

Impact of zero tillage winter grain crops on soil health indicators

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Summary

A field study was carried out to understand the impacts of reduced soil disturbance (zero till) on soil characteristics and function (soil 'health') in arable farm conditions in two regions of Scotland. Fields were sown with winter barley or oilseed rape, either following ploughing or sown directly without soil tillage. Three indicators of soil function or 'health' were used: worm counts (biological), soil organic matter (chemical) and soil aggregate stability (physical). Fields were visited in July and August and final assessment of the crop performance was gathered verbally from land managers.

Sowing winter barley or oilseed rape crops into undisturbed (zero tillage) soils was associated with higher soil organic matter, higher worm counts, and higher soil aggregate stability compared with ploughed soils, although there were exceptions. Zero tillage was, however, associated with increased weed cover and lower yields (grain and straw), indicating a trade-off between soil cultivation and weed management, and an economic cost to the farm business.

Background. Consultation with arable / mixed farmers was undertaken through farm visits and stakeholder events to characterise farmers' goals for improving sustainability and identify knowledge gaps. Farmers indicated they were motivated to improve soil quality and function, reduce inputs (nitrogen fertiliser, crop protection), increase resilience to extreme weather events, and encourage greater biodiversity, but also to understand the role and function of farm biodiversity. Barriers to changing their farming practices included gathering evidence to prove that practices are effective at providing these outcomes in commercial farm settings and being able to understand the underpinning processes.

Focussing on soil management, the **aim** of this field study was to understand the impacts of reduced soil disturbance (zero till) on soil characteristics and function (soil 'health'). Three indicators of soil function were used:

1. Biological diversity and activity (worm density, type and activity). Higher abundance and diversity of worms is associated with improved soil aeration, drainage, and nutrient turnover.
2. Physical structure (soil aggregate stability). Soil aggregate stability provides a measure of soil structural stability and vulnerability to water erosion; erosion and associated structure degradation can result in loss of nutrients and carbon. Increases in water-stable aggregates potentially indicates increased soil porosity, which is associated with greater water infiltration and resilience to extreme climate events.
3. Chemical composition (soil organic matter content). Higher soil organic matter is associated with improved soil moisture retention, greater activity of detritivores, and improved soil carbon storage.

We monitored winter sown crops of barley and oilseed rape in two regions (Aberdeenshire and Angus), that were either ploughed prior to planting or had zero soil disturbance before planting by direct drilling, with differences in soil management in previous crop cycles (**Table 1**).

Methods. The study was conducted in 2024. The paired fields at each site were visited in July or August to collect samples in each field along two linear transects (10 sample loci per field: Aberdeenshire) or along three linear transects (3 loci per transect, nine loci in total per field: Angus).

Table 1. Farm and field site characteristics.

Location	Previous field management	Soil type	Crop	Soil
Aberdeenshire	Ploughed	Noncalcareous gleys with humic gleys Strichen series	Winter oilseed rape	Plough vs Zero till no fertiliser addition
	Ploughed	Brown earths Tarves series	Winter barley	Plough vs Zero till NPK fertiliser addition
Angus	3 year zero till, annual organic matter inputs	Brown earths Balrownie series	Winter oilseed rape	Plough vs Zero till
			Winter barley	Plough vs Zero till

At each locus, using a 50 x 50 cm quadrat, the percentage of ground covered by weeds (monocots, dicots) and by the crop was recorded. A separate 20 x 20 cm quadrat was placed on the ground (within the 50 x 50 cm quadrat) and the number of middens and wormcasts was counted. The surface litter/debris was scraped away within this smaller quadrat and a 20 x 20 x 20 cm soil pit was dug out and the soil placed onto a white surface. The soil was hand sorted to remove worms; these were transferred to a pot to count the number of juveniles. Each adult worm was placed adjacent to a ruler and a sample locus label and photographed, and the number of adults in each functional group was recorded (using the [CSC earthworm ID guide](#)). After counting, the worms were returned to the soil pit. Approx. 0.5 Kg of excavated soil was transferred into a bag and any remaining soil was returned to the soil pit. Soil samples were stored at 6 °C until analysis.

