RESEARCH ARTICLE

Earthworm communities and their relation to above-ground organic residues and water infiltration in perennial cup plant (*Silphium perfoliatum*) and annual silage maize (*Zea mays*) energy plants

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Funding information
Fachagentur Nachwachsende Rohstoffe

Abstract

Perennial energy cropping systems are hailed as a sustainable way of mitigating and potentially adapting to climate change. As a result of the absence of tillage, soils cropped with perennials like cup plant (*Silphium perfoliatum*) promote abundant and functionally diverse earthworm communities. Hence, ecosystem service provision because of earthworm activity and functional redundancy, for example, litter decomposition, water infiltration and nutrient turnover, is considerably enhanced in perennial cropping systems. We studied the abundance and functional role of earthworms in non-tilled perennial systems and reduced-tilled annual systems to assess their relationship with the respective above-ground organic residues and their implications for the soil water dynamic. We sampled earthworms and simultaneously measured the saturated infiltration rate for two consecutive years in cup plant and maize (*Zea mays*) fields. Furthermore, we sampled above-ground litter each trimester in both systems and analysed the total C and N content and CN ratios. Our field investigations revealed significantly higher earthworm abundance, species diversity and richness in cup plant systems likely because of the absence of tillage and the formation of a litter layer. High abundances of juveniles in both maize and cup plant systems pointed to harsh habitat conditions likely because of temperature variations, waterlogging and bulk density. The respective field litter was of minor importance as a food source in both systems because of poor quality, but may positively affect the soil water balance in cup plant systems. Earthworm populations in maize may have been supported by organic fertilizer while earthworm populations in cup plants may have additionally benefitted from the extensive root network and a higher on-site plant diversity. Reduced tillage regimes in maize systems may have enhanced saturated infiltration rates. A direct link between earthworms and infiltration was not validated, but may not be excluded in the future, as earthworm populations may develop slowly because of adverse habitat conditions. Our results show

that perennials support abundant and diverse earthworm populations and indicate the importance of functional redundancy and the diversity of food sources. The combination of both earthworm abundance and perennial cropping systems is capable of increasing on-site ecosystem stability and supporting adaptation to climate change by increasing functional redundancy and, ultimately, providing ecosystem services. The noticeable occurrence of the latter, however, may be delayed because of the slow establishment of earthworm communities and delayed build-up of ecosystems stability. Hence, a transitional phase is inevitable to reap the benefits of perennial energy cropping systems and must be accounted for.

1 | INTRODUCTION

Climate change mitigation and adaptation have become one of the most pressing issues of our time (UNFCCC, 2021). At the same time, we are obliged to reconcile possible solutions to this issue with aspects of sustainability and security of supply in food and energy production. Especially the bioenergy sector has great potential to do so, as it may be able to generate energy and fuels from renewable sources without competing with food production (Dauber et al., 2012). In this context, a promising strategy for producing sustainable energy and simultaneously increasing on-site ecosystem stability, the ability of an ecosystem to maintain a consistent functioning through time in a temporally variable environment (Yang et al., 2018), may be the establishment of perennial energy plants on marginal soils (Jablonowski & Schrey, 2021; Ruf & Emmerling, 2021).

In contrast to productive farm land, marginal soils – even under high resource input – may be unsuitable for food production because of slope, inadequate drainage and similar issues leading to low yields and market returns close to zero (Khanna et al., 2021; Richards et al., 2014). Nevertheless, these lands may be used to cultivate robust perennial energy plants. Compared with annual cash crops and the most commonly used annual energy plant, maize (*Zea mays*), they offer an array of advantages regarding resource input, maintenance and sustainability (Gansberger et al., 2015). One of the most promising perennial energy plants for anaerobic digestion is cup plant (*Silphium perfoliatum*). Cup plant is highly suitable for biogas production because of high biomass yields and reasonable biochemical methane potential (Ruf & Emmerling, 2022). It can be harvested for up to 15 years once established while requiring significantly less resources than maize (Gansberger et al., 2015). A special characteristic of the cup plant is its early canopy closure

which ensures weed suppression from the second year on and allows for better utilization of cold-season rainfall (Gansberger et al., 2015). Furthermore, it has been shown to prevent soil erosion and to promote C sequestration (Gansberger et al., 2015; Ruf et al., 2018). These traits may also be critical advantages when facing increasingly erratic weather patterns like drought and heavy rainfall and, thus, may aid climate change adaptation.

The cup plant's early canopy closure and its litter layer furthermore balance soil moisture and temperature variation and, combined with the abandonment of tillage, promote the development of abundant and diverse earthworm communities (Emmerling et al., 2021; Felten & Emmerling, 2011; Schorpp & Schrader, 2016). Depending on their respective ecological group and the burrowing and feeding behaviour associated with it, earthworms deliver a variety of important ecosystem services, which may aid climate change adaptation and sustainability in management. Earthworms in general promote the mineralisation of organic residues, and nutrient turnover, improve soil structure, and stimulate soil-microbial activity (Bertrand et al., 2015; Hoang et al., 2016). Earthworms affect soil microorganisms and, thus, increase connectivity in the soil food web and functional redundancy leading to a higher ecosystem stability (Gong et al., 2018; Shu et al., 2019; Yang et al., 2018).

Earthworms may be assigned to different, sometimes overlapping ecological groups: (1) anecics create deep vertical burrows, in which they drag surface litter to feed on, (2) endogeics feed on organic matter within the soil and burrow horizontally in the top soil, (3) epigeics live within litter layers and feed on plant residues (Bouché, 1977; Lee, 1985). The ecological group association is of special importance, since it is indicative of underlying ecological processes and ecosystem functioning. Depending on their ecological group association, earthworms may aid the soil water balance potentially supporting adaption to climate

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change-induced drought followed by heavy rainfall. It has been reported, that geophagous endogeic earthworms may improve water infiltration into the soil (Ernst et al., 2009). Capowiez et al. (2014) found, that an increased burrow volume of the endogeic *Allolobophora chlorotica* was linked to increased water transfer. Regarding deep-burrowing anecic earthworms, Shipitalo and Butt (1999) highlighted the potential of anecic earthworm burrows to transmit large amounts of water through the soil. Anecics were also reported to prevent plant biomass reduction under intensive rain-conditions (Andriuzzi et al., 2015). Considering cup plant in and of itself, Ruf et al. (2018) found, that growing cup plant enhances soil aggregate stability and proposed, that an improved soil structure may contribute to preferential flow and infiltration. This indicates, that particularly the combination of cup plant and earthworms and their conjoined effect on the soil water balance may be important regarding impacts of erratic weather patterns and heavy rainfall caused by climate change.

Earthworm abundance, diversity of ecological earthworm groups and ecosystem service provision, like improvement of soil water infiltration, are affected by habitat conditions. Hence, it is crucial to assess earthworm abundance and diversity in maize and cup plant to understand their effect on the cropping system and the soil-water balance in sustainable energy production. The main objective of this study was to investigate earthworm abundance and diversity and their relationship with crop litter and soil water infiltration in annual maize stands and in perennial cup plant stands to draw conclusions regarding ecosystem stability and climate adaption in bioenergy production. In a 2-year field study, we collected litter, sampled and identified earthworms and measured the saturated infiltration rate on commercially managed cup plant and maize fields in two consecutive years to address the following hypotheses: (I) Cup plant systems support functionally diverse earthworm communities. (II) Cup plant increases ecosystem stability in energy cropping systems. (III) Earthworms potentially improve the soil water balance in energy cropping systems prone to waterlogging.

