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Applied Soil Ecology 18 (2001) 187–192

Applied Soil Ecology

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Earthworm, infiltration, and tillage relationships in a dryland pea–wheat rotation

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Received 18 January 2001; accepted 24 April 2001

Abstract

Dryland farming in the Mediterranean climate of the Pacific Northwest, USA supports extremely low earthworm populations under conventional tillage. Increases in earthworm populations are being observed in fields under no-till cropping systems. A 30+ year experiment with four tillage levels in a pea (*Pisum sativum* L.)-winter wheat (*Triticum aestivum* L.) rotation was evaluated for earthworm populations and ponded infiltration rates. Where tillage has been limited to 2.5 cm depth, *Apporectodea trapezoides* (Duges) mean population was 25 m^{-2}. Plots subject to tillage by plow (25 cm depth) or chisel (35 cm depth) averaged less than 4 earthworms m^{-2}. The shallow tillage treatment also had the highest average infiltration rate of 70 mm h^{-1} compared to 36 for chisel, 27 for spring plow, and 19 mm h^{-1} for fall plow treatments. The highly variable nature of earthworm counts and infiltration measurements prevented conclusive correlation between the two, but increases in both can be attributed to minimum tillage. Published by Elsevier Science B.V.

Keywords: Tillage; Earthworm; Infiltration

1. Introduction

Changes in tillage practices taking place in dryland cropping regions of the United States of America and elsewhere are causing both intended and unintended changes in soil physical and biological properties. In the Pacific Northwest of the USA, substantial earthworm populations are being noticed in dryland fields that have been converted to untilled cropping systems, whereas few earthworms have been found in dryland fields under conventional tillage. The dominant cropping system in the region is winter wheat/summer fallow, with annual cropping in areas with greater precipitation. The Pacific Northwest has a Mediterranean climate, with mild wet winters and long, hot, dry summers, but even in the interior of North America with substantial summer rainfall earthworm populations can be extremely low under conventional intensive cultivation (Clapperton et al., 1997).

Cropping systems that eliminate tillage have also been found to increase water infiltration after several years (Dao, 1993; Azooz and Arshad, 1996). The mechanisms for the increase are not clearly understood, and in some cases an increase in earthworm populations could be a contributing factor (Edwards et al., 1988).

Understanding how eliminating tillage brings about changes in soil ecology is the key to exploiting the benefits and avoiding the detriments of no-till systems. Knowing the mechanisms responsible for important changes in soil properties will allow us to effectively target desirable properties. Increases in earthworm populations have been attributed to stubble left on

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0929-1393/01/$ – see front matter Published by Elsevier Science B.V.
PII: S0929-1393(01)00145-7

the surface (Doube et al., 1994; Mele and Carter, 1999), how nutritious a particular crop might be to earthworms (Fraser and Piercy, 1998), or a reduction in tillage-related physical disruption (Haines and Uren, 1990). Infiltration increases under no-till have been related to decreased soil disturbance (Mielke and Wilhelm, 1998; Pitkanen and Nuutinen, 1998) or increased numbers of earthworm holes (Friend and Chan, 1995).

This research was conducted to measure earthworm populations and infiltration capacity present after more than 30 years of four different levels of soil tillage. It was hypothesised that tillage intensity affects earthworm populations and that greater earthworm populations may be related to greater water infiltration.

2. Materials and methods

Earthworm counts and infiltration measurements were made in long term plots started in 1967 at a research station near Pendleton, OR, USA. The plots were designed to test tillage effects on crop yield in a pea/winter wheat rotation. The pea/winter wheat rotation is common locally. The soil series is Walla Walla silt loam (coarse, silty, mixed mesic Typic Haploxeroll) under a mean annual precipitation of 430 mm. The pea crop was switched from fresh green pea to dry pea production in 1991. Every second pea crop received $22\,kg\,N\,ha^{-1}$ and wheat received $90\,kg\,N\,ha^{-1}$, both broadcast as ammonium nitrate before seeding. Herbicide use was uniform across tillage treatments.

The experimental design was a split-plot in four randomized complete blocks, with the crop rotation entry points (wheat and pea) as main plots and four tillage treatments as subplots. The four subplot treatments were different depths and timings of tillage (Table 1). The plots were $7.7\,m \times 36.5\,m$. Lime was applied at $2016\,kg\,ha^{-1}$ to the eastern half of each plot in 1976. Soil samples taken in 1995 measured pH ranging from 5.4 to 5.9 in the surface 20 cm.

2.1. Earthworm counts

In the spring of 1998 and again in 1999 we counted earthworms in fall plow and minimum till treatments by digging one $25\,cm \times 25\,cm \times 25\,cm$ sample from the center of the unlimed half of winter wheat plots. This resulted in a total of 16 samples (two treatments times four blocks times 2 years). The samples were hand sorted for earthworms and cocoons. Because of the high variability of earthworm count data, the data from the 2 years were pooled for analysis.

