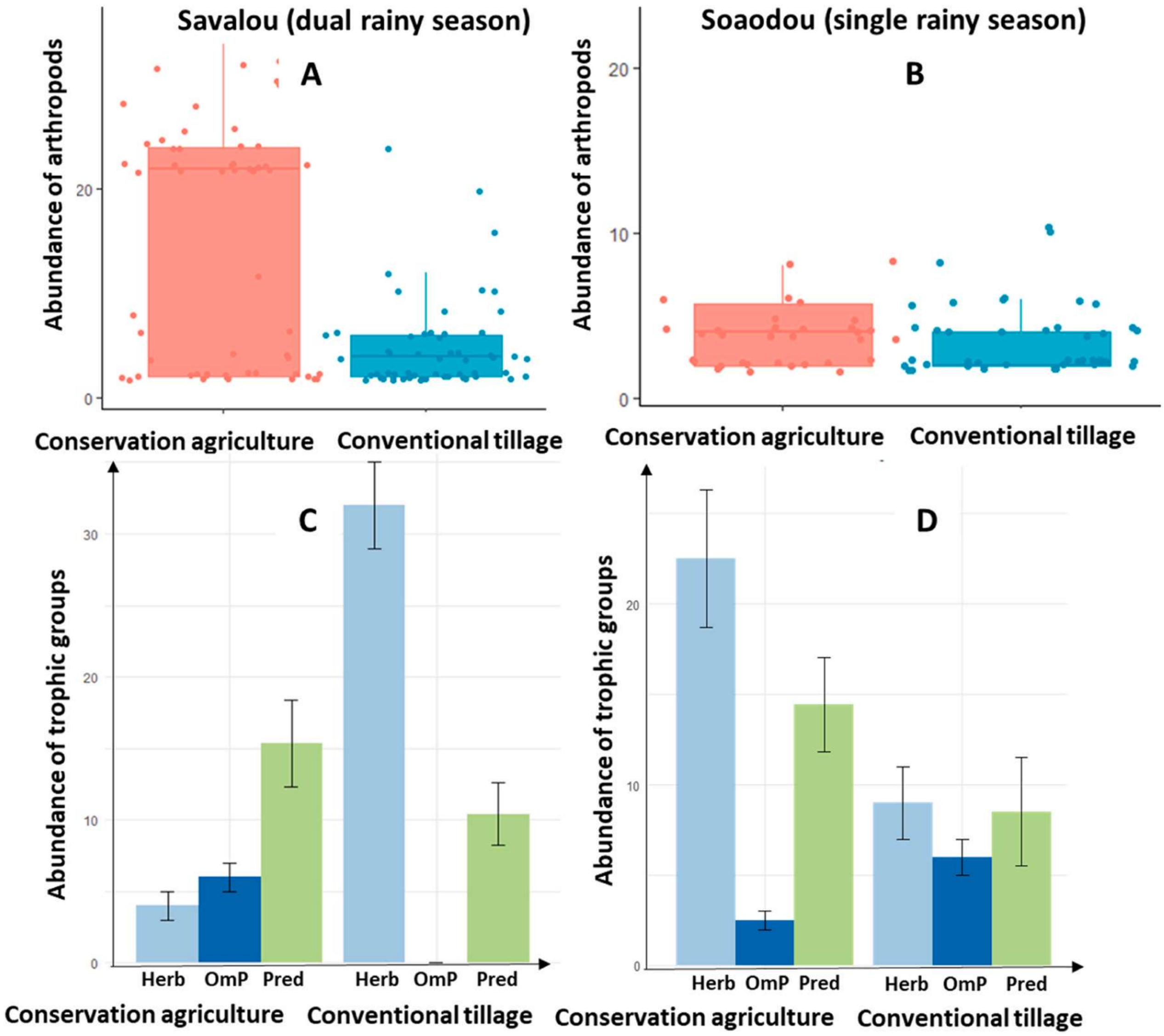

Fig. 2. Variability in the abundance of arthropods collected through soil monolith (30 ×30 ×30 cm) sampling at the two soil management practice treatments (n = 12) A) from the site of Savalou and B) from the site of Soaodou; Abundance of arthropod trophic groups collected through soil monolith C) from the site of Savalou and D) from the site of Soaodou; Herb = Herbivore, OmP = Omnivore-Predator, Pred = Predator.

