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TILLAGE TREATMENTS AND EARTHWORM DISTRIBUTION IN A SWISS EXPERIMENTAL CORN FIELD

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Summary—A pedobiological investigation was performed on a soil erosion research area of the Geographical Institute of the University of Basel from April to November 1989. The site belongs to, and is cultivated by, the Agricultural School Centre "Kantonale Landwirtschaftliche Schule" Stickhof/Eschikon in Lindau near Zürich (northern Switzerland). In a cropping experiment with corn (*Zea mays*), the influence of four tillage systems on earthworm populations was studied. Aspects of soil physics and soil chemistry were integrated into the investigation. The earthworms were extracted by means of the hand sorting method at six dates in 1989 chosen to represent typical periods of corn cropping. The four tested tillage systems had an influence on earthworm species composition, abundance, and biomass: (1) The consequence of tillage itself was a reduction of about 50% of abundance (number of individuals m^{-2}) and 30% of biomass (g live w m^{-2}), but these losses were equalized during the following months. (2) The minimum tillage (strip zone tillage with a rotary cultivator and simultaneous seeding) caused a higher soil compaction, a negative selection of horizontally burrowing ("endogé") species, and a subsequent diminution of their abundance. (3) Ploughing had a disadvantageous effect on vertically burrowing ("anécique") species. (4) The winter catch crop cover enhanced the food supply and hence the earthworm biomass. An undersown cover had an additional favourable effect on earthworms.

INTRODUCTION

Cultivation techniques in agricultural systems are known to influence biomass and activity of soil animals. Earthworms, by their feeding and burrowing action, are important agents of physical and chemical soil improvement. Their role is also essential in biologically-impoverished arable land. A large amount of work on the ecology of earthworms and their relationships with soils and land use was reviewed by Lee (1985).

During the last 30 yr, agriculture has become more and more intensified. Increased soil puddling, crusting, erosion, and eluviation of nutrients in the concerned arable land followed. The normal activity of soil organisms, too, was affected. The possibility to ensure the nutrient supply of crops with mineral fertilizers cause the neglect of their fertility enhancing effect. In many cases, the main contribution of soil fauna consisted in creating stable soil aggregates and favourable structures for water drainage and aeration (Guild, 1955). The present study was performed according to the holistic geoecological approach of the Geographical Institute of the University of Basel (Glasstetter and Leser, 1987).

STUDY AREA

The study area belongs to the Agricultural School Centre "Kantonale Landwirtschaftsschule" Strickof. It is situated between the towns of Zürich and Winterthur on the Swiss Plateau, hence its name "Morainic Hill Country" (Fig. 1). The study area has a mean annual precipitation of 1100 mm. The growing season has a duration of 200–205 days (April–October) with mean temperatures ranging between 13.0 and 13.5°C. The experimental 0.75 ha corn plot was installed in 1986 on a former meadow site on the southwestern 6° slope of a drumlin. The soil is a glacial till brown earth with a silty–sandy loam texture. The plot was divided into four 14 m large parallel test strips, each of them receiving a different treatment (see Table 1).

METHODS

Excavation, hand-sorting of a given soil volume and determination of earthworm species, live weight, and number of individuals is a simple and yet adequate method for a direct spatial and quantitative investigation of the horizontal and vertical distribution of abundance and biomass (Bouché and Gardner, 1984; Glasstetter, 1989).

Earthworms were sampled in representative soil volumes of 0.1 m^3 (0.5 × 0.5 × 0.4 m) each. Two horizontal soil layers were sorted separately. The upper one (0–0.2 m depth) corresponded to the topsoil. It was separated by a plough pan from the subsoil layer (0.2–0.4 m). Each test strip A, B, C and D was sampled once at six chosen dates (Table 3). The