2 | MATERIALS AND METHODS

2.1 | Sampling site and management

In 2019 and 2020, we investigated four cup plant fields paired with four maize fields in close proximity for comparison. The fields were located in the Western German federal state Saarland near the villages of Oberthal-Gronig (cup plant 1 and maize 1, 49.51°N, 7.07°E), Remmesweiler (cup plant 2 and maize 2, 49.44°N, 7.13°E), Dörrenbach (cup plant 3 and maize 3, 49.44°N, 7.22°E) and Fürth (cup

plant 4 and maize 4, 49.43°N, 7.22°E) (Figure S1). All fields under investigation were similar in soil texture and identified as either Stagnosols or stagnic Cambisols prone to temporal water-logging conditions. All fields were commercially managed by farmers in the vicinity to produce either feedstock for biogas plants or animal fodder. The type and amount of fertilizer used differed between fields, amounting to field-specific N inputs prior to sampling and in between consecutive samplings (Table S1). The cup plant fields in this study were established in 2016 (to 2018), thus being 3–5 years. under cultivation before field investigations and at the time of first sampling. Prior to cup plant establishment, the fields were either cropped with maize in monoculture, subject to crop rotation or used for grass production. Cup plant fields were amended with digestate, slurry or mineral fertilizer and treated with herbicides if necessary (Table S1). Tillage was completely omitted. The average yield ranged from 10.49 ± 0.98 to 19.01 ± 3.57 Mg DM ha^{-1}.

During our field investigations, maize was continuously grown on the selected fields. In the previous years, the fields were subject to maize in monoculture or part of a crop rotation. Management of maize fields included shallow field cultivation via extirpator and the use of catch crops. Maize fields were amended with digestate, slurry, manure or mineral fertilizer and treated with herbicides if necessary (Table S1). The average yield ranged from 11.32 ± 0.21 to 17.92 ± 4.15 Mg DM ha^{-1}.

2.2 | Earthworm sampling and measurement of saturated infiltration rate

Earthworms were sampled three times per field and date in spring and fall 2019, late spring 2020 and spring 2021. Extraction of earthworms was conducted simultaneously with the measurement of the saturated infiltration rate using methods described in Emmerling et al. (2015). Briefly, the extraction of earthworms was conducted simultaneously with the measurement of the saturated infiltration rate. Following Emmerling et al. (2015), a double-ring infiltrometer (UKB System Technology GmbH, Göttingen) was inserted into the ground at a depth of 5 cm. Vegetation in the inner ring was removed and a plastic bag was placed on top of the soil surface to avoid muddying. Both rings were filled with a solution of 800 μL allyl isothiocyanate (AITC) and 16 mL methanol diluted with 10 L of tap water (Emmerling et al., 2015). Earthworms reaching the soil surface were collected. The rings were refilled with tap water until a steady flow was established and the saturated infiltration rate could be determined. Saturated infiltration was reached, when three consecutive intervals were measured to be less than 5 s

apart. The saturated infiltration rate K [mm h^{-1}] was calculated according to Emmerling et al. (2015). Additionally, a visual inspection of the temporal development of infiltration rates was conducted to ensure saturated conditions. Afterwards, the top 25 cm of soil from the inner ring was removed and hand sorted to retrieve any remaining earthworms. Live earthworms were stored in fresh moist soil until species identification and biomass measurement in the lab. Earthworms were cautiously washed in tap water to remove adhesive residues and mucus, dried off with tissue paper and finally weighed ($\pm$0.01 g).

Identification of species was conducted according to Graff (1953) and Sims and Gerard (1999). Earthworms were classified as adults, when the clitellum was fully developed. Earthworms without clearly visible clitellum were classified as juveniles. *Aporrectodea rosea* and *Aporrectodea caliginosa* were addressed by genus only, since they belong to the same ecological group and juveniles of these species cannot be identified with certainty. Earthworms were assigned to ecological groups according to Bouché (1977). Only adult individuals of *Lumbricus terrestris* L. were acknowledged as anecics, while juveniles were classified as endogeics because they do not behave like the deep-burrowing adult individuals (Lowe & Butt, 2002).

2.3 | Sampling and analysis of organic residues

Above-ground organic residues, subsequently referred to as litter, were sampled in all four seasons of 2019 and 2020 resulting in eight sampling dates. Each field was sampled three times. To quantify the amount of litter present in the field, a stainless-steel frame (0.5 m × 0.5 m) was randomly placed on the soil surface. Dead organic matter within the frame was transferred into a plastic bag. Protruding litter parts were cut off at the edges of the frame or above the soil surface. In the lab, adhering soil particles were removed from the collected litter. The litter was weighted, dried and ground before measurement of total C and N by dry combustion using a TruMac CN Analysator (LECO, St. Joseph, USA).

In the fall of 2020, fresh and visibly senescent leaves were detached from cup plant and maize plants and organic residues originating solely from the respective crop were collected from the soil surface. The collected leaves and organic residues, too, were cleaned from adhering soil particles, dried and ground. Total C and N were measured and a fibre analysis was conducted. Cellulose, hemicellulose and lignin were measured with a Fibretherm FT12 system (C. Gerhardt GmbH, Königswinter, Germany) according to Verband Deutscher Landwirtschaftlicher

Untersuchungs- und Forschungsanstalten e. V. (VDLUFA) (2012a, 2012b, 2012c).

2.4 | Physical and chemical parameters of soil

Soil texture of all soil horizons was determined according to the Köhn method (International Organization for Standardization (ISO), 2002) with a Sedimat 4–12 (Umweltgerätetechnik UGT, Müncheberg, Germany). For pH measurement, air-dried soil was mixed with 0.01 M CaCl$_2$ in a 1:2.5 ratio, shaken, filtrated and measured with a pH Cond 340i glass electrode (WTW GmbH, Weilheim). Bulk density was determined using undisturbed samples of known volume (100 cm^3) which were dried in a compartment drier for 24 h at 105°C. Parameters for soil horizons to a depth of 20–30 cm were grouped for topsoil examinations and parameters for soil horizons below a depth of 30 cm were grouped for subsoil examinations. Subsoil horizons were examined to a depth of 80–100 cm. In the field, soil moisture and temperature were measured continuously with 5TM Sensors (METER Group AG, Munich, Germany) and recorded by GP2 data loggers (Delta-T Devices Ltd, Cambridge, United Kingdom). During the last field investigation, gravimetric soil moisture was determined in the lab by drying at 105°C and soil temperature was measured manually with a digital puncture thermometer (Testo SE & Co. KGaA, Titisee-Neustadt, Germany) ($n = 3$). Hourly precipitation and air temperature data were obtained from the DWD Climate Data Center (CDC) (2018, 2021a, 2021b, 2021c). Hourly precipitation data was accumulated for time periods of 12, 6, 3 and 1 month prior to each earthworm extraction.

2.5 | Statistical evaluation

Earthworm count and biomass data were converted to individuals per m^2 and biomass per m^2 [g m^{-2}]. Only complete individuals were included in the statistical evaluation. For total earthworm abundance and biomass as well as for total abundance and biomass of endogeics, generalized linear mixed models using Template Model Builder (glmmTMB, Brooks et al., 2017) were applied. Model predictors were specifically chosen to depict seasonal and management aspects in the following order: crop, season, history and fertilizer and additionally field number as random effects variable. The predictor "crop" described the current crop (cup plant/maize), "season" described a combination of season and year (spring2019/fall2019/late_spring2020/spring2021) and the predictor "history" described the prior management (maize/

meadow/rotation). For the predictor "fertilizer", six levels were chosen, to properly depict the fertilizer application prior to and in-between earthworm extractions (digestate/ manure/mineral/none/slurry/slurry and manure/organic and mineral). The estimated total N [kg] input as well as the estimated N input from organic sources [kg] based on fertilizer type and amount were accounted for by adding the following Boolean predictors (yes/no): below100, below130, below150, below_100orgN, below_130orgN, below_150orgN (Table S1). Additionally, predictors were added to account for interactions of the current crop type with "season" and the respective N input. Subsequently, the model with best goodness of fit was selected based on the Akaike information criterion (AIC). A type III analysis of variance (ANOVA) was performed using the "car" package (Fox & Weisberg, 2019) resulting in a Type III Wald chi-square test with an analysis of deviance table as output. Total earthworm abundance, total earthworm biomass, total endogeic earthworm abundance and total endogeic earthworm biomass had to be square root-transformed to ensure normal distribution of model residuals. Tukey HSD was conducted for post-hoc testing using the "emmeans" function (Lenth, 2020). The Shannon–Wiener index was calculated by applying the "diversity" function from the package "vegan" (Oksanen et al., 2020). Species richness was calculated by counting the number of species per extraction. The Shannon-Wiener Index and species richness were subject to Welch Two Sample t-tests to assess differences between crop types.

