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Weed development in spring wheat after contrasting soil tillage and nitrogen management

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Summary

Soil tillage and nitrogen (N) management effects on weed specie composition was evaluated in 2013 and 2014 on a clayey soil after 5-years of organic management at the Royal Agricultural University's Harnhill Manor Farm, UK. Three tillage systems – Conventional Tillage (CT), and High and Low Intensity Non-inversion Tillage (HINiT & LINiT) – were compared at four N fertiliser rates of 0, 70, 140 and 210 kg N ha^{-1}. Broad-spectrum herbicide was applied before soil operations across the site in both years. Previous organic management legacy of high weed biomass promoted greater weed prevalence in 2013 while 2-years of herbicide inclusion reduced weed biomass in 2014. Contrasting weather conditions across the seasons affected weed incidence. In the 2014 wet season, early weed dry weight (DM) was higher under HINiT than CT and LINiT, while no differences were observed in the 2013 dry year. At midseason, weed DM was higher under HINiT than CT and LINiT in both years, which was related to higher DM of the dominant weeds *Stellaria media* and *Sinapsis arvensis*. Grass weed DM was higher under non-inversion tillage than CT. N fertilisation increased midseason total weed DM and weed prevalence at harvest. Spring wheat yield was the highest under CT while LINiT produced 17% higher yields than HINiT. Despite higher but still tolerable weed prevalence under both non-inversion tillage systems and with the application of N, weeds alone was not the only yield-limiting factor. However, results show that CT is the most reliable option for weed control in changing weather, while N fertilisation rates needs to be considered.

Introduction

Weed infestation is a major yield-limiting factor for UK wheat production (Turley *et al*., 2003), in particular organic farming (Turner *et al*., 2007; Vijaya Bhaskar *et al*., 2014*a*). Tillage is one of the main methods to reduce weed pressure (Ozpinar, 2006), while it can also prepare an ideal seedbed for crop germination, growth and development (Gajri *et al*., 2002). Tillage often modifies weed abundance and species composition in crops by changing the seed distribution both vertically and horizontally; affecting the seeds viability, emergence and seedling survival (Chauhan, 2013; Håkansson, 2003). Tillage also dismembers vegetative structure of perennial weeds, and thereby stimulates bud growth and depletes their food reserves (Streit *et al*., 2002; Swanton *et al*., 2000). Due to this effect, ploughed soils commonly present a lower incidence of perennial grass weeds compared with less disturbed soils under reduced tillage (Demjanová *et al*., 2009). Inverting soil, however, can relocate buried seeds back to the topsoil (Colbach *et al*., 2006; Håkansson, 2003), often breaking seed dormancy and allowing seed germination, particularly of broadleaf weeds which have greater longevity and marked dormancy (Froud-Williams *et al*., 1983). Under reduced tillage practices, weed seeds are mostly left on the surface and distributed less down the soil profile due to reductions in soil disturbance, increasing germination and seedling survival of small seeded weeds (Ball, 1992; Nalewaja, 2001).

Development of herbicides has diminished the historic reliance on tillage systems for primary weed control (Nalewaja, 2001). However, a rising number of weeds resistant to a wide range of herbicide active ingredients have also been identified in the UK (Davies & Finney, 2002), increasing interest in the complementary use of cultivation techniques and herbicide applications, towards a more integrated weed control strategy (Finch *et al*., 2014). For instance, the use of pre-crop emergence herbicides under reduced tillage controls weed seedlings at the soil surface (Calado *et al*., 2010). However, integration of tillage systems and herbicide can often alter herbicide's effectiveness for weed control, mainly related to soil residues cover intercepting the herbicide (Buhler, 1995; Chauhan, 2013; Vijaya Bhaskar *et al*., 2014*b)*. Emphasising tillage influences on weed control is important in selecting an effective herbicide, with the associate costs also affecting profitability of the crop enterprise (Sayili *et al*., 2006).

Nitrogen (N) fertilisation modifies soil fertility directly, affecting not only crop growth but also weed density and composition (Jørnsgård *et al*., 1996; Yin *et al*., 2006). Weed growth can, however, also be indirectly influenced by N fertilisation by promoting faster growth of the crop, which in turn can increase crop competitiveness against weeds, resulting in the reduction of weed species number and biomass (Tang *et al*., 2013). Conversely, weed growth can response positively to N fertilisation possibly due to differential N-use efficiently compared with the crop (Sheibani & Ghadiri, 2012). Among weed species, N response also greatly differs (Yin *et al*., 2006). In a long-term experiment, Moss *et al*. (2004) reported that *Stellaria media* L. was highly favoured by N-rich conditions while other species, e.g. *Medicago lupulina* L., were highly disadvantaged. The aim of the current field experiments was to evaluate, within the scope of a transition from a long established organic farming system, contrasting tillage systems combined with different N fertilisation rates influences on weed infestation in the context of competitiveness and performance of spring wheat yield in a clay soil in the UK. Weed species composition, total weed biomass and prevalence were studied.

Material and methods

Site description

Field experiments were established from March to August 2013 and 2014 at the Royal Agricultural University's Harnhill Manor Farm, Cirencester, UK (51°42'N, 01°59'W) at an altitude of 135 m above sea level. The land was managed organically since 1983 and the soil series (SSEW) was Evesham with a clay textur (23% sand, 38% silt, 40% clay). Table 1 shows the initial soil physiochemical properties measured before the experiments were established (March 2013).