In the spring of 2000, 20 cm diameter cores were taken from the center of all plots by driving a metal tube 25 cm deep, and then quickly removing the core with a lever. We pulled two samples from each plot, one from the unlimed half and another from the limed half. This resulted in a total of 64 cores: four tillage

Table 1
Tillage operations over the 2-year winter wheat–pea cropping cycle[a]

Treatment	Fall after winter wheat		Spring after winter wheat		Fall after pea	
	Tillage	Depth (cm)	Tillage	Depth (cm)	Tillage	Depth (cm)
Disk, chisel	Disk, twice	10	Sweep, rodweed	2.5	Chisel plow, twice rodweed twice	30–38 2.5
Fall plow	Moldboard plow	20–25	Spring-tooth harrow, twice roller harrow	5–7.5	Moldboard plow disk harrow roller harrow	20–25 5–10
Spring plow	–	–	Moldboard plow spring-tooth harrow, twice roller harrow	20–25 5–7.5	Moldboard plow disk harrow roller harrow	20–25 5–10
Minimum till	Skew tread[b]	2.5	Sweep rodweed	2.5 2.5	Skew tread, 2–3 times	2.5

[a] Treatments began in 1967. The minimum till treatment was changed to no tillage with disk-drill placed fertilizer in 1997.
[b] Skew tread: rotary cultivators set at an angle to the line of travel.

treatments times two crops times four blocks times two cores per plot. The soil samples were washed through a screen with 1.2 mm openings and worms and cocoons remaining on the screen were counted. The screen was fine enough to retain all of the cocoons and all but very small, recently hatched earthworms.

Some researchers have warned that certain sampling methods may miss earthworms capable of escaping through deep vertical burrows. The species we have identified in cropped fields on this research station is exclusively *Apporectodea trapezoides*. We have not seen these earthworms moving downward as we pull cores. Lee (1995) notes that *Apporectodea trapezoides* is frequently found as the only earthworm species in a soil, and they have been classified as endogeic (working beneath the surface), although in some cases they are known to surface feed also. Our tools allow us to drive and remove cores in less than 10 s and do not require the use of heavy equipment or engines which might cause general ground vibration before we sample. We have found most earthworms above 10 cm, and very few below 20 cm, when sampling in the spring.

Earthworms are in very low numbers in conventional cropping systems locally, resulting in many samples with counts of zero. The count data were, therefore, transformed as the square root of the sum of the count plus 0.5 before performing analysis of variance (Little and Hills, 1978).

2.2. *Infiltration measurements*

In the spring of 2000, double ring infiltration measurements (Bertrand, 1965) were made in plots planted to winter wheat. Two measurements were made in each plot, one in the unlimed half and another in the limed half. This resulted in a total of 32 measurements: four tillage treatments times four blocks times two measurements per plot. The inner ring diameter was 30 cm and the outer 46 cm. The rings were driven into the soil about 10 cm. The water level was maintained at approximately 5.5 cm above the average soil surface using a float valve. Rainwater was used to avoid effects of salts found in our groundwater. After 3 h of infiltration, the water was turned off and the steady-state infiltration rate measured using sonic depth gauge readings over a period of 15 min. In rings with extremely fast infiltration, the ring was refilled before the water level reached 2.5 cm above the average soil surface.

The infiltration measurements were lognormally distributed according to the Shapiro–Wilk test; therefore means were calculated using uniformly minimum variance unbiased estimators (UMVU) and confidence intervals using Land's method (Parkin and Robinson, 1992). If the 90% confidence intervals did not overlap for two populations of samples, they were considered significantly different.

Since the one-time lime application did not appear to affect earthworm counts or infiltration, data from the east and west half of each plot were treated as replicate subsamples.

3. Results

Earthworm populations differed significantly (Table 2). The minimum till treatment had more earthworms than the treatments with plowing, disking, or chiseling. The means from data collected from two treatments in 1998 and 1999 support the 2000 data, although the mean earthworm estimate for fall plow is much higher than in the 2000 data.

Ponded infiltration results indicate a likely separation between treatment means (Fig. 1). The confidence intervals barely overlap for minimum till and disk–chisel, and neither overlaps with fall plow.

A plot of infiltration versus combined earthworm plus cocoon counts indicates a potential trend toward a correlation between earthworm activity and infiltration (Fig. 2). Only 2000 earthworm data from plots with infiltration measurements were included here. All

Table 2
Mean earthworm and earthworm cocoon counts under pea/winter wheat rotation[a]

Treatment	Earthworms		Earthworm cocoons	
	1998–1999	2000	1998–1999	2000
Number per square metre				
Disk, chisel	–	1.7	–	0
Fall plow	11.8	3.4	0.7	1.7
Spring plow	–	5.6	–	0
Minimum till	28.0	25.0[b]	15.6	46.6[b]

[a] Means and F tests were calculated using transformed data $((\text{count}+0.5)^{1/2})$. Only wheat plots of two treatments were sampled in 1998 and 1999 ($n = 8$). In 2000, $n = 16$.

[b] This mean differs from the others in the same column ($P > F = 0.01$).

