

Herbicide versus Manual Weeding: Ground-Dwelling Ant Assemblages in Young Cashew Orchards of Northern Côte d'Ivoire

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ABSTRACT

Cashew (*Anacardium occidentale* L.) orchards are expanding rapidly across the savannas of northern Côte d'Ivoire, where herbicides increasingly replace manual weeding. We compared ground-dwelling ants in eight young (1–5-year-old) cashew orchards, four chemically and four manually weeded, across two villages. Ants were sampled using 120 pitfall traps in May 2023, and topsoil (0–10 cm) was analysed. We recorded 1,109 workers representing 22 species, 10 genera and four subfamilies. *Pheidole* sp1 and *Tetramorium sericeiventre* occurred in 63% and 47% of traps, respectively. With orchards as experimental units, weeding practice had no detectable effects on species richness, Shannon diversity, Pielou evenness, worker activity-density or assemblage composition (PERMANOVA, $R^2 = 0.13$, $p = 0.28$). Herbicide-weeded orchards had fewer species overall (15 vs 20), owing entirely to rare species. Soil properties did not differ between practices or explain assemblage structure. Replicated, multi-season studies are needed to assess herbicide effects on soil biodiversity.

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Introduction:

Soil organisms drive nutrient cycling, soil structure and pest regulation, and these services underpin the productivity of smallholder farms in the tropics [1]. Converting savanna and woodland to cropland, and then intensifying management, is one of the main threats to this belowground diversity [2, 3]. Among soil macrofauna, ants stand out. They are abundant and diverse in tropical ecosystems, move large volumes of soil, redistribute organic matter and nutrients around their nests, prey on other invertebrates and disperse seeds [4-7]. Ant assemblages also respond quickly to changes in habitat structure, which has made them standard bioindicators of land-use change [8, 9].

Côte d'Ivoire is the world's leading producer of raw cashew nuts, with about 945,000 t harvested in 2024 [10]. Production has expanded mainly in the northern savanna, where cashew is replacing cotton and food crops and where woodland and savanna are cleared to plant new orchards [11, 12]. Young orchards are weeded intensively until the canopy closes, because weeds such as *Chromolaena odorata* compete with seedlings and fuel dry-season fires. Weeding is done either

by hand, with a machete or hoe, or with commercial herbicides. Herbicides save labour, and their use is spreading quickly in West African smallholder agriculture [13]. In the cashew belt of northern Côte d'Ivoire, herbicides make up about 70% of the pesticide products used by farmers, mainly glyphosate, paraquat, atrazine and 2,4-D-based formulations, and more than 90% of growers in the Poro region rely on them for weed control [14].

The two practices could affect ground-dwelling ants differently. Manual slashing leaves cut vegetation as surface litter, whereas herbicides kill weeds in place and may add direct toxic or sublethal effects on non-target arthropods. Yet both practices open the ground layer, and habitat openness is one of the strongest drivers of ant community structure [9]. Studies in Côte d'Ivoire have shown that ant assemblages respond to land-use type and management intensity in cocoa and mango systems [15-17], and that termite diversity recovers as cashew orchards age and management relaxes [12]. To our knowledge, no study has compared weeding practices in cashew orchards.

This study addresses that gap in the Dikodougou department of northern Côte d'Ivoire. We asked: (1) Do herbicide and manual weeding differ in ground-dwelling ant species richness, diversity, activity-density and assemblage composition in young orchards? (2) Do topsoil properties differ between practices, and do they explain variation in ant assemblages? We expected herbicide-weeded orchards to support fewer ant species and a different assemblage than manually weeded orchards.

Materials and methods:

Study area

The study was carried out in the villages of Nangakaha and Tapéré, about 1 km and 14 km from the town of Dikodougou (Poro region, northern Côte d'Ivoire; 9°03'–9°59' N). The area lies in the Sudanian savanna zone. The climate is tropical with a single rainy season from April to October, an annual rainfall of about 1,150 mm peaking in August, and a mean annual temperature of about 26 °C. Natural vegetation is a mosaic of wooded savanna, open forest and gallery forest with *Vitellaria paradoxa* and *Parkia biglobosa*. Soils are ferrallitic, developed on granite, and low in organic matter [18]. Farming, now increasingly based on cashew, is the main livelihood of the Sénoufo population.

