Maize establishment methods for reduced environmental impact

An Innovative Farmers and Farm Net Zero Field lab

Final report

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Summary

Maize is an important crop for dairy farmers but is often associated with a high risk of soil erosion and runoff. This is mainly due to a late harvest, wide rows and the use of heavy cultivation leading to unstructured and unstable soil profiles. During the field lab, farmers trialled alternative methods of establishing their maize, including strip tillage, disc cultivation and direct drilling, and assessed the impact on yield, soil structure and fuel use.

Summary of results:

- *Heavy cultivation is not necessary to achieve good maize yields: any differences between the yields from different techniques were not consistent.*
- *Lighter cultivation and direct drilling techniques can save time and fossil fuel use (disc cultivation over ploughing saved £77.58 per hectare).*
- *Ploughed bare soil was shown to be most at risk of ersosion post harvest of all the establishment methods.*
- *Undersowing maize did not reduce yield or quality compared to bare soil, but protected the soil from compaction caused by rainfall, and showed faster water infiltration rates (associated with reduced soil erosion). This suggests that ensuring plant cover remains after harvest is a useful strategy to reduce soil erosion and protect soil organic matter.*
- *Undersowing the crop with grass in July (during the maize growing season) produced more understorey biomass than rye which was sown after harvest.*
- *When measured, phosphate and potash indices did not differ between treatments.*
- *Disc cultivated areas had higher soil organic matter than ploughed areas.*
- *Weed control can be an issue when ploughing is not carried out.*

Take home messages

The trial has shown that maize is not dependent on ploughing, and that yield, and quality are not influenced by cultivation system, provided an adequate seed bed is created. It has also shown that disc cultivations, strip till or direct drilling can be adopted even in soils which have been regularly ploughed and intensively cultivated, and the benefits also have a legacy effect benefitting soil in later years.

The value of under-sowing the maize crop during its growing season (rather than after harvest) was also highlighted, as a means of soil protection during and after harvest. Reduction in fuel use reduces the emissions associated with the crop, and less intensive cultivation reduces the number of passes, saving farmer time. Although all cultivation causes loss of soil organic matter, ploughing and power-harrow cultivating is likely to be worst.

Main report

1 Field lab aims

Farmers trialled different cultivation techniques to test their impact on soil structure and crop yield, to show that the negative environmental impacts often associated with maize growing can be reduced. Opinion is still divided among UK farmers as to whether maize can be established other than through heavy cultivation. There have been relatively few UK trials on the topic, and results are often closed sourced. The trial was coordinated by Jerry Alford of the Soil Association, and the researchers were Plymouth University.

2 Background

Maize can be a valuable crop, particularly in dairy farming areas. Maize is a good silage crop due to its high starch, high energy, intake potential and high dry matter yield potential. It uses water efficiently which is important given unpredictable weather systems. It is also known to sequester high levels of carbon, and as a C4 crop it is particularly efficient at converting sunlight to biomass through photosynthesis.

Maize has always been a crop associated with late harvest creating high risk of runoff following extreme weather. Maize seed doesn't like a poor seedbed, unlike other big-seeded crop, consequently the desire for a very fine seedbed means power harrow cultivations are commonly used in addition to ploughing, leaving a very unstructured and unstable soil profile. Maize is then grown on wide rows with nothing to slow down the rainfall if it fails to infiltrate quickly, an issue compounded by the over worked seedbed which can be prone to soil erosion risk. There are also questions about the effect of ploughing on soil organic matter and soil health, particularly structure.

In 2022 Malcolm and Catherine Barrett carried out a small field trial comparing maize grown with a plough-based cultivation, Sumo trio cultivation and direct drilled using a Mzuri drill as part of their involvement in the Farm Net Zero project. The results showed that soil health metrics were all improved by reducing intensity of cultivation, and although there were no yield assessments done there was no visible difference in yield along with slight but insignificant changes in quality.

One significant difference was noted when fuel use was measured, with direct sowing with a Mzuri strip till drill showing significant reductions in fuel use. There was also a major reduction in time

Table 1. Fuel use comparison between 3 cultivation systems for maize 2022

	Operations	Fuel use (L/Ha)	Fuel Cost £/ha at 64.3p/litre*
Conventional	Plough, power harrow, Drill	9.11	£58

Sumo Cultivator	Sumo Cultivator, Drill	5.06	£33
Direct sown	Direct Drill	2.02	£13

*Farmers weekly 1/5/2025

The different cultivation and drilling equipment used:

Plough plus power harrow: The conventional equipment used for establishing maize, a plough inverts the soil, and a power harrow follows the plough and breaks up soil, aerates it, and creates a fine, level seedbed.

Disc cultivator: A disc-based cultivator which has rotating, angled discs that cut into the soil at a shallow depth mixing the soil and creating a loose seedbed, this will be followed by a drill to plant seeds.

Maize drill: a precision drill which plants the seeds into a prepared seedbed at a consistent depth, meaning that it requires a very consistent fine seedbed.

Strip Till cultivator: a seedbed cultivator/subsoiler which cuts a slot into unprepared ground creating a narrow seedbed which can then be planted into by a drill. The slot is cut 20-30cm into the ground helping break compaction layers and helping rooting depth pf the plants.

Mzuri strip till drill: A Mzuri drill is a type of single-pass system which cultivates and seeds in a targeted strip, leaving surrounding soil undisturbed. Mzuri is the name of the manufacturer, other strip till drills are available**.**

Direct drill: A direct drill is the broad category of machine that places seed directly into the ground without prior soil cultivation. They generally only cut a slot to place seeds in and disturbance in minimised. Whilst the Mzuri type cuts a strip others just cut a slot with a cutting disc. They are then typically followed by press wheels that close the furrow and firm the soil over the seed.

3 <u>The 2023 trials</u>

It was decided to repeat the trial in 2023 across more farms as a Farm Net Zero field lab, looking specifically at crop yield. Initially with 5 farms agreeing to participate but a wet spring and concerns about timeliness meant 2 dropped out, with trial results being lost from the third.

The trial looked at effects of a strip till cultivator compared with ploughed and direct drill plots to prepare the seed bed. Maize has always been associated with a plough-based system often following a compaction-busting subsoiler pass, and farmer attempts to use the subsoiler rows without a following plough and cultivator pass to create a seedbed have not always been successful due to the poor soil to seed contact in the drill rows. Recent development of better cultivating legs on strip till machines which create a better seedbed have resolved this. However, farmers' concerns remain that though they may save time and diesel by strip tilling, yield will be lower and so costs saved would be offset by lower yields.

Farm 1 Plough based

The maize field followed a grass ley which was destroyed by glyphosate prior to ploughing and power harrowing. An area was left unploughed and instead was strip tilled, with the drill following the next day to drill the whole field. GPS ensured that the maize was drilled in the strip till rows. The field was sprayed with a pre-emergent spray following normal farm practice.

Results:

Yield was assessed by hand harvesting quadrants from 2 areas from similar parts of the fields and weighing. Fresh weight yields were recorded and are shown in Table 2.

Table 2. Farm Crop yield from plough strip till comparison

	t/ha	% of control
Ploughed and maize drill	38.57	
Strip Till and maize drill	36.7	95

Despite herbicide use both before and after drilling there was a noticeable difference in weeds between the 2 plots as seen from the boundary shown in Picture 1 with strip till area on the left. Broad leaved weeds in the strip till plot included more biennial species such as

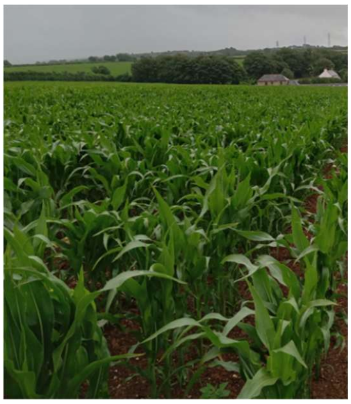
dock and thistle along with Bent grasses (Agrostis) indicating the lack of total control from the Glyphosate. However, maize did not appear affected because the weeds were not competitive at the seedling stage when it is more susceptible to weed competition. Weed populations in the ploughed area were annual weeds such as nightshade with some low level of grassweeds, again, mainly Agrostis species.