Figure 1 shows the monthly rainfall and mean temperatures during 2013 and 2014 growing seasons (March–August). Year-to-year variations in rainfall were observed over the study period. The total rainfall was 292 and 400.5 mm for 2013 and 2014, respectively. The mean total rainfall over the last 10 years was 377.2 mm. The 2013 season was therefore a dry year, while 2014 was considered to be wet. Rainfall distribution also varied between years (Figure 1). In 2013, 63% of the total season rainfall was recorded during spring months, particularly March and May, while in 2014 spring rainfall only counted for 50% of the total season rainfall. Temperature differed only slightly between seasons. Mean air temperature in 2013 of 11.7°C, and in 2014, 12.8°C, were lower compared with the mean temperature over the last 10 years of 13.9°C.

Experimental design and treatment structure

Experiments followed a randomised complete block design in a split-plot arrangement replicated three times. Each block (90 m × 100 m) was divided into three tillage treatments of 30 m × 100 m (main plots) – Conventional plough-based Tillage (CT); High Intensity Non-inversion Tillage (HINiT); and Low Intensity Non-inversion Tillage (LINiT). Details of the tillage treatments used are specified in Table 2. The amount of crop residues left on the soil surface were CT 0%; HINiT <30%; and LINiT >30%.

Main plots were divided into four fully randomised split plots (7.5 m × 100 m) of mineral nitrogen (N) fertiliser application rates of 0 (N0), 70 (N70), 140 (N140) and 210 kg N ha^{-1} (N210). N fertiliser was applied as ammonium nitrate solution (34.5% N), with half rate applied at Zadoks, Chang & Konzak decimal growth stage (GS) 13 and the remainder at GS 21 (Zadoks *et al*., 1974).

Spring wheat cv. Paragon was sown at a rate of 480 seeds m^{-2} on 10 April 2013 and 18 April 2014, and harvested on 27 August 2013 and 31 August 2014, respectively. Before the establishment of the experiments, the land was treated with systemic herbicide Roundup, a.i. glyphosate, at a rate of 4 L ha^{-1} on 22 August 2012. Before primary cultivation operations (20 March 2013 and 24 March 2014), weeds were controlled again by glyphosate (2 L ha^{-1}) applied across all the plots.

Plant sampling

Weeds were hand-harvested using 0.25 m^2 random quadrats for each split-plot with three replications. Dry weight (DM) yield was recorded after drying samples at 105°C overnight. Assessments were conducted on/before wheat GS31 (early assessment) and on/after GS61 (midseason assessment). At midseason assessment, weed species were separated and grouped accordingly to broadleaf and grass weeds. At crop maturity, spring wheat and weeds were hand-harvested using 0.25 m^2 random quadrats for each split-plot with three replications, recovering all above ground plant material for analysis. Samples were dried at 105°C overnight and DM recorded. Ears were threshed by hand and the amount of grain was weighed to obtain grain yield, which was subsequently corrected to 15% moisture content.

Statistical analysis

Statistical analyses were performed using the split-plot analysis of variance (ANOVA) model in Genstat (15th Edition VSN International Ltd, Hemel Hempstead, UK) using Fisher's protected least significant difference at P<0.05. Uniformity of variance and residuals of all the data sets were verified before reporting results.

Results

Season effect on weed biomass and spring wheat yield

Weed biomass significantly varied between the seasons (Table 3). Early weed DM was significantly higher in 2014 compared with 2013, while midseason total weed biomass and broadleaf weed DM were significantly higher in 2013 than in 2014. Grass weed DM was not significantly influenced by year. At harvest, total weed biomass and spring wheat grain yield were significantly higher in 2013 compared to 2014 (Table 3).

Influence of tillage on weed biomass and wheat grain yield production

Early weed DM was significantly affected by tillage, with HINiT resulting in higher biomass compared to CT and LINiT (Table 3). There was a significant year × tillage interaction affecting early weed DM (Table 3). In 2014, HINiT resulted in higher early weed DM compared to LINiT and CT, while in 2013 differences between tillage systems were reduced (Figure 2). At midseason, HINiT resulted in significantly higher total weed DM and broadleaf weed DM compared to LINiT, followed by CT (Table 3). CT resulted in lower midseason weed DM and broadleaf weed biomass in 2014 than in 2013, while no differences were observed between years on HINiT and LINiT (Figure 2). Grass weed DM was significantly higher under HINiT and LINiT than under CT (Table 3). Total weed biomass at harvest was significantly affected by tillage and year × tillage interaction effect, resulting in higher DM under HINiT and LINiT compared to CT across both years (Table 3; Figure 2).

Spring wheat grain yield was significantly affected by tillage and year x tillage interaction (Table 3). Significant higher grain yield was produced by CT than LINiT and followed by HINiT (Table 3). In 2013, grain yields under LINiT were higher than HINiT and statistically similar to those under CT, while in 2014 CT resulted in higher grain yield than HINiT and LINiT (Figure 2).

