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Tillage impacts on soil microbial biomass C, N and P, earthworms and agronomy after two years of cropping following permanent pasture in New Zealand

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Abstract

Conversion of pasture land to crop rotation by plow tillage and reversion to pasture for replenishment of nutrients is a common practice in New Zealand. It is known that plow tillage decreases soil organic matter and causes biological degradation. The objective of this study was to investigate the effects of tillage practices on soil microbial biomass carbon (MBC), microbial biomass nitrogen (MBN), microbial biomass phosphorus (MBP), and earthworm (*Aporrectodea caliginosa*) populations used as indicators of soil biological status and of sustainability of permanent pasture (PP) to crop rotation using different tillage practices. The experimental site at Massey University (Turitea Campus) was established in 1995, where PP land was converted to double crop rotation using plow tillage (PT) and no-tillage (NT). Crops were summer fodder maize (*Zea mays L.*) and winter oat (*Avena sativa L.*); and PP was used as a control. Plant establishment and crop yields were similar in NT and PT, although adoption of NT reduced weed growth. Microbial biomass contents in PP and NT treatments were almost twice as much in 0–5 cm depth soil as in 5–10 cm depth soil. No quantitative differences occurred between 0–5 and 5–10 cm depths in the PT treatment. Conversion of PP to PT cropping resulted in a 45% decline in MBC, 53% in MBN and 51% in MBP in the 0–5 cm soil layer. Microbial biomass content ratios in the 5–10 cm layer did not differ significantly among the tillage practices and cropping regimes. At 0–10 cm depth, concentrations of MBC, MBN and MBP were significantly higher in the PP and NT than in the PT treatment. MBC and MBN levels in autumn were significantly higher than in summer and winter. Earthworm populations and live mass were also significantly higher in the PP and NT than in the PT treatment. It was concluded that adoption of NT can protect soils from biological degradation and maintain soil quality as compared with PT management.

Keywords: Plow tillage; No-tillage; Soil microbial biomass; Earthworm; Pasture; Maize; Oats

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1. Introduction

Crop production with different tillage practices and subsequent soil management are important factors for sustainable agriculture world-wide. Plow tillage (PT) has shown a number of detrimental effects on soil physical, chemical and biological properties and thus adversely affects the soil ecosystem (Carter and Stewart, 1996). Soil structure degradation, soil erosion and organic matter losses are major issues that have brought renewed interest in conservation tillage, especially no-tillage (NT) because of its potential to reduce the negative effects of PT.

In New Zealand, there is a growing acceptance of conservation tillage as an efficient method of crop establishment (Choudhary and Baker, 1994), but its application is mainly limited to use with establishing pastures and forage crops. Rotation of PP with forage crops using PT is a common practice. Establishment of summer maize and winter oats using PT is popular in the Manawatu region (Hughes, 1985). However, such operations are not sustainable because of the decline in soil physical, chemical and biological properties. Previous conservation tillage research in New Zealand has shown that NT is associated with higher soil bulk density, soil strength, aggregate stability, organic matter content, plant-available water and earthworm populations (Francis et al., 1987; Francis and Knight, 1993; Hermawan and Cameron, 1993; Horne et al., 1992; Ross and Hughes, 1985).

Soil organic matter is of great importance due to its influence on soil physical, chemical and biological properties and creating a favourable medium for biological reactions and life support in the soil environment. The microbial biomass of a soil is a comparatively labile pool of soil organic matter (Jenkinson and Ladd, 1981), a substantial pool of soil nutrients (Sparling et al., 1992), and can be used as an index of the biological status of the soil fertility. It is also used as an indicator of management-induced changes brought by tillage practices, incorporation of crop residues, N fertilisation, crop rotation sequence and changes in soil moisture regimes (Powlson et al., 1987). Consequently, loss of organic matter during cultivation, and especially loss of the soil microbial component, can adversely affect both the physical, biological and nutrient status of soils (Carter, 1986; Carter and White, 1986).

Preliminary studies from New Zealand have indicated a marked loss of soil organic C and microbial C in Manawatu soils (Sparling and Shepherd, 1986). Maize grown with continuous cultivation on Kairanga silty clay loam for 11 years decreased the total C content in the top 20 cm of soil by 21% and microbial C by 49% compared to levels under long-term PP (Sparling et al., 1992). However, these studies were unable to detect any decline in microbial biomass within the first two to three years of cultivation.