Picture 1. Weed control – Strip-till and ploughed land.

F**arm2** -Arable Disc cultivator based

This farm had been moving away from a plough-based system, so soil health was a priority, with no ploughing taking place. The trial control plots were in a grazed overwinter cover crop disced with a Sumo Trio Disc cultivator and drilled with a maize drill. The trial plots were shallow disced, strip tilled and either drilled with a standard maize drill or a Mzuri drill. The final plot was direct drilled using a Mzuri drill.

One area of the control plot had very poor weed control and so was analysed separately.



Picture 2 maize plants 10/7/23

Results:

Strip till Maize plants appeared shorter than those in the disc cultivated areas during the early part of the growing season. Picture 2 shows the disc cultivated area on left and strip till on right.

Fresh weight crop yield was assessed from random quadrants in the field from 2 sites per practice and fresh-weight results are shown in Table 3.

Table 3. Freshweight yields of maize trial plots 2023

	Plot yield t/ha Fresh weight	% of control
Control-Disc plus Maize drill	32.45	
Strip Till plus Maize drill	39.25	120%
Strip Till-plus Mzuri Drill	32.57	100%
Mzuri –direct drill (headland)	26.65	82%
Control-poor weed control	24.93	77%

The results show that there was a benefit of the strip till cultivator. Drill type did not appear to reduce yield to an important extent although the seeding metering system on the Mzuri drill did lead to uneven seed distribution which may have influenced yield due to competition effects.

The direct drilled plot results were more variable perhaps reflecting its use on the field headland and the less precise placement of the seed. The effect of weeds was obvious and so indicates that weed control remains an issue despite less soil movement.

Soil Analysis

Plymouth University took soil samples, and utilised developing technology to analyse the legacy effects of these treatments in the spring and summer of 2024 after the next crop had been drilled. The full report is in Appendix 1, but the key findings show that there was a difference in soil samples between the strip-till Maize drilled plots and the strip-till Mzuri drilled plots, unfortunately analysis not being done against the control due to mapping issues.

Soil Organic Matter (SOM) and Soil Organic Carbon (SOC)

Soil organic matter is vital for healthy, productive soils as it performs myriad functions including improving soil structure, infiltration, water retention, and reducing erosion risk, as such, it is an important soil health indicator. Soil organic matter is primarily made of carbon (58%) making soil organic carbon an equally good soil health indicator and also provides a means to measure the carbon sequestering potential of min-till practices. Soil organic matter and soil organic carbon were analysed by loss on ignition (LOI) and Dumas, respectively.

Both soil organic matter and soil organic carbon values were significantly higher in the strip-till Mzuri drill plots than the strip-till plus Maize drill plots (Fig. 1).

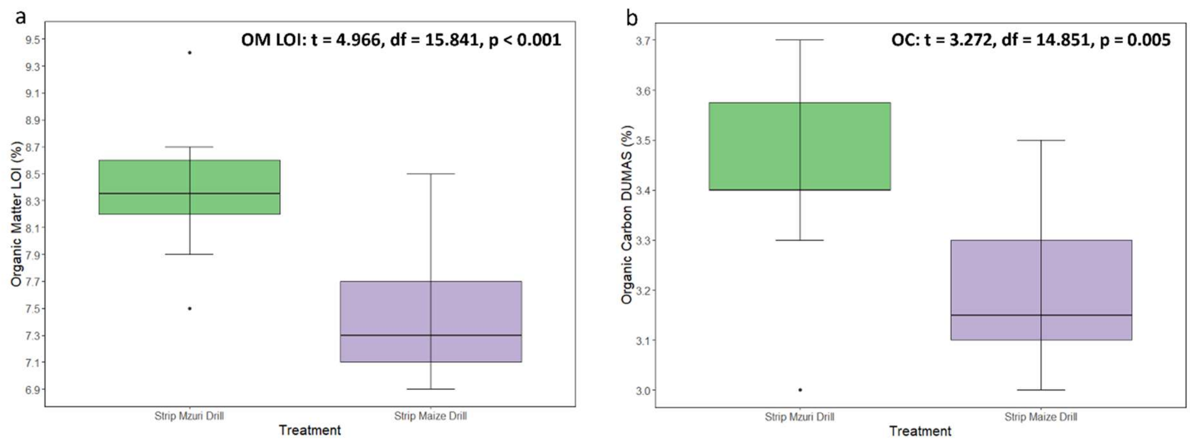


Figure 1. Distribution of (a) soil organic matter (LOI) and (b) soil organic carbon (Dumas) values across the two different strip-till drilling treatments. Green: Mzuri drill, purple: Maize drill.

Nutrient Analysis

Significantly higher values of potassium (K), magnesium (Mg), and total nitrogen (TN) were identified in the strip-till Mzuri drill plot compared to the strip-till Maize drill plot. No difference was found in soil phosphorus (P) levels. Please see the full report at Appendix 1 for further information.

Gravimetric Soil Moisture and Aggregate Stability

Gravimetric soil moisture is the mass of water per mass of soil (i.e., grams of water per gram of soil). Soil water-holding capacity and organic matter are positively correlated; therefore, we would expect the treatment with higher organic matter content to have higher gravimetric soil moisture values. This was found to be the case, the strip-till Mzuri drill plot had higher mean gravimetric soil moisture percentages than the strip-till Maize drill plot (Fig. 2a).

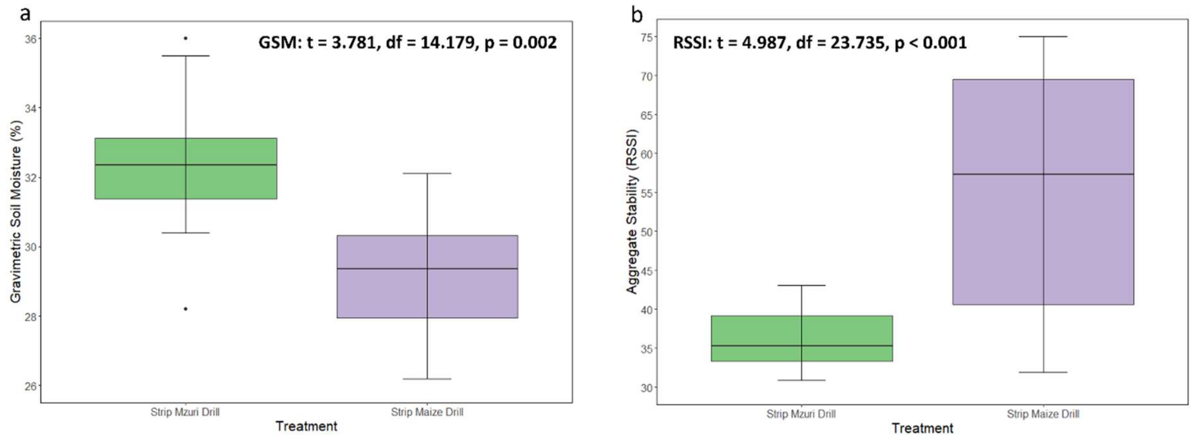


Figure 2. (a) Distribution of gravimetric soil moisture percentages, and (b) rainfall simulation survivability index (RSSI) scores describing how well soil particles hold together when subjected to a controlled rainfall event across the two different strip-till drilling treatments. Green: Mzuri drill, purple: Maize drill.

The Rainfall Simulation Survival Index (RSSI) measures the stability of soil aggregates under simulated rainfall conditions. The index is used to understand erosion potential and the soil's ability to withstand erosion caused by heavy rainfall, with a higher survival index indicating greater aggregate stability and a lower risk of erosion. The strip-till Maize drill plot had a higher survival index and a much broader spread of values than the Mzuri drill plot (Fig. 2b).

The results suggest that the strip-till maize drill plot should be less likely to suffer from erosion from heavy rainfall due to having greater aggregate stability. However, this cannot necessarily be attributed to the treatments - please read the full research report at Appendix 1 for further information on this.

Penetrometer Resistance

Soil penetrometer resistance can be used to measure soil compaction. Penetration resistance is the force required to move a specially tipped metal rod through the soil. The resistance value is comparable to the force required for a plant root to grow through the soil. Root penetration is usually restricted around 300 PSI.