Study design and characterization of weeding practices

Two contrasting weed-management practices commonly used by cashew farmers in the study area were compared: chemical weeding using herbicides and manual weeding using hand tools. Before orchards were selected, one focus-group discussion was held in each village (Nangakaha and Tapéré) in May 2023 to document local weed-management practices. The survey involved 26 farmers, 13 per village. Discussions were conducted in Sénoufo with the help of a local facilitator, recorded, transcribed and coded by theme in QDA Miner Lite; percentages below refer to coded responses. Chemical weeding accounted for 75% of the practices reported and manual weeding for 25%. Manual weeding was done mostly with machetes (80%) and otherwise with hoes (20%). Eight herbicide brands were cited: Bibana 480 SL (28.6%), Herbextra 720 SL (2,4-D amine salt, 720 g L⁻¹; 21.4%), Roundup (glyphosate; 10.7%), Glycol (10.7%), and Herbastop 720 SL, Hercule 480 SL, Plusfort and Gnankpô Plus (7.1% each). None of the farmers used biopesticides. Most farmers weeded twice a year (62.5%), the others once (25%) or three times (12.5%).

For the experimental comparison, two young cashew orchards managed under each weeding practice were drawn at random in each village from the list of farms compiled during the focus groups, giving eight orchards in total (two villages × two weeding practices × two orchards). The orchards were 1-5 years old and covered approximately 1-5 ha. Each orchard was assigned to a practice according to the weeding method its owner reported using routinely: herbicide spraying in the chemically weeded orchards, and slashing with machetes or hoes in the manually weeded orchards. The exact age of each orchard, the herbicide product applied and the date of the last weeding before sampling were not recorded.

In each orchard, three 50-m transects were established approximately 10 m apart near the centre of the plot to reduce

edge effects. Five pitfall traps were installed along each transect at 10-m intervals, giving 15 traps per orchard and 120 traps across the eight orchards. A 25 m × 25 m quadrat was established approximately 1 m from each transect for soil sampling.

Ant sampling and identification

Traps were plastic cups sunk flush with the soil surface and containing an ethanol-glycerol solution [19]. They were operated for 48 h in May 2023, a period long enough to limit the digging-in effect. Specimens were stored in 70% ethanol, sorted, mounted and identified to genus with Fisher and Bolton [20] and to species or morphospecies by comparison with the reference collection of Dr Kouakou at the Pôle Scientifique et d'Innovation de Bingerville (Université Félix Houphouët-Boigny). Mounted voucher specimens were placed in entomological boxes and added to this reference collection.

Soil sampling and analysis

In each quadrat, six cores (0-10 cm depth, 10 cm diameter) were taken in a zigzag pattern and pooled into one composite sample, giving three composites per orchard (24 in total). Samples were air-dried and delivered to ENVAL Laboratoire (Abidjan, Côte d'Ivoire) on 26 June 2023 and analysed between 7 and 21 July 2023. Soil pH was measured in water following NF ISO 10390 (2005) and electrical conductivity at 25 °C (EC) following ISO 11265 (1994). Particle-size fractions (clay, silt and sand) were determined by the pipette method (NF X 31-107, 2003). Total nitrogen (N) was determined following NF ISO 11261 (1995; modified Kjeldahl method) and organic carbon (C) by the laboratory's in-house method. Cation exchange capacity (CEC) was determined following NF X 31-130 (1999), exchangeable potassium (K) after ammonium acetate extraction (NF X 31-108, 2002), and available phosphorus (P) by the Olsen method as modified by Dabin.

Data analysis

Ants are social, and one trap near a nest can capture many workers of a single colony. We therefore based diversity and composition analyses on species incidence (presence or absence per trap) and used worker counts only as a measure of activity-density [21]. Weeding practice was applied at the orchard level, so the orchard (n = 8) is the experimental unit. Traps and transects are subsamples, and all tests account for this nesting [22].