Influence of N management on weed biomass and wheat grain yield production

N fertilisation did not significantly affect early weed biomass (Table 3). Total midseason and broadleaf weed DM was significantly lower under unfertilised conditions compared to any N rate applied (Table 3). Grass weed DM was higher at high rates of N applied, such as 140 and 210 kg N ha^{-1}, compared to lower N rates (Table 3). N fertilisation significantly affected total weed DM at harvest and spring wheat grain yield (Table 3). Lower weed DM at harvest was observed under unfertilised conditions than when N was applied. Grain yield ranged from 4.25 to 5.02 t ha^{-1} as affected by N fertilisation, with higher yield produced with application of 140 and 210 kg N ha^{-1} (Table 3).

Influence of tillage and N management on weed biomass and specie composition

Total midseason and broadleaf weed biomass, and total weed DM at harvest were significantly higher under HINiT and LINiT when N fertilisation was applied compared to unfertilised conditions, while under CT there was not response to N supply (Figure 3).

A total of 39 weed species were recorded in 2013, and 29 species in 2014, irrespectively of management treatments. Only the dominant weed species – listed in Table 4 – were significantly affected by the management practices, while other species were not significantly affected or occurred too infrequently to permit treatment effects to be appropriately tested.

There was a significant year effect on all dominant weed species (Table 5). In 2013, *Stellaria media*, *Fallopia convolvulus*, *Lolium perenne*, and *Avena fatua* biomass was significantly higher than in 2014, while *Sinapsis arvensis, Galium aparine* and *Avena sativa* DM was higher in 2014 than in 2013 (Table 5). Significant tillage effects on all dominant weed species were observed except on *Avena* spp. *Stellaria media* and *Sinapsis arvensis* biomass was higher under HINiT compared with CT and LINiT (Table 5). *Fallopia convolvulus* and *Lolium perenne* biomass was significantly higher under LINiT compared to HINiT and CT, while *Galium aparine* DM was significantly higher under LINiT than HINiT, followed by CT (Table 5).

Stellaria media DM was higher under CT and HINiT in 2013 than in 2014, while no differences between years were observed under LINiT (Figure 4). *Sinapsis arvensis* DM under HINiT was significantly higher in 2014 compared to 2013, while under LINiT and CT no differences were observed across seasons. Under LINiT, *Lolium perenne* biomass was higher in 2013 than in 2014. No differences across years were observed in *Lolium perenne* DM under CT and HINiT (Figure 4).

N management and tillage × N fertilisation interaction significantly affected *Stellaria media* and *Sinapsis arvensis* biomass (Table 5). Higher *Stellaria media* DM was produced when 70 kg N ha^{-1} was applied, particularly when compared to unfertilised conditions and to 210 kg N ha^{-1} applied (Table 5). Under HINiT, application of 70 and 140 kg N ha^{-1} significantly increased *Stellaria media* DM, while no significant interactions were observed under CT and LINiT (Figure 5a). *Sinapsis arvensis* DM increased when N was applied compared to unfertilised plots (Table 5). Year × N management interaction significantly affected *Sinapsis arvensis* DM, resulting a higher response to N application, particularly when high N rates were applied, in 2014 compared to 2013 (Figure 4). Under HINiT, *Sinapsis arvensis* growth was significantly increased when N was applied compared to unfertilised conditions, while no differences were observed under LINiT and CT (Figure 5a). *Lolium perenne* DM was significantly higher in 2013 when 140 kg N ha^{-1} was applied, while in 2013 there were not differences (Figure 4). Significant increase of *Lolium perenne* DM was also observed in 2013 under LINiT and when high N rates were applied (Figure 5b).

Discussion

Season effect on weed biomass and spring wheat yield

High weed prevalence, and its negative impacts on organic cereal crop performance on this field site have previously been reported (Cosser *et al*., 1996*a,b*, 1997; Vijaya Bhaskar *et al*., 2014*a,b*). To overcome this challenge, a pre-cultivation herbicide glyphosate was applied across the experimental site on both 2013 and 2014 seasons. However, the legacy of high weed pressure from the formerly organic management resulted in greater weed prevalence in 2013, following the herbicide application and dry weather conditions. In contrast, 2014 was the second year with herbicide inclusion exerting greater effect on controlling weeds at harvest compared with 2013. Travlos (2012) observed a reduction on weed biomass after two crop seasons with application of herbicide as a result of significant reduction of produced seed in the first year after herbicides. Season conditions also affected tillage systems effects on weed biomass and prevalence. The continuity of herbicide inclusion in 2014 appears to have reduced weed biomass under CT when compared with 2013, while similar HINiT and LINiT effects between the two cropping seasons suggests that higher herbicide rates are perhaps needed under reduced tillage, as reported by Bostrom *et al*. (2000).

Weed biomass growth varied as the growing season progress. Increases on weed biomass growth from early to midseason assessments were mainly related to weed community grow, while as the season progress towards harvest there was a natural decay of their biomass. Jørnsgård *et al*. (1996) also reported differences on weed biomass from germination till the end of the growing season.

Higher spring wheat grain yield in the 2013 dry year than in 2014 wet shows that weeds were not the only yield-limiting factor, as the year with the highest weed prevalence coincided with the highest yield, i.e. 2013. Similarly, lower yield under HINiT and LINiT in 2014 compared with 2013 was observed despite lower weed prevalence in 2014. Gruber *et al*. (2012) also reported that even though a high weed density was observed there was no evidence that weeds alone were restricting main crop yield. Wheat yield was, therefore, the result of complex interactions between seedbed conditions, weed pressure and weather conditions (Rial Lovera, 2015).

