Alternative tillage practice for establishing maize silage and reducing soil nitrogen mineralisation

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Abstract

Intensive cultivation practices require significant energy inputs and repeated working of the soil, ultimately resulting in a breakdown of soil structure. Nitrogen (N) mineralization can also be extremely high in these situations, especially following permanent pasture. Where this nutrient release exceeds the demand of the subsequent crop it can create an environmental risk. Four field trials were undertaken in farm paddocks to determine if strip tillage, a reduced cultivation approach, could be used to establish maize silage and reduce soil N mineralisation. Trials were conducted in two seasons (2007-08, 2008-09). At each site strip tillage (ST) was compared to conventional tillage (CT). There were 4 or 6 replicates of each treatment. Tillage practice had no significant effect on mean plant spacing at any site. There was also no effect of tillage practice on silage yield at harvest; across sites, yields averaged 22.6 t DM ha^{-1} and 23.0 t DM ha^{-1} for the ST and CT treatments, respectively. The dry matter (DM %) content averaged 35% across treatments and sites. Early in the season, soil minN levels were often significantly ($P<0.01$ to 0.08) lower under ST. This was due primarily to lower minN in the mid-row of ST plots than in the mid-row of CT plots (reflecting differences in cultivation in this zone). An estimation of the balance of minN supply during the season (accounting for soil N prior to cultivation and at harvest, fertiliser N, and plant N in the harvested silage) indicated less minN was released under ST. Thus ST appears to have good potential as an alternative approach to establish maize silage and to reduce soil N mineralisation.

Additional keywords: Strip tillage, conventional tillage, forage, *Zea mays*

Introduction

Maize rotations typically include a grass phase, the length of which can vary considerably. This can be as short as six months in continuous cropping systems and up to several years in mixed arable-pastoral systems. The restorative benefits of grass phases on soil quality are well documented in New Zealand (Haynes and Beare, 1997; Francis *et al*., 1999). However, during the conversion of pasture back into cropping, soils are often exposed to intensive cultivation practices. Such practices require significant energy inputs and repeated working of the soil, increasing the rate of organic matter decomposition and ultimately resulting in a loss of soil structure. Mineralisation of nutrients such as nitrogen (N) can also be very high in these situations. Recent work in the Waikato has shown that > 300 kg N ha^{-1} can be released in the first year following cultivation of permanent pasture (Johnstone *et al*., 2009). Where such mineralisation exceeds crop N demand (approximately 200-250 kg N ha^{-1} in maize), it can be both a waste to the farmer and pose an environmental risk. One alternative to manage paddocks coming out of pasture is to adopt a reduced cultivation approach such as strip tillage (ST). Strip tillage significantly reduces the area of land that is cultivated compared with conventional approaches, offering a number of agronomic and economic benefits (Hoyt *et al*., 1994; Vetsch *et al*., 2007; Overstreet and Hoyt, 2008). Work over the past decade across the North Island of New Zealand has shown that reduced tillage practices often have no adverse affect on yield or profitability of row crops like maize, sweet corn, squash and peas (Reid *et al*., 2001; Pearson and Wilson, 2002; Searle and Hosking, 2007). These findings are largely consistent with those reported overseas, where the practice is widely used. In maize, many studies have shown that no yield penalty associated with ST, and that gross margins are often improved as a result of reduced cultivation (Al-Kaisi *et al*., 2005; Licht and Al-Kaisi, 2005; Vetsch *et al*., 2007; Archer and Reicosky, 2009). This project was undertaken to demonstrate to farmers that ST can be used to establish maize silage and reduce soil N mineralisation.

Materials and Methods

Background

Four trials were conducted in farm paddocks in two seasons (2007-08, 2008-09). Paddocks were located in central Hawke's Bay and Waikato. All had been in pasture for varying durations (6 months up to 30+ years) and were sprayed off with herbicide approximately 1-4 weeks prior to cultivation.