Species richness per trap was modelled with a Poisson generalized linear mixed model (GLMM). Fixed effects were practice, village and their interaction; random intercepts were orchard and transect nested within orchard. Because the Poisson model was underdispersed (Pearson $\chi^2/df = 0.45$), we refitted it with a Conway–Maxwell–Poisson distribution, which gave the same conclusions. Worker counts per trap were modelled with a negative binomial (NB2) GLMM with the same structure. Fixed effects were tested with Type III Wald χ^2 tests, and estimated marginal means were back-transformed to the response scale.

For each trap, the data set gives Shannon diversity (H', log base 2) computed from the relative worker counts of each species, and Pielou evenness, J' = H'/log₂ S [23, 24]. These

two indices use worker counts, so they are sensitive to colony proximity and are reported alongside the incidence-based measures. J' is undefined when a trap holds a single species (21 traps), so evenness was analysed for the 99 traps with two or more species. Both indices were analysed with linear mixed models with the same fixed and random effects as above, tested with F tests and Kenward-Roger degrees of freedom. Because evenness residuals were not normally distributed, we checked the result with a Wilcoxon rank-sum test on orchard means (four orchards per practice).

For each practice and each village $\times$ practice combination, we built sample-based (incidence) rarefaction curves [25]. We estimated asymptotic richness with the bias-corrected Chao2 estimator [26] and computed sample coverage [27]. Uncertainty in observed richness was estimated by resampling traps with replacement (999 bootstrap samples).

For each transect, we computed the number of traps (0-5) in which each species occurred and calculated Bray-Curtis dissimilarities between the 24 transects. Effects of village, practice and their interaction were tested with permutational multivariate analysis of variance (PERMANOVA; 9,999 permutations) [28]. Permutations moved whole orchards and kept transects together within orchards, so the test has the orchard as its unit. Homogeneity of multivariate dispersion was checked with PERMDISP. As a complementary test, we repeated the PERMANOVA on orchard-level Jaccard dissimilarities ($n = 8$). Assemblages were ordinated by two-dimensional non-metric multidimensional scaling (NMDS). Species associated with a practice or a village were identified with the group-equalized indicator value (IndVal.g) [29],

tested by permuting practice labels among orchards within villages (9,999 permutations).

Each soil variable was compared between practices with a linear mixed model (practice and village as fixed effects, orchard as a random intercept) and F tests with Kenward-Roger degrees of freedom. The relationship between soil and ant composition was tested by fitting soil vectors onto the NMDS (envfit), with orchard-level restricted permutations, and by single-variable PERMANOVAs with permutations constrained within orchards.

All analyses were run in R 4.3.3 [30] with the packages glmmTMB [31], lme4, car 3, emmeans, vegan [32] and permute 0.9-7. Significance was set at $\alpha = 0.05$.

Results:

Composition of the ant fauna

The 120 traps captured 1,109 workers of 22 species in 10 genera and four subfamilies (Table 1). Every trap caught at least one ant. Myrmicinae contributed 11 species, 56% of occurrences and 79% of workers; Formicinae contributed 8 species and 32% of occurrences. Ponerinae (2 species) and Dolichoderinae (1 species) were scarce. Two species dominated: *Pheidole* sp1 occurred in 63% of traps and supplied 52% of all workers, and *Tetramorium sericeiventre* occurred in 47% of traps. Six species were recorded only once. Each orchard yielded 5–13 species. Thirteen species were shared between villages; six were found only at Nangakaha and three only at Tapéré.

Table 1. Ground-dwelling ants collected in young cashew orchards of the Dikodougou department, by village and weeding practice. Values are the number of pitfall traps in which each species occurred.