3.2. Variation in the abundance of arthropods collected from pitfall traps according to soil management practices, trophic groups, arthropod species and experimental sites

A total of 1012 ground-dwelling arthropods (including 724 from Soaodou and 288 from Savalou) were collected in the pitfall traps at the two experimental sites during the two sampling periods (Table 3). Among these ground-dwelling arthropods, the ants *Camponotus* sp. were the most abundant (32 % of the arthropod species collected), followed by *Camponotus vagus* (20.8 % of arthropod species collected) and *Gryllus* sp. (12.5 % of the arthropod species collected). The abundance of arthropods collected in pitfall traps varied significantly according to soil management practices, arthropod species, experimental site, and arthropod trophic groups (Table 2). Arthropod abundance was higher in conservation agriculture soils than in conventional tillage soils at the two experimental sites (Fig. 3**A,** Fig. 3**B**). The Student's t-test showed no significant effect of arthropod abundance between the two experimental sites ($t = -1.03$; $Df = 107$; $P = 0.30$) but significant effects between conservation agriculture soils and conventional tillage soils within each site (Savalou: $t = 2.18$; $Df = 40$; $P = 0.034$; Soaodou: $t = 3.31$; $Df = 115$; $P = 0.0012$). According to the trophic groups of arthropods collected by pitfall traps, herbivores were slightly more abundant than predators in both conventional tillage and conservation agriculture in Savalou (Fig. 3C) while omnivore-predators were the most abundant followed by predators and then herbivores in Soaodou (Fig. 3D). Omnivore-predators were the most abundant in conservation agriculture in Savalou, while they were less abundant in the plots where conventional tillage was practiced ($t = 6.66$; $Df = 23$; $P < 0.00001$). Herbivore abundance was higher in the conventional tillage plots than in the conservation agriculture plots but the t.test did not find significant effect ($t = -1.17$; $Df = 22$; $P = 0.25$). In Soaodou, unlike Savalou, omnivore-predators were similarly the most abundant in the plots of both types of agricultural practices ($t = 0.93$; $Df = 23$; $P = 0.36$) while predators were more abundant in conservation agriculture plots than conventional tillage

Table 3
Abundances of arthropods collected from pitfall traps classified according to trophic groups, orders and families.

Number	Species	Families	Orders	Trophic groups	Abundance
1	*Axinotoma fallax*	Carabidae	Coleoptera	Predator	8
2	*Camponotus atriceps*	Formicidae	Hymenoptera	Omnivo-predator	92
3	*Camponotus* sp.	Formicidae	Hymenoptera	Omnivo-predator	324
4	*Camponotus vagus*	Formicidae	Hymenoptera	Omnivo-predator	210
5	*Chalconotus* sp.	Scarabaeidae	Coleoptera	Omnivo-predator	6
6	*Chlaenius* sp.	Carabidae	Coleoptera	Predator	8
7	*Chlaenius variolosus*	Carabidae	Coleoptera	Predator	46
8	*Chrysomya albiceps*	Chrysomyinae	Diptera	Predator	14
9	*Ctenus* sp.	Ctenidae	Araneae	Predator	48
10	*Diacantha* sp.	Chrysomelidae	Coleoptera	Herbivore	6
11	*Gryllus* sp.	Gryllinae	Orthoptera	Herbivore	126
12	*Heteroligus meles*	Scarabaeidae	Coleoptera	Herbivore	4
14	*Onthophagus* sp.	Scarabaeidae	Coleoptera	Herbivore	14
15	*Oxidus gracillis*	Paradoxosomatidae	Polydesmida	Herbivore	60
16	*Paederini* sp.	Staphylinidae	Coleoptera	Predator	2
17	*Parachlaenius* sp.	Carabidae	Coleoptera	Predator	38
18	*Peucetia* sp.	Oxyopidae	Araneae	Predator	2
19	*Pheropsophus africanus*	Carabidae	Coleoptera	Predator	2
20	*Pseudocolaspis* sp.	Chrysomelidae	Coleoptera	Herbivore	2

(t = 5.58; Df = 23; P < 0.00001).