Influence of tillage on weed biomass and wheat grain yield production

The current study shows that the effectiveness of tillage in controlling weeds is also much influenced understandably by weather conditions across the seasons. Under relatively warm and drier conditions experienced in 2013, the tillage relevance in controlling early weed growth was reduced, while higher early weed growth in 2014 seems to be related to higher rainfall conditions in April. Fernández-Getino *et al*. (2015) reported that increased rainfall was positively correlated with increases in weed biomass. Under those cold and wet conditions in 2014 inverting the soil with CT resulted in the lowest early weed DM as also reported by Fernández-Getino et al. (2015). Under HINiT, lower plant residue cover and increasing soil disturbance compared with LINiT, may have allowed drier and warmer soil conditions encouraging more weed germination. This is an assumption, however, as soil conditions and weeds proportions may have been compensating, as suggested by Colbach *et al*. (2006).

Although, the approach employed for the herbicide application did not allow the specific impact on weed dynamics to be tested, it is possible to speculate on its relative effect on weed occurrence. Mavunganidze *et al*. (2014) reported that a broad-spectrum herbicide such as glyphosate controls both grass and broadleaf weed species. In the present study, however, grass weed biomass was lower compared with broadleaf weeds following herbicide application, as reported elsewhere (Ewald & Aebischer, 2000; Marshall & Nowakowski, 1996).

Broadleaf weeds mainly accounted for differences between tillage treatments in the total weed DM, as Demjanová *et al*. (2009) also reported. This was observed as HINiT resulted in higher total weed and broadleaf weeds DM than LINiT and CT. Clements *et al*. (1996) and Swanton *et al*. (2000) also reported greater incidence of this weed group under reduced tillage. Due to rainfall conditions, crop sowing operations were slightly later in both years, which could have allowed the emergence, after herbicide application, of the weeds retained in soil under non-inversion tillage. This condition combined with increases in soil disturbance intensity is the possible reason for high biomass of short-lived annual broadleaf weeds under HINiT. Higher presence of soil residue cover under LINiT can create shadowing, reducing germination of broadleaf species after herbicide application (Teasdale *et al*., 1991). Grass weed DM was higher under HINiT and LINiT, as this weed group is highly affected by intensive soil mechanical disturbance, especially ploughing (Demjanová *et al*., 2009; Streit *et al*., 2002).

Weed prevalence at harvest was promoted by non-inversion tillage treatments in both years compared with CT. Weeds that escaped foliar contact herbicide were likely to grow, but the subsequent soil inversion under CT is thought to have reduced weed presence across the seasons, as also reported elsewhere (e.g. Nakamoto *et al*., 2006; Santín-Montanyá *et al*., 2013). This situation also provided a head-start for the crop, such that it can effectively compete with later-emerging weeds.

Spring wheat grain yield was higher under CT showing an inverse relationship between lower weed prevalence and crop performance. Others (e.g. (Gruber *et al*., 2012; Yagioka *et al*., 2015; Fernández-Getino *et al*., 2015) also reported that lower weed pressure under CT can be one of the factors allowing higher grain yields compared with reduced tillage practices. Wheat yield under LINiT, however, was higher than under HINiT despite similar weed prevalence observed. This confirms, as expected, that weed pressure is not the only yield- limiting factor under reduced tillage systems, as also reported by Gruber *et al*. (2012).

Influence of N management on weed biomass and wheat grain yield production

N fertilisation significantly increased midseason total weed DM, and weed prevalence at harvest which is consistent with others (e.g. Blackshaw *et al*., 2005; Lal *et al*., 2014). N fertilisation caused shifts in weed species, with grass weeds more advantaged under N-rich conditions in both years, while broadleaf weeds biomass increased when N was applied regardless of rate. However, broadleaf weeds were more relevant than grass weeds, showing higher weed biomass as Maskell *et al*. (2010) and Storkey *et al*. (2011) have also reported.

Weed growth as affected by N application appears to have not affected final grain yield particularly at higher N rates, as both crop yield and weeds biomass increased with N, as also reported by Jørnsgård *et al*. (1996) and O'Donovan *et al*. (1997). At lower N rates, however, weed prevalence can be one of the factors reducing grain yield, as observed when 70 kg N ha^{-1} was applied. Under unfertilised conditions, grain yield is likely to be more influenced by lower N availability than by weed presence. These results suggests that rich N fertilisation can potentially increase crop competitiveness against weeds, as other reported (Tang *et al*., 2013; Sheibani & Ghadiri, 2012).

Influence of tillage and N management on weed biomass and specie composition

The application of N fertiliser under HINiT and LINiT produced an increase on broadleaf weed biomass, total midseason biomass and weed prevalence at harvest. This is the result of favourable conditions under reduced tillage allowing weed seed germination and N promoting weed growth, as also observed by Małecka & Blecharczyk (2008).