Trial design and crop management

In each paddock, areas were set up to compare a conventional tillage (CT) approach with ST. Conventional tillage at all sites was by a single plough pass followed by power harrow (Sites 1 and 4), discs (Site 2), or roll only (Site 3). The effective cultivation depth under CT was approximately 20-30 cm. Strip tillage was by a modified power harrow (Site 1) or either a single (Site 2) or double pass (Sites 3 and 4) with a mole knife implement (the cultivated strip was 33 cm wide at Site 1 and 15 cm wide at Sites 2-4). The effective cultivation depth under ST was approximately 15-25 cm. Row spacing at all sites was 76 cm. Experimental design was a randomised complete block at Sites 1 and 4 comparing the two tillage treatments (CT and ST) each replicated 4 or 6 times. Individual plots were eight rows wide by at least 10 m in length. Sites 2 and 3 were larger demonstration trials. Six or nine paired plots were established for each treatment, each plot was eight rows wide by 10 m long. With the exception of tillage practice, each crop was grown according to the farmer's standard practice. Sites 2 and 3 were irrigated as required by centre pivot. A summary of important crop and management details is provided in Table 1.

Background measurements

Prior to cultivation, intact cores were collected from the trial area to determine soil bulk density. Sampling depth was either 0-15 cm (Sites 1-3) or 0-35 cm (Site 4). Basic soil fertility indicators (soil pH, Olsen P, exchangeable cations, CEC and base saturation) were measured on a composite sample of 20 cores collected at sowing. Sampling depth was 0-15 cm. In general, basic soil fertility indicators at sowing were interpreted as sufficient for maize production (Table 2). There were no major weed or pest and disease issues at any trial site. Growing conditions in both regions were favourable during each season; mean daily temperature and radiation levels were high during the most active periods of plant growth (November-February). Soil moisture was good at Sites 1 and 4 due to regular rainfall; irrigation was applied as required at Sites 2 and 3.

Table 1: Crop and management details of the four trial sites, 2007-09.

Site	Site 1	Site 2	Site 3	Site 4
Region	Hawke's Bay	Hawke's Bay	Hawke's Bay	Waikato
Soil type	Flaxmere sandy loam	Takapau sandy loam	Takapau sandy loam	Otorohanga silt loam
Pasture history[1]	20 years	<1 year	<1 year	>30 years
Conventional tillage approach	Plough, power harrow	Plough, discs	Plough, roll	Plough, power harrow
Strip tillage approach	Modified power harrow	Mole knife	Mole knife (x2)	Mole knife (x2)
Maize hybrid	39K38	38H20	39F58	36M28
Sowing rate (# ha^{-1})	108,000	115,000	105,000	105,000
Planting date	4 Nov 2007	16 Nov 2007	18 Nov 2008	18 Nov 2008
Fertiliser at sowing[2]	150 kg DAP ha^{-1}	200 kg DAP ha^{-1}	200 kg DAP ha^{-1}	Nil
In-season fertiliser[3]	190 kg Urea ha^{-1}	200 kg Urea ha^{-1}	225 kg Urea ha^{-1}	Nil
Harvest date	25 Mar 2008	2 Apr 2008	15 Apr 2009	26 Mar 2009

[1]Sites 1 and 4 had been in long-term perennial grass with regular dairy grazing, whereas Sites 2 and 3 had been in short-term annual grass with regular cropping. [2]DAP (diammonium phosphate) contains 18:20:0 NPK. [3]Urea is 46:0:0 NPK.

Table 2: Soil fertility characteristics at sowing of the four trial sites, 0-15 cm[1].

Site	Site 1	Site 2	Site 3	Site 4	Medium range
Soil pH	5.9	5.8	5.5	6.2	5.6-6.4
Olsen P (mg l^{-1})	9	19	15	42	14-30
MAF K	5	8	3	15	8-15
MAF Ca	10	10	4	11	5-10
MAF Mg	29	15	6	18	10-16
MAF Na	6	11	6	7	1-10
CEC (me 100 g^{-1})	15	20	18	22	12-25
Base saturation	70	53	29	62	50-85
Organic matter (%)	5.1	9.6	14.3	7.9	7-12
Bulk density (g cm^{-3})	1.23	1.03	1.03	1.14	

[1]Soil test results do not include starter fertiliser where applied.