A major role of earthworms in agroecosystems is to increase nutrient cycling rates. Earthworms consume large amounts of soil organic matter and influence the supply of plant nutrients in the soil by increasing the rate of mineralisation of crop residues and facilitating further mineralisation by micro-organisms (De Vleeschauwer and Lal, 1981). Therefore, changes in microbial nutrients and earthworm activity can bring marked changes in soil fertility status, which are often reflected in crop performance.

This study was initiated to determine short-term tillage-induced changes in MBC, MBN and MBP dynamics, earthworm populations and agronomy, and to compare the biological status of soils under PP and within the first two to three years of conversion of PP to field crops.

2. Methods and materials

2.1. Tillage site

A soil tillage experimental site was established at Massey University, Turitea campus (latitude 40°23′S, 175°38′E) in 1995. PP land was converted to a double-crop rotation using plow and NT. This Ohakea silt loam soil (Typic endoaqualf) has been classified as Gleyic Luvisol (FAO), a weakly clay-illuvial pseudo-madentic-pallic soil, and is a very young yellow–grey earth with poor natural drainage. It was expected that this relatively heavy soil type would be sensitive to cultivation management changes and be therefore suitable for comparison of tillage methods. The site has a 30-years-average rainfall of 963 mm per annum.

The three treatments were PP, PT and NT, each with four replicates in a randomised block design. PP site consisted of high fertility grass species including ryegrass (*Lolium perenne* L.), yorkshire fog (*Holcus* *lantus* L.), poa (*Poa spp*) and cocksfoot (*Dactylis glomerata* L.) represented 65% of the sward, white clover (*Trifolium repens* L.) and other legumes ~20% (suckling clover (*T. dubium* Sibth), subterranean clover (*T. Subterraneum* L.) and lotus (*Lotus spp*)). Few weed species including catsea (*Hypochaeris radicata* L.), hawkbit (*Leontodon taraxacoides* (villars) Mèrat), ribgrass (*Plantago lanceolata* L.), and chickweed (*Cerastium glomeratum* Thuill) constituted the remaining 15% of the pasture community. PT treatment involved spraying with glyphosate, mouldboard ploughing to 20 cm depth, followed by rolling, and two passes of a power harrow for seedbed preparation. In the NT, weeds were controlled by spraying 4 l/ha of glyphosate.

In November 1996, a summer crop of fodder maize (*Zea mays* L.) and in April, 1997 a winter crop of oats (*Avena sativa* L.) were sown on PT and NT treatments with an Aitchison seed drill. Standard applications of fertilisers and pesticides were adopted. At maturity both crops were grazed by sheep. Seedling emergence was counted three weeks after sowing by using quadrats of 0.25 m^2 to calculate plant establishment percentage.

2.2. Soil sampling

Three sets of soil samples were collected in early summer before sowing maize and after harvesting of maize in autumn, and after oats in winter. Two soil cores (25 mm diameter) were randomly taken each from 0–5 to 5–10 cm depths, from each of the four replicates each time, except before maize sowing during summer when, inadvertently, only 0–10 cm depth soil samples were collected. The soil samples were sieved through 2 mm sieve in a field-moist state soon after collection, and stored at 4°C. These ''fresh'' samples were used to assess soil biological status and effects of seasonal changes. Soil bulk density was determined at the beginning of this study (October 1996) from undisturbed soil core samples of known volume for the 0–5 and 5–10 cm soil layers.

2.3. Soil microbial biomass

2.3.1. Microbial biomass C

Carbon was determined by a fumigation–extraction method (Vance et al., 1987). Fumigated and non-fumigated soils were extracted with 0.5 M K_2SO_4 for 30 min (1:5 soil:extractant ratio), filtered and an aliquot analysed for organic C by acid-dichromate oxidation. The additional oxidisable C obtained from the fumigated soils were taken to represent the microbial C flush and converted to MBC using the relationship: *microbial C=C flush/0.35*.

2.3.2. Microbial biomass N

Nitrogen was measured following the method described by Ross (1992). The K_2SO_4 extracts from fumigated and non-fumigated soil samples were digested in aqueous $K_2S_2O_8$ (0.165 M) for 30 min at 121°C. The resultant $NO_3^-{-}N$ and $NH_4^+{-}N$ were measured by an autoanalyser procedure. Microbial N was estimated using the relationship: *Microbial N=N flush/0.45* (Jenkinson, 1988).