Most of the weeds species identified are commonly report in spring wheat production (HGCA, 2010) and their presence was influenced by the agricultural managements adopted and time of assessment as reported by Menalled *et al*. (2001). However, species composition in crops is also primarily influenced by weather conditions across seasons (Håkansson, 2003; Shrestha *et al*., 2002). *Stellaria media* and *Sinapsis arvensis* DM was higher under N-rich conditions and when combined with HINiT, as others reported (e.g. Moss *et al*., 2004; Ozpinar, 2006). However, the wet conditions observed in 2014 could have possibly reduced soil N availability, increasing the response of *Sinapsis arvensis* when N was applied, while no N fertilisation effect was observed in 2013 dry season.

The increase of *Fallopia convolvulus* and *Galium aparine* DM under LINiT is perhaps the result of less competition with other dominant weed species which were more common under HINiT. Seedbed conditions under LINiT were more advantageous for *Lolium perenne* to grow than under HINiT and CT, as this grass is more susceptible to mechanical disturbance of soil (Håkansson, 2003; Tuesca & Puricelli, 2007). Additionally, the fast growth behaviour of *Lolium perenne* requires high N supply (Daepp *et al*., 2001), which resulted in higher biomass production under LINiT when combined with N fertilisation in 2013. Its lower DM in 2014 seems, however, to have offset effects of the management practices.

Conclusions

Although weed community response to tillage was specific to year-to year weather and soil conditions, some overall conclusions are possible. Conventional plough-based tillage (CT) controls weeds better. In contrast, High Intensity Non-Inversion Tillage (HINiT) promotes infestations by broadleaf weed species rapidly increasing the total weed biomass, even when broad-spectrum herbicide is applied. This disadvantage can negatively affect wheat production. Hence, rotational use of reduced tillage practices, such as Low Intensity Non-inversion Tillage, into CT systems may be a practical way to increase their adoption for more sustainable cereal production. The risk of increased weed pressure when applying N fertilisation can be reduced by lowered N rates in the field.

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Table 1. *Key topsoil characteristics (0-25 cm)*

Parameter	Value	Parameter	Value
SMN (kg ha^{-1})	25.3	P (mg l^{-1})	8.0
pH (water)	6.9	K (mg l^{-1})	208.7
Organic matter (%)	4.7	Mg (mg l^{-1})	105.3

Table 2. *Specifications of the tillage treatments adopted in 2013 and 2014*

	Primary cultivation	Secondary cultivation
CT	Five furrow Kverneland reversible plough (20 cm)	Kuhn power harrow combination seed drill (8 cm)
HINiT	ST bar attached to Simba X-press (25 & 12 cm) (2 passes)	Vaderstad Rapid-A system disc combination seed drill (8 cm)
LINiT	ST bar attached to Simba X-press (25 & 12 cm) (1 pass)	Eco-dyn integrated seed drill (26 cm)

Table 3. Analysis of variance for year, tillage and N management effects. Mean values for weed aboveground biomass and spring wheat grain yield parameter

Source	df	Early total weed DM (t ha^{-1})	Midseason total weed DM (t ha^{-1})	Broadleaf weed DM (t ha^{-1})	Grass weed DM (t ha^{-1})	Total weed DM (t ha^{-1}) at harvest	Grain yield (t ha^{-1})
Year (Y)	1						
2013		0.0338a	1.438b	1.131b	0.307a	1.140b	5.595b
2014		0.0837b	1.138a	0.816a	0.321a	0.905a	3.701a
SED		*0.01069****	*0.0915****	*0.0700****	*0.0697^{ns}*	*0.0850***	*0.1469****
Tillage (T)	2						
CT		0.0198a	0.528a	0.4468a	0.0812a	0.507a	5.473c
HINiT		0.1186b	1.953c	1.5921c	0.3612b	1.301b	3.833a
LINiT		0.0378a	1.382b	0.8821b	0.5004b	1.259b	4.638b
SED		*0.01309****	*0.1121****	*0.0857****	*0.0854****	*0.1041****	*0.1800****
N rate (N)	3						
N0		0.0559a	0.661a	0.5581a	0.1024a	0.715a	4.248a
N70		0.0694a	1.427b	1.1963b	0.2310a	1.193b	4.381a
N140		0.0553a	1.543b	1.1079b	0.4348b	1.087b	4.945b
N210		0.0544a	1.521b	1.0323b	0.4888b	1.094b	5.019b
SED		*0.01511^{ns}*	*0.1294****	*0.0990****	*0.0986****	*0.1202****	*0.2078****
Y × T	2	*0.01851****	*0.1585**	*0.1212***	*0.1208^{ns}*	*0.1472****	*0.2545****
Y × N	3	*0.02137^{ns}*	*0.1831^{ns}*	*0.1400^{ns}*	*0.1395^{ns}*	*0.1699^{ns}*	*0.2939^{ns}*
T × N	6	*0.02618^{ns}*	*0.2242****	*0.1714****	*0.1708^{ns}*	*0.2081**	*0.3599^{ns}*
Y × T × N	6	*0.03702^{ns}*	*0.3171^{ns}*	*0.2424^{ns}*	*0.2416^{ns}*	*0.2943^{ns}*	*0.5090^{ns}*

Values are mean; df, degree of freedom; and SED (in italics), Standard errors of difference for treatments and treatments interactions.