Crop measurements

Mean plant spacing was determined at all sites approximately four weeks after sowing (WAS). For this measurement, two 4 m sections of adjacent rows were marked in each plot, and the distance between each individual plant recorded. Mean plant spacing and standard deviation estimates were derived from these figures. At Sites 3 and 4 whole plant (above-ground only) samples were collected from all plots 4, 8 and 12 WAS. In each instance a composite of 10 plants was randomly selected. Plant dry biomass, total N concentration and N uptake were calculated. Silage yields were determined at each site at commercial maturity (after kernels had reached a ⅔ milk line). For this measurement, two 2.5 m-sections of adjacent rows were harvested from each individual plot. Plant population and total standing plant biomass were determined. A sub-sample of mulched silage was collected from all plots and analysed for DM content (% DM) and total N concentration, and crop N removal was estimated.

Soil nitrogen measurements

At Sites 3 and 4 soil mineral N (minN, the sum of nitrate-N and ammonium-N) was measured at sowing, and at 4, 8 and 12 WAS, and at harvest. At sowing four cores were collected from within the plant row and four from the mid-row of each individual plot. On subsequent dates only two cores were collected from each sampling position. Sampling depth was either 0-30 cm (Site 3) or 0-60 cm (Site 4). The shallower samples taken at Site 3 was due to a stony subsoil layer below 30 cm. Samples were analysed separately by plant and mid-row positions for both tillage approaches (CT and ST); the exception to this was at sowing, when plant and mid-row positions under CT were composited. A weighted mean was calculated for the ST plots to reflect the proportion of row width that was and was not cultivated (as represented by the plant and mid-row, respectively). At Site 1 soil minN was only measured prior to cultivation (a composite from across the trial area, 0-60 cm) and at harvest (by each individual plot, as described for Sites 3 and 4). Soil minN was not followed at Site 2.

Statistical analyses

Relevant data were analysed using a one-factor ANOVA. Significance values were recorded where $P<0.10$ values between 0.05 and 0.10 are considered weakly significant and should be interpreted with appropriate caution. Values of P above 0.10 were considered not significant (ns). Least Significant Difference (LSD) values were calculated to separate treatment means and were based on a P value < 0.05.

Results and Discussion

Crop performance

There was no significant effect of tillage practice on mean plant spacing at any site (Table 3). However, at two sites variation around the mean spacing (indicated by the standard deviation) was significantly higher ($P<0.03$ to 0.09) under ST. This appeared to reflect seed placement issues related to cloddy seed beds under ST. Despite these observations, there was no significant effect of tillage practice on silage yield at any of the four sites. Across sites the average silage yield was 22.6 t DM ha^{-1} and 23.0 t DM ha^{-1} for the ST and CT respectively. Individual plant biomass was also unaffected by tillage practice, indicating that plants reached similar biomass potentials. Dry matter content was largely unaffected by tillage practice. The exception to this was at Site 2, where DM was significantly higher under ST than CT. The practical importance of this effect appeared minor as the difference was small (< 2% DM) and could be accounted for by delaying harvest until these plots had achieved a higher DM. The ideal range for ensiling maize silage is between 32 and 38%. Total N concentration in the harvested maize silage was unaffected by tillage practice and ranged from 0.8 to 1.1% across sites.