The generalized linear mixed model evaluating K was fitted with predictors "crop" (cup plant/maize), "year" (2020/2021) and "history" (maize/meadow/rotation) as fixed effects and the field number as random effects variable. Data was sqrt-transformed to ensure normally distributed model residuals. Correlation tests were conducted by means of the command "cor.test" using the Pearson correlation coefficient from the "stats" package (R Core Team, 2020) followed by visual inspection.

Litterfall as well as litter total C and N content and the CN ratio were examined with a linear model using the sampling date and crop type as predictor variables and subsequent ANOVA. Data was log-transformed, if necessary. Additionally, the seasonal trend was removed by using the decompose function from the "stats" package (R Core Team, 2020). Afterwards, slopes and differences between crop types were evaluated by applying a paired Student's t-Test ("stats" package, R Core Team, 2020) or a simple analysis of variance (ANOVA) (Fox & Weisberg, 2019). C and N contents as well as CN ratio of fresh and senescent maize and cup plant leaves as well as maize and cup plant residues were analysed via linear models and a type III ANOVA with crop (cup plant/maize) and stadium (fresh/ senescent/residual) as predictor variables. Data for fresh,

senescent and residual plant material was log-transformed to ensure normal distribution. Furthermore, the packages "ggplot2" (Wickham, 2016), "dplyr" (Wickham et al., 2021), "reshape2" (Wickham, 2007) and "multcomp" (Hothorn et al., 2008) were used.

3 | RESULTS

3.1 | Earthworm abundance and biomass

Total earthworm abundance was generally higher in cup plant fields (Figure 1) (χ^2 ($df = 1$) = 15.01, $p = .0001$). Over the course of our field investigations, the number of individual earthworms per m^2 in cup plant fields was 29.5%–189.9% higher than in maize fields. Earthworm abundance as a whole varied not only between sampling dates but also in relation to current crop type (χ^2_{season} ($df = 3$) = 11.95, $p_{season} = .0076$; $\chi^2_{crop:season}$ ($df = 3$) = 13.17, $p_{crop:season} = .0043$). The fourth sampling in the spring of 2021 yielded the most earthworms per m^2 in general as well as for both crop types. Furthermore, our model identified the land use history as significant factor (χ^2 ($df = 2$) = 16.23, $p = .0003$). Fields with a history of diverse crop rotation or former grassland and field grass sites hosted more earthworms, than sites with a history of monotonous maize cropping. On average, former field grass sites were habitat for 156.9 ± 20.1 individuals per m^2, monotonous maize fields hosted only 74.1 ± 10.0 individuals per m^2. The biggest differences according to posthoc testing, however, were found between histories of continuous maize cropping and diverse crop rotation (145.4 ± 15.4 individuals per m^2), while former grassland sites resided in-between because of large standard error. Additionally, the type of applied fertilizer was found to be a significant factor (χ^2 ($df = 5$) = 15.63, $p = .0080$). The model indicated that the application of slurry as well as the omission of fertilizer application between two sampling campaigns increased earthworm abundance compared with the remaining alternatives (digestate, manure, mineral, slurry and manure, organic and mineral).

All values in the text are given as means with standard error (means ± SE). For more statistical information on total earthworm abundance, see Table S2. The Appendix S1 further contains field and management characterisations, visualizations of earthworm biomass as well as figures containing trimestrial development of field litter characteristics and a precipitation timeline.

Total earthworm abundance in maize was positively correlated with soil moisture and bulk density in the top soil ($\rho_{soil\ moisture} = .49$ $p_{soil\ moisture} < .05$; $\rho_{bulk\ density} = .41$ $p_{bulk\ density} < .01$) and negatively correlated with the soil temperature in the top soil ($\rho = -.59$ $p < .01$). Earthworm
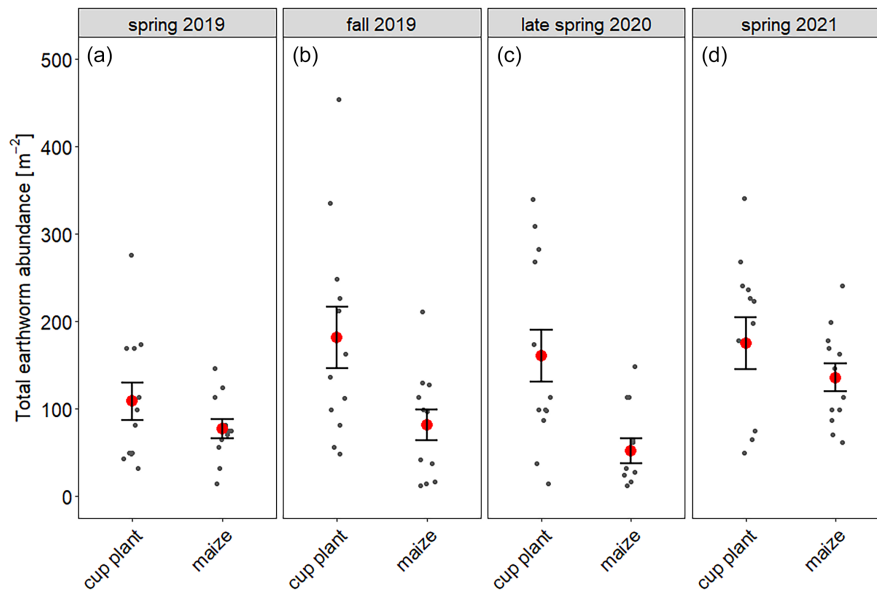
FIGURE 1 Total earthworm abundance as individuals per m^2 (means ± SE) in maize and cup plant fields for (a) the first sampling in spring 2019, (b) the second sampling in fall 2019, (c) the third sampling in late spring 2020 and (d) the fourth sampling in spring 2021. Means are indicated by the red dot.

abundance furthermore positively correlated with the cumulated precipitation within 3 months prior to sampling ($\rho = .44$ $p < .01$). Similar trends in cup plant systems were not found.

Earthworm biomass was statistically evaluated as well, but cautious interpretation is advised because of several missing values. Nevertheless, the current crop type was clearly identified as a significant factor (χ^2 $(df = 1) = 7.44$, $p = .0064$), as can also be seen in Table S3 and Figure S2. Especially during the third sampling in late spring 2021, the average earthworm biomass in cup plant fields was four times higher than in maize fields. Earthworm biomass fluctuated between sampling dates (χ^2 $(df = 3) = 12.04$, $p = .0072$). More substantial weight changes were associated with maize systems. Similar to abundance, earthworm biomass was significantly affected by the type of fertilizer (χ^2 $(df = 5) = 18.14$, $p = .0028$) and the application of slurry as well as the omission of fertilizer application were associated with higher earthworm biomass.

Earthworm biomass in maize fields correlated with the silt content in the topsoil and subsoil ($\rho_{top} = .45$ $p_{top} < .05$; $\rho_{sub} = .46$ $p_{sub} < .01$). Cumulated precipitation 1 month prior to sampling positively correlated with earthworm biomass ($\rho_{1\,month} = .41$ $p_{1\,month} < .05$). In cup plant systems, earthworm biomass correlated negatively with top soil bulk density ($\rho = -.44$ $p < .05$).

3.2 | Earthworm community structure

The majority of earthworms were classified as juveniles, which includes subadults (maize: 55%, cup plant: 57%).