Values followed by same letter, do not differ significantly at $P<0.05$; *= $P<0.05$, **= $P<0.01$; ***= $P<0.001$; and ns= not significant.

Table 4. Ranking of dominant weed species by contribution to the total midseason weed biomass in 2013 and 2014

Rank	2013			2014		
	Weed species	Code EPPO[a]	Contribution[b]	Weed species	Code EPPO[a]	Contribution[b]
1	*Stellaria media* (L.) Vill.	STEMM	29.8%	*Sinapsis arvensis* (L.)	SINAR	35.1%
2	*Fallopia convolvulus* (L.)	POLCO	12.1%	*Avena sativa* (L.)	AVESA	26.9%
3	*Avena fatua* (L.)	AVEFA	11.9%	*Stellaria media* (L.) Vill.	STEMM	15.2%
4	*Sinapsis arvensis* (L.)	SINAR	9.7%	*Galium aparine* (L.)	GALHM	14.8%
5	*Lolium perenne* (L.)	LOLPE	8.1%	*Lolium perenne* (L.)	LOLPE	2.0%

[a]http://eppt.eppo.org/search.php

[b]Contribution (%) of the weed specie DM to the midseason total weed DM in each year.

Table 5. Analysis of variance for year, tillage and N management effects. Mean values for dominant weed species biomass parameter

Source	df	*Stellaria media*	*Sinapsis arvensis*	*Fallopia convolvulus*	*Galium aparine*	*Lolium perenne*	*Avena fatua*	*Avena sativa*
Year (Y)	1							
2013		0.425b	0.138a	0.173b	0.082a	0.1161b	0.170b	0.0004a
2014		0.167a	0.385b	0.037a	0.162b	0.0220a	0.0001a	0.0061b
SED		*0.0379****	*0.0484****	*0.0237****	*0.0320**	*0.01660****	*0.0460****	*0.00263**
Tillage (T)	2							
CT		0.1166a	0.1263a	0.0579a	0.0046a	0.00791a	0.035a	0.0001a
HINiT		0.5952b	0.5530b	0.0876a	0.1276b	0.01885a	0.137a	0.0074a
LINiT		0.1763a	*0.1053a*	0.1690b	0.2339c	0.18037b	0.083a	0.0024a
SED		*0.0464****	*0.0593****	*0.0290****	*0.0392****	*0.02033****	*0.0563*^{ns}	*0.00322*^{ns}
N rate (N)	3							
N0		0.1558a	0.0958a	0.097a	0.054a	0.0529a	0.022a	0.0036a
N70		0.4048c	0.2926b	0.105a	0.123a	0.0675a	0.058a	0.0072a
N140		0.3461bc	0.2937b	0.102a	0.179a	0.0972a	0.111a	0.0009a
N210		0.2774b	0.3641b	0.115a	0.133a	0.0586a	0.148a	0.0013a
SED		*0.0536****	*0.0685****	*0.0335*^{ns}	*0.0452*^{ns}	*0.02347*^{ns}	*0.0650*^{ns}	*0.00372*^{ns}
Y × T	2	*0.0656****	*0.0839****	*0.0410*^{ns}	*0.0554*^{ns}	*0.02875****	*0.0796*^{ns}	*0.00456*^{ns}
Y × N	3	*0.0758*^{ns}	*0.0969***	*0.0473*^{ns}	*0.0640*^{ns}	*0.03319**	*0.0919*^{ns}	*0.00526*^{ns}
T × N	6	*0.0928****	*0.1187***	*0.0580*^{ns}	*0.0783*^{ns}	*0.04066*^{ns}	*0.1126*^{ns}	*0.00644*^{ns}
Y × T × N	6	*0.1313*^{ns}	*0.1678*^{ns}	*0.0820*^{ns}	*0.1108*^{ns}	*0.05750****	*0.1592*^{ns}	*0.00911*^{ns}

Values are mean; df, degree of freedom; and SED (in italics), Standard errors of difference for treatments and treatments interactions.

Values followed by same letter, do not differ significantly at $P<0.05$; *= $P<0.05$, **= $P<0.01$; ***= $P<0.001$; and ns= not significant.