Soil nitrogen mineralisation

At Sites 3 and 4 soil minN increased rapidly after cultivation before declining steadily due to plant N uptake (Table 4). Weighted soil minN levels (accounting for the separate results from mid-row and plant row positions) were significantly lower in ST plots 8 WAS at Site 3 and at sowing and 4 WAS at Site 4. Although side dressing with N fertiliser (104 kg N ha^{-1}) at Site 3 would have influenced soil minN results at 8 WAS, there is little reason to expect that the broadcast application would have affected observations made under each tillage practice differently. At both sites, lower soil N levels under ST were primarily due to less minN in the uncultivated mid row of the ST plots than in the cultivated mid row of the CT plots (Figure 1a). Generally, soil minN levels in the plant row of CT and ST plots were not significantly different during the season (Figure 1b). The exception to this was at 12 WAS at both sites, though the importance of these observations is not clear as the difference between treatments was relatively small (9-24 kg N ha^{-1}). In general, then, tillage intensity resulting from the two approaches (i.e. mole knife compared with ploughing) had little impact in this zone. The effect of tillage practice on residual soil N at harvest was not strong at any site. At Site 1 there was considerable variability in soil minN, limiting statistical analyses. At Site 3 the difference in residual N at harvest, though weakly significant, was comparatively small (28 kg N ha^{-1}). At Site 4, this observation appeared to be confounded by significantly higher plant N uptake under CT. In general, reduced cultivation will lower mineralisation rates (Johnson and Hoyt, 1999); this has been highlighted in many studies where soil minN is higher under CT than with no- or reduced-tillage approaches (Catt *et al*., 2002; Pearson and Wilson, 2002).

At Sites 1, 3 and 4 a simplified N balance was estimated for CT and ST. For this calculation, the sum of plant N and soil minN at harvest was adjusted for minN of the uncultivated soil; these uncultivated samples were representative of 'baseline' soil minN levels in each paddock, and were taken either prior to cultivation at Site 1 or from the uncultivated mid-row of the ST plots at sowing at Sites 3 and 4. Fertiliser N was also subtracted where applied (equivalent to 87 kg N ha^{-1} at Site 1 and 140 kg N ha^{-1} at Site 3). Using this approach, net mineralisation during the cropping season for the CT and ST plots respectively was estimated to be 188 kg N ha^{-1} and 90 kg N ha^{-1} (Site 1, $P<0.08$), 134 and 105 kg N ha^{-1} (Site 3, $P<0.01$), and 288 and 232 kg N ha^{-1} (Site 4, $P<0.04$). These estimates assume that there was minimal leaching and volatilization loss of either soil-generated N or fertiliser-supplied N and that there was a minimal supply of N from below the major rooting depths (60 cm at Sites 1 and 4, and 30 cm at Site 3). The large difference among sites in their ability to mineralise N during the season appeared likely to reflect the combined influence of different durations under pasture (up to 30 years at Site 4 and less than 1 year at Site 3), pasture quality (very poor at Site 1) soil type and depth, and local environmental conditions (particularly soil temperature and soil moisture). Collectively, these factors determine the potential N pool in the soil and its subsequent rate of release following cultivation.

Conclusions

Collectively, findings from both seasons suggest that ST has potential as an alternative approach to establish maize silage and reduce soil minN after pasture. This work confirmed that N mineralisation can vary significantly depending on cultivation approach. Current tools used by farmers to predict N requirements of maize (e.g. AmaizeN) do not account for this factor when generating recommendations. This may result in inaccurate predictions of soil N supply, ultimately reducing farmer profit. Until cultivation approach is incorporated into such programmes, farmers should consider collecting a representative soil minN sample from the paddock shortly before making in-season N fertiliser decisions. These test results can be entered into AmaizeN to provide the best estimate of what is currently available and ensure that crops are not N deficient.

Table 3: Effect of tillage practice on mean plant spacing and standard deviation at 4 WAS and on crop performance indicators at harvest, all sites.