Analysis of the two treatments revealed significant differences in penetrometer resistance at 5-10 cm depths (Fig. 3). The strip-till Mzuri drill plot was less compacted at this depth compared to the strip-till plus Maize drill plot. At all other measured depths (0-5 cm, 10-15 cm, 15-20 cm, and 20-25 cm) no differences were detected.

This result likely reflects the increases in SOM observed in the strip-till Mzuri drill treatment. Increases in SOM from reduced tillage practices are usually seen in the surface layer (<10 cm depth). Less run-off and erosion would be expected due to SOM improving the soil's structure, infiltration, and water-holding potential.

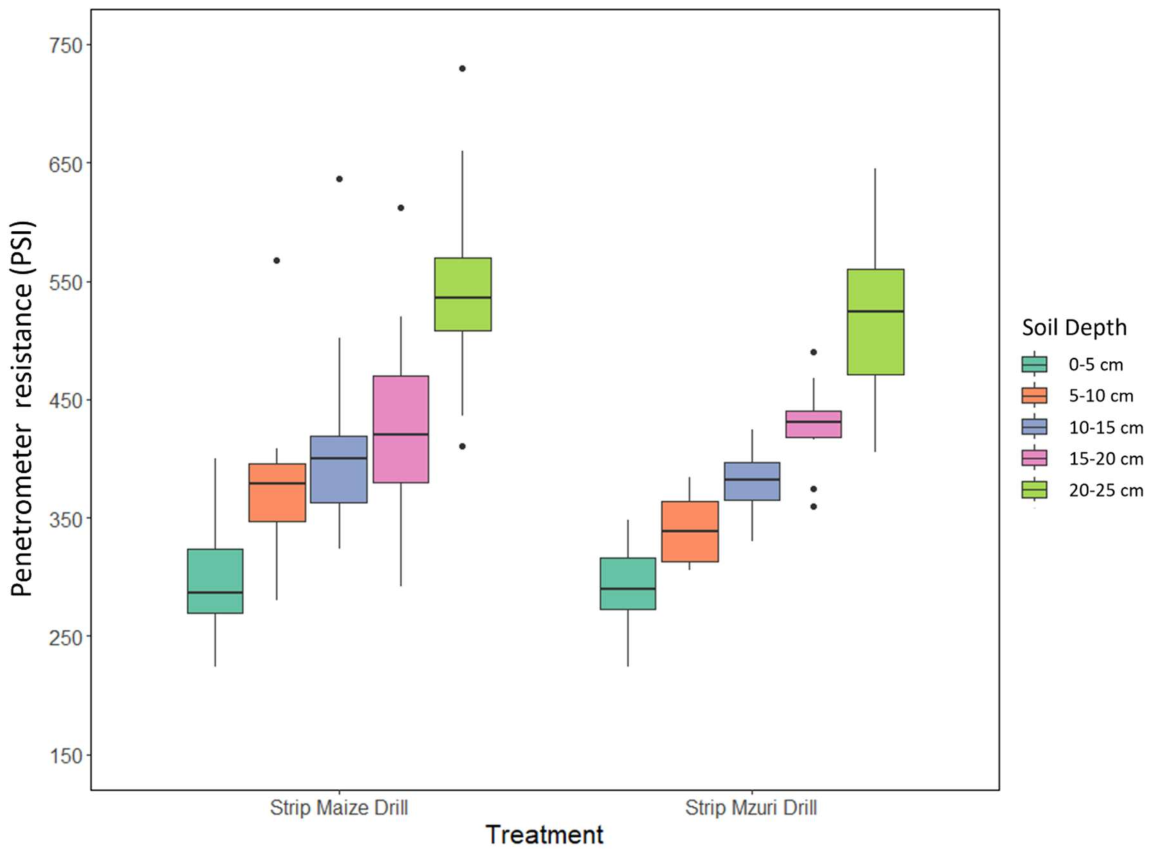


Figure 3. Mean penetrometer resistance of soils at different depths (0-5 cm, 5-10 cm, 10-15 cm, 15-20 cm, and 20-25 cm) across two strip-till treatment plots. Penetration resistance varied significantly between drilling methods at 5-10 cm ($t = -2.240$, $df = 27.999$, $p = 0.033$).

4 2024 Trials

It was decided to continue the trial in a second year to look at direct drilling and comparing plough based to disc based cultivations to reflect equipment available to most farmers

Farm 1: The direct drilling trial was hosted on a farm which had not been undergoing reduced tillage which means that soil health and structure may be compromised, and one of the trial fields followed potatoes with no cultivations post-harvest.

Duchy College farm: At the other farm at Duchy College, it was decided to compare the standard practice of plough-based maize with a disc cultivator-based system with analysis of soil and yield during the year. Duchy also wanted to trial under-sowing the maize with a cover crop.

Farm 1: Plough vs Mzuri Direct Drilled

The trial was in 2 adjoining fields with one being ploughed and one direct drilled with a Mzuri drill. All other treatments were the same and yield was assessed by sampling 2m lengths and calculating yield from that. Visually, the Mzuri direct drilled field was less consistent and shorter, and the results showed that the Mzuri direct drilled crop yield was 88% of ploughed. However, we also measured cob weights and found that Mzuri direct drilled cob yield was 93% of ploughed maize yield and cobs made up a greater proportion of harvested crop as shown in Figure 4.

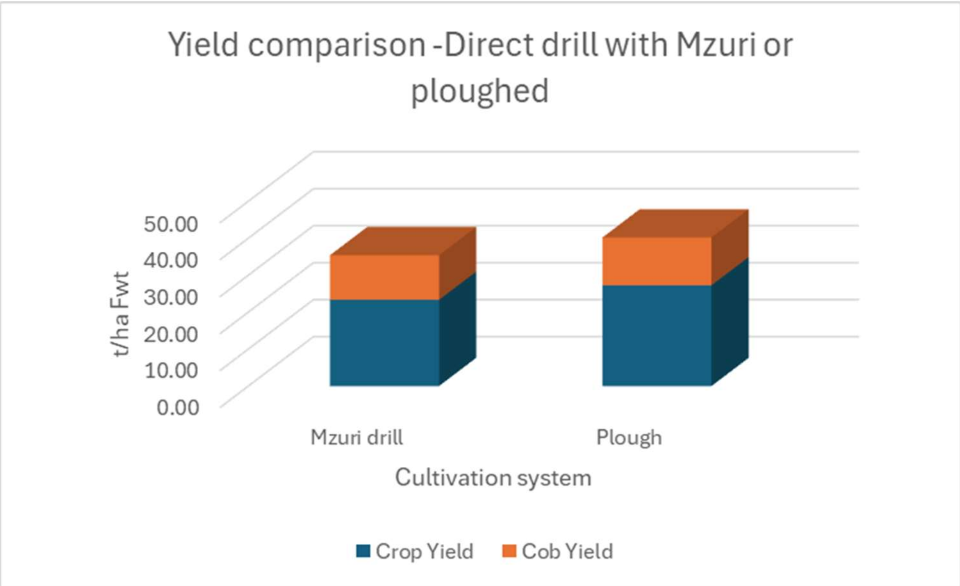


Figure 4. Crop and Cob yield 2025

The wider drill rows associated with the maize drill resulted in more interrow competition which did appear to make plants thinner with evidence of crop lodging. Unfortunately, as fields trials were not split field, it means that we cannot prove that this was down to cultivation system or other factors.

Farm 2 Duchy College – Plough vs Disc Cultivation

The trial field was long term grass, split into two with one half ploughed and the other half disc cultivated using a Sumo Trio (designed to perform subsoiling, discing, and pressing in a single pass, creating an ideal seedbed while minimizing soil disturbance).

The ploughed area was power harrowed to create a seedbed whilst the Sumo Trio cultivator left a seed bed which was suitable for drilling. Maize was drilled on the 7th of May 2024 at 45,000 seeds/acre, with all fertiliser and herbicide treatments being the same across the field.