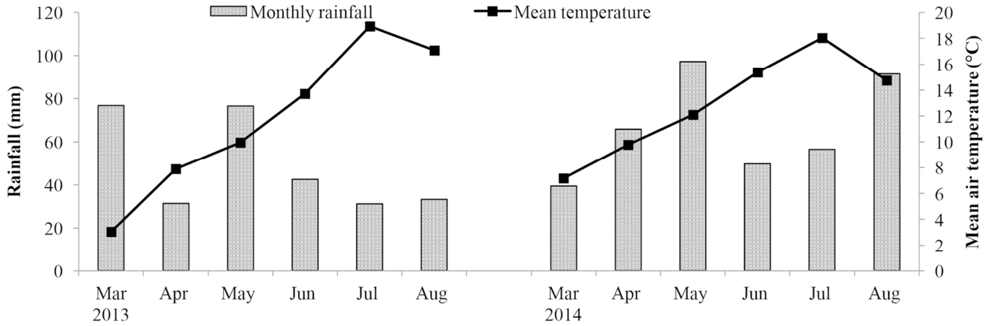
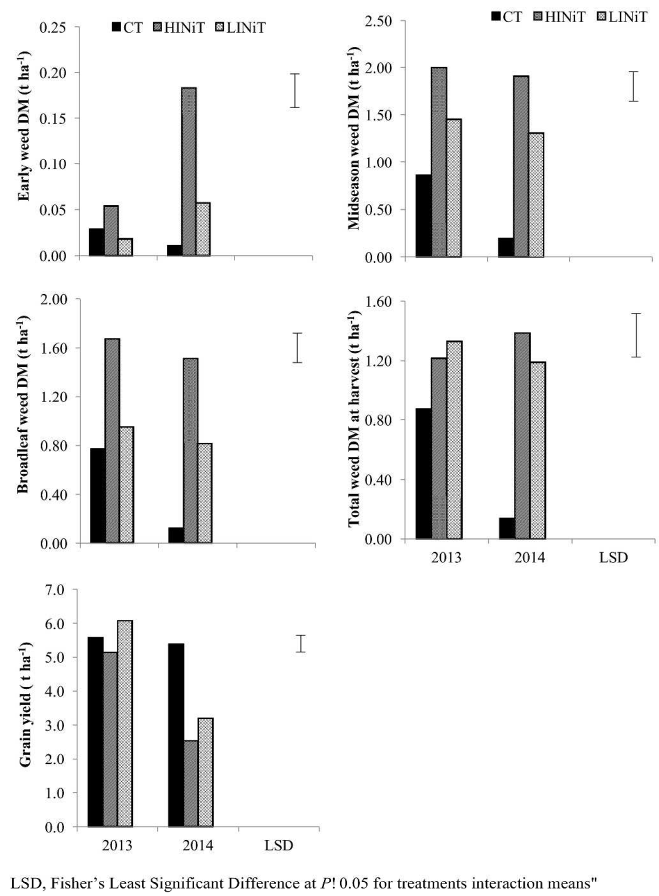
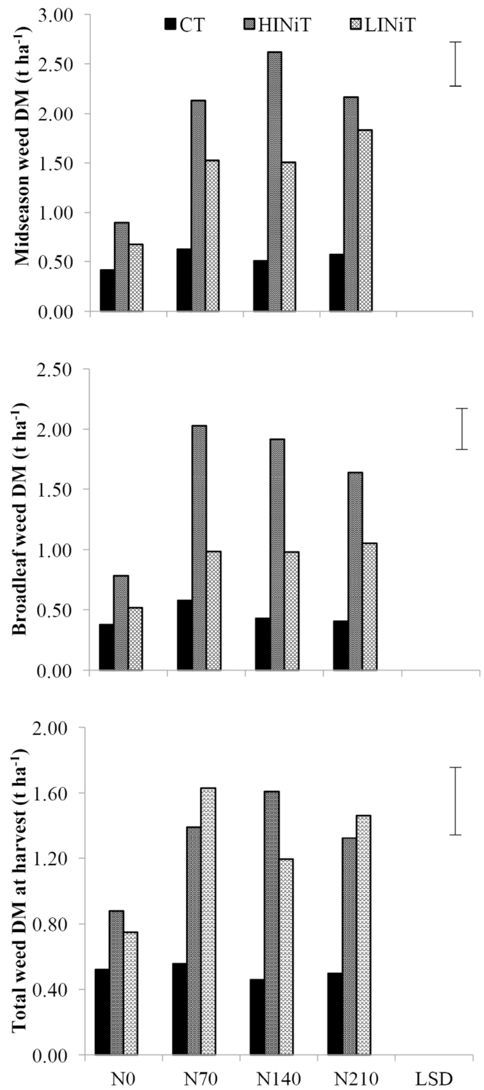


Figure 1. Mean air temperature and rainfall during 2013 and 2014 cropping seasons. Royal Agricultural University meteorological station
170x62mm (300 x 300 DPI)