Subfamily	Species	Nangakaha manual	Nangakaha herbicide	Tapéré manual	Tapéré herbicide	Traps occupied, n (%)	Worker s, n
Dolichoderinae	<i>Tapinoma</i> sp1	0	2	0	0	2 (1.7)	2
Formicinae	<i>Camponotus acvapimensis</i> Mayr, 1862	8	4	7	3	22 (18.3)	43
	<i>Camponotus cinctellus</i> (Gerstaecker, 1859)	1	1	0	6	8 (6.7)	18
	<i>Camponotus maculatus</i> (Fabricius, 1782)	5	7	3	12	27 (22.5)	56
	<i>Camponotus sericeus</i> (Fabricius, 1798)	1	5	8	18	32 (26.7)	55
	<i>Camponotus</i> sp1	0	2	3	0	5 (4.2)	5
	<i>Lepisiota</i> sp1	0	0	1	0	1 (0.8)	1
	<i>Lepisiota</i> sp2	3	0	0	0	3 (2.5)	5
	<i>Paratrechina longicornis</i> (Latreille, 1802)	1	0	0	0	1 (0.8)	2
Myrmicinae	<i>Crematogaster bicolor</i> Smith, 1860	1	0	0	0	1 (0.8)	20
	<i>Crematogaster</i> sp1	2	1	1	5	9 (7.5)	19
	<i>Crematogaster</i> sp2	0	0	0	1	1 (0.8)	3
	<i>Monomorium bicolor</i> Emery, 1877	0	5	7	1	13 (10.8)	20
	<i>Monomorium</i> sp1	6	2	2	0	10 (8.3)	21
	<i>Monomorium</i> sp2	1	0	0	0	1 (0.8)	4
	<i>Pheidole</i> sp1	15	18	23	20	76 (63.3)	575
	<i>Pheidole</i> sp2	4	0	0	0	4 (3.3)	21
	<i>Tetramorium sericeiventre</i> Emery, 1877	13	17	21	5	56 (46.7)	186
	<i>Tetramorium</i> sp1	0	1	1	0	2 (1.7)	2
	<i>Tetramorium</i> sp2	0	0	1	0	1 (0.8)	1
Ponerinae	<i>Mesoponera</i> sp1	1	7	1	4	13 (10.8)	20

Subfamily	Species	Nangakaha manual	Nangakaha herbicide	Tapéré manual	Tapéré herbicide	Traps occupied, n (%)	Workers, n
	<i>Paltothyreus tarsatus</i> (Fabricius, 1798)	12	7	2	1	22 (18.3)	30
	Species richness	15	14	14	11	22	
	Total occurrences	74	79	81	76	310	1,109

Effects of weeding practice on richness, diversity and activity-density

Local diversity did not differ between weeding practices (Table 2). On average, a trap held 2.55 species (95% CI 2.04–3.19) in manually weeded orchards and 2.54 (2.03–3.18) in herbicide-weeded orchards (GLMM: practice $\chi^2 = 0.10$, $p = 0.75$; village $\chi^2 = 0.18$, $p = 0.67$; practice $\times$ village $\chi^2 = 0.22$, $p = 0.64$). Shannon diversity per trap was 0.98 ± 0.57 under manual weeding and 0.97 ± 0.66 under herbicide (LMM: practice $F_{1,4} = 0.08$, $p = 0.79$; village $F_{1,4} = 0.25$, $p = 0.65$; interaction $F_{1,4} = 0.19$, $p = 0.68$). Pielou evenness was 0.78 ± 0.20 and 0.83 ± 0.16 , respectively (practice $F_{1,3.9} = 0.005$, $p = 0.95$; village $p = 0.95$; interaction $p = 0.55$); a Wilcoxon test on orchard means gave the same result ($W = 5$, $p = 0.49$). Worker activity-density was 21% lower under herbicide (7.4 vs 9.3 workers per trap), but this difference was small relative to variation among orchards and not significant

(NB GLMM: practice $\chi^2 = 0.61$, $p = 0.43$; village $\chi^2 = 0.17$, $p = 0.68$; interaction $\chi^2 = 0.12$, $p = 0.73$).

At the scale of all 60 traps per practice, manually weeded orchards yielded 20 species and herbicide-weeded orchards 15 (Fig. 1). The bootstrap intervals overlapped (14–20 vs 12–15 species). The difference came entirely from rare species. Seven species were found only under manual weeding, with 12 occurrences between them, and two only under herbicide (3 occurrences). Thirteen species were shared. The manual-weeding curve had not levelled off: it held seven uniques, its Chao2 estimate was 44 species, and that estimate rests on a single duplicate, so it is highly uncertain. Under herbicide, the curve was close to its asymptote (Chao2 = 16; coverage 0.99). Within each village, herbicide orchards had one (Nangakaha) and three (Tapéré) fewer species than manual orchards at equal effort (30 traps).