It was also decided to investigate undersowing the maize with grass to investigate whether it affected crop yield or had any other benefits on soil stability to reduce erosion risk. Two mixes were drilled on the 4th of July 2024 - a straight Westerwolds mix at 8kg/ha as is commonly used, and a more complex mix with 3.6kg Westerwolds plus 1.4kg of a mix of red, white, Alsike and Crimson clovers plus plantain. The species mix was intended to allow us to investigate the effect of nitrogen-fixing due to clovers on yield in the following year. There was an area left as bare soil as a control. Following conversations with local farmers on the effectiveness of undersowing versus post-harvest cover crops, two 12-metre-wide strips of forage rye were drilled across the field at 50kg/acre on the 4th of November 2024. This was designed to compare the winter growth rate of the post-harvest cover crop with the undersown mixes.

Harvest Results

Pre-harvest on the 11th of October 2024, replicate samples were cut from each plot and analysed using Limagrain's Near-Infrared Spectroscopy machine. The results from this are shown in the table below, they suggest that there were no clear differences in quality between the undersown plots. But there was a marginally higher dry matter and starch in the ploughed plots compared to the cultivated plots, suggesting earlier maturity in the ploughed area.

Table 4. NIR spectroscopy results

Plot	DM	STARCH	NDF	D-VALUE	CWD	ME
Cultivated Bare	29.7	34.1	40.2	71.7	48.3	11.5
cultivated Grass	28.9	34.9	39.6	72.2	49.1	11.6
Cultivated diverse	27.9	35.4	41.5	71.3	48.8	11.4
Average	**28.8**	**34.8**	**40.4**	**71.7**		**11.5**
Plough Bare	30.6	33.7	42.5	71.6	52	11.5
Plough Grass	30.4	33.7	44	70.3	52.5	11.3
Plough Diverse	33.4	38.3	40.4	72.6	54.1	11.6
Average	**31.4**	**35.2**	**42.3**	**71.5**	**52.8**	**11.4**

The field was then harvested later in October 2024 with Smallridge Bros. John Deere 9500 harvester fitted with a Harvest Lab yield monitor. This analysed yield and quality as DM and Starch. The results are shown in Figure 5. Green colours represent highest yield, red lowest yield.

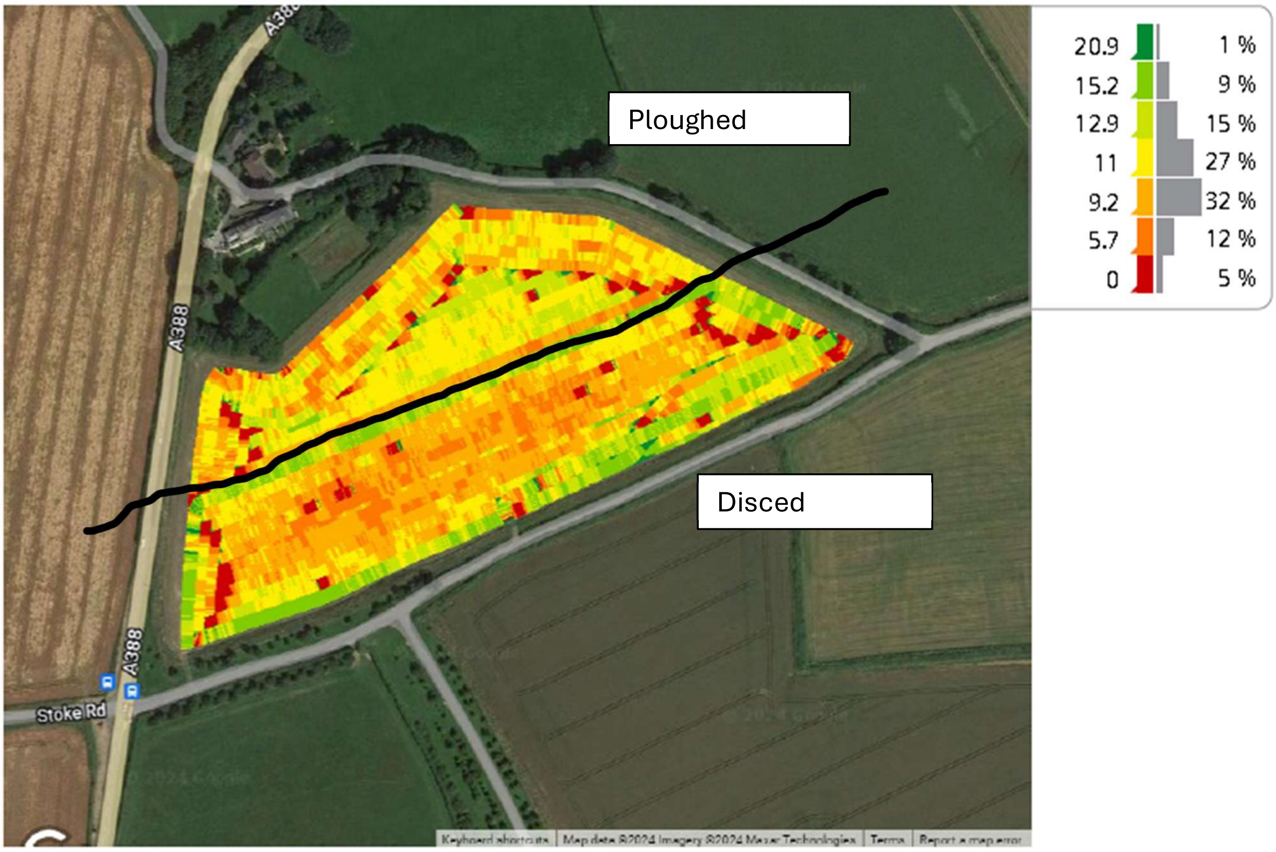


Figure 5. Harvest Lab Results Duchy College harvest

More detailed analysis of the Quality from the Harvest Lab monitor showed the following values Table 5.

Table 5. Yield and quality analysis of Harvest Lab results.

	Control- Ploughed	Disc cultivated	Disced as % of control
Area yield Fresh weight/ha	33.6t	34.1t	101.4
Area Yield DM/ha	11.4t/ha	12 t/ha	105.26
DM	34%	35.2%	103.5
Starch	30.2	31.3	103.6
Sugar	5.9%	5.9%	
Neutral Detergent Fiber	42.3%	42%	

These results showed that the disc cultivated area yielded marginally more maize of higher dry matter and starch than that from the ploughed area, although there was a more consistent crop visually on the ploughed part of the field. This may explain the differences in analysis between the Limagrain NIR results and the onboard Harvest lab monitor although the differences were not significant. Analysis shows there was a slight but not significant increase in yield under the disc cultivation system compared with plough based (Fig. 6).

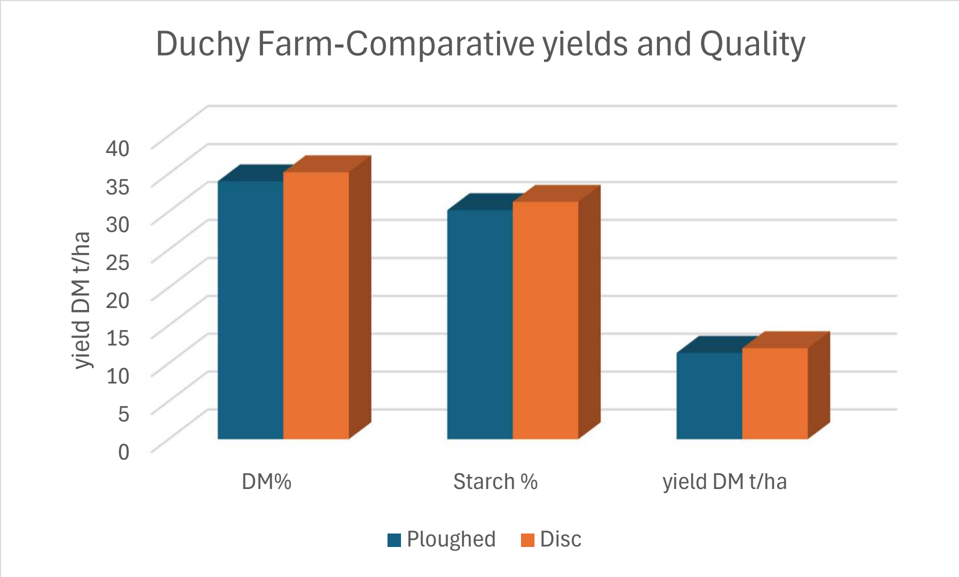


Figure 6. Yield and Dry Matter comparison

There was no indication of any differences at harvest between the undersown areas, and grass growth at the time was poor. However, grass covers improved significantly over the winter.