Furthermore, 25% of earthworms originating from cup plant stands and 28% of earthworms originating from maize stands were categorized as adult. The remaining could not be identified because of damage and appear in Figure 2 as "not identified" (n.i.). Regarding species composition, we found *Aporrectodea caliginosa, Aporrectodea rosea, Lumbricus terrestris* and *Octolasion cyaneum* in cup plant fields. On the contrary, we found *Aporrectodea caliginosa, A. rosea, L. terrestris* and *O. cyaneum* as well as one single individual of *Lumbricus rubellus* and six individuals of *Allolobophora chlorotica* in maize stands. The occurrence of *Lumbricus rubellus* and *A. chlorotica* was restricted to a single field within a single sampling campaign amounting to less than 2% of the total earthworm abundance in maize. *Aporrectodea spec.*, consisting of both *A. caliginosa* and *A. rosea*, made up the largest group in cup plant and maize field with 58% and 68%, respectively. The second largest group consisted of *L. terrestris* with shares of 16% in cup plant communities and 15% in maize communities, followed by *O. cyaneum* with 9% in cup plant and 2% in maize fields. The remaining share of earthworms could not be identified. Regarding unidentified earthworms, the developmental stage or the species association or both could not be identified, therefore ecological category association is also uncertain.

The Shannon-Wiener Index, that was calculated based on species abundance, ranged from 0.46 ± 0.11 to 0.60 ± 0.09 in cup plant and from 0.12 ± 0.06 to 0.48 ± 0.10 in maize. The overall difference between cup plant and maize regarding the Shannon-Wiener Index was significant ($t = 3.367$, $df = 94.981$, $p = .0011$). Similarly, species
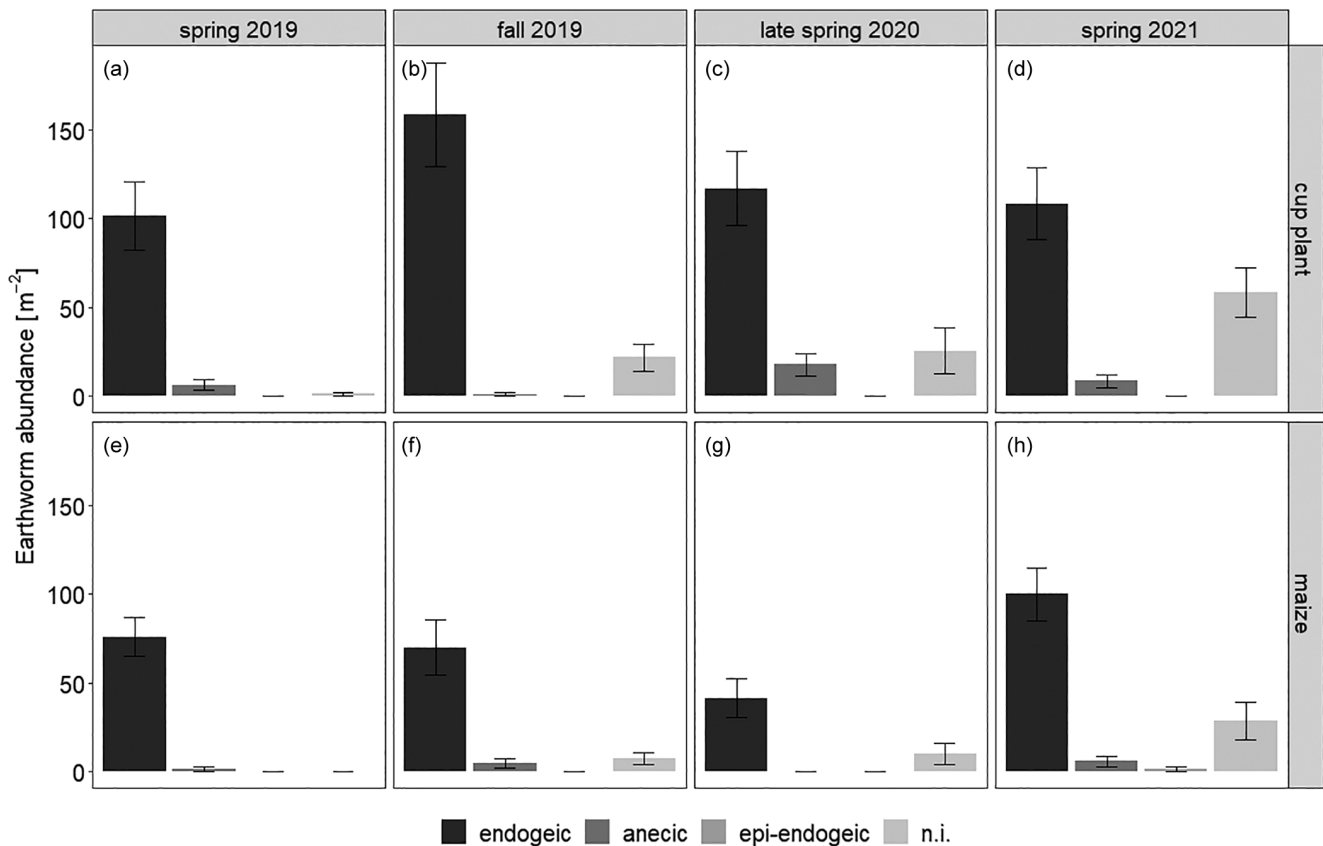
FIGURE 2 Total earthworm abundance by ecological category as individuals per m^2 (means ± SE, $n = 12$) in maize and cup plant fields for (a, e) the first sampling in spring 2019, (b, f) the second sampling in fall 2019, (c, g) the third sampling in late spring 2020 and (d, h) the fourth sampling in spring 2021. The term "n.i." refers to individuals that could not be identified (= "not identified").

richness was significantly higher in cup plant systems ($t = 3.575$, $df = 94.545$, $p = .0006$).

The majority of earthworms were categorized as endogeics (Figure 2). The share of endogeics ranged from 62% to 93% in cup plant and from 74% to 98% in maize with variations between sampling campaigns. Influential factors regarding endogeic earthworm abundance were found to be reflecting those also affecting the total earthworm abundance: Endogeic earthworm abundance was higher in cup plant stands ($\chi^2 (df = 1) = 18.75$, $p < .0001$) (Figure S3). A large number of endogeic earthworms was found during the second sampling. The sampling date as well as its interaction with current crop type were identified as significant factors ($\chi^2_{season} (df = 3) = 19.19$, $p_{season} = .0002$; $\chi^2_{crop:season} (df = 3) = 17.35$, $p_{crop:season} = .0006$), as were land use history and type of applied fertilizer ($\chi^2_{history} (df = 2) = 17.98$, $p_{history} = .0001$; $\chi^2_{fertilizer} (df = 5) = 19.00$, $p_{fertilizer} = .0019$).

A trend was found towards higher endogeic earthworm biomass in cup pant fields ($\chi^2 (df = 1) = 3.84$, $p = .0501$; Figure S4). The sampling date as well as interactive effects with crop type were found to be important ($\chi^2_{season} (df = 3) = 9.13$, $p_{season} = .0276$; $\chi^2_{crop:season} (df = 3) = 6.47$,

$p_{crop:season} = .0911$). Depending on the sampling date, endogeic biomass amounted to 22% more (spring 2021) to more than twice as much (late spring 2020) compared with the respective maize systems. Statistical evaluation further indicated that the fertilizer type as well as amount of applied N had a significant effect ($\chi^2_{fertilizer} (df = 5) = 18.08$, $p_{fertilizer} = .0028$; $\chi^2_{below100} (df = 1) = 4.71$, $p_{below100} = .0300$). Higher earthworm biomass was found after the application of slurry or a mixture of slurry and manure. Apart from that, a 43% higher endogeic biomass in cup plant and a 137% higher biomass in maize was linked to an N input below 100 kg N ha^{-1}.

Anecic earthworm abundance was small (Figure 2). In total, the share of anecic earthworms in maize systems was 2% (spring 2019) to 6% (fall 2019) between sampling with no anecic earthworms found in late spring of 2020. In contrast, the share of anecics in cup plant ranged from 1% (spring 2019) to 11% (late spring 2020). After exclusion of all measurements including unidentifiable individuals, no significant differences in anecic abundance were found between cup plant and maize systems for any of the sampling dates.