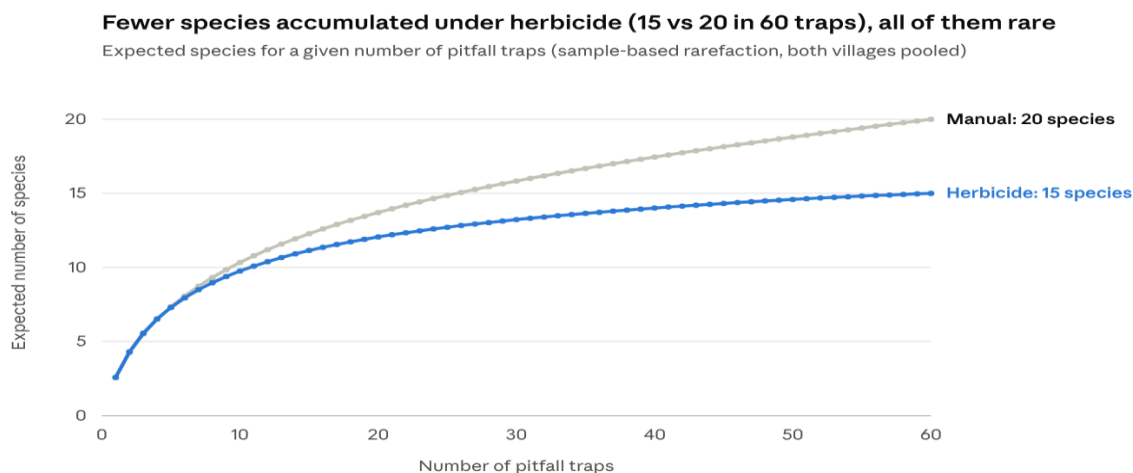


Fig. 1 Sample-based rarefaction curves of ground-dwelling ant species in manually weeded (grey) and herbicide-weeded (blue) young cashew orchards, Dikodougou, northern Côte d'Ivoire. Curves show the expected number of species for 1–60 pitfall traps, with both villages pooled (two orchards per practice per village). Bootstrap 95% intervals for observed richness at 60 traps were 14–20 (manual) and 12–15 species (herbicide).

Table 2. Ant diversity by village and weeding practice. Species and workers per trap are estimated marginal means (95% CI) from the GLMMs. Total-richness metrics (occurrences to sample coverage) are incidence-based.

Village	Practice	Traps	Occurrences	Observed species	Uniques (Q1)	Chao2	Sample coverage	Species per trap	Shannon H'	Pielou J'	Workers per trap
Nangakaha	Manual	30	74	15	6	32.4	0.92	2.43 (1.77–3.35)	0.90 ± 0.59	0.77 ± 0.24	10.2 (5.6–18.5)
Nangakaha	Herbicide	30	79	14	3	15.4	0.96	2.62 (1.91–3.57)	0.99 ± 0.60	0.80 ± 0.19	7.3 (4.0–13.2)
Tapéré	Manual	30	81	14	5	20.0	0.94	2.68 (1.97–3.66)	1.06 ± 0.55	0.78 ± 0.16	8.6 (4.7–15.5)
Tapéré	Herbicide	30	76	11	3	13.9	0.96	2.48 (1.80–3.41)	0.95 ± 0.72	0.87 ± 0.11	7.6 (4.2–13.7)
Both	Manual	60	155	20	7	44.1	0.96	2.55 (2.04–3.19)	0.98 ± 0.57	0.78 ± 0.20	9.3 (6.1–14.2)
Both	Herbicide	60	155	15	2	15.7	0.99	2.54 (2.03–3.18)	0.97 ± 0.66	0.83 ± 0.16	7.4 (4.9–11.3)
Both	All	120	310	22	6	30.9	0.98	—	0.97 ± 0.61	0.80 ± 0.18	—

Assemblage composition

When orchards were treated as the replicates, assemblage composition did not differ significantly between weeding practices or villages (Table 3; Fig. 2). Village explained 15% of the variation among transects and practice 13%, but neither effect stood out from the variation among orchards (restricted permutations: $p = 0.16$ and 0.28). Orchard-level Jaccard analyses gave the same result, and multivariate dispersion did not differ among groups (PERMDISP, $F = 1.20$, $p = 0.33$). Treating the 24 transects as independent replicates would have produced apparently significant effects of village ($p = 0.002$), practice ($p = 0.004$) and their interaction ($p =$

0.049); these p -values reflect pseudoreplication and are shown in Table 3 only for comparison.

