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The effect of tillage system and residue management on grain yield and nitrogen use efficiency in winter wheat in a cool Atlantic climate

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ABSTRACT

The effects of soil tillage and straw management systems on the grain yield and nitrogen use efficiency of winter wheat (*Triticum aestivum* L. em. Thell.) were evaluated in a cool Atlantic climate, in central Ireland between 2009 and 2011. Two tillage systems, conventional tillage (CT) and reduced tillage (RT) each with and without incorporation of the straw of the preceding crop, were compared at five levels of fertiliser N (0, 140, 180, 220 and 260 kg N ha^{-1}).

CT had a significantly higher mean grain yield over the three years but the effect of tillage varied between years. Yields did not differ in 2009 (Year 1), while CT produced significantly higher grain yields in 2010 (Year 2), while RT produced the highest yields in 2011 (Year 3). Straw incorporation had no significant effect in any year.

Nitrogen application significantly increased the grain yields of all establishment treatment combinations. Nitrogen use efficiency (NUE) ranged from 14.6 to 62.4 kg grain (85% DM) kg N ha^{-1} and decreased as N fertiliser rate was increased.

The CT system had a significantly higher mean NUE over the three years but the effect of tillage varied with years. While there was no tillage effect in years 1 and 3, CT had a significantly higher NUE than RT in year 2. Straw management system had minimal effect on NUE in any year.

The effect of tillage and N rate on soil mineral N content also varied between years. While there was no tillage effect in years 1 and 3, RT had significantly larger soil N contents than CT in the spring before N application, and post-harvest in year 2. N application rates had no effect on soil N in year 1, increased residual N content in year 2 and had an inconsistent effect in year 3. Straw management had no significant effect on soil mineral N content.

These results indicate that RT establishment systems can be used to produce similar winter wheat yields to CT systems in a cool Atlantic climate, providing weather conditions at establishment are favourable. The response to nitrogen is similar with both tillage systems where the crop is successfully established. Straw management system has very little effect on crop performance or nitrogen uptake.

1. Introduction

Wheat (*Triticum aestivum* L. em. Thell. and *Triticum turgidum* L.) is the third most commonly grown crop in the world, grown on over 200 million ha annually (Rajaram and Braun, 2008). In Western Europe, 90% of the total wheat area is planted with winter cultivars. Within this region, an Atlantic climate coupled with applied nitrogen (N) rates in excess of 200 kg ha^{-1}, gives Ireland very high yield potential with mean grain yields from 8.6 to 10.2 t ha^{-1} (CSO, 2011). Despite the high yields, financial returns are increasingly challenged by production costs including crop establishment and nitrogen fertiliser, generating interest in alternative systems that can reduce costs while maintaining high yields.

Tillage, which mechanically manipulates the soil by cutting, shattering, inverting or mixing (Gajri et al., 2002) is an integral part of crop establishment as it affects physical, chemical and biological soil properties. The degree of soil tillage and the resulting location of crop residues influences crop establishment, growth and yield as well as the efficiency in utilisation of fertilizers, pesticides and other inputs (Haakansson, 1994). Tillage can also alter soil properties such as structural stability and organic matter turnover (Rasmussen, 1999; Van Den Bossche et al., 2009).

There is a continuum of tillage systems for the establishment of annual crops, from soil inversion with intensive tillage to no-till systems (Davies and Finney, 2002). Conventional tillage normally

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refers to systems which include soil inversion by ploughing to 175–280 mm, followed by secondary cultivation prior to or in combination with seeding. Conservation tillage, also known as minimum cultivation/tillage and reduced cultivation/tillage refers to the range of non-inversion tillage systems which leaves at least 30% of the soil surface covered with residues after planting (Davies and Finney, 2002; IPCC, 2000). In cool Atlantic climates the use of no-till systems is limited (Morris et al., 2010), and reduced tillage is normally practiced as a stale-seedbed technique where cultivation to 50–150 mm depth following harvest encourages weed and volunteer crop growth, which is controlled by herbicide in advance of seeding with a cultivator drill.

Various studies have shown the effect of tillage systems on soil organic matter (Simon et al., 2009), soil mineral nitrogen content (Stenberg et al., 1999), crop nitrogen uptake and crop performance (Malhi et al., 2006). When practised over a period of 12–15 years, conservation tillage can measurably enhance the quantity and quality of soil organic matter (SOM) in the soil surface layer (Kay and VandenBygaart, 2002; Simon et al., 2009), thereby enhancing the nutrient supplying capacity of a soil by increasing readily mineralisable organic nutrient levels (Van Den Bossche et al., 2009). As a consequence, conservation tillage systems have been shown to achieve higher grain yields than conventional systems with the same N application rate (Grandy et al., 2006; Sip et al., 2009). However, other studies have found that conservation tillage may lead to a more nutrient rich soil surface layer, but require greater amounts of fertiliser N due to the unavailability of soil mineral N to the growing crop. As a result, conservation tillage systems can require larger N application rates to achieve the same grain yield as conventional systems (McConkey et al., 2002). Some studies have found that conservation tillage had no significant effect on the mineral N content of the soil, or the fertiliser N recovery of the crop (Giacomini et al., 2010; Lopez-Bellido and Lopez-Bellido, 2001; Thomsen and Christensen, 2007). The large variation in grain yield and N uptake responses suggests that the effect of different tillage systems depends on the dominant soil type and climatic conditions.