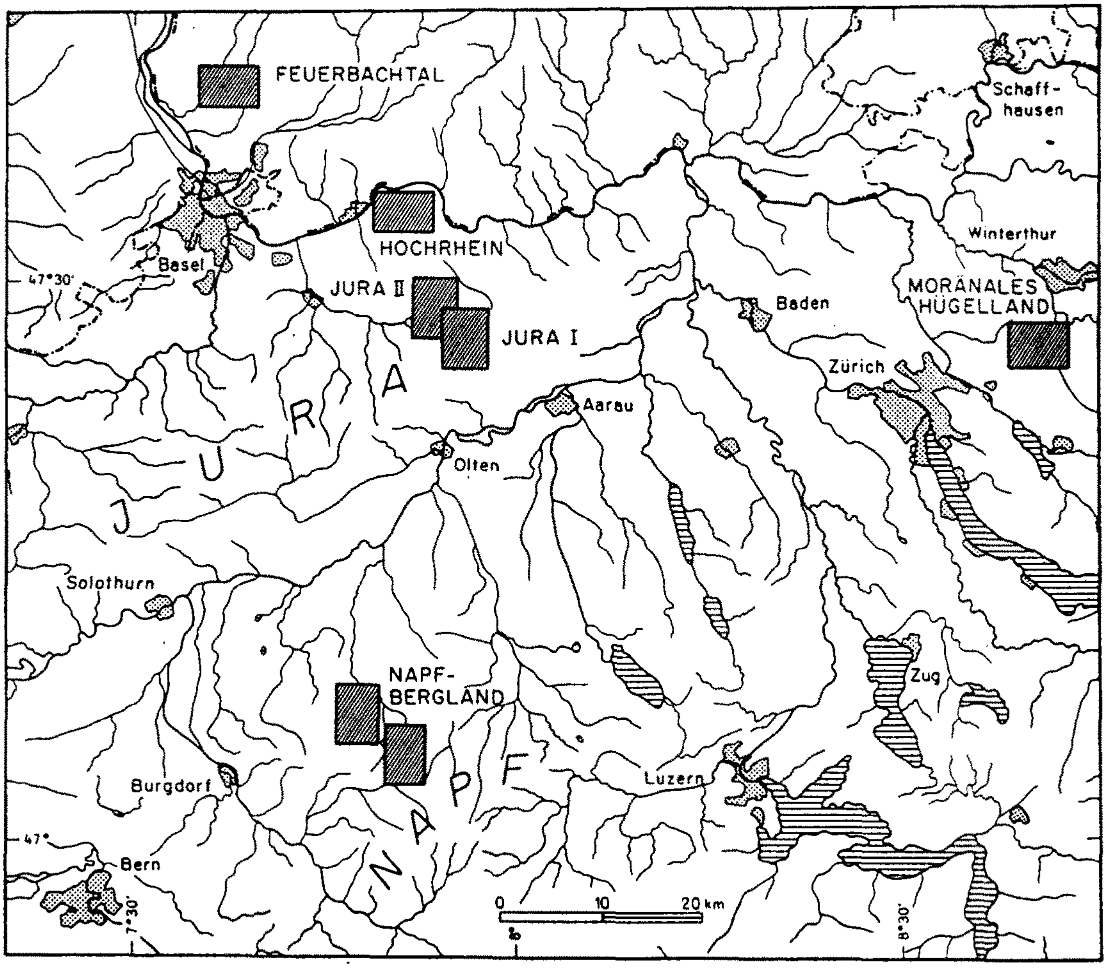

Fig. 1. The study are Moränales Hügelland (Morainic Hill Country) is situated on the Swiss Plateau at an altitude of 530 m asl. It is the easternmost of the study areas (most of them are drainage basins) of the project "Quantitative soil erosion research on arable land" (see Prasuhn and Schaub, 1988).

earthworms were transported alive to the laboratory and were treated the same day. The adults were determined alive. The juvenile forms were put into species groups according to their pigmentation, type of prostomium and ratio of the adult individuals. Biomass (g m^{-2} live weight) and abundance (number of individuals m^{-2}) were also determined on the day of extraction.