3.3 | Water infiltration

On average, saturated infiltration rates were 47% higher in maize fields (Figure 3), hence the crop was identified as a significant factor (χ^2 ($df=1$) $=5.58$, $p=.0182$). Furthermore, the year of sampling was found to be significant (χ^2 ($df=1$) $=4.98$, $p=.0257$). In 2020 saturated infiltration rates were on average 35% higher in cup plant systems and 67% higher in maize systems, which was characterized by generally higher precipitation. A relationship between the total earthworm abundance or biomass and infiltration rates could not be found. Similarly, no correlation was found between saturated infiltration rates and abundance or biomass of either endogeic or anecic earthworms. The land use history of the field had no effect.

3.4 | Cup plant and maize litter

The amount of litter exhibited a strong seasonal influence ($F=14.604$, Pr($>F$) <0.0001, $df=7$) with particularly high litter biomass in the fall season. In fall, available litter biomass in cup plant systems was four times as high as in maize systems (Figure 4). The average litter biomass amounted to ca. $2.0\,\mathrm{Mg\,ha}^{-1}$ in cup plant and $0.6\,\mathrm{Mg\,ha}^{-1}$ in maize with the crop type as a significant factor ($F=157.405$, Pr($>F$) <0.0001, $df=1$).

After stripping off the seasonal trend, a slight decline in both, maize and cup plant systems, became evident (Figure 5). The decline in both slopes was significant (cup plant: $t=-3.073$, Pr($>|t|$) $=0.0219$, $df=6$; maize: $t=-3.532$, Pr($>|t|$) $=0.0213$, $df=6$). Furthermore, the

development of litter biomass in both crops was significantly different ($t=5.635$, $p=.0008$, $df=7$), as values derived from cup plant systems were three to four times as high as those derived from maize systems.

Total C and N and the CN ratio of the trimestrial collected litter are presented in Table 1. Litter total C and N content showed significant effects with respect to crop type (total litter C: $F=70.384$, Pr($>F$) <0.0001, $df=1$; total litter N: $F=22.864$, Pr($>F$) <0.0001, $df=1$). Cup plant litter contained on average 8% to 35% more total C than maize litter. For total litter N a significant interaction of crop type and sampling date was found. Generally, cup plant litter in general contained 7% to 39% more total N (Table 1). In fall 2020, cup plant litter total N was more than twice as high as in maize litter. In spring 2020, on the contrary, the total N content in maize litter was 23% higher than in cup plant. The sampling date was a significant factor for total litter C and N as well as litter CN ratios (total litter C: $F=3.556$, Pr($>F$) $=0.0013$, $df=7$; total litter N: $F=9.543$, Pr($>F$) <0.0001, $df=7$; litter CN: $F=8.326$, Pr($>F$) <0.0001, $df=7$), whereas the crop type alone had no significant influence on litter CN ratios. A trend towards an interaction of crop type and sampling date was found ($F=2.062$, Pr($>F$) $=0.0500$, $df=7$).

All three entities were stripped off seasonal trends as illustrated in the Figures S6, S8 and S10. For comparison, Figures S5, S7 and S9 of the Appendix S1 show the trimestrial development of the above-ground field litter C- and N-content as well as CN ratio before stripping off the seasonal trend. After the removal of a seasonal trend, cup plant litter still contained 17%–30% more total C than maize litter. Hence, the crop type was a significant factor ($F=116.621$, Pr($>F$) <0.0001, $df=1$). In both systems, the
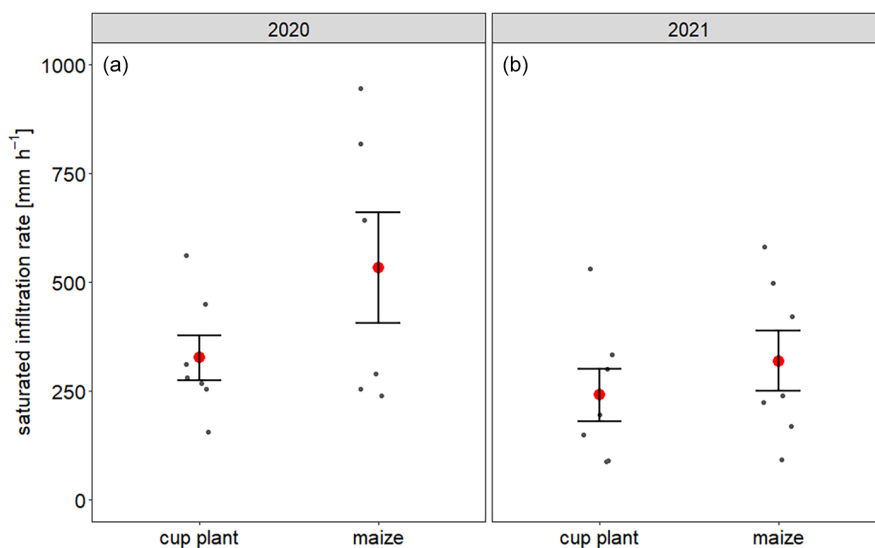

FIGURE 3 Saturated infiltration rates in cup plant and maize fields [$\mathrm{mm\,h}^{-1}$] (means $\pm$ SE) measured in (a) late spring 2020 and (b) in spring 2021. Means are indicated by the red dot.
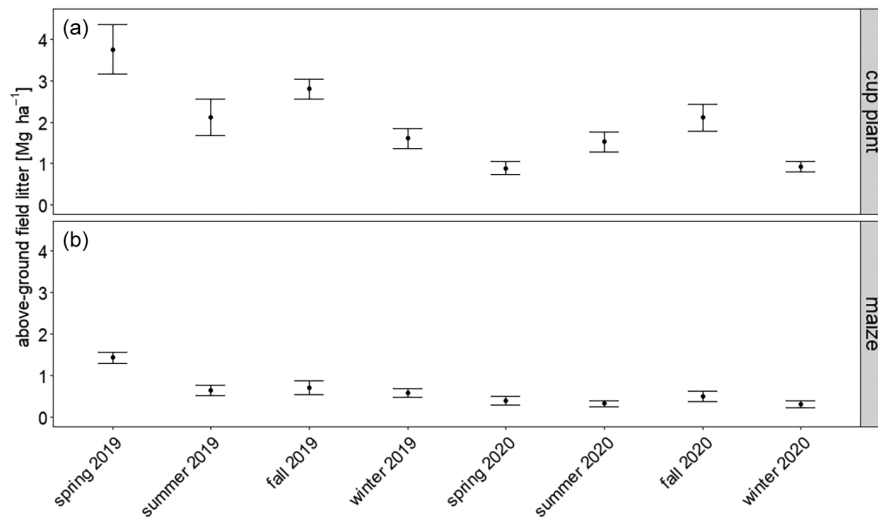
FIGURE 4 Trimestrial development of total above-ground crop litter [Mg ha^{-1}] (means ± SE, $n = 12$) per season collected from (a) cup plant fields and (b) maize fields.
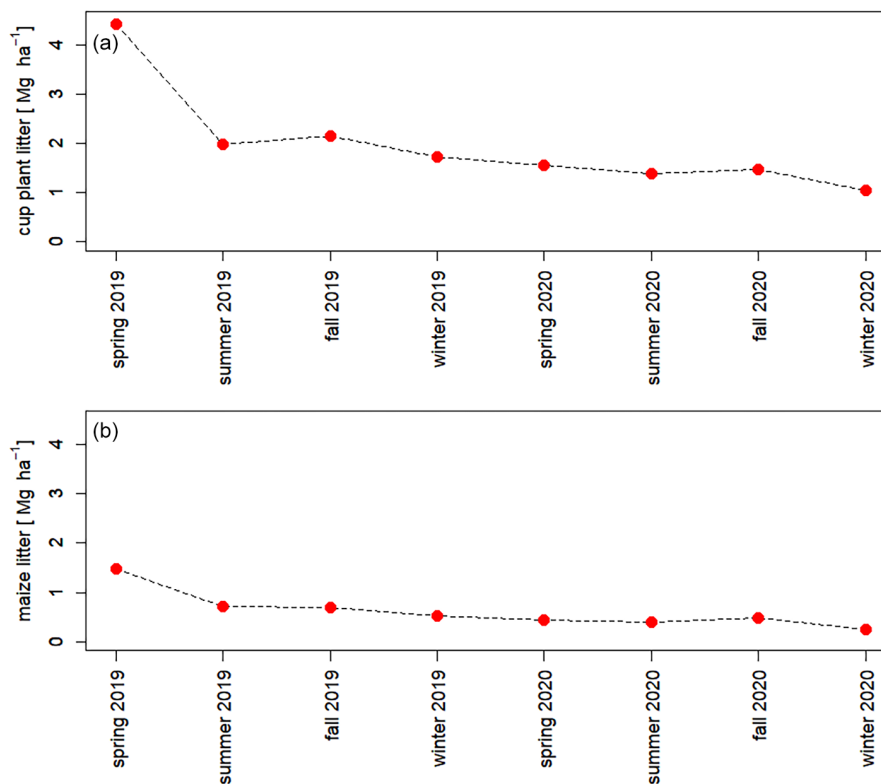