	Mean plant spacing (cm)[1]	Standard deviation (cm)[2]	Silage yield (t DM ha^{-1})	Individual plant dry biomass (g $plant^{-1}$)	Dry matter content(%DM)	Total N conc.(%N)
Site 1						
CT	12.5	5.5	24.3	232	42	0.8
ST	13.4	6.2	22.9	221	43	0.8
P-value[3,4]	ns (1.8)	ns (2.7)	ns (3.3)	ns (33)	ns (6)	ns (0.2)
Site 2						
CT	11.6	5.2	20.9	187	28	1.1
ST	12.0	5.5	20.9	198	30	1.1
P-value	ns (2.4)	ns (1.9)	ns (1.4)	ns (20)	0.01 (1)	-[5]
Site 3						
CT	13.0	4.3	18.7	187	37	1.1
ST	13.7	5.8	19.5	190	36	1.1
P-value	ns (1.4)	0.09 (1.9)	ns (2.3)	ns (30)	ns (2)	ns (0.1)
Site 4						
CT	12.6	4.2	28.1	266	33	1.0
ST	12.8	5.4	26.9	254	33	0.9
P-value	ns (0.8)	0.03 (1.1)	ns (2.4)	ns (35)	ns (2)	ns (0.2)

[1]Each farmer's target sowing rate was equivalent to 108,000 plants ha^{-1} (12.2 cm), 115,000 plants ha^{-1} (11.4cm), 105,000 plants ha^{-1} (12.5cm) and 105,000 plants ha^{-1} (12.5cm) at Sites 1-4, respectively. [2]66% of plants had a mean spacing ± the standard deviation. [3]ns = not statistically significant at P<0.10. Values between 0.05 and 0.10 are considered weakly significant and should be interpreted with caution. [4]LSD values are provided in parentheses and represent the smallest difference necessary between two means for a statistically significant test result (P<0.05). [5]Total N data were not replicated at Site 2.

Table 4: Effect of tillage practice on soil mineral N (minN) and plant N uptake during the season, Sites 1, 3 and 4.

	Sampling occasion									
	Precult.[1]	Sowing	4 WAS[2]		8 WAS		12 WAS		Harvest	
	Soil minN[3]	Soil minN[3]	Soil minN[3]	Plant N uptake[4]	Soil minN[3]	Plant N uptake[4]	Soil minN[3]	Plant N uptake[4]	Soil minN[3]	Plant N uptake[4]
Site 1										
CT	51								131	195
ST									50	179
P-value[5,6]									ns (145)	ns (32)
Site 3										
CT	20	27	78	3	195	83	69	164	83	211
ST		21	71	4	120	90	74	181	55	210
P-value		ns (9)	ns (31)	0.01 (<1)	0.01 (21)	ns (17)	ns (41)	ns (48)	0.09 (33)	ns (26)
Site 4										
CT	75	131	197	29	49	155	51	175	69	294
ST		84	155	27	60	129	49	174	59	248
P-value		0.03 (38)	0.08 (48)	ns (7)	ns (19)	ns (39)	ns (8)	ns (101)	ns (21)	0.06 (47)

[1]Precultivation soil minN was taken either prior to cultivation at Site 1 or from the uncultivated mid row of ST plots at sowing at Sites 3 and 4. [2]WAS = weeks after sowing. [3]kg N ha^{-1}, 0-60cm. [4]kg N ha^{-1}. [5]ns = not statistically significant at $P<0.10$. Values between 0.05 and 0.10 are only weakly significant and should be interpreted with caution. [6]LSD values are provided in parentheses and represent the smallest difference necessary between two means for a statistically significant test result ($P<0.05$).