Table 1. Tillage treatments used for the cropping experiment with corn in the test area "Morainic Hill Country" (see Fig. 1)

Treatment	Description
Minimum	Pre-seeding overall application of herbicides to eliminate plant canopy
tillage	In spring, corn is sown directly into undisturbed stubble
A	Post-emergence overall application of herbicides
	In autumn, rye as a catch crop is sown directly into undisturbed stubble and harvested in spring
	Winter—cover
Conventional	In spring, prior to conventionally seeding corn, seedbed preparation is done with a rotary harrow
B	Pre-emergence overall application of herbicides
	Autumn—plough
	Winter—fallow
Catch	In spring, prior to conventionally seeding corn, the crop field is ploughed followed by a rotary harrow for seedbed
crop	preparation
C	Pre-emergence band application of herbicides
	Interrow cultivation
	In autumn, rye as a catch crop is sown using a rotovator and drill-combination
	Winter—cover
Underseed	In spring, prior to conventionally seeding corn, the field is ploughed followed by a rotary harrow for seedbed preparation
D	Pre-emergence band application of herbicides
	Interrow cultivation
	In summer, grass is undersown
	Winter—cover

Table 2. Earthworm species found in four differently treated corn strips A–D (Table 1). Morpho-ecological earthworm groups in arable fields: a = anécique, e = endogé. According to Bouché (1977)

Earthworm species	Group	Strips			
A. rosea rosea (Savigny, 1826)	e	A	B	C	D
A. icterica (Savigny, 1826)	e	A	B	C	D
Lumbricus terrestris Linné, 1756	a	A	B	C	D
N. caliginosus caliginosus (Savigny, 1826)	e		B		D
N. longus longus (Ude, 1886)	a	A	B	C	D
Octolasion cyaneum (Savigny, 1826)	e	A	B		
Octolasion lacteum lacteum (Oerley, 1885)	e			C	

RESULTS

In the four compared strips (A–D) seven earthworm species belonging to two morpho-ecological groups (cf. Bouché, 1977) were found (see Table 2 and Fig. 2). The season variations of biomass did not follow a special trend, either in or between the differently treated strips. Abundance, however, was highest in spring and autumn in the ploughed strips (B–D) and lowest in summer. A comparison of vertical earthworm distribution in the four test strips showed the predominance of the biomass and abundance in the topsoil layer in spring, before field treatment. In early June, there was more biomass in the subsoil (beneath the plough pan) than in the topsoil. It was vice versa for abundance. Obviously, a majority of the large-bodied individuals had a tendency to penetrate deeper into the soil during, or just after, seedbed preparation. As shown in Tables 3 and 4, this is especially true for *N. longus*, the most frequent "anécique" earthworm species of all four test strips. At the end of August, in September and in October, biomass and abundance were in most cases clearly prevailing in the topsoil layer. A decrease of earthworms after field treatment in mid-May could be shown in test strips C and D for biomass and in B–D for abundance. In strip A, there was no soil disturbance and no change in vertical distribution. For comparison, five 0.1 m^3 soil units were sampled in September in the adjacent permanent meadow. The number of species (6:8), biomass (59:187 g), and abundance (110:244 individuals) were definitely lower in the corn field than in the grassland respectively.

DISCUSSION

The aim of soil tillage is to create an optimal seedbed for the crop but more and more often, heavy machines are used. Soil structure and pore volume are affected. Ploughing may counteract soil compaction, but it destroys structural elements, as for instance vertical draining earthworm burrows (Ehlers, 1975). This was also demonstrated for the corn plot investigated in spite of a uniform soil texture and moisture.

Tillage treatments influenced the distribution of morpho-ecological earthworm types. The large-bodied "anécique" species *N. longus* was clearly dominant in strip A. Obviously, small, "endogé" species could not succed in the compacted soil. In the three ploughed strips (B–D) the endogé species (in particular *Allolobophora rosea*, *A. icterica* and *N. caliginosus*) found better living conditions. They are small-bodied and are able to develop a normal activity in ploughed soil. Thus, they had clear advantages, whereas the large-bodied anécique species would be injured or their burrows destroyed by ploughing. In contrast to the results of this study, Barnes and Ellis (1979) demonstrated a measurable negative effect of tillage on the number of earthworms. They found a higher abundance in a direct drilled minimum tillage plot than in a ploughed one. Bauchhenss (1986) observed a higher biomass and abundance in field plots with minimum tillage and direct drilling compared to conventionally tilled plots. It is not clear what causes the relatively low numbers in our minimum tillage plot.