FIGURE 5 Trimestrial development of above-ground crop litter [Mg ha^{-1}] after removal of the seasonal trend for (a) cup plant fields and (b) maize fields. The red dots indicate the sampling once per season.

total litter C content increased significantly (cup plant: $t = 2.47$, Pr(>|t|) = 0.0485, $df = 6$; maize: $t = 3.331$, Pr(>|t|) 0.0158, $df = 6$).

After removal of the seasonal trend, total N ranged from 7.5 to 13.5 g kg^{-1} in cup plant crop litter and from 4.3 to 11.9 g kg^{-1} in maize crop litter (Figure S8). The respective CN ratios ranged from 32 to 47 in cup plant crop litter and from 31 to 57 in maize crop litter (Figure S10).

Significant differences could not be found for either total N content or CN ratios of the collected above-ground crop litter.

A relationship between litter and earthworms was found in maize systems, where the number of earthworms per m^2 positively correlated with the average annual litter total N ($\rho = .58$ $p < .001$). Consequentially, the earthworm number negatively correlated with

the average annual CN ratio of the litter ($\rho=-.53$ $p<.001$). The same was found regarding the earthworm biomass $[\text{g m}^{-2}]$ ($\rho_{\text{litter total N}}=.55$ $p_{\text{litter total N}}<.01$;

TABLE 1 Total C and N of above-ground crop litter $[\text{g kg}^{-1}]$ (means $\pm$ SE, $n=12$) and crop litter CN ratio in cup plant and maize per season in 2019 and 2020 before removal of the seasonal trend.

	Total litter C $[\text{g kg}^{-1}]$	Total litter N $[\text{g kg}^{-1}]$	Litter CN ratio
Cup plant			
2019			
Spring	382.5 ± 14.5	10.1 ± 1.4	45.9 ± 6.2
Summer	342.3 ± 17.4	10.2 ± 0.7	35.7 ± 3.8
Fall	374.3 ± 9.8	13.2 ± 1.1	31.0 ± 3.1
Winter	353.3 ± 10.1	8.1 ± 0.8	49.3 ± 5.3
2020			
Spring	382.0 ± 12.5	7.7 ± 0.6	53.1 ± 4.9
Summer	372.8 ± 12.1	14.1 ± 0.8	27.3 ± 1.5
Fall	379.1 ± 9.7	14.8 ± 1.3	27.8 ± 2.6
Winter	381.2 ± 17.4	9.2 ± 0.4	42.0 ± 2.4
Maize			
2019			
Spring	332.4 ± 18.1	8.9 ± 0.8	41.4 ± 5.1
Summer	253.4 ± 18.3	9.5 ± 0.4	27.5 ± 2.6
Fall	296.0 ± 15.1	12.2 ± 1.1	27.2 ± 3.5
Winter	293.9 ± 20.5	5.8 ± 0.4	53.3 ± 5.1
2020			
Spring	353.2 ± 12.5	9.4 ± 2.1	53.0 ± 7.4
Summer	308.5 ± 20.6	10.2 ± 1.1	34.1 ± 4.6
Fall	295.5 ± 16.8	6.8 ± 0.4	45.8 ± 4.8
Winter	316.9 ± 21.7	7.9 ± 0.9	48.8 ± 8.1

$\rho_{\text{litter CN ratio}}=-.57$ $p_{\text{litter CN ratio}}<.01$). For cup plant systems no such relationship was found.

The CN ratios of crop litter and pure cup plant and maize leaves and residues varied significantly ($F=214.3$ $\text{Pr}(>F)<0.0001$, $df=1$ Figure 6). In the fall, the CN ratio of cup plant crop litter reached 29 ± 2 and that of maize crop litter reached 36 ± 3. Fresh and senescent leaves of cup plant, however, contained significantly less total N ($F=388.3$, $\text{Pr}(>F)<0.0001$, $df=1$) and, hence, their CN ratio was twice as high as those of maize. Matured residuals, which were collected from the soil surface, differed with a CN ratio of 80 in cup plant residuals and a CN ratio of 77 in maize residuals. Similar and above CN ratios were measured in the trimestrial collected crop litter as well; mainly in spring and winter. The maximum mean CN ratios per crop and sampling date were at 53 for both, cup plant and maize crop litter. In fall of 2019 and 2020 as well as in summer 2020, we found mean cup plant crop litter CN ratios of 31 ± 3, 28 ± 3 and 27 ± 1, respectively, which were lower than the CN ratio of fresh cup plant leaves (CN 37). Generally, maize leaves contained up to three times more fibre than cup plant leaves because of high levels of cellulose and especially hemicellulose. Lignin contents of maize and cup plant leaves were similar, yet fresh maize leaves only contained half as much as fresh cup plant leaves.

4 | DISCUSSION

4.1 | Earthworm communities in cup plant and maize fields

To draw a conclusion regarding ecosystems service provision and beneficial effects on ecosystem stability, it was necessary to first assess earthworm abundance with respect
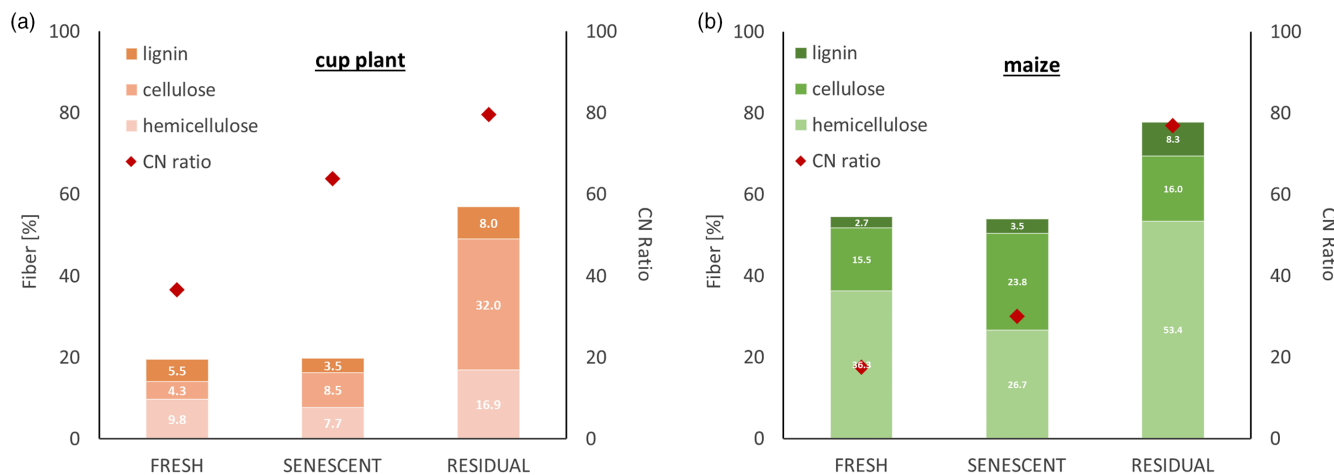
FIGURE 6 Lignin, cellulose and hemicellulose contents [%] of fresh and senescent cup plant (a) and maize (b) leaves and of pure residual cup plant and maize litter collected from the soil surface in fall 2020 ($n=2$). The respective CN ratios are indicated by a red diamond ($n=3$).