3.3. Herbivory and pest predation rate

The rate of herbivory did not vary according to the type of soil management system (Df = 1; LRT = 0.41; P = 0.52) and experimental site (Df = 1; LRT = 2.64; P = 0.10). The average herbivory rate was 9.8 % in the conservation agriculture plots and 11.6 % in the conventional tillage plots. The average herbivory rate was 11±0.7 % in the conservation agriculture plots and 14.64 ±1.4 % for conventional tillage in Soaodou, while in Savalou the herbivory rate was 8±0.7 % for both types of plots.

The type of soil management practice had a significant effect on the predation rate of plasticine larvae (Df = 1; LRT = 11.54; P = 0.0006). Overall, the predation rate was 58.9 % in conservation agriculture plots and 21.8 % in conventional tillage plots. The Student's t-test (t = 9.5146; Df = 77; P < 0.00001) showed that the predation rate was higher in conservation agriculture than in conventional tillage. The experimental site (Df = 1; LRT = 0.12; P = 0.72) and colour of the artificial prey (Df = 8; LRT = 0.93; P = 0.99) did not influence the rate of predation by generalist predators. Predation rates (Fig. 4) were higher in the conservation agriculture plots than in the conventional tillage plots in both Savalou (t = 6.66; Df = 28; P < 0.00001) and Soaodou (t = 6.55; Df = 37; P < 0.00001).

3.4. Structural equation modelling

At both experimental sites, conservation agriculture increased predation more than conventional tillage (Fig. 5; Table 4). The abundance of predators alone increased in Savalou whereas in Soaodou the abundance of predators and omnivo-predators increased as the abundance of herbivores increased. In Savalou, predation increased strongly as the abundance of omnivo-predators increased whereas in Soaodou predation increased more as the abundance of predators increased. The abundance of herbivores was higher in conventional tillage plots than in conservation agriculture plots in Savalou, but they did not differ between management systems in Soaodou. Conventional tillage alone increased herbivory in Savalou while conservation agriculture increased it more at Soaodou.

The SEM analysis combining the results from both sites together showed significantly greater overall positive effects of conservation agriculture on herbivore abundance, predator abundance, omnivore-predator abundance and predation rate for these cropping systems. On the other hand, herbivory was also positively influenced by conservation agriculture. However, herbivore abundance was negatively related to predation rate, which was substantially enhanced by conservation agriculture as compared to conventional tillage (Fig. 6; Table 5).

4. Discussion

Our study consisted of understanding how the two soil management practices (conservation agriculture and conventional tillage) modify soil arthropod communities and their biocontrol potential. Soil arthropods play an important role in the structuring and composition of the soil for proper mineral assimilation, thus contributing to the good growth of cultivated plants (Pauli et al., 2016). In this study, we focused on an additional ecosystem service provided by arthropods: the biological regulation of herbivorous insect pests through predation. Monolith sampling showed that the abundance of ground-dwelling arthropods varied with the soil management practices and that conservation agriculture harbored more arthropods than the plots with conventional tillage, confirming previous observations (e.g., Stinner and House, 1990). Conservation agriculture contributes to the stability of ground-dwelling arthropod communities through the presence of continuous soil cover, the addition of mulch, and crop diversification. This, together with the presence of a mosaic of surrounding habitat types, appears to be associated with abundant and diverse soil macrofauna communities