Minimum tillage in Switzerland is used to reduce soil erosion. A combination with organic fertilizers or mulching enhances organic matter content, aggregate stability, earthworm abundance, and species diversity (see Lee, 1985, p. 286). In the present test, mulching with *Lolium perenne* in spring created optimal conditions for earthworms in summer, autumn and winter. Rye as a frost-resistant catch crop had also a positive effect. The conventional treatment was (from the biological point of view) the less optimal one: organic matter content and earthworm quantities were lower than in all three alternative systems. The corn yield in the conventional plot was lower than in

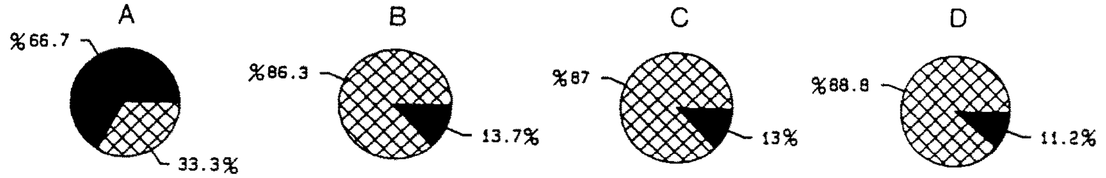

Fig. 2. Distribution of individuals belonging to anécique species (black) and endogé species (hatched) in four differently treated corn plots A–D (see Table 1) in percent of all individuals sampled.

Table 3. Seasonal and vertical distribution of earthworm biomass in four differently treated corn test strips (see Table 1)

Species	Soil layer	A minimum tillage (1)	(2)	(3)	(4)	(5)	(6)	$\bar{X}$	B conventional (1)	(2)	(3)	(4)	(5)	(6)	$\bar{X}$	C catch crop (1)	(2)	(3)	(4)	(5)	(6)	$\bar{X}$	D underseed (1)	(2)	(3)	(4)	(5)	(6)	$\bar{X}$
A. icterica	Topsoil	1	0	0	1	0	3	1	11	8	4	11	9	7	8	46	45	13	31	8	18	27	42	60	13	12	38	36	34
	Subsoil	0	0	0	0	0	0	0	7	2	4	8	0	14	6	12	1	2	10	17	27	12	3	4	15	1	28	17	11
A. rosea	Topsoil	2	0	2	1	0	2	1	9	6	1	1	2	2	4	3	1	0	0	0	8	2	2	0	1	1	1	3	1
	Subsoil	0	0	0	0	0	0	0	0	0	0	0	8	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
O. cyaneum +	Topsoil	3	20	0	0	0	0	4	7	0	3	0	0	0	2	6	2	0	3	0	0	2	0	1	4	0	0	0	1
O. lacteum	Subsoil	0	0	8	0	0	0	1	2	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0
N. caliginosus	Topsoil	0	0	0	0	0	0	0	1	3	0	0	0	0	1	0	0	0	0	0	0	0	4	0	1	0	0	0	1
	Subsoil	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N. longus	Topsoil	22	36	12	37	53	87	41	12	15	6	4	27	10	12	34	3	0	14	0	33	14	15	25	3	16	27	27	19
	Subsoil	0	0	5	0	0	11	3	0	0	26	0	5	0	5	0	0	15	0	0	0	3	0	0	14	0	0	0	2
L. terrestris	Topsoil	16	0	3	0	0	0	3	0	0	0	0	15	0	3	0	0	0	0	0	18	3	2	0	0	0	0	0	2
	Subsoil	0	0	6	13	0	0	3	0	0	0	10	10	0	3	0	8	0	0	0	0	1	0	0	11	0	0	0	2
Total	Topsoil	44	56	17	39	53	92	50	40	32	14	16	53	19	30	89	51	13	45	8	77	48	63	86	22	29	66	66	56
Total	Subsoil	0	0	19	13	0	11	7	9	2	30	18	23	14	15	12	11	17	10	17	27	16	3	4	40	1	28	17	15