Soil assessments

Soil samples, Visual Evaluations of Soil Structure (VESS), infiltration rates, aggregate stabilities and earthworm counts were collected across the plots following harvest and before cultivations to ascertain the impact on soil quality.

The baseline soil assessments were collected on the 22nd April 2024; it must be noted that these were taken before the trial design was finalised and as such, only four plots were sampled rather than the final six. VESS, infiltration rates, aggregate stabilities and earthworm counts were taken at 3 locations per plot, geolocated to allow repetition. These assessments were repeated through the winter in all six plots to track the impact of the undersown mixes. A summary of the results following harvest and overwinter are shown in the Figures 7, 8, 9, and 10 below.

Average VESS Scores

Visual Evaluation of soil structure allows you to observe and record how aggregated the soil structure is (aggregation is the crumb structure naturally occurring in healthy soil) in the top 30cm. The score ranges from 1 (very good structure) to 5 (poor structure). A low score implies water air and roots will easily move through the soil and ensure better infiltration and also crop access to nutrients and so better growth.

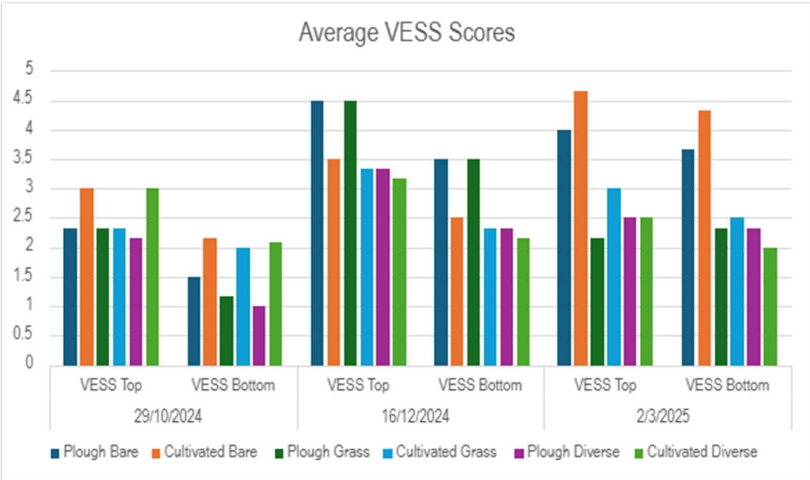


Figure 7. Average VESS scores

Both the ploughed and cultivated bare plots became more compacted as winter progressed due to the effects of rainfall. The covered plots also got more compacted but not to the same extent, suggesting that the plant cover helped to reduce surface compaction from rainfall. There was no noticeable difference between Westerwolds grass and diverse grass mix, both of which were sown during the maize growing season.

Average worm counts

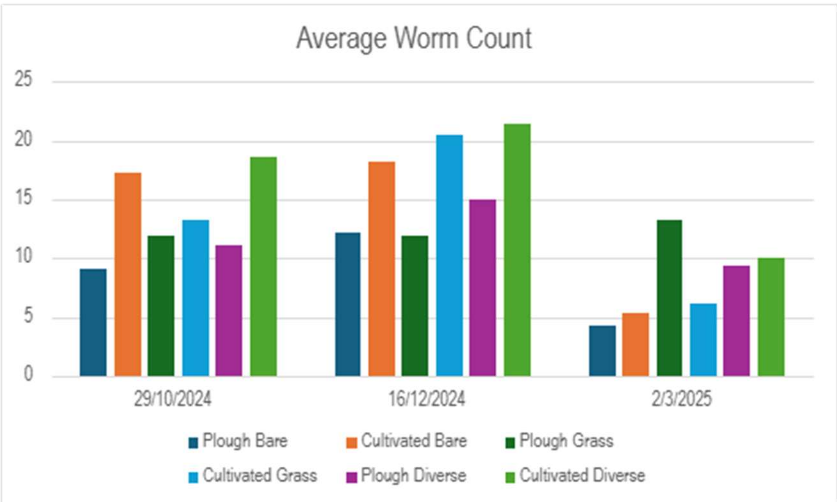


Figure 8. Average Earthworm scores

Worms are a good indicator of soil health and can be counted during the VESS assessment. They are more generally found more in more friable soils as movement is easier. Ploughed plots generally had lower worm counts than cultivator only, which is common because ploughing disturbs burrows and buries organic matter deeper than the disc cultivator which mixes organic matter into the soil profile.

Average Infiltration time

Measuring the time for a measured quantity of water to soak into the ground, this test is a good assessment of the effect of practices on a field's erosion risk and drought tolerance.

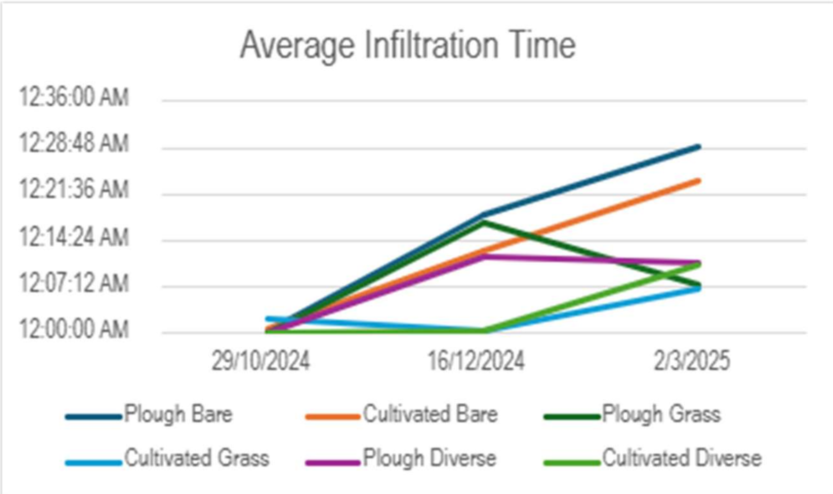


Figure 9. Infiltration time

Both the ploughed and cultivated bare patches had much longer infiltration times as winter progressed due to the effect of rainfall on the bare soil and consequent surface compaction. The benefit of the grass on infiltration post-harvest is shown by the improvement of infiltration post-harvest in the plough grass plots, demonstrating that the grass is a useful tool to reduce overwinter compaction and erosion risk.

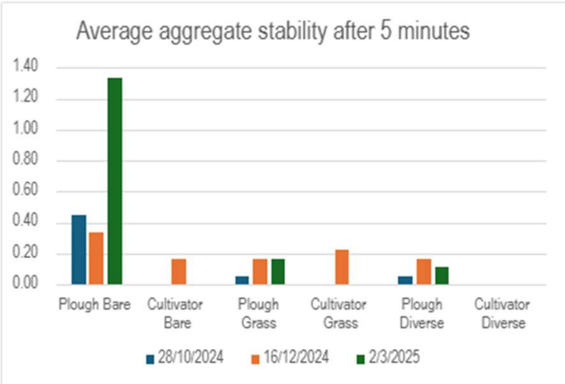
Aggregate Stability

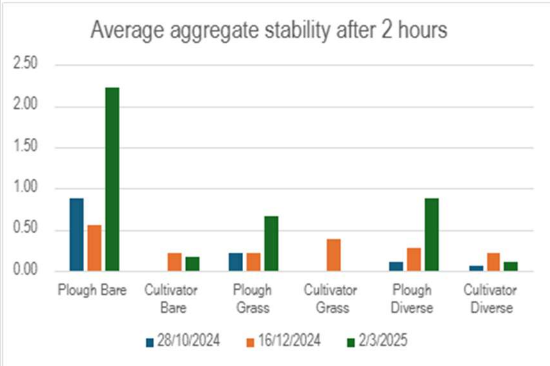
Aggregate stability is a measure of how well the soil holds together when saturated with water. This can be used to infer soil organic matter content as soil organic matter holds soil particles together. It can also be used as an indicator of soil erosion, as low stability soils have a greater risk of erosion.

