Applied Soil Ecology 108 (2016) 25–46

Contents lists available at ScienceDirect

Applied Soil Ecology

journal homepage: www.elsevier.com/locate/apsoil

Improving above and below-ground arthropod biodiversity in maize cultivation systems

Stuart L. Norris[a,b,*], Rod P. Blackshaw[e], Robert M. Dunn[a], Nigel R. Critchley[c], Kate E. Smith[d], John R. Williams[d], Nicola P. Randall[b], Philip J. Murray[a]

[a] Rothamsted Research, North Wyke, Okehampton, Devon, EX20 2SB, UK
[b] Harper Adams University, Newport, Shropshire, TF10 8NB, UK
[c] ADAS UK Ltd, c/o Newcastle University, NEFG Offices, Nafferton Farm, Stocksfield, Northumberland NE43 7XD, UK
[d] ADAS UK Ltd, Battlegate Road, Boxworth, Cambridge, CB23 4NN, UK
[e] Blackshaw Research & Consultancy, Parade, Chudleigh, Devon, TQ13 0JF, UK

ARTICLE INFO

Article history:
Received 13 March 2016
Received in revised form 16 July 2016
Accepted 27 July 2016
Available online xxx

Keywords:
Maize
Above-ground
Below-ground
Diversity
Richness
Density

ABSTRACT

Maize (*Zea mays* L.) is a multi-use crop, but its cultivation has a number of associated environmental and ecological impacts. Few investigations have been undertaken to understand the impact of different maize cultivation techniques on above- and below-ground arthropod communities. This study has shown that strip tillage cultivation of maize improves arthropod community structure and biodiversity though a reduction in the area disturbed by cultivation and increased non-crop. Furthermore, increasing the richness of non-crop plants within strip tillage systems further increased the numbers of above- and below-ground taxa. Although there was a significant reductions in maize yield under strip tillage cultivation systems compared to the more conventional cultivation techniques making adoption unlikely, our results do show with simple changes in maize cultivation practice there can be benefits to biodiversity. The research challenge is now not to be able to enhance biodiversity, but to develop integrated crop management practices that sustain yields.

1. Introduction

Maize is a versatile crop, with uses as food for humans and livestock, and is becoming increasingly important as a feedstock for biogas generation (Hochholdinger and Tuberosa, 2009; Adams and Douglas, 1997; Banse et al., 2008). In the UK Maize is predominantly cultivated as an alternative to grass silage (Hochholdinger and Tuberosa, 2009; Adams and Douglas, 1997; Banse et al., 2008; Hart et al., 2015; Rosegrant, 2008; Alignier and Baudry, 2015) with land under maize cultivation in the UK increasing from 1000 ha in the 1970s to 184,000 ha in 2014 (DEFRA, 2014).

Globally there is a need to produce such versatile crops to meet modern agricultural demands (Werling et al., 2014). Such pressure to increase maize production must be balanced with the maintenance of ecosystem services including biodiversity to achieve sustainability (DeFries et al., 2004; Tsiafouli et al., 2015).

The conventional maize cultivation practice is to prepare the soil by deep ploughing and tilling, and for the maize crop to be drilled in straight rows, 50–70 cm apart. This leaves up to 50–70% of the field left plant-free (Nakamoto and Tsukamoto, 2006; Aune et al., 2012). Maize crops are vulnerable to early competition and as such are usually treated with a comprehensive herbicide programme in order to reduce weed competition during early growth; this reduces food and habitat resources for above- and below-ground arthropods (Hawes et al., 2009; Bardgett et al., 2005; Neilson et al., 2002) as well as leaving the surface vulnerable to soil erosion, surface runoff, and nitrate leaching into ground water (Feil et al., 1997).

Maize cultivation practices to reduce negative environmental impacts have been developed since the 1980s (Hartwig and Ammon, 2002). These include conservation tillage systems to reduce surface flow and sediment loss (for example non-inversion cultivation), rough scouring of the soil surface in autumn and late season sowing of forage grass as a catch crop. Late season sowing of a catch crop has been shown to be effective at reducing

Abbreviations: CP, conventional plough; RG, strip tillage into ryegrass; BSM, strip tillage into a biodiverse seed mix; NI, non inversion; NMDS, non-metric multidimensional scaling.

* Corresponding author at: Rothamsted Research, North Wyke, Okehampton, Devon, EX20 2SB UK.
E-mail addresses: stuart.norris@vixenecology.co.uk, stuart.norris@googlemail.co.uk (S.L. Norris).

http://dx.doi.org/10.1016/j.apsoil.2016.07.015
0929-1393/

environmental impacts in the US, however due to poor establishment of late sown cover crops in the UK there is currently more interest in the sustainability of over-sowing maize to ensure adequate cover crop establishment. Intercrops of *Lolium perenne* L. or legume mixes can be used to reduce run-off and provide resources for arthropod communities, as well as birds and mammals. Intercropping techniques have also been shown to improve biological pest control (Finke et al., 1999; Liedgens et al., 2004; Gardi and Jeffrey, 2009), reduce sediment loss (Briones and Bol, 2003; Hartwig and Ammon, 2002) and maintain the farmland biological community over winter (Hawes et al., 2009). Intercropping management practices have also been shown to reduce the costs associated with chemical inputs (Finke et al., 1999; Liedgens et al., 2004; Nakamoto and Tsukamoto, 2006) although additional chemical inputs may be required to reduce competition of intercrops with maize (Liedgens et al., 2004). Despite the benefits of intercropping systems, there is a need to establish intercrops earlier in the UK than in warm climates to achieve sufficient ground cover to reduce soil erosion and sediment loss (Hartwig and Ammon, 2002).