2.3.3. Microbial biomass P

Phosphorous was measured using a modified fumigation and $NaHCO_3$ extraction technique (Brookes et al., 1982). Fumigated, non-fumigated and spiked (with 1 ml of 250 ug P ml^{-1} to estimate % recovery of P from the soils) soil samples were extracted with 0.5 M $NaHCO_3$ for 1 h. The filtrate was decolourised and acidified using phosphate-free charcoal and 1M HCl. The phosphate concentration was measured at 882 nm by the method of Murphy and Riley (1962). For each sample, both the extraction and subsequent analyses were performed in triplicate. MBP was estimated using the relationship: *Microbial P=(P flush)/(0.4 × % recovery from the spike)*, where 0.4 is the average proportion of microbial P recovered from the soil (Brookes et al., 1982).

2.4. Earthworms

Earthworm populations were determined in situ from four random positions in each plot by saturating the soil with a formaldehyde solution within a 0.25 m^2 wooden frame for 20 min (Edwards and Lofty, 1977). Mature and immature earthworms coming to the surface within the frame area were hand picked. Earthworm populations collected from each plot were counted and their live weight measured.

2.5. Statistics

A general linear models procedure (GLM) was used (SAS Institute, 1989) for analysis of all experimental data. An analysis of variance (ANOVA) using test of least significant difference (LSD) at the 5% confidence level was used to discriminate parametric differences between PP, NT and PT treatments.

3. Results and discussion

3.1. Effects of tillage practices on microbial biomass C, N and P

Tillage practices significantly affected MBC, MBN and MBP concentrations during the three seasons (Table 1). In the combined depth of 0–10 cm, MBC concentrations declined by 29%, and MBN and MBP by 32% within two years of converting PP to cropping with PT. No such decline in microbial biomass occurred with NT cropping. This decline in microbial biomass is an early indication of a possible future decline in soil organic matter with PT practices. The higher amounts of microbial nutrients in the PP and NT as compared to the PT treatment apparently resulted from the retention of pasture organic matter, high input of C and no soil disturbance. This was not unexpected as Sparling et al. (1992) earlier found great decline in microbial C under continuous maize cropping compared with soils under pasture in the Manawatu area. These authors found that in soil at 0–20 cm depth, 14 years of continuous cultivation resulted in a decline of 60% in microbial C compared with the levels under PP. In a recent study, Saggar et al. (1998) found that cultivated soils with consistently lower MBC and MBN have lower metabolic quotients than their counterparts in PP and result in reduced N mineralisation. Their results indicate that higher metabolic quotients in cultivated soils are reflective of stressed microbial communities, smaller pools of metabolisable N and deterioration in soil quality.

Our results also suggested that changes in MBN and MBP were associated with changes in MBC and organic matter concentrations (data not reported). Powlson et al. (1987) suggested that increases in soil microbial biomass contents were indicative of an enlarging pool of soil organic C. Our data clearly suggest that NT sustained the soil C status equivalent to that in PP, and also helped in maintaining the microbial N and P pools.

3.2. Effects of soil depth on microbial biomass C, N and P

In the PP and NT treatments, MBC, MBN and MBP concentrations in PP and NT were almost twice as much in 0–5 cm than in 5–10 cm soil depth and were in order of PP=NT>PT. No quantitative difference occurred between 0–5 and 5–10 cm depths in the PT treatment (Table 2). On average over the three sampling times, MBC declined by 45%, MBN by 53% and MBP by 51% in the 0–5 cm soil layer when PP was converted to PT. Similar differences were observed between the NT and PT treatments. There were no significant differences in microbial biomass concentrations at 5–10 cm depth between tillage practices or cropping regimes.

The tillage-induced subsistence of microbial biomass is explained as being due to the NT retaining more crop residues and sufficient substrate to sustain the microbial biomass. In the PT treatment, the crop

Table 1
MBM C, N and P in a silt loam soil after two years of PT and NT cropping following PP

Treatment	Microbial biomass contents (kg ha^{-1}) at 0–10 cm depth											
	MBC				MBN				MBP			
	Summer	Autumn	Winter	Mean	Summer	Autumn	Winter	Mean	Summer	Autumn	Winter	Mean
PP	844a	1023a	762a	876	113a	116a	81a	103	66a	58a	81a	68
NT	947b	1016a	786a	916	116a	121a	80a	106	69a	55a	85a	70
PT	596b	749b	526b	624	80b	74b	56b	70	48b	39b	50b	46
LSD (0.05)	197	123	71	–	27	21	12	–	13	7	7	–

Values followed by the same letter in columns show no significant differences (P<0.05).