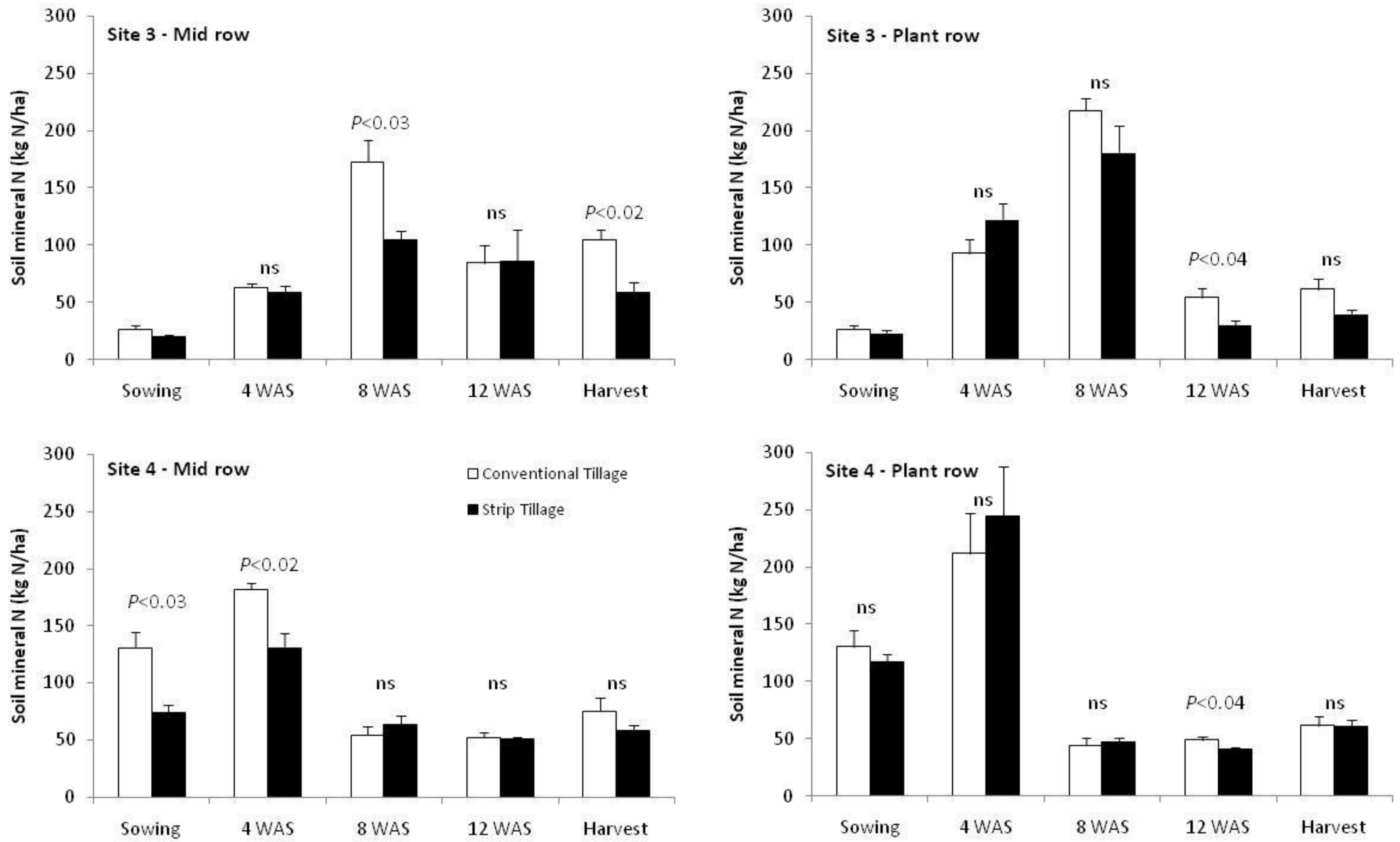

Figure 1: Effect of tillage practice on soil mineral N at sowing, at 4, 8 and 12 WAS, and at harvest in the mid-row and plant row separately (Site 3 and 4 only). Vertical bars indicate standard error. P-values represent the ANOVA outcome on the effect of tillage practice on each individual sampling zone separately; ns = not statistically significant. No means separation is provided at sowing at either site because the mid row and plant row results of the CT plots were composited. Seasonal N fertiliser application was equivalent to 140 kg N ha^{-1} (Site 3) and 0 kg N ha^{-1} (Site 4).

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