Shifts in a few common species drove most of the separation in the ordination. *Paliothyreus tarsatus* was frequent at Nangakaha (19 of 22 occurrences) and was the only significant indicator species, for Nangakaha (IndVal = 0.85, $p = 0.029$). *Camponotus sericeus* and *C. maculatus* were most frequent in herbicide-weeded orchards at Tapéré, and *Tetramorium sericeiventris* in manually weeded orchards there. No species was a significant indicator of either weeding practice (all $p \geq 0.22$).

Herbicide and manual orchards overlap in ant composition; orchards differ more than practice

NMDS of Bray–Curtis dissimilarity among 24 transects; lines join each transect to its orchard centroid

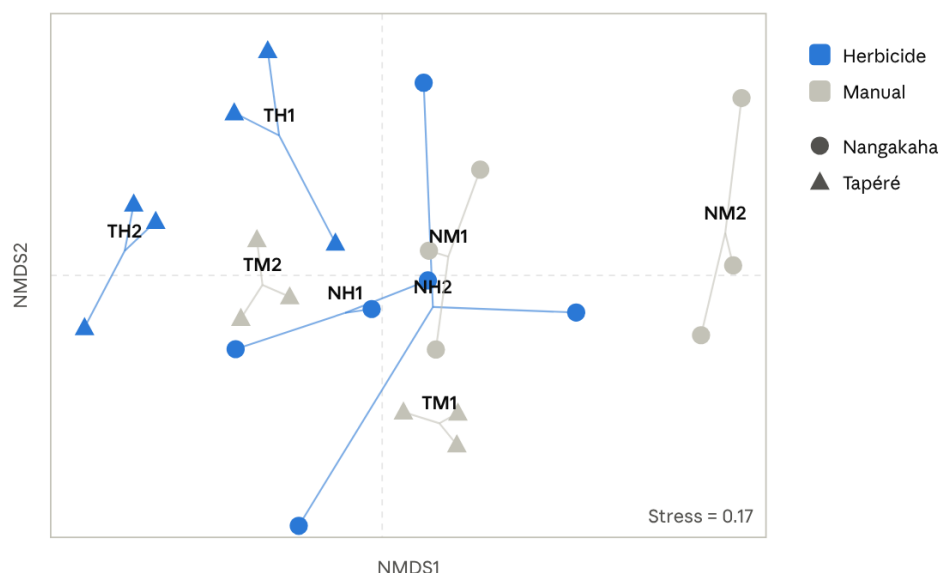


Fig. 2 Non-metric multidimensional scaling (NMDS) of ant assemblages in 24 transects (5 pitfall traps each), based on Bray–Curtis dissimilarity of species incidence frequencies. Colour shows weeding practice and symbol shows village. Lines join each transect to the centroid of its orchard (N, Nangakaha; T, Tapéré; M, manual; H, herbicide; 1-2, orchard number). Practice and village effects were not significant when orchards were permuted (Table 3).

Table 3. PERMANOVA of ant assemblage composition (Bray–Curtis dissimilarity on transect-level incidence frequencies, $n = 24$ transects in 8 orchards). The p -values in the last column come from the invalid unrestricted test and are given only for comparison.

Term	df	R ²	Pseudo-F	p (orchards permuted)	p (transects permuted, invalid)
Village	1	0.154	4.79	0.157	0.002
Practice	1	0.126	3.91	0.282	0.004
Village × Practice	1	0.076	2.36	0.628	0.049
Residual	20	0.644			

Soil properties

Topsoils were sandy (mean 66% sand, 14% clay), slightly acidic to neutral (pH 6.3–7.8) and poor in organic carbon (1.2%) and nitrogen (0.05%) (Table 4). None of the ten soil variables differed significantly between weeding practices or villages (all $p \geq 0.10$). Exchangeable K was 14–26% lower in herbicide-

weeded orchards in both villages, but the difference was not significant ($F_{1,5} = 4.21$, $p = 0.10$). No soil variable was correlated with the ant ordination (envfit, all $r^2 \leq 0.11$, $p \geq 0.32$). In single-variable PERMANOVAs, no soil variable explained more than 6% of the variation in ant composition (all $p \geq 0.14$).