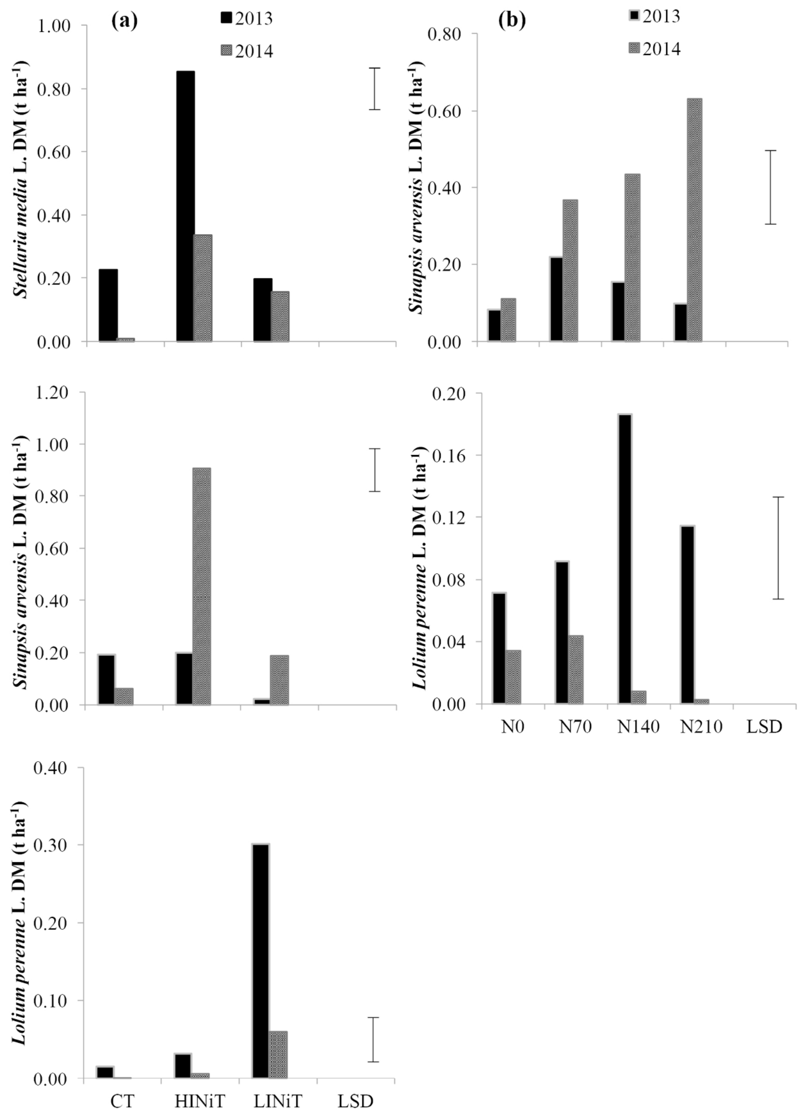


Aboveground weed biomass and spring wheat grain yield affected by year x tillage interaction
276x386mm (300 x 300 DPI)



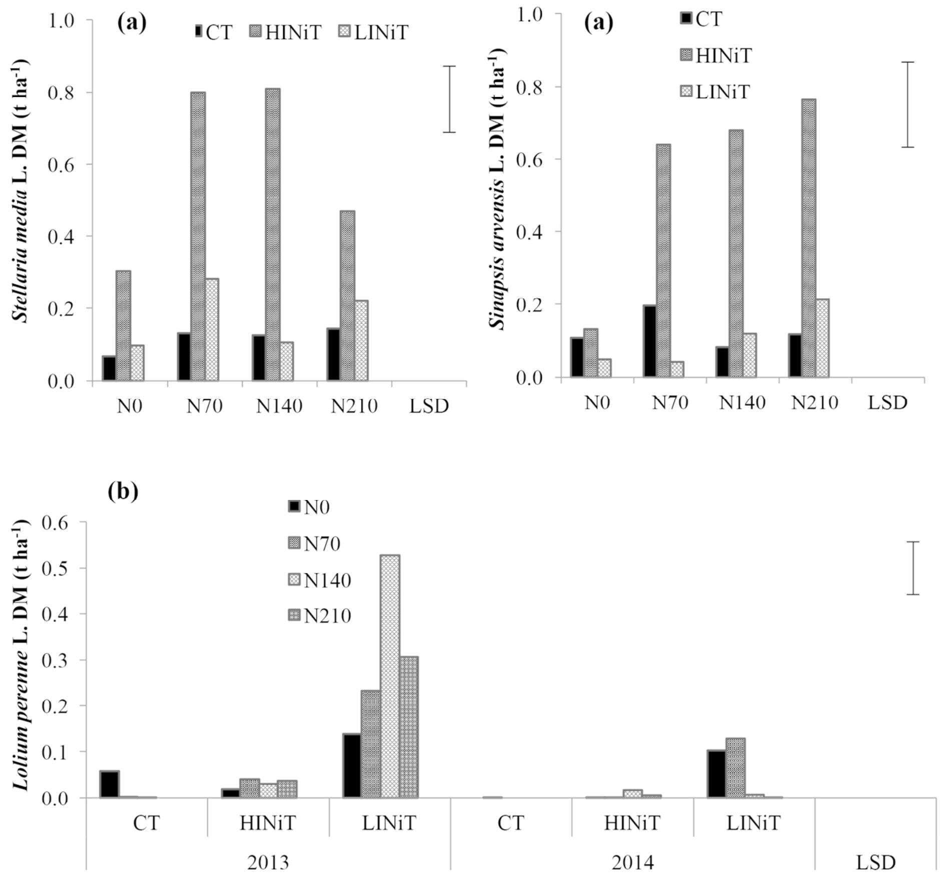
LSD, Fisher's Least Significant Difference at P<0.05 for treatments interaction means

Aboveground weed biomass and spring wheat grain yield affected by tillage x N management interaction
144x210mm (300 x 300 DPI)



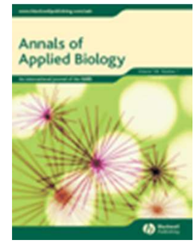
LSD, Fisher's Least Significant Difference at $P<0.05$ for treatments interaction means

Stellaria media, Sinapsis arvensis and Lolium perenne affected by year x tillage (a) and year x N management (b) interactions
156x220mm (300 x 300 DPI)



LSD, Fisher's Least Significant Difference at $P<0.05$ for treatments interaction means

Stellaria media and Sinapsis arvensis affected by tillage x N management (a); and Lolium perenne affected by year x tillage x N management interaction (b)
170x170mm (300 x 300 DPI)



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