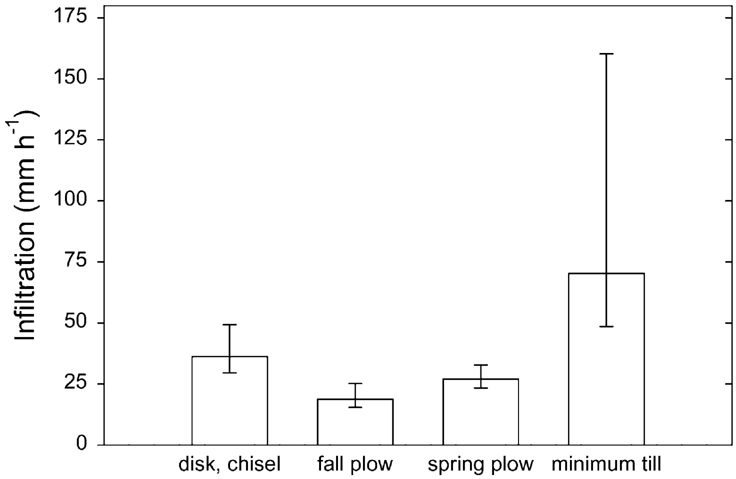

Fig. 1. Steady-state ponded infiltration measured in spring 2000 of the winter wheat crop using the double ring method. Means of the lognormal data were calculated using uniformly minimum variance unbiased estimators (UMVU) and 90% confidence intervals using Land's method (Parkin and Robinson, 1992).

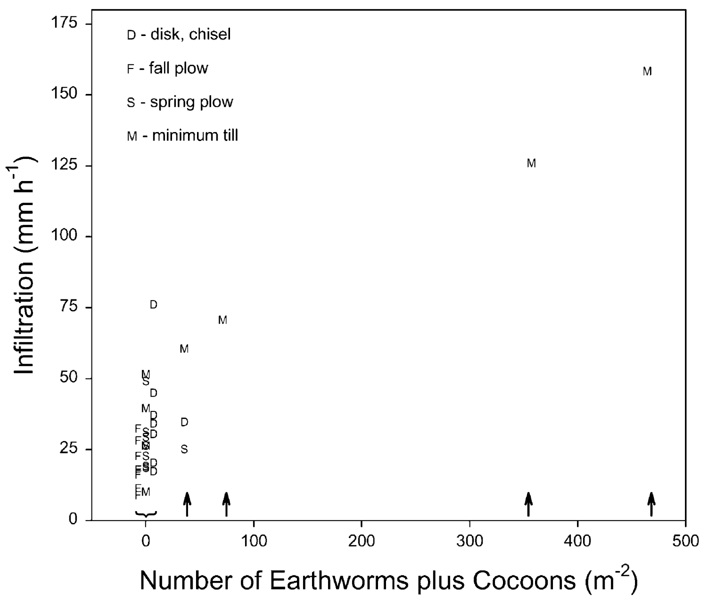

Fig. 2. Infiltration vs. combined earthworm and cocoon counts taken spring 2000 in winter wheat plots. Symbols with zero earthworm and cocoon counts are spread slightly to make them more visible. Arrows indicate 1, 2, 10, and 13 earthworm plus cocoons per 20 cm diameter core.

but six samples had zero earthworms or cocoons. The two points with high infiltration and high earthworm activity would have had an overwhelming effect on correlation statistics, so statistics were not computed.

4. Discussion

Even the highest mean earthworm populations measured in this experiment (28 m^{-2}) were very low compared to other cropping regions, where populations over 200 m^{-2} are commonly reported (Buckerfield, 1992; Marinissen, 1992; Clapperton et al., 1997). It is possible that populations of the exotic *Aporrectodea trapezoides* in these plots have been building slowly since the introduction of minimum tillage cropping systems. Evidence for this includes infiltration data made on these plots in 1985 (Pikul et al., 1993). Infiltration measurements made at that time indicated a saturated hydraulic conductivity of less than 15 mm h^{-1}, with no significant difference between treatments.

Earthworm counts and infiltration measurements are subject to high spatial variability. Estimates and comparisons could be improved if the number of samples was increased. Unfortunately, the long-term value of the plots investigated here prohibited extensive destructive sampling. Another limitation in this data set is the size of the plots in relation to earthworm mobility. It is possible that, even though these 24 ft wide plots produced statistically significant earthworm population differences, the minimum tillage plots provided a source of earthworms which may have elevated counts in neighboring plots. The value of this research is in demonstrating that substantial earthworm populations can exist where tillage is reduced, and these populations may have some relationship to increased infiltration.

The site of this experiment has practically no slope, so increased infiltration capacity has not played a critical role in crop productivity. Much of the surrounding region, however, is severely affected by runoff and erosion. Practices that improve infiltration would be expected to improve water storage and reduce erosion.

Lumbricus terrestris (L.) and other surface feeding anecic species can create obvious pathways for water infiltration (Willoughby et al., 1997). In this study, *Aporrectodea trapezoides* did not appear to create surface-connected vertical burrows. It is possible that increases in infiltration in this study result from factors correlated with, but not caused by earthworm population increases, such as soil aggregation, modification of existing tillage pans, or other structural changes.

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