Arthropods are an important component of ecosystems, facilitating a number of crucial functions such as organic matter recycling and pest control (Bardgett et al., 2005; Gardi and Jeffrey, 2009; Hawes et al., 2009). The degree of arthropod biodiversity in agroecosystems depends on four main characteristics: the diversity of vegetation within and around the crop, the permanence of the various crops within the system, the intensity of management and the extent of the isolation from natural vegetation (Altieri, 1999).

Arable agricultural practices, such as ploughing, directly and indirectly effect above- and below-ground biodiversity (Van der Putten et al., 2001; Firbank et al., 2003; Stockdale and Committee, 2006; Overstreet et al., 2010; Tsiafouli et al., 2015). Direct effects on arthropod biodiversity include body damage, habitat destruction/modification, and the modification of nutrient availability. Indirect effects include soil compaction, reduction of soil organic matter, reduction of complexity and diversity of carbon inputs, disturbance of trophic interactions from selective pressure on target and non-target organisms, and toxicity from residual and breakdown products of biocides (Overstreet et al., 2010; Van Capelle et al., 2012). All the above factors impact on the diversity and density of the arthropods which affect the stability of the above- and below-ground ecosystem with associated effects on biogeochemical processing that would be expensive to replace (Altieri, 1999; Gardi and Jeffrey, 2009). Despite this knowledge, the degree to which maize cropping affects both the above- and below-ground arthropod communities is little understood, with few studies looking at more than one or two taxa and their community dynamics within maize systems (Briones and Bol, 2003).

In this paper, we investigate the effect of four contrasting maize establishment and ground cover management techniques on above- and below-ground arthropod richness, density, diversity and community structure. Our goal is to understand how above- and below-ground arthropod biodiversity and community structures are affected by contrasting soil cultivation and ground cover management practices and how these different maize cultivation techniques affect maize yield. We hypothesise that a reduction in the area disturbed by tillage and an increase in non-crop vegetation positively affects arthropod biodiversity.

2. Materials and methods

2.1. Experimental sites

Field trials were established during June 2012 at two study sites, one in Devon in South West England, and the second in Norfolk in East Anglia. The study sites were positioned on a freely draining, slightly acidic loam soil of the Eutric Chromic Endoleptic Cambisols in Devon and a sandy loam soil of the Calcaric Leptosols soil series in Norfolk (Driessen, 2001), and both were typical of land under maize cultivation.

At each site, four cultivation methods with three replicates of each were established in a fully randomised block design. At the Devon site each plot was 10 m wide with a 2 m uncultivated buffer area between plots, and 60 m in length. However at the Norfolk site each plot was 12 m wide, 80 m long with no buffer between plots; as such the outmost 2 m of the plots at Norfolk were excluded from sampling. Due to the difference in plot size and arrangement between sites samples were collected from an 8 m by 50 m area are in the centre of each plot at the two sites. The four cultivation and ground cover management practises tested were: (1) conventionally ploughed and subsoiled (CP), (2) Non-inversion (NI), (3) strip tillage into perennial ryegrass that was over-sown at a rate of 35 kg ha^{-1} (RG) in June 2012, and (4) strip tillage into a biodiverse seed mix (BSM). The BSM strip crop was over-sown by broadcasting and raking seed into the soil between the maize rows in June 2012 at 15 kg ha^{-1} on a by weight rate of *Medicago lupulina* L. 20%, *Onobrychis viciifolia* Scop. 25%, *Trifolium hybridum* L. 20% *Trifolium incarnatum* L. *subsp. Incarnatum* 20%, *Lotus corniculatus* L. 10%, *Malva moschata* L. 5%. Initial topsoil samples (0–15 cm) were collected from each block in autumn 2012 and analysed for pH, extractable and water soluble P, extractable K and Mg, total N, P, K, Mg and available S, and organic carbon content (by wet chemistry oxidation method) and particle size distribution (Table 1).

At the two sites herbicides and fertilisers were applied in keeping with conventional agronomic practise for local conditions (Table 2).

2.2. Arthropod sampling

Arthropods extracted by soil cores were characterised as belowground taxa, while those collected in pitfall traps were characterised as aboveground taxa; this is a technical categorisation to subdivide the habitats from which arthropods were collected. Soil arthropod sampling was carried out in the last week of April immediately before the maize crop was drilled, the last week of June and immediately after harvest in 2013 and 2014. Eight soil cores (8 cm diameter × 10 cm depth) were taken from the midline of the non-crop rows (inter-row area), in a W shape across each plot (Smith et al., 2008). Soil cores were placed on Berlese-Tullgren funnels with a mesh size of 5 mm and soil invertebrates were trapped in a receiver vial at the base of each funnel filled with

Table 1
Soil physiochemical properties and slope of the two field trial sites (Bow, Devon and Fakenham, Norfolk).

	Devon		Norfolk	
	Mean	(s.e.)	Mean	(s.e.)
pH	7.3	(0.03)	7.9	(0.03)
Available P (mg/l)	76	(3.67)	45	(2.08)
P Index	5		4	
Available K (mg/l)	242	(7.09)	142	(1.33)
K index	3		2	
Available Mg (mg/l)	121	(7.97)	48	(0.88)
Mg Index	2		1	
Sand%	51		66	
Silt%	28		19	
Clay%	21		15	
Available sulphate (mg/l)	26	(1.07)	20	(0.39)
Total Nitrogen (mg/l)	0.3	(0.01)	0.2	(0.01)
Soil organic matter (%w/w)	1.2	(0.05)	1.7	(0.12)
Textural class	Sandy clay loam		Sandy loam	
Slope (%)	10		3	