Table 2
Effect of depth on MBM C, N and P under PP, NP and PT

Treatment	Microbial biomass carbon, nitrogen and phosphorus (kg ha^{-1})											
	Autumn						Winter					
	0–5 cm Depth			5–10 cm Depth			0–5 cm Depth			5–10 cm Depth		
	MBC	MBN	MBP	MBC	MBN	MBP	MBC	MBN	MBP	MBC	MBN	MBP
PP	642a	78a	38a	379a	39a	21a	476a	53a	54a	286a	29a	27a
NT	636a	82a	37a	380a	39a	18a	491a	50a	57a	295a	30a	27a
PT	349b	32b	19b	400a	42a	20a	258b	29b	26b	268a	27a	24a
LSD (0.05)	78	17	5	NS	NS	NS	57	11	7	NS	NS	NS

NS: no significant difference.
Values followed by the same letter in columns show no significant differences (P<0.05).
Soil bulk density values for the 0–5 and 5–10 cm soil depths were 1.01 and 1.21 Mg m^{-3} for PP; 1.10 and 1.24 Mg m^{-3} for NT; and 1.21 and 1.25 Mg m^{-3} for PT treatments.

residues are uniformly distributed throughout the soil and resulted in a decrease of MBC at 0–5 cm depth. These results were not unexpected because higher proportions of MBC in the surface soil in reduced-tillage practices compared to plow tillage have been observed previously (Carter, 1986, 1991; Carter and Rennie, 1982).

3.3. *Effects of seasonal changes on microbial biomass C, N and P*

To determine the seasonal effects on microbial biomass, the autumn and winter data at 0–5 and 5–10 cm soil depths were pooled as shown in Table 1. The summer data were from 0 to 10 cm depth. Seasonal variations in microbial biomass concentrations were found during the summer, autumn and winter periods.

3.3.1. *Seasonal changes in microbial biomass C*

The MBC concentrations in all the three treatments during autumn were significantly higher than the summer or winter, and were in the order of autumn>summer=winter (Fig. 1). These results showed that MBC concentrations in autumn were 22% higher in PP, 15% in NT and 25% in PT than in summer or winter. An enhancement in microbial C in autumn is most probably due to the moderately warm environment for microbial growth and activity. A high mass of maize roots in the surface soil could be another factor which helped to enhance MBC contents during the autumn period. However, this was not measured in these experiments.

The decline in MBC following the winter oat harvest probably resulted from a combined effect of increased soil moisture content and decreased soil temperatures that reduced soil microbial activity. This was not totally unexpected as it has been suggested previously that seasonal changes often stimulate a change in the size of the soil microbial biomass (Carter and Rennie, 1982; Lynch and Panting, 1980).

Data on short-term effects of crop rotation on MBC are often variable, but consistent long-term effects of crop rotation to increase microbial biomass have been demonstrated by Carter (1986) and Granatstein et al. (1987). Powlson et al. (1987) suggested that MBC may be a good indicator for detecting management effects on soil biological or biochemical properties before any other seasonal or crop rotation changes can be detected.

3.3.2. *Seasonal changes in microbial biomass N and P*

Seasonal changes in MBN in all the three treatments were in the order of summer=autumn>winter (Fig. 1). The significant increases in MBN during summer and autumn represent an indirect effect of greater C mineralisation in that particular period. Seasonal responses in MBP (Fig. 1) showed a different pattern from those for MBC and MBN. MBP in PP and PT during winter was significantly higher than in summer and autumn, whereas in NT significant differences in MBP were found between the three seasons. This MBP increase in winter indicates a marked gain of P, which could have been due to the application of 200 kg ha^{-1} of

