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The cropping systems at Apelsvoll , Bioforsk- Arable Crop Division (photo: Audun Korsaeth), typical earthworm channels in soil and three species of earthworms common in Norwegian agricultural soils (photo : Reidun Pommeresche).

Long-term effects of cropping systems on the earthworm populations in a loam soil

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Six cropping systems, ranging from conventional arable without livestock to organic livestock farming dominated by ley, have been compared in 1990 and 2004 in SE Norway. Ley in the crop rotation increased density and biomass of earthworms and channels in both organic and conventional systems. A ley proportion higher than 25 % only increased the density of channels. Among the arable systems, the organic system had a higher density and biomass of earthworms as compared to the conventional systems. Among the fodder systems, the optimised system had the highest density of earthworms in 2004, but there were no differences between these systems in earthworm biomass or density of earthworm channels.

Since earthworms are important to improve and maintain good soil fertility and soil structure (Edwards and Lofty, 1977; Marinissen, 1994), it is important and interesting to study the long-term effect of different cropping systems and different managements on earthworm populations.

Arable and fodder systems are compared

Six different cropping systems (Tab. 1) were established on a loam soil in 1990 in the central part of southeast Norway, at Apelsvoll. Systems 1, 2 and 3 reflect arable cereal production. Systems 4, 5 and 6 reflect fodder production, with 2-3 years of ley (grass-clover mix) in the rotation. In system 1, which reflects the conventional arable practice in Norway in 1985, the soil is ploughed annually in autumn. In system 2, which incorporates perceived system improvements, spring rotor harrowing is practised rather than ploughing. In the remaining systems, the soil is ploughed in spring in all but the ley years.

Cropping systems and management

All systems have a 4-year crop rotation, with each crop present every year (25 % ley means one out of four years in ley). Animal manure (cattle slurry) is used in systems 4, 5 and 6. Some changes in rotations and fertiliser levels were made after the first 10 years, but the main features, such as manure use and incidence of ley, have been maintained throughout the period. Exception is system 6 which were conventional fodder production in the first 10 years.

Table 1. The dominant management and amount of ley in the cropping systems studied at Apelsvoll.

Table 1. Dominant management in two periods of the cropping systems studied at Apelsvoll

System	Period 2000-2004	Period 1990-1999
1. Con ar	Intensive arable cereal, no slurry, NPK*, 0% ley	Intensive arable, no slurry, NPK*, 0% ley
2. Opt ar	Optimised arable cereal, no slurry, NPK*, 0% ley	Integrated arable, no slurry, NPK*, 0% ley
3. Org ar	Organic arable cereal, no slurry, 25% clover ley	Organic arable, some slurry, 25% clover ley
4. Opt fo	Optimised fodder, with slurry, NPK*, 50% ley	Intensive fodder,with slurry, NPK*,50% ley
5. Org fo	Organic fodder, with slurry, 50% clover ley	Organic fodder, with slurry, 50% ley
6. Org fo	Organic fodder, with slurry, 75% clover ley	Conventional fodder, slurry, NPK*, 50% ley

Slurry = wet-composted cattle slurry, 4.8% DM, applied at 36 (system 4), 28 (system 5) and 40 (system 6) Mg ha^{-1} yr^{-1}.
Inorganic fertilisers with N as NH_4NO_3 were applied in systems 1, 2 and 4 in both periods, and in systems 6 in the first period.

Sampling of earthworms

Earthworm data were sampled under the wheat crop from each system (two replicates) in autumn 1994 and 2004, with the exception of system 6 in 2004, which was in the third ley year. Worms were hand-sorted from three soil blocks (50 cm x 50 cm x 25 cm depth) in each plot. The density of juvenile and adult worms (ind/m^2) and the dead fresh weight (g/m^2) were recorded. The density of earthworm channels was recorded on the horizontal face (50 x 50 cm) at 25 cm depth in the soil (channels/m^2) under each soil block.

Figure 1.Typical specimen of field worm (*Aporrectodea caliginosa*) the most common earthworm in Norwegian agricultural soils.
In Norwegian : grå meitemark.

Earthworm species

The earthworm species observed were field worm (*Aporrectodea caliginosa*) (Fig 1), pink worm (*Aporrectodea rosea*) and night crawlers (*Lumbricus terrestris*) (Fig.2). In systems 1, 3, 5 and 6 the number of each species was in decreasing order, field worms > pink worms > night crawlers (Figure 3). System 2 and 4 differed, with pink worms representing the smallest and the largest worm fraction, respectively.

Figure 2. Typical specimen of the night crawler (*Lumbricus terrestris*) often represented in high numbers in deciduous forest soil and more undisturbed agricultural areas (pasture, fruit gardens), but also found in more cultivated soils. In Norwegian : stor meitemark.

Reduced tillage has shown to favour night crawlers (Chan 2001), because of less destruction of its permanent burrows. Ploughing often increases the amount of more “soil eating species” like the field and pink worms, but no single explanations for the large amounts of pink worms in the conventional fodder system (4) are found.

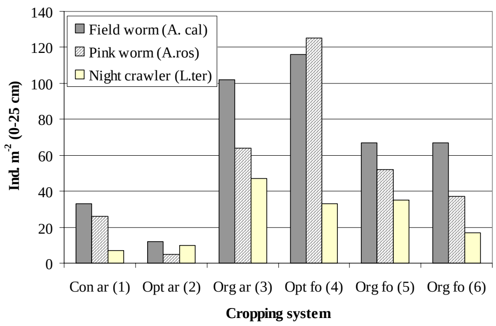

Figure 3. The density of individuals of each species within each cropping system, 2004.