To measure aggregate stability, three lumps of soil were taken from three points in each trial plot. These were air dried and then submerged in water. The soil was scored after five minutes and again after two hours. The scoring system is as follows:

- 0 – soil remains intact
- 1 – soil crumbles around the edges

- 2 – soil breaks into angular pieces
- 3 – soil slumps into a pyramid
- 4 – soil has completely disintegrated





Figures 10 and 11. Change in average aggregate stability

Ploughed bare soil had the worst aggregate stability, and this got worse through the winter. Covered plots had much better aggregate stability. This suggests that the ploughed bare soil is at the greatest risk of erosion, and that ensuring plant cover remains after harvest is a useful strategy to reduce soil erosion and protect soil organic matter.

Soil Organic Matter and Nutrient Analysis

Soil organic matter analysis was completed from samples taken in replicate post-harvest on 25/10/2024, the results are shown below in Table 6. There are differences in soil organic matter across all fields, but the indication is that the disc cultivation side had higher organic matter than the ploughed areas. There were no differences in soil P and K indexes.

Table 6 - Soil organic matter analysis of trial plots

	Undersown treatment	sample 1	Sample 2	mean of plot samples	Trial means
Cultivated	Grass	7.7	8.2	7.95	
Cultivated	Diverse	9	8.6	8.8	
Cultivated	Bare	8.5	8.2	8.35	8.37
Plough	Grass	8.2	8.3	8.25	
Plough	Diverse	8.6	8	8.3	
Plough	Bare	7.7	8.1	7.9	8.15

Grass growth

Having been sown on 4th of July into a standing maize crop, grass growth appeared to be poor at harvest (Picture 3 23/10/2024) but post-harvest, the undersown grass grew well and produced more biomass than the rye drilled in October. (Picture 4 3/2/2025). The rye cover crop on the left drilled in October did eventually offer some cover (photo 5 taken 28th March 2025).

Picture 3. Harvest 23/10/2024

Picture 4. Rye and grass growth 3/2/2025

Picture 5. Rye and grass cover crops 28/3/2025

However, this was much later than the undersown grass so the benefits will not have been as substantial in terms of protecting the bare ground from the effects of winter rainfall. The importance of ground cover in the high- risk period during November, December and January is critical.

Economic Considerations

The cost of cultivations is the only difference between the 2 systems, although weed control costs may vary between disc cultivations where weeds may not be killed, and ploughing where they are buried and generally killed. Comparisons of contractor charges are best to account for the differences and from the NAAC National Association of Agricultural Contractors guide Farmers Weekly April 2025 costs are

	Plough	Disc
Plough –light land	79.21	
Power harrow-deep	82	
One pass tillage train		83.63
Drill-maize precision drill	60.63	24.54
Total	221.84	144.26

Overall, use of a disc cultivation system, provided a good seedbed can be achieved with one pass, will result in a saving of £77.58 per hectare.

5 Conclusions

One of the reasons to carry out this trial was to address the concerns that it was farm practices, rather than the maize crop itself, which are the cause of soil erosion issues associated with maize: The poor and unstable soil structure left after ploughing and power harrow-based establishment, which capped following rain preventing water infiltration, the wide rows creating channels for water to flow, and the bare ground left after harvest which following harvest equipment and trailers can be rutted and compacted again reducing infiltration and risking erosion.

The trial has shown that maize is not a crop dependent on ploughing and that yields, and quality are not influenced by cultivation system provided an adequate seed bed is created. It has also shown that disc cultivations, strip till or direct drilling can be adopted even in soils which have been regularly ploughed and intensively cultivated, and the benefits also have a legacy effect benefitting soil in later years.

It has also shown that undersowing with grass does not affect crop yield but does influence infiltration and erosion risk post-harvest and demonstrates why it should be caried out where maize follows maize or before spring crops. The increased biomass present when sown into a standing maize crop, shows why this is a better option than planting post-harvest, whilst also providing potential grazing overwinter or early spring. The presence of grass at harvest, even at low levels can increase soil resilience, reduce level of compaction from trailers and reduce the erosion risk if there is heavy rain post-harvest.

6 Effect on Farm Emissions

The reduction in fuel use reduces the emissions associated with planting the crop as well as reducing the cost of production. Any form of cultivation causes loss of soil organic matter and both disc cultivation and ploughing will result in SOM loss, with ploughing and power-harrow cultivating likely to be worse.

However, the improved soil structure will result in less intensive cultivations in future years giving further reductions in costs and emissions.

7 Recommendations & next steps

The Barretts (triallists) and University of Plymouth will continue to monitor soil health associated with different establishment methods.

Catharine and Malcolm Barrett, supported by Soil Association, have produced a technical film for farmers to share their experiences of non-ploughed maize. This will be available from the Innovative Farmers website and Farm Net Zero website when complete.

8 Acknowledgements

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We would like to thank:

The farmers who took part in the trials

The Barretts who have been generous in their time sharing their experiences and filming a technical guide

University of Plymouth for their soil sampling

Alex Bebbington for his part in the Duchy trials including soil sampling

Anthony Baggaley Duchy College farm manager here at the time of the trial, and the Duchy College farm team, and Alex Hollands who has taken over as farm manager

Tamar Agri Ltd – the contractors who put up with our requests

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Beth Wallace – Duchy College HE Agriculture student for soil sampling over the winter.

Southwest seeds -for advice and supply of grass seed

Rob Ayres-Nickerson's for advice and support

Appendix 1: More detailed soil report from The University of Plymouth team

Students and researchers from the University of Plymouth took soil samples and utilised emerging technology to analyse the legacy effects of the field trials in May 2024, after the next crop had been drilled. Soil sampling permitted assessment of the different strip-till drilling techniques on a range of soil health indicators, including organic matter, organic carbon, nitrogen, moisture, penetrometer resistance (compaction), aggregate stability, and microbial activity.

However, due to a positioning issue with What3Words when sampling was undertaken, no samples were collected from the control or direct drill only plots. Spatial surveys using state-of-the-art gamma sensing technology provided an insight into the field-scale legacy effects of the different treatments.

Soil Organic Matter (SOM) and Soil Organic Carbon (SOC)

Soil organic matter is vital for healthy, productive soils as it performs myriad functions including improving soil structure, infiltration, water retention, and reducing erosion risk, as such, it is an important soil health indicator. Soil organic matter is primarily made of carbon (58%) making soil organic carbon an equally good soil health indicator and also provides a means to measure the carbon sequestering potential of min-till practices. Soil organic matter and soil organic carbon were analysed by loss on ignition (LOI) and Dumas, respectively.

Both soil organic matter and soil organic carbon values were significantly higher in the strip-till Mzuri drill plots than the strip-till Maize drill plots (Fig. 1; Table 1). The higher values could be attributed to the lower soil disturbance prioritised by the Mzuri system but could also reveal the legacy effects of different treatments during previous FNZ trials.

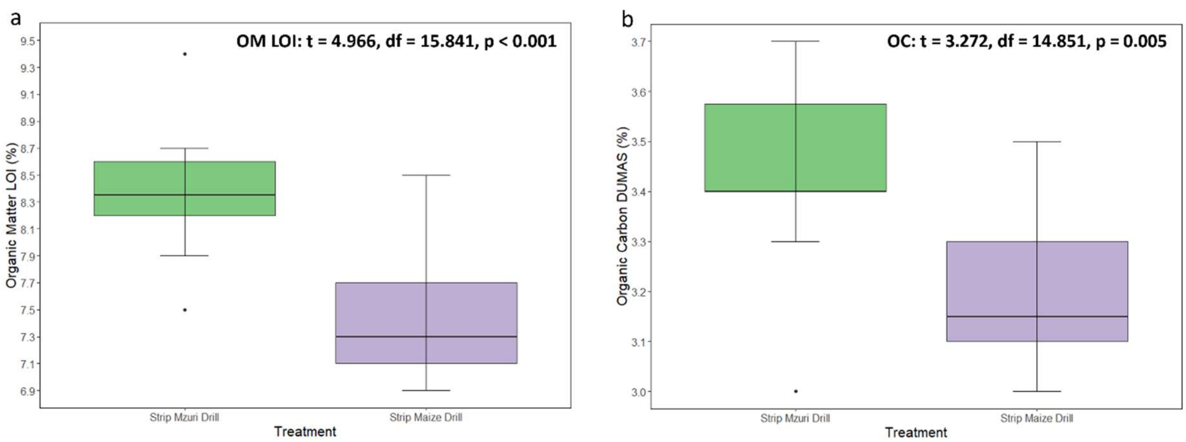

Figure 1. Distribution of (a) soil organic matter (LOI) and (b) soil organic carbon (Dumas) values across the two different strip-till drilling treatments. Green: Mzuri drill, purple: Maize drill.