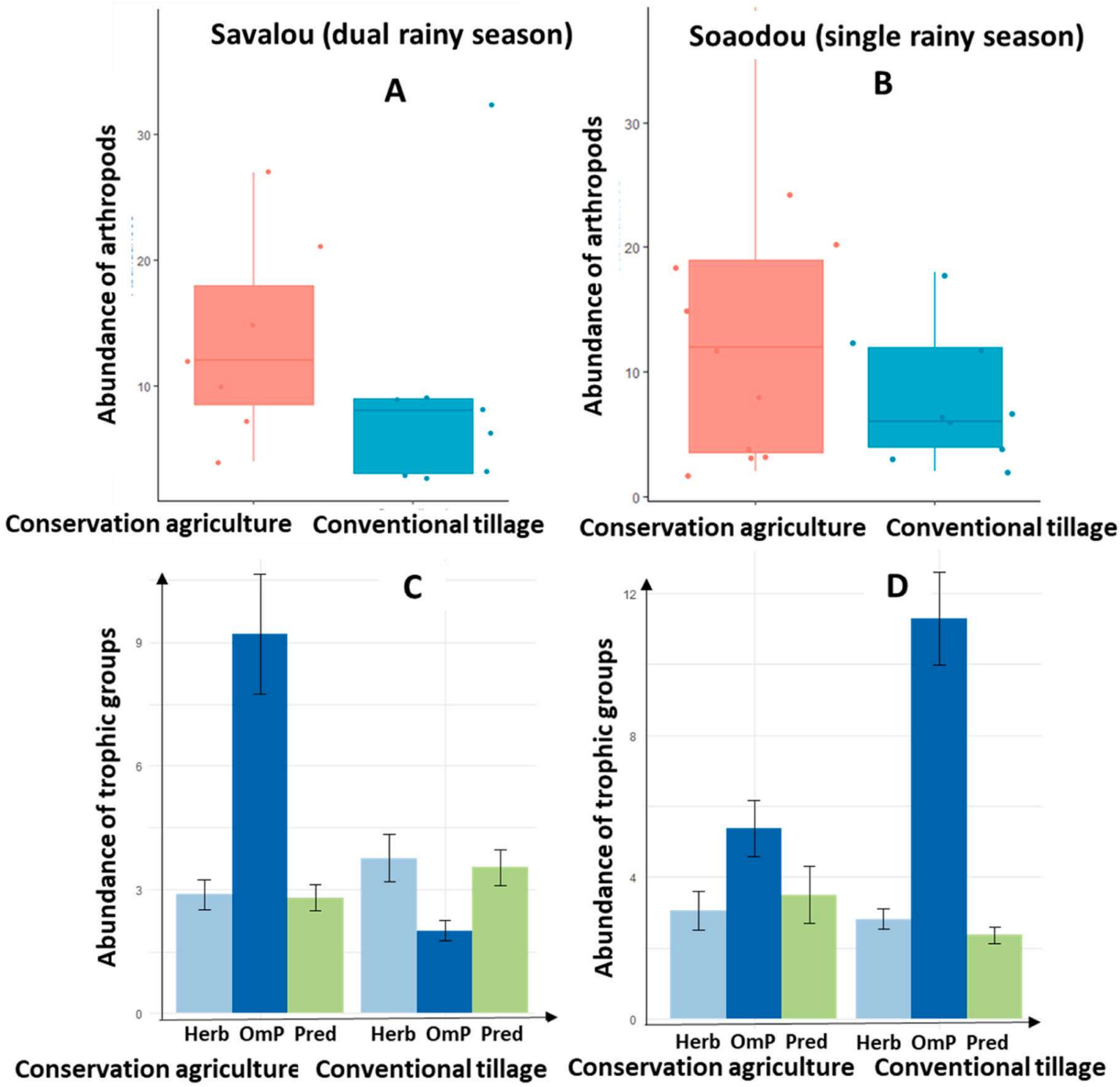

Fig. 3. Variability in the abundance of arthropods collected through pitfall traps at the two soil management practice treatments (n = 12) at Savalou (A) and Soaodou (B); Average abundance of arthropod trophic groups collected through pitfall traps at Savalou (C) and Soaodou (D); Herb = Herbivore, OmP = Omnivore-Predator, Pred = Predator.