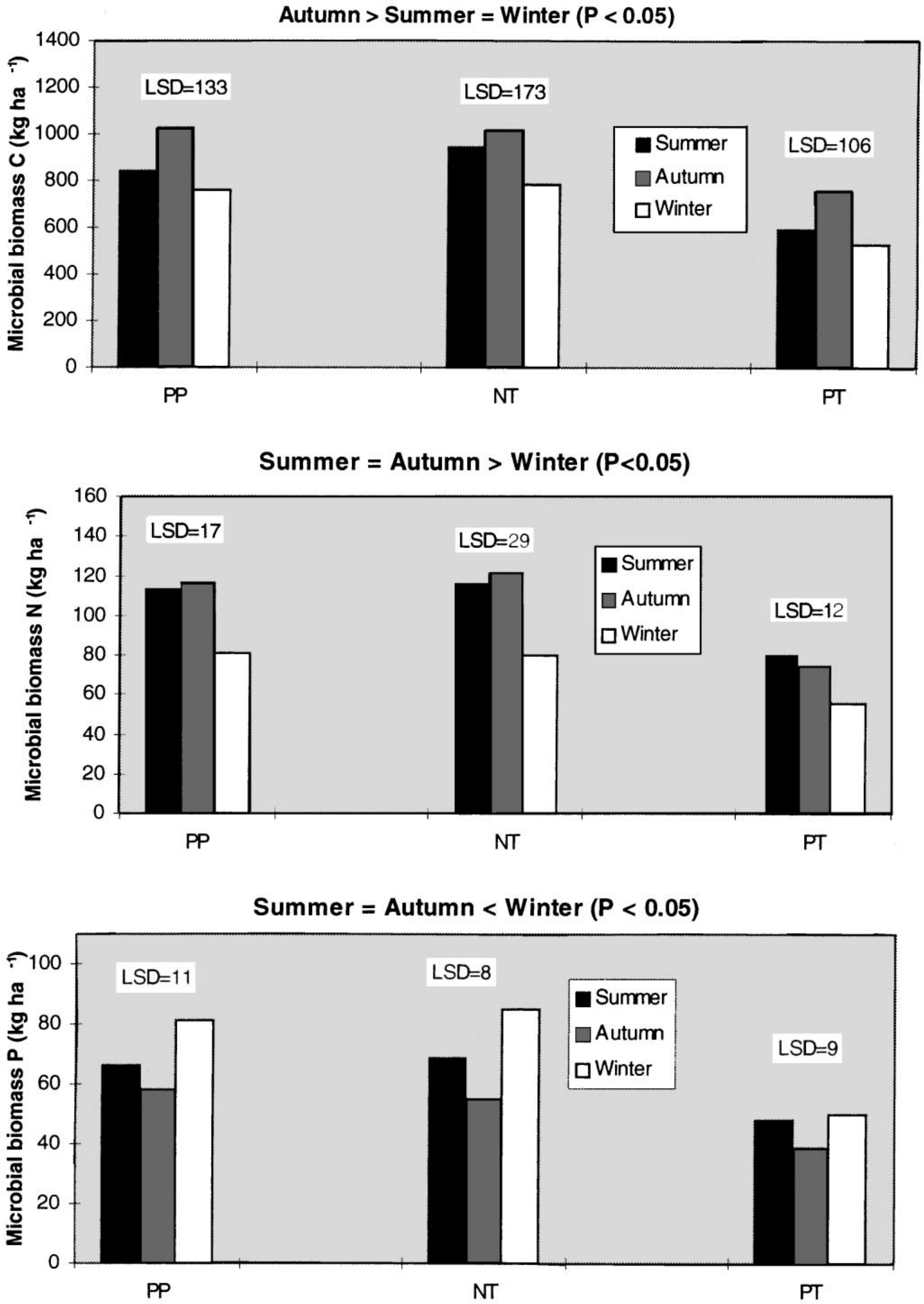

Fig. 1. Seasonal changes in biomass C, N, and P at 0–10 cm depth in the PP, NT and PT.

Table 3
Effects of tillage practices on soil pH and earthworm population

Treatment	Soil pH (0–10 cm)	Earthworm population (no. m^{-2})	Earthworm live mass (g m^{-2})
PP	5.43a	429a	140a
NT	5.44a	363b	99b
PT	5.48a	110c	33c
LSD (0.05)	NS	48	23

Values followed by the same letter in columns show no significant differences (P<0.05); NS=not significant.

fertiliser (Nitrophoska with 12% N, 10% P, 10% K) at the time of planting winter oats in April, 1997. These results confirm earlier observations by Buchanan and King (1992) that MBP can fluctuate with season and management, and can be higher during winter and early spring than in autumn and late spring.