Density of earthworms

The conventional fodder system (4), using both animal manure and inorganic fertiliser had the highest density of earthworms in 2004, but this was not significantly higher than in the organic arable system (3) with no manure or fertilisers (Fig 4). Only systems 3 and 5 had significant increases in the density of individuals in the period.

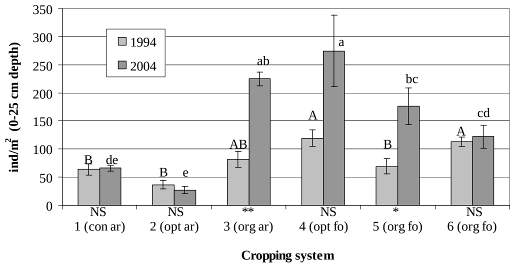

Figure 4. Earthworm density in contrasting cropping systems. Different capital letters over the bars indicate significant differences within 1994 values, small letters differences within 2004 values. The symbols under the bars indicate significance levels of the changes between 1994 and 2004(NS=not significant). The vertical lines show +/- standard error.

Biomass of earthworms

The systems organic arable (3), conventional fodder (4), and organic fodder (5) showed large increases in biomass from 1994, and had the highest biomass in 2004 (Fig. 5).

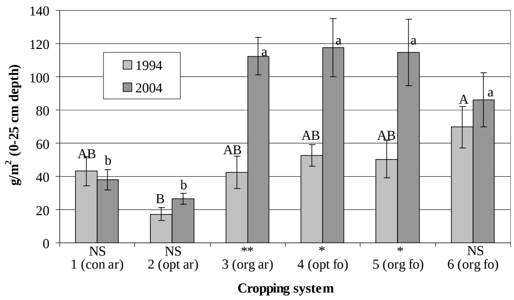

Figure 5. Biomass of earthworms in contrasting cropping systems. Legends as in Fig. 4.

The two conventional arable systems (1 and 2) had the lowest ED and EB, and the level was almost unaltered from 1994 to 2004

Earthworm channels at 25 cm depth

Systems 3-6 had significant increases in density of earthworm channels from 1994 to 2004. Again, the lowest 2004-values were found in the conventional arable systems (1 and 2). The density of earthworm channels was highest and significantly higher in the organic fodder system (6) with three out of four years (75 %) in clover leys, and in the conventional fodder system with two out of four years (50 %) in ley (4) (Fig.6).

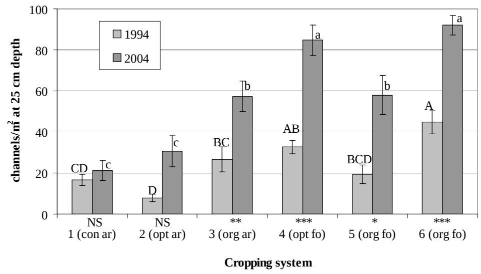

Figure 6. Number of earthworm channels at a horizontal face at 25 cm depth in the soil. Legends as in fig. 4.

These results indicate that high amount of added "food" for the earthworms (system 4) as well as organic ley production with less amount of added "food", but 3 years of ley (system 6) stimulate earthworm activity in the deeper soil layer. The channels and earthworms in the deeper soil layer are very important to increase and maintain good soil fertility and structure.

Ley and manure important "food" for earthworms

In accordance with Edwards and Lofty (1977) and Scullion et al. (2002), our results (2004-data) show that leys in the crop rotation positively affect earthworm populations. Grass and clover produce more organic matter accessible to the soil fauna than do cereals and vegetable. Some of this "food" for the earthworms enters the soil through dying roots, foliage, and root exudates. The reason for the higher earthworm density in the conventional fodder system (4) than in the organic ones (5 and 6) may be the greater supply of nutrients in system 4 (more than double the amount of cattle slurry + NPK-fertilisers).

Ley in organic arable systems positive for earthworms

Continues monoculture cereal or vegetable production does not favour the establishment of large earthworm populations. The large positive effects of one year of ley in the organic arable system (3) as compared to the two conventional systems may have several explanations related to crop rotation, management and use of pesticides. The two conventional systems may have shown especially low values because the crop the year before was potatoes, demanding especially much soil management (disturbance) and leaving minor amounts of "food" (organic matter) to the next seasons soil fauna.

Conventional fodder systems showed high density of earthworms

Among the fodder systems, there were significantly higher density of earthworms in the conventional system (4) as compared to the organic systems (5 and 6), but not higher biomass or density of channels. These three systems are more similar in management and crop rotations than are the three arable systems. Hence, the smaller variations among the fodder systems regarding earthworm-related properties were expected, and are in accordance with the findings of Scullion et al. (2002).

Figure 7. The area with the cropping systems was established in 1990, to study nutrient supply and yields, and to monitor environmental impacts from different conventional and organic cropping systems (photo: A. Korsaeth).

Figure 8. The cropping systems are located in the south eastern parts of Norway, at Apelsvoll, near lake Mjøsa (photo: A. Korsaeth)

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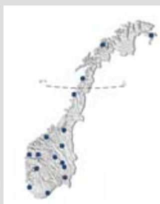

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