(Rivers et al., 2016).

In healthy soils, heterogeneity results in a wide range of habitats and resources to maintain high levels of soil biodiversity. The abundance and diversity of soil macrofauna can vary greatly from one soil to another, depending on the organic matter content, the mineral composition of the soil (particularly the texture), the pH, all of which are influenced by soil tillage practices and land management practices. Soil organisms maintain complex relationships with each other, but also influence entire ecosystems by controlling the cycling of materials essential to plant life (carbon, nitrogen, phosphorus, potassium, etc.). The SEM showed that conservation agriculture increased the abundance of predators while conventional tillage increased the abundance of predatory omnivores. These predators were mainly ants of the *Camponotus* genus found both in the soil and on the soil surface, unlike the study by Pauli et al., (2016) in which ants of the *Pheidole* genus dominated maize-wheat cropping systems. Minimum tillage favours predators for the natural regulation of herbivores. Conventional tillage, on the other hand, favours predatory omnivores because tillage produces plant debris that predatory omnivores can decompose. In accordance with our hypotheses, conservation agriculture with zero-tillage and crop rotation has the potential to conserve certain ground-dwelling predators, e.g. ants, Araneae, Carabidae. A similar trend was found by Brévault et al., (2007) who showed that in a cotton (*Gossypium hirsutum* L.) cropping system with mulch and no ploughing in Cameroon, the Araneae were associated with conservation agriculture and the Carabidae with conventional ploughing. The analysis also showed that an increase in the abundance of predators contributes to an increase in the abundance of predatory omnivores. This