Table 4. Topsoil (0–10 cm) properties by village and weeding practice (mean $\pm$ SD, $n = 6$ composites per group). F and p test the practice effect in a linear mixed model with orchard as a random effect (Kenward–Roger $df = 1, 5$).

Variable	Nangakaha manual	Nangakaha herbicide	Tapéré manual	Tapéré herbicide	F (p)
pH (water)	6.70 $\pm$ 0.31	6.79 $\pm$ 0.28	6.62 $\pm$ 0.18	6.84 $\pm$ 0.50	1.36 (0.30)
Clay (%)	12.00 $\pm$ 1.67	13.67 $\pm$ 3.50	16.17 $\pm$ 2.40	13.83 $\pm$ 3.19	0.04 (0.85)
Silt (%)	19.83 $\pm$ 1.83	19.33 $\pm$ 3.78	19.33 $\pm$ 2.16	17.50 $\pm$ 2.26	0.89 (0.39)
Sand (%)	67.17 $\pm$ 1.72	66.00 $\pm$ 5.97	63.50 $\pm$ 2.59	67.67 $\pm$ 3.50	0.36 (0.57)
Organic C (%)	1.22 $\pm$ 0.05	1.17 $\pm$ 0.07	1.15 $\pm$ 0.07	1.17 $\pm$ 0.05	0.54 (0.50)
Total N (%)	0.055 $\pm$ 0.005	0.053 $\pm$ 0.008	0.050 $\pm$ 0.009	0.052 $\pm$ 0.012	0.00 (1.00)
Available P (mg kg ⁻¹)	87.60 $\pm$ 8.24	74.79 $\pm$ 9.93	76.09 $\pm$ 8.76	79.26 $\pm$ 8.87	0.98 (0.37)
Exchangeable K (cmol kg ⁻¹)	0.23 $\pm$ 0.04	0.17 $\pm$ 0.05	0.21 $\pm$ 0.05	0.18 $\pm$ 0.06	4.21 (0.10)
CEC (cmol kg ⁻¹)	12.16 $\pm$ 0.52	11.53 $\pm$ 0.52	11.71 $\pm$ 0.51	11.64 $\pm$ 0.34	2.80 (0.16)
EC at 25 °C (μ S cm ⁻¹)	76.48 $\pm$ 31.06	78.97 $\pm$ 30.91	48.03 $\pm$ 15.30	66.82 $\pm$ 35.09	0.54 (0.50)

Discussion:

Weeding practice had little detectable effect on ant assemblages

Contrary to our expectation, herbicide-weeded and manually weeded orchards supported ant assemblages of similar local richness, Shannon diversity, evenness, activity-density and composition. The estimate for richness per trap was almost identical (herbicide/manual ratio 1.00, 95% CI 0.73-1.37). Activity-density was about 20% lower under herbicide, but the interval (ratio 0.79, 0.44-1.45) is compatible with anything from a halving to a 45% increase.

The most likely explanation is that both practices produce the same habitat. Herbicides and slashing both remove the ground layer, leaving open, sun-exposed soil between young trees whose canopies have not yet closed. Habitat openness is among the strongest structuring forces in ant communities: it favours thermophilic, behaviourally dominant generalists and excludes shade- and litter-dependent species [9]. The assemblage we sampled fits this picture. Two generalist myrmicines, *Pheidole* sp1 and *Tetramorium sericeiventris*, occupied half to two-thirds of the traps, and the rest of the fauna was dominated by *Camponotus* species typical of open savanna and farmland [15, 16]. Clearing savanna to establish the orchard had probably already removed disturbance-sensitive species, so the choice of weeding method acted on a fauna that was already filtered. In the terms of Andersen [9], the disturbance that matters most for ants is the change in habitat structure, and that change is similar under both practices.