All values (round numbers) are given in g m^{-2} live wt with gut contents. Investigated soil layers: topsoil = 0.0–0.2 m depth; subsoil = 0.2–0.4 m depth. Sampling dates (1989): (1) 21 April; (2) 3 May (before first seedbed preparation); (3) 8 June; (4) 22 August; (5) 21 September (corn growth and ripening); (6) 16 October (2 days after corn harvest).

Table 4. Seasonal and vertical distribution of earthworm abundance in four differently treated corn test plots (see Table 1)

Species	Soil layer	A minimum tillage (1)	(2)	(3)	(4)	(5)	(6)	$\bar{X}$	B conventional (1)	(2)	(3)	(4)	(5)	(6)	$\bar{X}$	C catch crop (1)	(2)	(3)	(4)	(5)	(6)	$\bar{X}$	D underseed (1)	(2)	(3)	(4)	(5)	(6)	$\bar{X}$
A. icterica	Topsoil	4	0	0	8	0	4	3	44	44	16	40	36	32	35	128	84	44	64	20	52	65	140	144	44	28	84	88	88
	Subsoil	0	0	0	0	0	0	0	32	16	28	16	0	36	21	32	4	8	16	24	44	21	12	12	52	4	32	32	24
A. rosea	Topsoil	12	4	16	8	0	8	4	92	54	20	8	24	32	38	28	4	0	0	4	8	7	24	0	8	8	8	12	10
	Subsoil	0	0	0	0	0	0	0	0	12	0	4	20	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0
O. cyaneum +	Topsoil	4	12	0	0	0	0	3	8	0	8	0	0	0	3	4	8	0	4	0	0	3	0	4	8	0	0	0	2
O. lacteum	Subsoil	0	0	8	0	0	0	1	4	0	0	0	0	0	1	0	4	0	0	0	0	1	0	0	0	0	0	0	0
N. caliginosus	Topsoil	0	0	0	0	0	0	0	4	28	0	0	0	0	5	0	0	0	0	0	0	0	20	0	4	0	0	0	4
	Subsoil	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N. longus	Topsoil	20	28	8	24	40	40	27	24	20	8	4	12	8	13	28	4	0	8	0	20	10	12	24	4	8	16	20	14
	Subsoil	0	0	4	4	0	0	8	2	0	0	16	0	4	0	3	0	0	12	0	0	0	2	0	0	8	0	0	1
L. terrestris	Topsoil	8	0	4	0	0	0	2	0	0	0	0	4	0	1	0	0	0	0	0	8	1	4	0	0	0	0	0	1
	Subsoil	0	0	4	4	0	0	1	0	0	0	4	4	0	1	0	4	0	0	0	0	1	0	0	4	0	0	0	1
Total	Topsoil	48	44	28	40	40	52	42	172	144	52	52	76	72	95	188	132	44	76	24	88	86	200	172	68	44	108	120	119
Total	Subsoil	0	0	16	4	0	8	5	36	28	44	24	28	36	32	32	12	20	16	24	44	25	12	12	64	4	32	32	26

All values are given in number of individuals m^{-2} (round numbers). For soil depths and sampling dates, see Table 3.

the catch crop and undersown test strips, but much higher than in the minimum tillage plot. Bauchhenss (1986) found a significantly higher earthworm biomass in the alternative treatment than in conventional plots in 13 of 19 compared sites.

Assuming that earthworm biomass and abundance are parameters for estimating soil mixing and aggregate stability (Peters, 1985), it is probably that long-term conventional corn cropping will ruin natural soil fertility. The future of crop management cannot consist in yield raising at the expense of long-term soil fertility. Conservation farming and promotion of soil organisms are the main steps towards the urgent comprehensive protection of our arable soils.

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