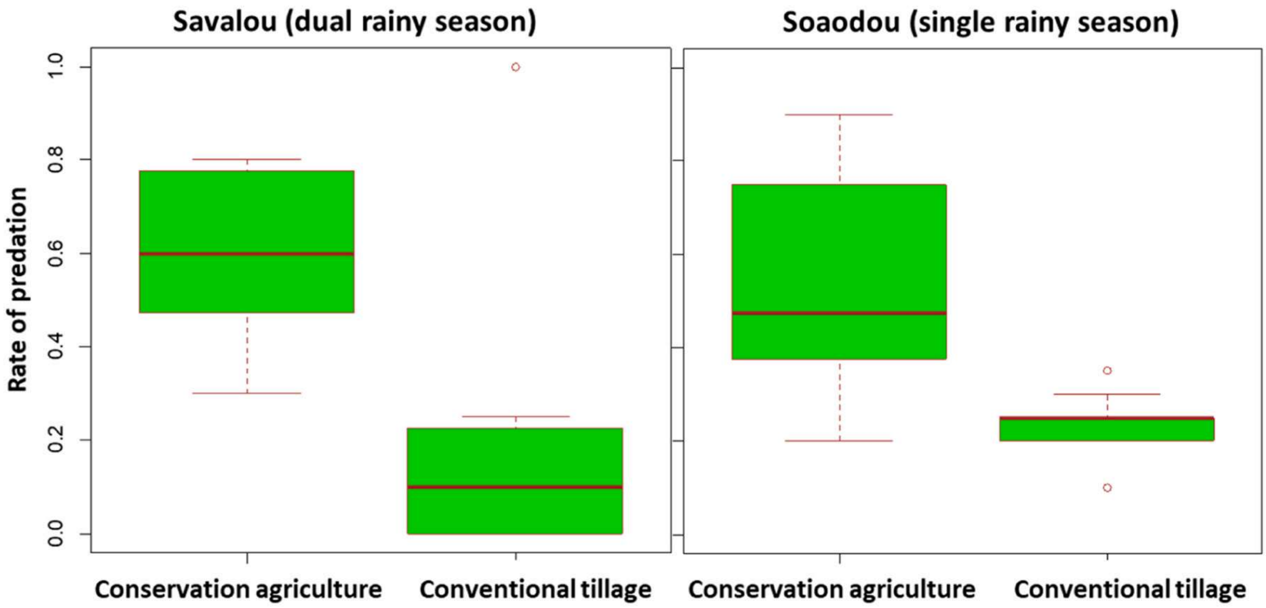

Fig. 4. Predation rate between treatments of soil management practices.

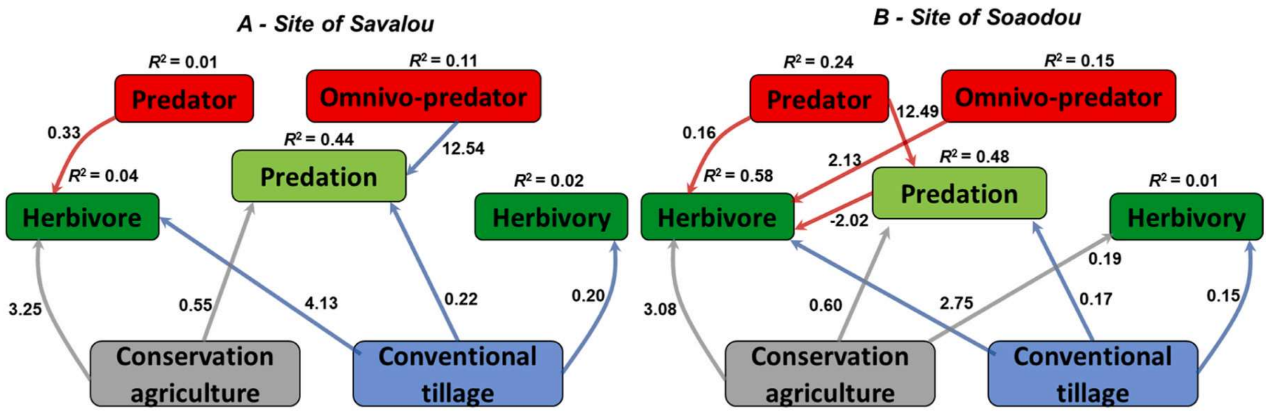

Fig. 5. Structural equation model of relationships between the soil management practices and herbivory rate, herbivore abundance, predator abundance, omnivore-predator abundance and the predation rate across the two experimental sites. The lines show the significant effects between the variables. The values on the lines show the estimates of relationships between variables.

relationship between the trophic group of predators and predatory omnivores contributes to the stability of arthropod communities. In the Savalou site, the absence of omnivore-predators in the monoliths of conventional tillage plots showed that this agricultural practice disrupts the communities of arthropods living in the soil. These arthropods also play a fundamental role in the formation of soils and the maintenance of their fertility. By digging tunnels in the earth, arthropods aerate and loosen the soil, which favors plant growth (Bagyaraj et al., 2016).

The two soil management practices have significant effects on the abundance of arthropods circulating on the soil and trapped by pitfall traps (cf. Fig. 5). Conservation agriculture and conventional tillage have significantly increased the abundance of herbivores, predators and predatory omnivores. The effect was also significantly positive on the rate of herbivory and the rate of predation. The different trophic groups of arthropods are favoured by the two types of soil management. On the other hand, the predation rate is negatively correlated with the abundance of herbivores. The predation rate was higher in conservation agriculture than in conventional tillage. Conservation agriculture practices promote an abundance of predators and omnivores, which in turn have top-down effects on herbivores. Similarly, Pauli et al., (2016) showed higher activity densities and greater diversity of generalist predatory arthropods, fewer herbivores and higher predation on the soil surface in maize-wheat intercropping systems in central Mexico.