3.4. *Effect of tillage practices on earthworm populations*

Earthworm populations and live earthworm masses were significantly different in the PP, NT, and PT treatments (Table 3). Within two years of conversion from PP to cropping with PT, earthworm populations were reduced by 74%. No-till cropping, in contrast, had a minimal negative effect on earthworms. The amount of crop residues on the soil surface, and low soil disturbance under the PP and NT treatments, were the most likely factors which encouraged the proliferation of the earthworm population. These results are similar to those reported by other researchers (Francis et al., 1987; Francis and Knight, 1993; House, 1985; Karlen et al., 1994). Compared with data the year before from the same experimental plots (Guo, 1997), the earthworm population had decreased in PT by 31%, and increased by 30% in NT and 27% in PP. These results confirm that continuous tillage plays a major role in declining earthworm populations. Previous studies found that the greater the intensity and frequency of tillage, the lower the population density of earthworms (Gerard and Hay, 1979; Mackey and Kladivko, 1985).

3.5. *Impact of tillage practices on seedling emergence and dry matter (DM) yield*

Summer fodder maize and winter oats seedling emergence were counted 22 days after sowing. The seedling emergence for maize was 95% under NT and 96% under PT. For winter oats 94% seedlings emerged under NT and 93% under PT. These results show that the two tillage practices had no effect on establishment of either crop. This was not unexpected as soil conditions at the time of sowing were ideal, and the same drill was used in both sowing systems. These results are similar to those of Choudhary (1988), in which the emergence of corn and mungbean was similar in PT and NT treatments. Hughes (1985) also reported that crop establishment did not differ between PT and NT treatments after three years of maize–oats rotation in the Manawatu area.

The DM yield of winter oats was measured 9 and 13 weeks after sowing to determine differences at mid and full-crop maturity. Crops grown by NT often appeared smaller or stunted in the early stages of growth but these differences usually diminished later (Choudhary and Baker, 1994). However, our data showed no significant differences between NT (3711 kg ha^{-1}) and PT (3424 kg ha^{-1}) treatments during the middle and maturity stages of plant growth. Nevertheless, final DM yields were 8% higher in the NT than in the PT treatment. These results are similar to those of Hughes et al. (1992) which showed that crop yields from PT and NT practices were similar after 10 years of a continuous rotation of maize and oats in the Manawatu. The DM yield of summer fodder maize was not measured.

3.6. *Effects of tillage practices on weed growth*

In New Zealand, both annual and perennial weeds are prominent and grow actively throughout the year. Before planting winter oats in April, both PT and NT treatments were sprayed with glyphosate to kill and suppress weed growth. The DM yields of spurry weed (*Spergula arvensis* L.) in the PT and NT treatments were 72 and 40 kg ha^{-1}, respectively. The reason for the flush of the weed growth in the PT treatment could be that the existing pool of weed seeds was activated by tillage and germinated vigorously. On the other hand, the NT treatment did not allow much spurry weed growth primarily due to no soil disturbance. However, the oats DM yield data suggest that proliferation of this weed did not affect the final yield in the PT treatment.

4. Conclusions

This study, which spanned two cropping seasons, showed that conversion to PT from PP resulted in a 45%, 53% and 51% decline in MBC, MBN and MBP, respectively, at 0–5 cm soil depth. This decline in microbial biomass is an early indication of a future loss of soil organic matter, which is an integrated index of soil biological degradation. In contrast, after two years of continuous cropping with NT, the microbial biomass nutrient status remained similar to that of the PP treatment. There were no significant differences between tillage practices or cropping regimes in MBC, MBN and MBP concentrations at 5–10 cm depth. Conversion from PP to PT cropping reduced earthworm populations by 74% whereas NT cropping had only a minimal effect.

Plant establishment and crop yields of the summer fodder maize and winter oats were similar in the PT and NT treatments. Adoption of NT generally reduced weed growth in the oats crop in winter. As the continued application of PT practices will lead to a further decline in microbial biomass nutrients, this is likely to affect crop yield in the longer term.

Overall, this study has indicated that, as long as C inputs are maintained, adoption of NT can protect soils from biological degradation and maintain soil quality as compared with PT management. Furthermore, it suggests that NT with appropriate crop rotation can be used as an effective tool to maintain (enhance) soil productivity while promoting agricultural sustainability at a level similar to that in clover-based PP.

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