Water-stable aggregate stability was tested. The soil aggregates (2-8 mm) were air dried in metal trays at room conditions (approx. 1 week) then subjected to water stability analysis using the wet-sieving method ([wet sieving apparatus, Eijkkelkamp](#)). The test works by submerging air-dried aggregates in water. During the test, aggregate breakage is mainly caused by slaking due to compression of trapped air when water enters the aggregates. Before testing, the air-dried soil (~200 g) was passed through an 8 mm sieve, discarding any soil remaining on top of the sieve, then passed through a 2 mm sieve. Soil remaining on top of the second sieve (i.e. aggregates of 2-8 mm diameter) was retained for aggregate stability testing. Water-stable aggregate stability is calculated as a % of total soil weight (i.e. $100 \times (\text{mass of stable aggregates} / (\text{mass of stable} + \text{unstable aggregates}))$).

Soil passing through the sieve (i.e. < 2 mm diameter) was collected for LOI (loss on ignition) analysis (Hutton Scientific Services, Aberdeen).

Land managers views were gathered, after the trials, on the agronomic and economic performance of zero tillage and ploughed crops.

Results.

Soil biological diversity and activity. Juveniles accounted for the majority (86-97%) of worms in soil samples. Worm activity, in terms of the number of worm casts and middens, was highest in the barley crop in Angus (plough or zero till) and lowest in the barley crop sown into ploughed soil in Aberdeenshire (**Figure 1A**). There were no strong patterns in worm activity in relation to crop species or soil management.

Worm abundance was highest in oilseed rape fields, but did not vary consistently with soil management, and lowest in winter barley fields, particularly in ploughed soils (**Figure 1B**).