The above findings are consistent with the hypotheses of our study. Predators are more abundant in conservation agriculture. This finding could be explained by the fact that predators consume herbivores, which reduces the number of herbivores (which consume plants) and promotes the growth of the plant populations (Dassou et al., 2016). Our results also showed that there were differences in the herbivore abundance across sites and treatments, but no differences in terms of herbivory. This could be explained by the use of pesticides to control pests in these cotton farming systems. Thus, conservation agriculture promotes the abundance of soil macrofauna compared to conventional tillage.

Table 4
Pathway coefficient estimates, Critical-values and P-values from the structural equation modeling of pitfall arthropods across the two experimental sites.

Responses	Predictors	Df	Critcal-values	Estimates	P-values
Site of Soaodou					
Abundance of herbivores	Conventional tillage	37	7.64	4.13	< 0.00001
Abundance of herbivores	Conservation agriculture	37	7.60	3.25	< 0.00001
Abundance of herbivores	Abundance of predators	37	1.82	0.33	0.045
Rate of predation	Abundance of omnivopredators	37	2.1	12.54	0.037
Rate of herbivory	Rate of predation	37	0.76	0.04	0.44
Rate of predation	Conservation agriculture	37	4.74	14.78	< 0.00001
Rate of predation	Conventional tillage	37	4.74	0.22	< 0.00001
Abundance of omnivopredators	Rate of predation	37	2.08	1.88	0.0445
Site of Savalou					
Abundance of herbivores	Conventional tillage	46	7.88	2.75	< 0.00001
Abundance of herbivores	Conservation agriculture	46	8.83	3.08	< 0.00001
Rate of herbivory	Rate of predation	46	0.03	0.002	0.97
Rate of predation	Conservation agriculture	46	13.04	0.60	< 0.00001
Rate of predation	Conventional tillage	46	3.77	0.17	< 0.00001
Abundance of herbivores	Rate of predation	46	−1.02	−2.02	0.049
Abundance of herbivores	Abundance of omnivopredators	46	2.135	2.13	0.038
Abundance of herbivores	Abundance of predators	46	8.16	0.16	< 0.00001