to ecological group association in cup plant and maize. In our field study, 3- to 5-year-old cup plant systems showed significantly more earthworms than continuously cropped (2 years) maize systems. Overall species richness and diversity as indicated by the Shannon-Wiener-Diversity Index were found to be higher in cup plant systems as well. Therefore, our first hypothesis that cup plant systems support functionally diverse earthworm communities was validated. Our findings are in line with Emmerling (2014) and Schorpp and Schrader (2016). The first author found nine different species in cup plant fields aged 1–6 years, the latter authors found five different species in 4-year-old cup plant fields. In our study, four different species were found in cup plant systems aged 3–5 years. While earthworm numbers [individuals m^{-2}] in our study were similar to those found by Schorpp and Schrader (2016), the share of juveniles in our study was higher. Furthermore, the earthworm community structure in maize and cup plant fields was similar, while Schorpp and Schrader (2016) reported a more complex structure 3 years after cup plant establishment. The most important factor for earthworm abundance and the most pronounced difference between cup plant and maize was the absence of tillage, as mentioned before by Emmerling (2014) and Schorpp and Schrader (2016) as well as by Pelosi et al. (2009), van Capelle et al. (2012) and Bertrand et al. (2015). Soil disturbances, such as tillage, predominantly affect anecics and epigeics, while endogeics may even profit from ploughing, as it enhances the incorporation of organic residues (Pelosi et al., 2009; van Capelle et al., 2012).

The high number of juveniles in maize may be because of the reduced tillage regime. In cup plant, however, the high number of juveniles and the similarities in earthworm community structure to maize may point to overall harsh habitat conditions in both cropping systems:

First, the bulk density of our fields indicated a certain degree of compaction with bulk density ranging from 1.15 to 1.56 g cm^{-3} in the topsoil and from 1.49 to 1.79 g cm^{-3} in the subsoil. Earthworm abundance is positively correlated with topsoil bulk density in maize, implying a potentially higher soil moisture. In cup plant, however, earthworm biomass showed a weak negative correlation with topsoil bulk density. This may be caused by an energy trade off, as burrowing activity was impeded because of higher spatial resistance (Beylich et al., 2010; Jégou et al., 2002). Positive and negative effects on soil fauna are possible and may be species-dependent at medium levels of compaction (Beylich et al., 2010; Jégou et al., 2002). However, soil moisture and oxygen conditions are crucial in this context, as they may severely hamper earthworm abundance (Beylich et al., 2010; Li et al., 2021).

Second, in the course of our field investigations, we found drought conditions during spring of 2020 and intensive rainfall in the winter months (Figure S11). Earthworms are sensitive to both, excessive waterlogging conditions and flooding but also to severe drought and high temperatures (Singh et al., 2019). Drought conditions may lead to a decline in earthworm growth, cocoon production and burrowing activity, as the soil hardens significantly (Anh et al., 2014; Singh et al., 2019). Flooding or water logging conditions can lead to the perishing of earthworms, when oxygen levels decrease for an extended period of time (De Lange et al., 2013). When the time interval between perturbations, such as drought, waterlogging or even tillage, becomes shorter than the time needed for an earthworm generation to develop, population growth and development may be reduced (De Lange et al., 2013). Those findings may in part also be the reason why anecic earthworms were found only in small numbers in both maize and cup plant fields, when compared with observations by Schorpp and Schrader (2016). Anecic earthworms like *L. terrestris* are restricted to relatively stable environments (Butt & Lowe, 2011). Furthermore, *L. terrestris* is considered a K-strategist (Butt & Lowe, 2011) and does not enter any kind of aestivation or diapause; although this behaviour would be beneficial under e.g., flooding or excessive waterlogging conditions (De Lange et al., 2013). However, survival of these K-strategist earthworms is possible but comes at the expense of reproduction (Kiss et al., 2021), hence, anecic earthworm number remain low. Nevertheless, it may be assumed, that the establishment of a structural more complex earthworm community with a higher share of anecics may simply be delayed because of the young age of the cup plant fields in this study and harsh environmental conditions, but will eventually proceed in the future. Kiss et al. (2021) found that endogeic earthworms, on the other hand, may perish even sooner than anecics under low oxygen conditions because of flooding. Endogeic species are considered r-strategists and characterized by a high reproduction rate; which indicates that they recolonize previously disturbed habitats faster causing a high abundance of juveniles (Butt & Lowe, 2011; De Lange et al., 2013; Kiss et al., 2021), as observed in our field investigations. In both systems, we found a particularly high share of endogeic earthworms.

We furthermore observed that earthworm population size in cup plant remained stable throughout our field investigations, while earthworm population size in maize showed a higher degree of variation. One difference may be the ground cover in cup plant systems, as litter biomass was three to four times higher than in maize in our study. The litter layer as well as the thick canopy cover in cup plant stands may create a suitable soil microclimate and thus, shelter the habitat from adverse abiotic conditions (Chen et al., 2014; Feledyn-Szewczyk et al., 2019; Felten & Emmerling, 2011; Gansberger et al., 2015). For cup

plant systems, this was also indicated by the absence of a correlation of earthworm abundance and biomass with abiotic factors, such as soil temperature, precipitation patterns and soil texture. Earthworm populations in maize were more sensitive to abiotic factors. The continuity of earthworm population size in cup plant may indicate a higher ecosystem resistance and may hint at the establishment of ecosystem stability and quicker recovery from perturbation (De Lange et al., 2013; Ferris et al., 2001).

4.2 | Availability of food sources in cup plant and maize and its implications for ecosystem service provision

Earthworm populations as well as richness and diversity are considerably affected by food availability in general and by availability of labile C and food quality in particular (Curry & Schmidt, 2007; Leroy et al., 2008; Li et al., 2021; Singh et al., 2019). Studies have repeatedly emphasized the importance of crop litter as food source for earthworms (Bertrand et al., 2015; Blanco-Canqui & Lal, 2009; Curry & Schmidt, 2007). However, high crop litter CN ratios in our study seemed unfavourable for earthworms and indicated a potential N immobilization most of the time, as the critical CN ratio for immobilization ranges from 24 to 44 (Chen et al., 2014; Curry & Schmidt, 2007). Therefore, it may be concluded that the respective above-ground crop litter was not the only or necessarily primary food source for earthworms.

Earthworm abundance in maize responded to the crop litter N content and CN ratio. Felten and Emmerling (2011) reported, that maize litter may be a food source of higher quality, yet they found less earthworms, possibly as a result of scarcity of litter. Hence, our results are in line with Felten and Emmerling (2011). Crop litter was scarce in our case as well and plant organs such as stems and roots are decomposing slowly. As a result of vegetative luxury N uptake i.e., surplus accumulation of N in maize plants (Nasielski et al., 2019), it may be assumed, that the N content and CN ratio of maize litter may reflect the fertilizer regime, to which earthworm may have originally responded. Fertilizer type was a crucial factor in our study. In addition, higher endogeic earthworm biomasses were linked to N-input below $100\,\mathrm{kg\,ha^{-1}}$. This implied, that organic fertilizer must be considered as a vital source of available C for earthworms in maize systems, which is in accordance with Curry and Schmidt (2007) and Leroy et al. (2008). In cup plant systems, earthworm populations did not respond to crop litter biomass, its total C and N content or the respective crop litter CN ratios. In some cases, cup plant crop litter CN ratios were lower than fresh cup plant litter CN ratios. This finding may be explained by a considerably higher degree of weed infestation, that was observed in cup plant systems during the course of our field investigations. This indicates, that the lower crop litter CN ratios may be because of the presence of other plant species with intrinsically lower CN ratios, such as clover. In their 2019 study, Feledyn-Szewczyk et al. (2019) found, that in comparison to conventional arable lands, perennial energy crops, especially perennial grasses, are characterized by a higher number and diversity of weed species. They attributed their findings to different habitat conditions, like absence of tillage and herbicide application as well as more shade. Higher plant diversity and, thus, a higher diversity of food sources apart from litter and fertilizer may offer better feeding conditions for different earthworm species and promote earthworm diversity (Curry & Schmidt, 2007; Eisenhauer et al., 2013; Milcu et al., 2006; Singh et al., 2019). It may further be assumed that a higher diversity of food sources combined with a subsequently higher earthworm diversity may improve decomposition of recalcitrant litter and nutrient turnover because of differences in CN ratios (Kuzyakov et al., 2000). The importance of plant diversity was also emphasized by the effect of land use history, as we found particularly low numbers of earthworms on fields, that were continuously cropped with maize in the past. Fields with a history of grassland use or diverse crop rotation harboured more earthworms. Furthermore, the extensive root network of the cup plant may deliver more root exudates offering another valuable food source for soil-dwelling animals (Curry & Schmidt, 2007; Gansberger et al., 2015; Milcu et al., 2006; Ruf et al., 2018). As a side effect, high-quality food sources as well as the applied fertilizer, may support decomposition of more recalcitrant organic matter as well (Chen et al., 2014). In conclusion, we assume, that cup plant systems are more beneficial to earthworms as well as to the whole soil food web because of abundance and diversity of food sources (Eisenhauer et al., 2013).