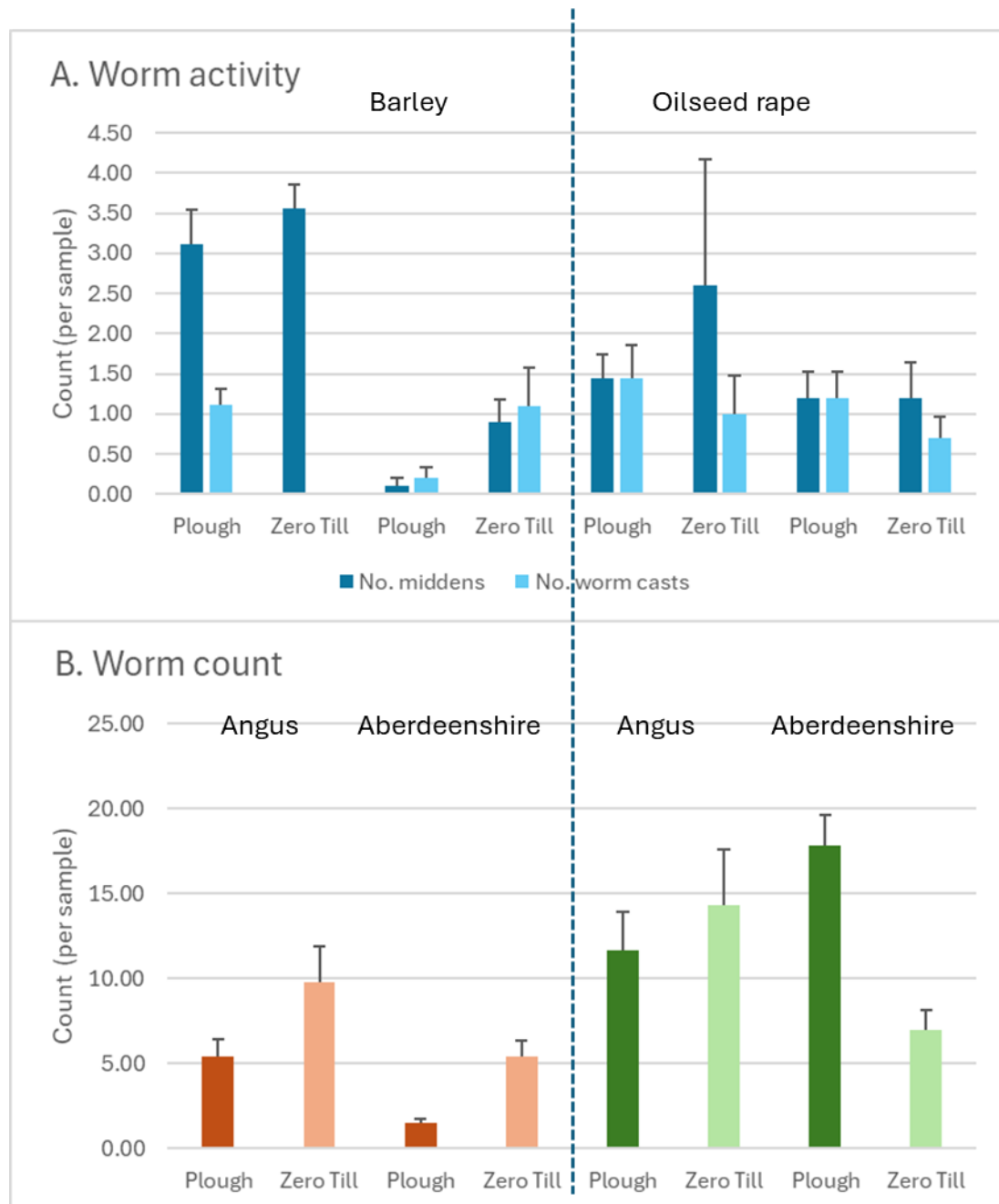


Figure 1. Worm activity (A) and worm numbers (B) detected in 20 x 20 x 20 soil pits, averaged across nine (Aberdeenshire) or ten (Angus) loci per field, in response to winter barley or winter oilseed rape sown into ploughed or undisturbed soil.

Soil physical structure. Soil aggregate stability was typically high (>50%), with most sites giving values greater than 80%, indicating low vulnerability to erosion (Bartlova et al., 2015). Values were highest in Oilseed rape field soils (**Figure 2**) compared with winter barley field soils, and higher in undisturbed soils compared with ploughed soils.

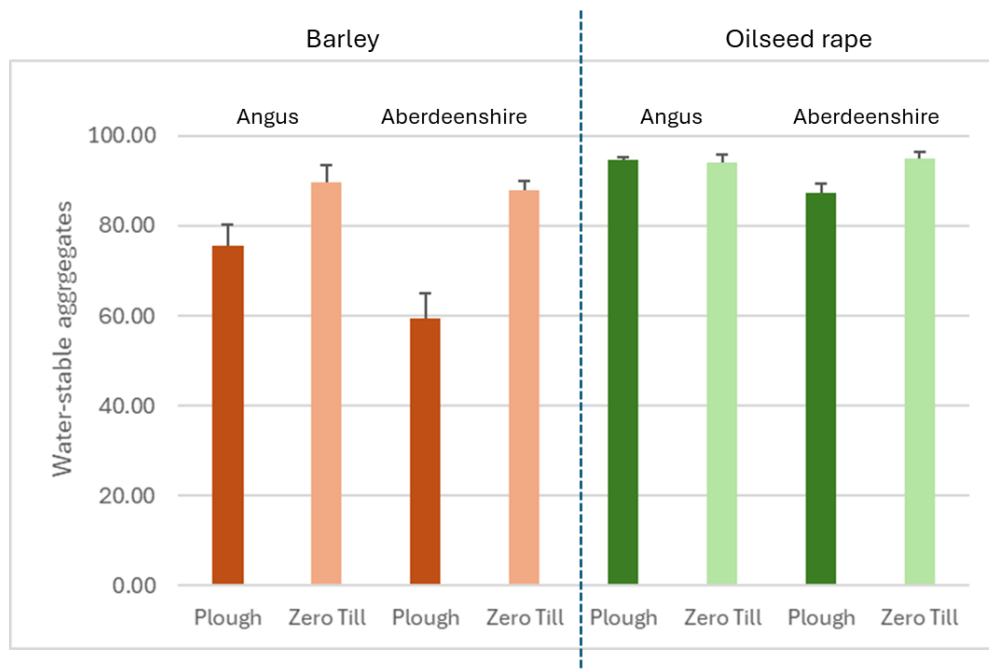


Figure 2. Proportion of water stable aggregates in the 2-8 mm fraction of soils sampled from winter barley and oilseed rape fields sown into ploughed or undisturbed soils. Values are the mean (\pm s.e.m.) of n=9 (Angus) or n=10 (Aberdeenshire) samples.