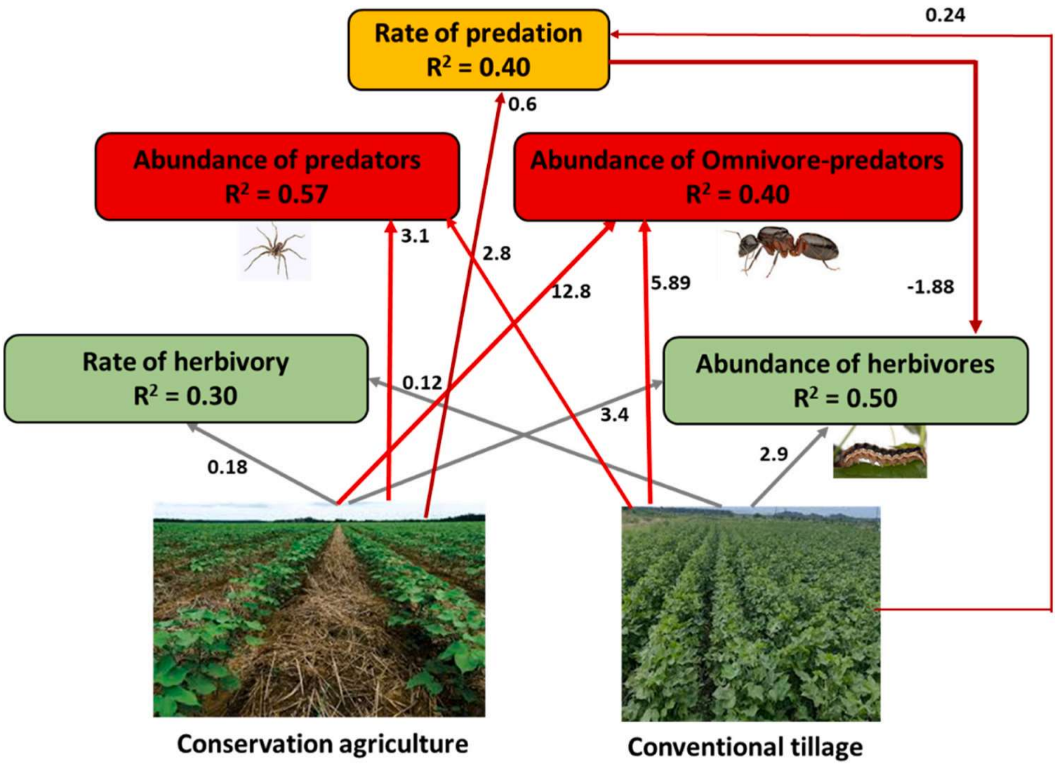

Fig. 6. Structural equation model of relationships between the soil management practices and herbivory rate, herbivore abundance, predator abundance, omnivore-predator abundance and the predation rate pulling together the results of both experimental sites. The lines show the significant effects between the variables. The values on the lines show the estimates of relationships between variables.

5. Conclusion

Conservation agriculture is a set of innovative agricultural practices that aim to achieve acceptable profits with improved production levels while preserving the environment. This type of agriculture also increases the abundance of ground-dwelling arthropods as well as herbivore predation and reduces herbivory. It can therefore be seen as a promising first step in a gradual transition towards pesticide-free, agroecological cotton farming in West Africa.

Table 5
Pathway coefficient estimates, Critical-values and P-values from the structural equation modeling of pitfall arthropods.

Responses	Predictors	Df	Critcal-values	Estimates	P-values
Abundance of herbivores	Conservation agriculture	65	9.1	2.9	< 0.00001
Abundance of herbivores	Conventional tillage	65	8.8	3.4	< 0.00001
Abundance of omnivopredators	Conservation agriculture	65	4.2	12.8	0.004
Abundance of omnivopredators	Conventional agriculture	65	3.50	5.89	0.01
Rate of herbivory	Abundance of omnivopredators	65	−0.73	−0.09	0.46
Rate of herbivory	Conservation agriculture	65	4.9	0.18	< 0.00001
Rate of herbivory	Conventional tillage	65	4.7	0.12	< 0.00001
Abundance of predators	Conservation agriculture	65	10.4	3.1	< 0.00001
Abundance of predators	Conventional tillage	65	9.2	2.8	< 0.00001
Rate of predation	Conservation agriculture	65	22.93	0.6	< 0.00001
Rate of predation	Conventional tillage	65	8.2	0.24	< 0.00001
Abundance of herbivores	Rate of predation	65	−1.85	−1.88	0.047
Abundance of predators	Abundance of omnivopredators	65	−0.25	−0.002	0.79
Rate of herbivory	Abundance of predators	65	−4.99	−0.31	0.75

Ethic statement

Submission declaration

- the article is not under consideration for publication elsewhere.
- the article's publication is approved by all authors and tacitly or explicitly by the responsible authorities where the work was carried out.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Anicet Dassou reports financial support was provided by Benin Cotton Research Institute (IRC), Cotton Interprofessional Association (AIC), and the TAZCO2 project (Transition Agroécologique des Zones Cotonnières du Bénin). Anicet Dassou reports a relationship with TAZCO2 project (Transition Agroécologique des Zones Cotonnières du Bénin) that includes: consulting or advisory and funding grants. No has patent pending to No. No conflict of interest If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

Data will be made available on request.

Acknowledgements

This research was funded by the Benin Cotton Research Institute (IRC), Cotton Interprofessional Association (AIC), and the TAZCO2 project (Transition Agroécologique des Zones Cotonnières du Bénin), which is funded by the Republic of Benin and the French Development Agency (AFD). We thank our assistants Maurelle Dagan and Justin Akpaki for contributing to the experimental and arthropod identification works.

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