Nutrient Analysis

Significantly higher values of potassium (K), magnesium (Mg), and total nitrogen (TN) were identified in the strip-till Mzuri drill plot compared to the strip-till Maize drill plot. No difference was found in soil phosphorus (P) levels (Table 1). For differences to be attributed to the different drilling treatments it would be necessary to obtain a full amendment history of the field detailing whether both treatments received the same amendments, if any, during this trail and what was applied to the field during the previous FNZ trial.

Table 1. Nutrient analysis of treatment plots. Mean values for phosphorus (P), potassium (K), and magnesium (Mg) in ppm. Mean values for total nitrogen (TN), total organic carbon (TOC), and organic matter (OM) in %.

	P	K	Mg	TN	TOC	OM
ST Maize Drill	23.8	100.7	89.2	0.358	3.2	7.4
ST Mzuri Drill	21.5	171.7	100.3	0.385	3.4	8.4

Gravimetric Soil Moisture and Aggregate Stability

Gravimetric soil moisture is the mass of water per mass of soil (i.e., grams of water per gram of soil). Soil water-holding capacity and organic matter are positively correlated; therefore, we would expect the treatment with higher organic matter content to have higher gravimetric soil moisture values. This was indeed the case, the strip-till Mzuri drill plot was found to have higher mean gravimetric soil moisture percentages than the strip-till Maize drill plot (Fig 2a).

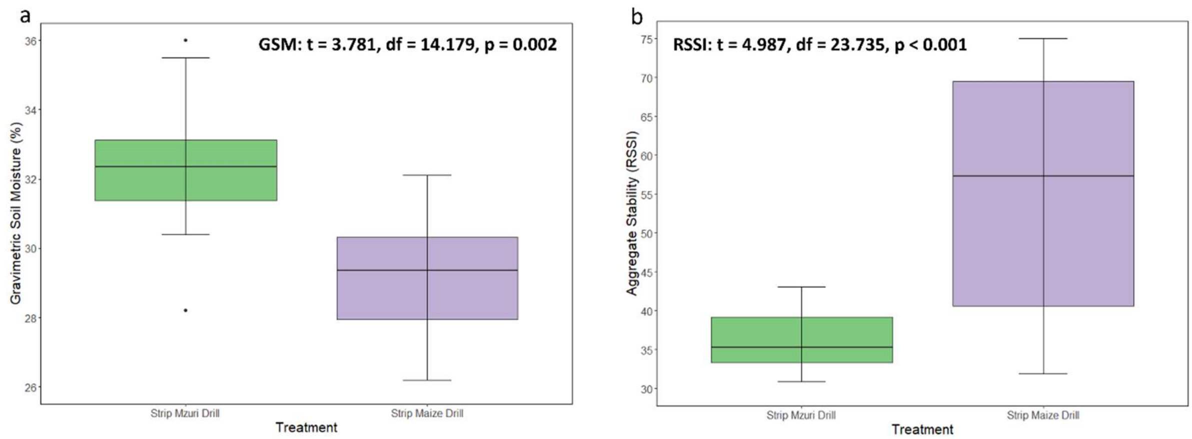

Figure 2. (a) Distribution of gravimetric soil moisture percentages, and (b) rainfall simulation survivability index (RSSI) scores describing how well soil particles hold together when

subjected to a controlled rainfall event across the two different strip-till drilling treatments. Green: Mzuri drill, purple: Maize drill.

Soil moisture and soil structure are intrinsically linked. Soil structure regulates the passage of water and soils with good structure can store more infiltrated water. The higher levels of organic matter and the greater water-holding capacity of the strip-till Mzuri drill plots suggest that the soil aggregates in this treatment should be more stable and resistant to rainfall than those in the strip-till Maize drill plot.

However, the opposite pattern was observed (Fig. 2b). The Rainfall Simulation Survival Index (RSSI) measures the stability of soil aggregates under simulated rainfall conditions. The index is used to understand erosion potential and the soil's ability to withstand erosion caused by heavy rainfall, with a higher survival index indicating greater aggregate stability and a lower risk of erosion. The strip-till Maize drill plot had a higher survival index and a much broader spread of values than the Mzuri drill plot.

This result was unexpected and may reflect the uneven sample size between treatments. It could also be an artifact of sampling, by chance, a greater proportion of disaggregated soil following the newly prepared seed bed, or disproportionate sampling of row compared to interrow, in one treatment than the other. Further investigation would be needed to ascertain whether this was a trend, an artifact of sampling, or due to legacy effects of previous trail participation.

Soil Microbiology

Analysis of soil microbiology showed that the strip-till Maize drill treatment had a significantly higher fungi:bacteria ratio and greater fungal hyphal diameter than the strip-till Mzuri drill treatment (Fig 3c). Fungi, in particular their hyphae, bind soils by physically enmeshing the soil particles which increases the formation and stability of micro- and macro-aggregates. The presence of more fungi and greater hyphal diameter in the strip-till Maize drill treatment likely explains the greater aggregate stability of the soil in this treatment.

In contrast, the strip-till Mzuri drill treatment had significantly higher total bacteria values (Fig. 3a). Anaerobic bacteria tend to initially dominate in min- and no-tillage systems due to a lack of plough induced soil aeration. It is unlikely that the different microbial assemblages between treatments are a result of differences in drilling methods as both methods are low disturbance and instead may point to the existence of legacy effects of previous trial participation.

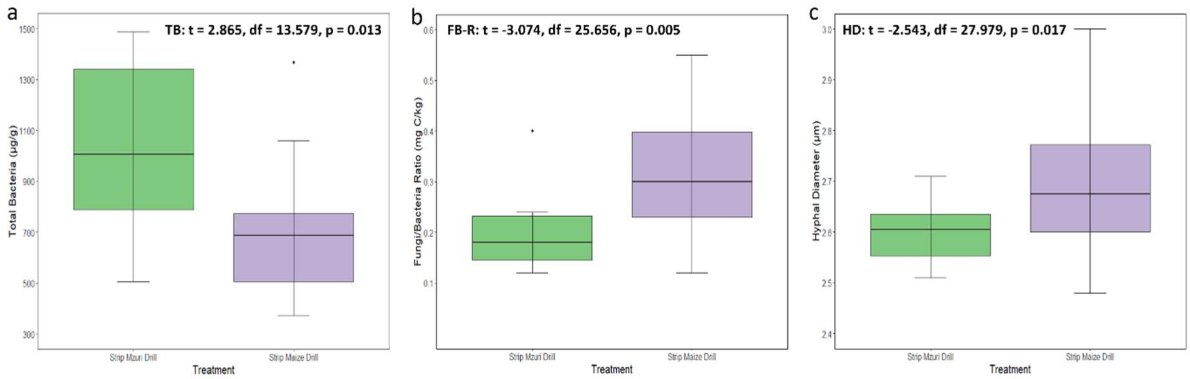

Figure 3

Penetrometer Resistance

Soil penetrometer resistance can be used to measure soil compaction. Penetration resistance is the force required to move a specially tipped metal rod through the soil. The resistance value is comparable to the force required for a plant root to grow through the soil. Root penetration is usually restricted around 300 PSI.

Analysis of the two treatments revealed significant differences in penetrometer resistance at 5-10 cm depths (Fig. 4). The strip-till Mzuri drill plot was less compacted at this depth compared to the strip-till Maize drill plot. At all other measured depths (0-5 cm, 10-15 cm, 15-20 cm, and 20-25 cm) no differences were detected. Organic matter generally improves soil structure making it softer and easier for roots to penetrate. Values of organic matter were found to be higher in the strip-till Mzuri plot which may explain the lower level of compaction observed at 5-10 cm. The differences between plots could also be attributed to the different footprints of the two drilling rigs or reveal legacy effects of previous trial participation.