Soil chemical composition. Soil organic matter ranged from 5-10%, with highest values observed in Aberdeenshire compared with Angus, and in undisturbed soils compared with ploughed soils (with the exception of the oilseed rape field in Aberdeenshire: **Figure 3**).

There was a positive relation between the percentages of soil organic matter and water stable aggregates (**Figure 4**). Soil worm abundance showed no relation with soil organic matter or aggregate stability (not shown).

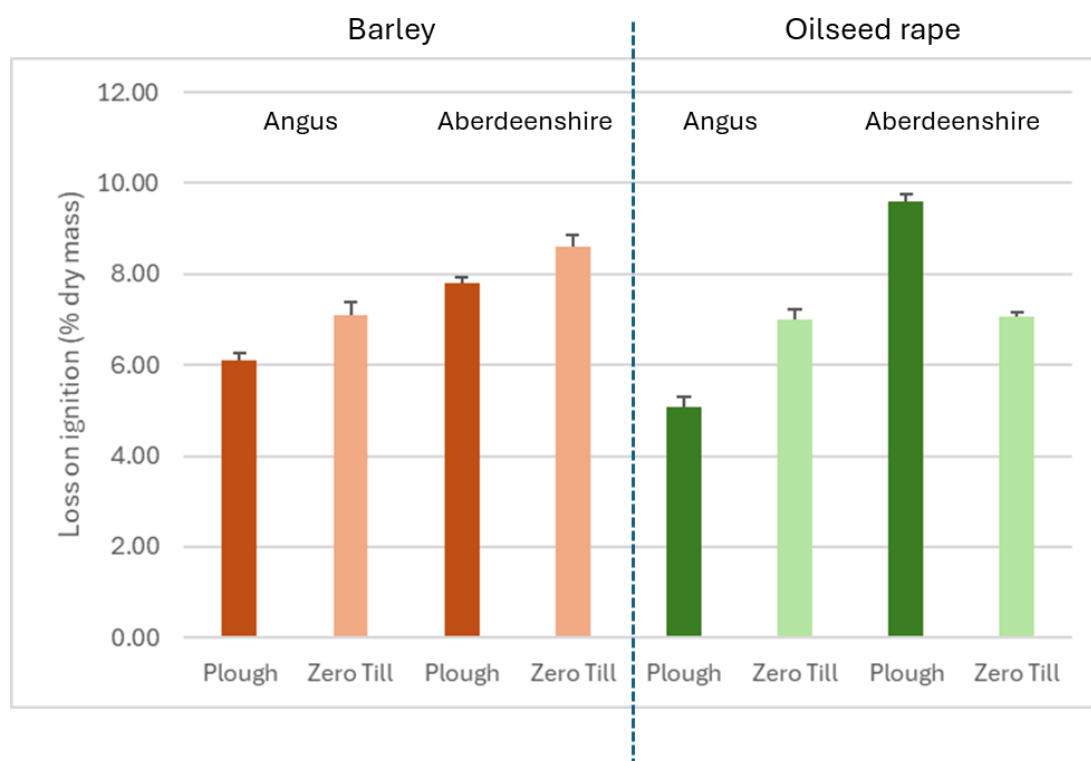


Figure 3. Percentage of mass lost on ignition for soils sampled from winter barley and oilseed rape fields sown into ploughed or undisturbed soils. Values are the mean (\pm s.e.m.) of $n=9$ (Angus) or $n=10$ (Aberdeenshire) samples.