The predominance of herbicides among the farmers we interviewed (75% of the practices reported) matches regional surveys. Across northern Côte d'Ivoire, herbicides are the main pesticides used in cashew orchards, and farmers explain this choice mainly by the shortage of labour for manual weeding [14]. Herbicide weeding is therefore the realistic baseline against which the ecological effects of orchard management should be assessed. Direct toxicity is a second route by which herbicides could affect ants: glyphosate, the most widely used active ingredient, can harm non-target organisms [14]. However, farmers in our survey weeded only one to three times a year, most often twice, and pesticide

application rates in cashew orchards of the region are generally low [14]. Ants nesting in the soil are also partly shielded from sprays. Our design cannot separate direct and habitat-mediated effects, and sublethal effects on colony growth or foraging would not show up in a single 48-h pitfall survey.

Rare species: a possible signal that needs testing

The one pattern consistent with our hypothesis was the lower total richness of herbicide-weeded orchards (15 vs 20 species, and fewer species in both villages at equal effort). This difference is carried by rare species. Seven species, together making up only 12 occurrences, were found exclusively under manual weeding. They include an arboreal *Crematogaster*, two *Lepisiota* species and the tramp *Paratrechina longicornis*. Slashing leaves cut stems and litter on the ground, which may offer nest sites, shade and prey that herbicide-treated orchards lack. But rare species are the part of an inventory most affected by chance: the manual-weeding sample was far from saturated, and Chao2 estimates based on one or two duplicates are unreliable. The pattern is therefore a hypothesis for a larger study, not a result.

Site effects and soil

Village explained slightly more compositional variation than weeding practice. The large ponerine *Paltothyreus tarsatus*, a predator of termites, was concentrated at Nangakaha. Differences of this kind between nearby sites are common in savanna ant faunas and are usually attributed to local resources and landscape context [33]. They show that site variation must be built into the design of management comparisons.

Topsoil properties did not differ between practices and did not explain ant composition. Soil carbon, nutrients and texture change slowly, and our orchards had been under their current weeding regime for at most a few years. The lower exchangeable K under herbicide in both villages is worth monitoring, because removing weeds with herbicides returns less fresh biomass to the soil than slashing does, but it was not significant. Our results agree with Jacquemin et al. [34], who found that soil properties weakly affect ant distribution at small spatial scales. Studies reporting strong soil effects have usually compared sites across wider soil gradients [35].

Replication matters

Our conclusions differ from what a trap-level or transect-level analysis of the same data would suggest. Treating transects as independent replicates produced apparently significant effects of practice and village on composition (Table 3), because transects in the same orchard share the same history, surroundings and colonies. The practice is applied to whole orchards, so the orchard is the replicate [22]. Field studies of agricultural practices on soil fauna in West Africa often sample many traps in few farms. They should either replicate at the farm level or analyse their data in a way that respects the nesting.

Limitations

The study has four main limitations. (1) There were only two orchards per practice in each village, so power to detect moderate effects was low. (2) Sampling covered one 48-h period at the start of the rainy season. (3) Pitfall traps capture only epigeic foragers and miss leaf-litter, subterranean and arboreal species. (4) The exact age of each orchard (1-5 years), the herbicide products applied and the time since the last weeding were not recorded. A stronger test would replicate at least five orchards per practice, include uncultivated savanna as a reference, sample in both seasons, add Winkler extraction and baits to the pitfalls, and record the herbicide history of each orchard.

Conclusion:

In young cashew orchards of northern Côte d'Ivoire, the choice between herbicide and manual weeding had no detectable effect on the local richness, Shannon diversity, evenness, activity-density or composition of ground-dwelling ants, nor on topsoil properties. Both practices keep the ground open, and the assemblages under both were dominated by a few disturbance-tolerant generalists. Herbicide-weeded orchards held fewer rare species in total, a pattern that a better-replicated study should test. Long-term, farm-replicated monitoring that includes reference savanna is needed before herbicide weeding can be considered neutral for soil biodiversity.

Declarations:

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Competing interests. The authors declare no competing interests.

Ethics approval and consent to participate. Farmers took part in the focus-group discussions voluntarily, after the aims of the study had been explained to them, and no personal data are reported. Fieldwork on private farms was carried out with the owners' permission.

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