Eisenhauer et al. (2013) showed, that plant diversity has a bottom-up effect on soil food webs and decomposer communities, thereby increasing species richness. Additionally, a higher complexity of soil food networks was found by Gong et al. (2018) in earthworm-worked soils, as earthworms increase the interaction between different microbial taxa. The soil-microbial community may further benefit from larger earthworm communities and extensive root systems, since both, the rhizosphere as well as earthworm burrows are associated with higher enzyme activity (Hoang et al., 2016). A higher above- and below-ground diversity as well as the greater interaction in the soil food web may lead to higher functional redundancy and thereby promote ecosystem resistance and resilience (Gong et al., 2018; Shu et al., 2019; Yang et al., 2018). Considering the overall higher diversity taken together

with the continuity and size of earthworm populations in cup plant systems, our second hypothesis, that perennials increase ecosystem stability in energy cropping systems can be considered valid.

4.3 | Infiltration in maize and cup plant systems affected by earthworms and crop residues

Our results showed, that saturated infiltration rates were higher in soils under maize, despite higher earthworm abundance in cup plant. Although positive effects of earthworms on infiltration rates have been reported (Ernst et al., 2009), we found no significant relationship. Our results are similar to those of Emmerling et al. (2015), who found only small to medium effects of earthworms on infiltration. The authors argued, that the lack of relationship may be because of the fact, that endogeics refill their burrows. The authors furthermore stressed the importance of subsoil bulk density. With respect to the subsoil bulk densities of $1.49–1.79\,\mathrm{g\,cm}^{-3}$ in our study, an inhibition of infiltration is possible. Furthermore, the swelling and shrinking of the soil may have caused ruptures of formerly continuous biopores. The absence of earthworm effects may in part be caused by the refilling of burrows by endogeics (Emmerling et al., 2015), but could also be because of earthworm populations and especially anecics not being fully established yet, as proposed in chapter 4.1. Although anecic earthworm burrows have the potential to transmit considerable volumes of water, a certain population size and earthworm biomass are important indicators for infiltration (Shipitalo & Butt, 1999). A link between increased burrow volume and increased water transfer was found for endogeis as well, as mentioned by Capowiez et al. (2014). Therefore, it may also be possible that a large number of endogeics contributes to infiltration capacity more than a small population of anecic earthworms. Furthermore, earthworm effects could have been overruled by management effects, as (reduced) tillage in maize has potentially aided water infiltration capacity (Amami et al., 2021). In light of these findings, we have to reject our third hypothesis.

However, it must be mentioned, that we removed any plants or soil covering residue before infiltration measurement. Considering both cropping systems as a whole, ground cover may play a crucial role in supporting infiltration (de Almeida et al., 2018). Ground cover like litter layers as well as mulching can considerably increase infiltration und decrease soil erosion, as it prevents rain drop splash and pore sealing (Carrà et al., 2021; de Almeida et al., 2018; Wang et al., 2020). Depending on organic C content and soil texture, ground cover may counteract

soil water repellency by maintaining soil moisture levels above the critical water content, although soil water repellency is more common in sandy soils (Bayad et al., 2020; Carrà et al., 2021; Hermansen et al., 2019). Soil water repellency in general can be associated with low infiltration rates and contribute to surface runoff, nutrient loss and erosion (Bayad et al., 2020; Carrà et al., 2021; Hermansen et al., 2019).

4.4 | Earthworm-controlled ecosystem services and perennial energy crops as opportunity for future agroecosystems

Earthworms provide important ecosystem services, that were not adressed in this study; such as decomposition, nutrient turnover and improvement of soil structure (Bertrand et al., 2015). As farmers may resort to no-till regimes, direct sowing and stubble retention to combat climate extremes and soil degradation (Karlen & Rice, 2015; Ugalde et al., 2007), earthworms may become more and more important because of their impacts on ecosystem functioning and service delivery. Earthworms can improve plant tolerance to stress factors, stabilize yields and aid the delivery of ecosystem services in disturbed environments (Plaas et al., 2019; Yang et al., 2018). Earthworms were also found to support litter mass loss even under unstable environmental conditions (da Silva et al., 2020). Detritivorous earthworms under no-till regimes are a valuable partner in combating plant pathogens as shown by Plaas et al. (2019) and van Capelle et al. (2021). Moreover, as mentioned before, earthworms strengthen ecosystem stability (Gong et al., 2018; Shu et al., 2019; Yang et al., 2018). Perennials could be a useful tool to amplify this effect, not only because they support large earthworm populations but also because of their beneficial effects on the soil water balance. Apart from the canopy and litter layer effect, its extensive root network may support infiltration by creating preferential flow pathways because of root penetration (Leung et al., 2018; Liu et al., 2019). Beneficial effect on soil biota and soil water balance could be improved by intercropping with tap-rooted crops (Liu et al., 2019). Considering increasingly erratic weather patterns, intercropping may also be an opportunity to stabilize yields. As single crop, maize outperforms cup plant under dry conditions (Schoo et al., 2017), but waterlogging can cause considerable damage and yield loss (Ren et al., 2014). Cup plant, on the other hand, displayed a higher water use efficiency under excess-moisture conditions (Ruf et al., 2019). Finding an appropriate crop to pair with may alleviate abiotic stresses and optimize yields, but more research is needed in that field (Jablonowski & Schrey, 2021; Nabel et al., 2018).

Regarding future studies of earthworms and filtration, we advise a higher number of replicates and a prompt identification of earthworms and measurement of biomass. Especially in loamy soils, infiltration measurement may be more time-consuming and earthworms may be exposed to the AITC solution for longer periods of time. A swift processing of earthworm samples could potentially minimize earthworm losses.

5 | CONCLUSION

Earthworm abundance and diversity in ecosystems are indicative of a system's functioning and stability in the face of disturbance and climate change. Cup plant as a perennial energy cropping system promotes large earthworm communities and the combination thereof may improve the resistance and resilience of agroecosystems. However, a certain threshold of ecosystem stability may be a prerequisite for anecic earthworm colonization. The development of larger anecic earthworm populations and subsequent ecosystem service delivery may have been delayed by waterlogging and drought conditions in our specific case.

Nevertheless, perennial cropping systems in general combined with abundant and functionally diverse earthworm communities may be a robust strategy to combat the effects of increasingly erratic weather patterns by, for example, improving the soil water balance. Agroecosystem stability may be further enhanced by intercropping multiple perennial crops. This approach, however, requires further investigation as to which crop combinations specifically promote biodiversity and, simultaneously, secure biomass yields as well.

However, farmers may shy away from growing perennials because of potentially lower biomass and methane yields, high establishment costs and, hence, lack of profitability (Gansberger et al., 2015), and resort to growing maize again instead. Beneficial ecosystem services could be incentives to appeal to farmers. Until establishment, however, some form of target-oriented support may be necessary; not only for the farmer, but for the sake of biodiversity and agroecosystem stability in the face of climate change.

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

DATA AVAILABILITY STATEMENT
The data that support the findings of this study are available from the corresponding author upon reasonable request.

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