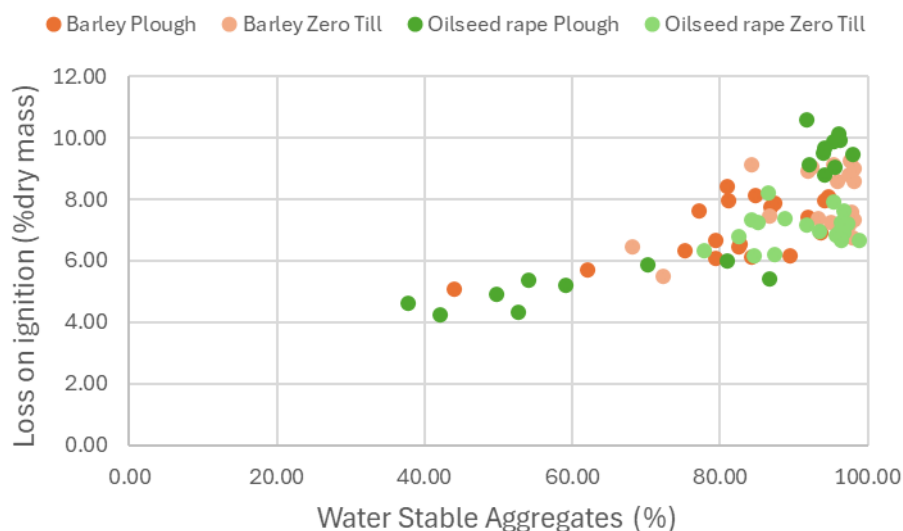


Figure 4. Relation between water stable aggregates (in the 2-8 mm fraction of soil) and soil organic matter (measured as loss on ignition) of soils sampled from sites sown with winter barley or oilseed rape in ploughed or undisturbed soil.

Agronomic and economic factors. In Aberdeenshire, for the two fields of winter barley and oilseed rape (plough versus zero tillage) several differences were observed from initial machinery operations (ground preparation, sowing) and throughout the growing season (e.g. weed cover: **Figure 5**).

In Aberdeenshire, a visual observation by the farmer growing the winter barley crop that was cultivated using zero tillage revealed that the crop was thinner (in mass) and was shorter in height but that the roots were longer than those of the conventional (ploughed) barley crop. At harvest, there was less straw (so fewer bales of straw to sell or use as animal feed). Moisture at harvest was 1-1.5 % lower as was bushel weight (lower by 1.5-2%). Using direct drilling to establish the crop meant an increase in sowing rate (more seed thus a higher seed cost) and during the growing season at least one more herbicide spray was needed to reduce the weed burden. The direct drilling of winter barley resulted in a yield that was, on average, lower by approximately 1.5 tonnes per hectare and the yields were variable within the area that was direct drilled. Conventional tillage (plough) consistently yielded 8 or 9 tonnes per hectare, whilst the zero tillage yields ranged from 4 to 8.5 tonnes per hectare. The conventional (plough) cultivation incurred one less spray but costs for ploughing were estimated at an additional £86.50 per hectare.

The two oilseed rape fields in Aberdeenshire, under the two different cultivation techniques, yielded 3.95 tonnes per hectare, and again the stems were thinner in appearance and an extra spray was needed for weed control in the zero tillage crop. Although the oilseed crop yields were the same in plough and zero tillage, the farmer said that they would only use zero tillage if the initial weed burden was not very high to avoid incurring extra costs in weed control.

In Angus, the integrated (zero tillage) and conventional (ploughed) treatments have been implemented for 13 years. The winter barley yields averaged 8.3 t ha⁻¹ in conventional (plough) treatments compared with 7.2 t ha⁻¹ in the integrated (zero tillage) treatment, but these trends were only significantly different in four of the 13 years, the greatest difference occurring in 2019. Further investigation is required to determine possible reasons for the differences in these specific years, but overall, both systems produced yields comparable to the national average of 7.5 t ha⁻¹.

Winter oilseed rape yields at the CSC were not statistically different between treatments across all years (averaging 3.7 and 3.2 t ha⁻¹ in the conventional and integrated treatments respectively). However, variability is high, and, in some years, the integrated treatments yielded less due to poorer establishment when direct drilled through the crop residue left from the previous cereal crop. These issues with establishment can be resolved using non-inversion till rather than direct drilling into stubble, providing better seed-soil contact.