The effect of straw incorporation on the following crop is inconclusive and has been shown to vary with system, location and climate (Coulter and Nafziger, 2008; Malhi and Lemke, 2007). Previous studies by Bakht et al. (2009) and Borresen (1999) reported significantly increased wheat grain and straw yields as a result of straw incorporation. Van Den Bossche et al. (2009) concluded that straw incorporation enhances soil fertility and may reduce fertiliser requirements. In contrast, Christian et al. (1999) reported lower wheat grain yields and Coulter and Nafziger (2008) found increased fertiliser N requirement when straw was incorporated. In addition, the use of tillage systems such as CT that incorporate straw below the seed have been shown to reduce plant height and rate of wheat plant development (Wuest et al., 2000).

Much of the research on the effects of crop establishment system on crop productivity has been conducted in warm, dry climates where periods of crop water stress are frequent (Bakht et al., 2009; Malhi et al., 2006; Sip et al., 2009). Lower soil temperatures, and lower evapotranspiration rates associated with conservation tillage and straw incorporation (Rasmussen, 1999) are beneficial in climatic areas with frequent droughts and low soil organic matter contents. However, in a cool, wet climate, the higher soil moisture and lower soil temperatures associated with conservation tillage establishment systems may have the potential to reduce early crop growth (Riley et al., 2005). The aim of the research described here was to determine the effects of tillage; specifically conventional plough based tillage and reduced tillage system combined with and without straw incorporation on the grain yield and nitrogen use efficiency of monoculture winter wheat in a cool Atlantic climate.

Table 1
Soil characteristics of the experimental site (Knockbeg research farm).[a]

Soil mechanical analysis	Depth (cm)			
	0–30	30–70	70–150	150+
Coarse sand % (2–0.5 mm)	10	7	9	29
Fine sand % (0.5–0.53 mm)	34	30	38	46
Silt % (53–2 μm)	34	43	17	15
Clay % (<2 μm)	22	20	39	9

Soil chemical analysis	
pH	6.6
Phosphorus (mg L^{-1})	9.7
Potassium (mg L^{-1})	59.9
Magnesium (mg L^{-1})	231.3
Copper (mg L^{-1})	6.2
Zinc (mg L^{-1})	4.8
Manganese (mg L^{-1})	424.4

[a] Soil texture class: medium clay loam. World reference base classification: Haplic Luvisol (humic epidystric).

2. Materials and methods

2.1. Site description

The experiment was conducted during the 2009 (Year 1), 2010 (Year 2) and 2011 (Year 3) growing seasons on a winter wheat (*T. aestivum* L. em. Thell.) crop at the Teagasc Crops Research Centre, Knockbeg site (52° 86′ 87 N, −6° 94′ 14 W) near Carlow, Ireland. The soil type is a Haplic Luvisol (humic epidystric) and is a medium textured clay loam of the Mortarstown series (Conry, 1987) (Table 1). Mean annual rainfall and temperature are 840.2 mm and 9.5 °C, respectively. The conventional and reduced cultivation crop establishment and straw incorporation treatments have been applied to the monoculture winter wheat trial plots reported in this paper since the autumn of 2000.

2.2. Treatments and experimental design

The experiment was laid out as a randomised complete block design in a split–split plot arrangement with four replications. The main plot factor was straw treatment: straw incorporated (+S) and straw removed (−S). The split plot factor was tillage treatments: conventional tillage (CT) and reduced tillage (RT). The split–split factor introduced in 2009 was fertiliser N rate (0, 140, 180, 220 and 260 kg N ha^{-1}). Individual tillage (split) plot size was 30 m × 15 m with individual N rate (split–split) plot size being 2.7 m × 15 m. To avoid differences in residual nitrogen carryover, split–split plots were assigned to alternate halves of the split plots in successive years, with the remainder receiving a standard fertiliser N for that year.

The CT plots were ploughed in mid September to 225 mm depth, cultivated with a rotary power harrow to 100 mm on the day prior to sowing, and sown with a cultivator drill fitted with disc coulters (Vaderstad Rapid) in the first half of October (Vaderstad-Verken AB, Hogstadvagen, Vaderstad). The RT plots were cultivated to 70–100 mm with a tine cultivator following the harvesting of the previous crop (mid-August) and consolidated with a ring roller. Re-growth was sprayed with glyphosate three to five weeks later. Seeding was with the same drill on the same date as the CT plots.

Straw from the previous crop was chopped and spread with an on-combine chopper and incorporated into the soil during the cultivation (RT) or ploughing (CT) operations for the +S treatments. Straw was baled and removed from the −S plots.