Gamma Spectrometry Spatial Survey

It was possible to explore the legacy effects of previous management decisions using state-of-the-art gamma spectrometry. Gamma spectrometry measures the concentrations of naturally occurring

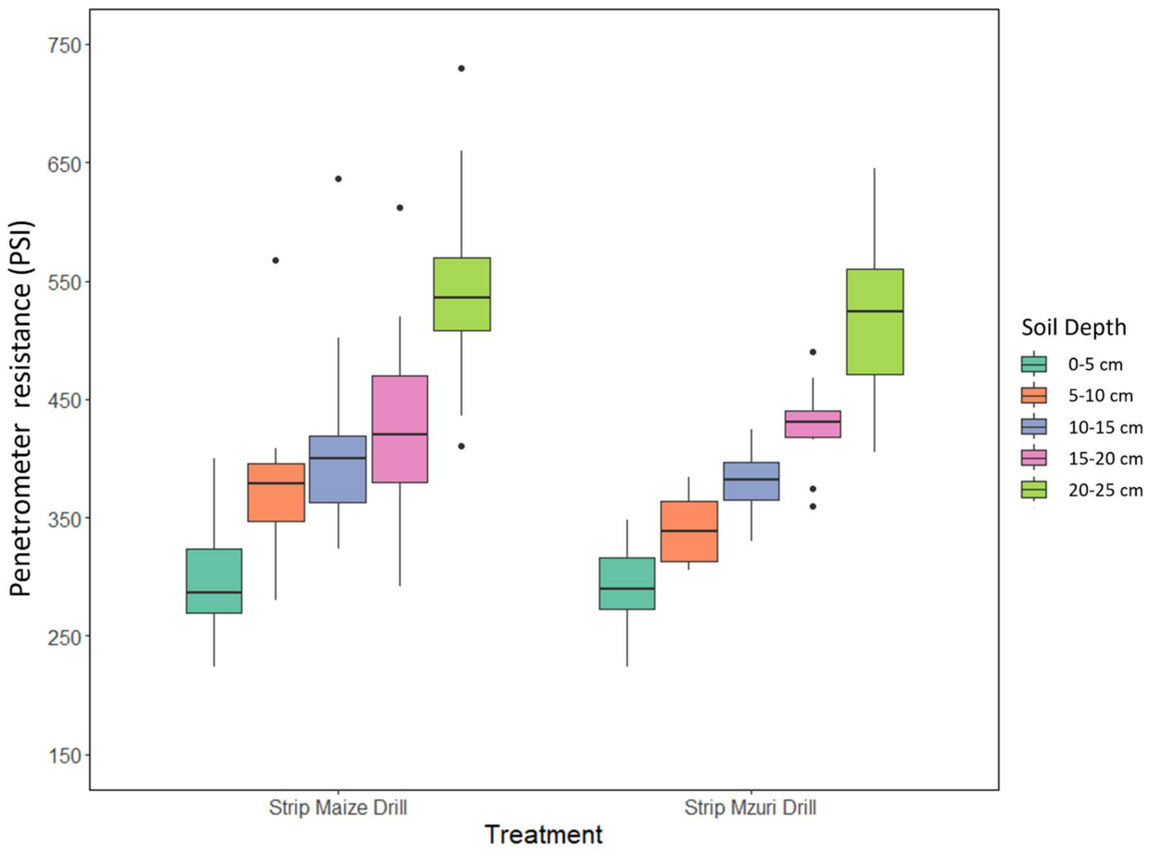

Figure 4. Mean penetrometer resistance of soils at different depths (0-5 cm, 5-10 cm, 10-15 cm, 15-20 cm, and 20-25 cm) across two strip-till treatment plots. Penetration resistance varied significantly between drilling methods at 5-10 cm ($t = -2.240$, $df = 27.999$, $p = 0.033$).

radionuclides including potassium-40 (^{40}K), thorium-232 (^{232}Th), and uranium-238 (^{238}U) which are influenced by land use and other treatments over time. Changes in the distribution of these radionuclides in the soil indicate changes in soil properties caused by past management or land use. Organic matter has been found to have a direct influence on the detection of radionuclide concentrations in the soil. The attenuating effect of organic matter on the gamma signal enables gamma spectrometry to be used as a soil mapping and agricultural decision-making support tool.

Sensor mapping of radionuclide signals picks up the field-scale effects of past management on organic matter. Sensor data places point data from soil samples in the wider context and gives confidence to the lower resolution point data. As seen in Figure 5, there are clear differences in the radionuclide activity concentrations in each half of the field. These differences correspond negatively to the amount of organic matter recorded from the point samples. Areas with higher activity concentrations have lower organic matter, and vice versa.

The clear demarcation of the two halves of the field would suggest that the two halves had been treated differently in the past. It would be useful to have details of the previous trial to see whether, for example, greater soil disturbance occurred on the right side (where organic matter values are lower and activity concentrations are higher) compared to the left side (where organic matter values are higher and activity concentrations are lower). The soil mapping suggests a legacy of past management activity is being detected but further information is required.

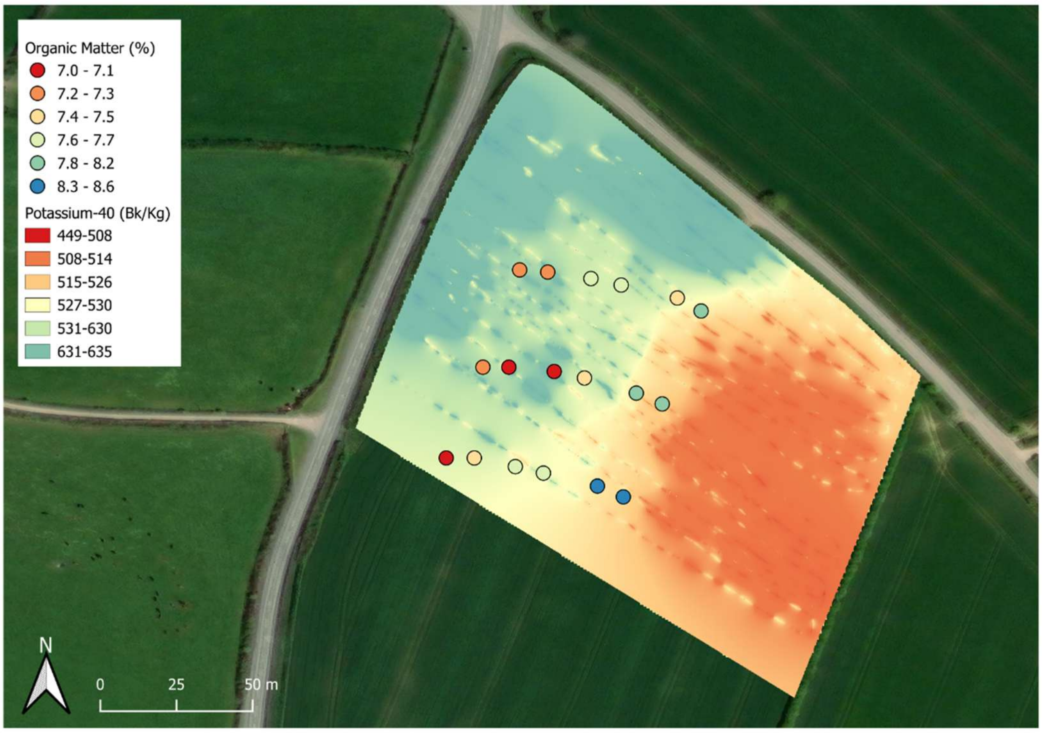

Figure 5. Soil spatial mapping using gamma spectrometry to measure the activity concentrations of potassium-40 (^{40}K) a naturally occurring radionuclide. Higher activity concentrations in blue, and lower activity concentrations in red. Point samples of organic matter (dots) describe a negative relationship with radionuclide activity concentrations and enable extrapolation of point data to the wider field context.