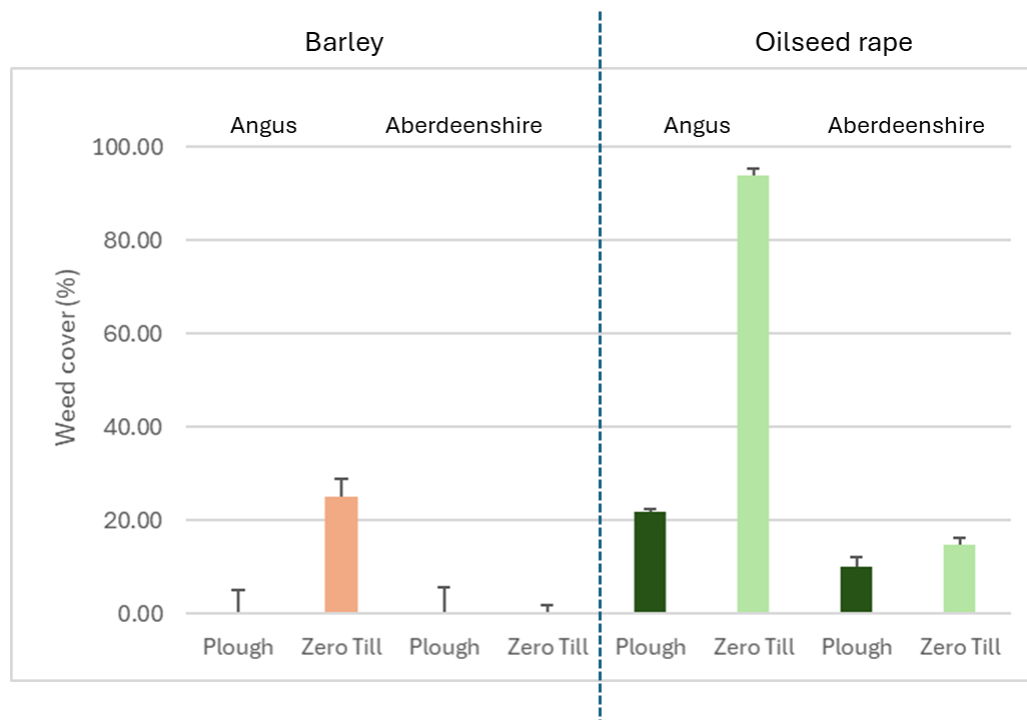


Figure 5. Percentage of ground covered by weeds in winter barley and oilseed rape fields sown into ploughed or undisturbed soils. Values are the mean (\pm s.e.m.) of n=9 (Angus) or n=10 (Aberdeenshire) samples.

Discussion

The study shows evidence for some impacts of soil cultivation (and associated organic matter inputs in Angus) on soil health monitored using biological, physical and chemical indicators. Worm counts were variable and generally low in barley fields, but higher in oilseed rape soils, suggesting differential effects of these crops on soil conditions for earthworms, although further investigation would be needed to confirm this observation. There was no direct correlation between worm counts and evidence of worm activity (soil middens and worm casts), which likely reflects variability in worm presence in shallow vs deep soil layers in response to soil conditions (moisture, temperature) at the time of sampling.

Higher soil organic matter might be expected in Aberdeenshire soils compared with Angus soils due to differences in soil derivation. The study confirmed that, in general, direct drilling is associated with improved soil organic matter content, although not in all soils, but is also dependent on the amount of additional organic matter added.

Stability of water-stable soil aggregates was high (Bartlova et al, 2015), ranging between 60% and 95%, particularly in undisturbed soils, but comparable with values obtained previously for Scottish arable soils (K. Loades, pers. comm.). The positive relation between soil %organic matter and %water-stable aggregates has been demonstrated previously (e.g. Tidsall & Oades, 1982) and relates to the binding potential of organic components (plant residues, plant or microbial exudates, fungal hyphae, humic material). Other studies have shown that stable soil aggregates can favour the build-up of soil organic carbon by protecting the imbedded organic matter from degradation (e.g. Reichmann et al, 2025).

In conclusion, sowing winter barley or oilseed rape crops into undisturbed soils was associated with higher soil organic matter, higher worm counts and higher aggregate stability, although there were exceptions. These improvements in soil health indicators were, however, associated with increased weed cover and lower yields (grain and straw), indicating a trade-off between soil cultivation and weed management operations, and highlighting that there is a fine balance between achieving environmental improvements that are affordable to the farm business. To overcome this trade-off, direct drilling might be interrupted every few cropping cycles with occasional tillage (e.g. one year in every six is advised from research conducted at the Centre for Sustainable Cropping) to achieve soil health benefits from direct drilling while reducing any build up of weeds or soil compaction.

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