European Journal of Agronomy 101 (2018) 49–56

Contents lists available at ScienceDirect

European Journal of Agronomy

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

Inter-row hoeing for weed control in organic spring cereals—Influence of inter-row spacing and nitrogen rate

Bo Melander[a,*], Khawar Jabran[b], Chiara De Notaris[c], Liubava Znova[d], Ole Green[c,d], Jørgen E. Olesen[c]

[a] Aarhus University, Department of Agroecology, Forsøgsvej 1, DK-4200, Slagelse, Denmark
[b] Duzce University, Department of Plant Protection, 081620, Duzce, Turkey
[c] Aarhus University, Department of Agroecology, Blichers Allé 20, DK-8830, Tjele, Denmark
[d] Agrointelli, Agro Food Park 13, Skejby, DK-8200, Aarhus N, Denmark

ARTICLE INFO

Keywords:
Spring barley
Spring wheat
Mechanical weed control
Problematic weeds
Yield
Grain quality

ABSTRACT

Inter-row hoeing has become increasingly important for weed control in organic spring cereals since the introduction of automatic steering systems. The technology requires a widening of current inter-row spacing for spring cereals in order to provide sufficient room for accurate operation of a hoe share between crop rows. However, there is considerable uncertainty about the optimal combination of inter-row hoeing, inter-row spacing and nitrogen (N) rate in terms of weeding effectiveness and crop yield. The aim of this study was to investigate the effect on weed and crop growth of the interaction between five inter-row spacings (125, 150, 200, 250, and 300 mm) and two N rates (50 and 100 kg NH_4-N ha^{-1}). Three field experiments were conducted in spring barley and two in spring wheat. One hoeing pass was applied for each inter-row spacing using a share width that worked 15–47 mm from the crop row. The immediate effect on weed numbers following hoeing was a 80–90% reduction in barley and a 63–80% reduction in wheat, but with no significant differences between spacings and N rates. However, the effect on weed biomass at crop anthesis was minor in barley because the crop itself substantially suppressed weed growth. Spring wheat was less competitive and inter-row hoeing reduced weed biomass by 60–70% compared to the standard 125 mm spacing without hoeing. The widening of inter-row spacing appeared not to reduce crop yield or grain quality. Prerequisites for successful inter-row hoeing in spring cereals include retained crop stands when increasing inter-row spacing and the avoidance of crop injuries from inaccurate steering.

1. Introduction

Weed harrowing is the principal physical weed control method applied in spring cereals. It is a full-width treatment affecting both the crop and weeds, usually employing one to three passes depending on the extent of the weed problem. Its weeding mechanisms and adjustments for optimal use are explained in Kurstjens and Kropff (2001) and Rasmussen et al. (2010) for example. The adoption of weed harrowing in practice has been difficult in many cases and there seems to be a steady move away from this technology towards other solutions. Optimal timing, settings and execution are the main challenges of weed harrowing mentioned by practitioners, which in many cases has resulted in poor weed control and occasionally significant crop yield loss. Erect dicotyledonous weed species with taproots and tall-growing grasses are particularly difficult annual weeds to control, and perennial weed species are not greatly affected (Rasmussen, 1998). Species such as *Sinapis arvensis* L., *Brassica rapa* L. and *Raphanus raphanistrum* L. are particular troublesome because they establish quickly, have fast initial growth rates and can emerge in series of cohorts. Weed harrowing needs to target very small, cotyledon-staged weeds, and repeated treatments with short intervals are necessary at times for satisfactory control (Rasmussen et al., 2010).

Inter-row cultivation with steerage hoes is widely applied in typical row crops where operation between crop rows is straightforward. The weeding device is usually a goosefoot share, providing a cutting action that can almost completely remove inter-row weeds unless soil conditions are wet or weeds have become too large to be controlled (Melander et al., 2005). Inter-row hoeing may also be used in cereals

* Corresponding author at: Aarhus University, Faculty of Science and Technology, Department of Agroecology, Research Centre Flakkebjerg, DK-4200, Slagelse, Denmark.

E-mail address: bo.melander@agro.au.dk (B. Melander).

https://doi.org/10.1016/j.eja.2018.08.005
Received 20 December 2017; Received in revised form 23 August 2018; Accepted 24 August 2018

Table 1
Experimental details showing the crops and the years in which they were grown. The factors N input, inter-row spacing ± inter-row hoeing and key assessments were conducted in all crops and years. Abbreviations for N input and hoeing treatments are shown in parentheses.

Crops and years	NH_4-N kg ha^{-1}	Inter-row spacing (mm) ± inter-row hoeing	Key assessments
Spring barley (2014, 2015, 2016) and spring wheat (2015, 2016)	50 (50N) 100 (100N)	125 non-hoed (125NH) 125 hoed (125H), 70 mm SW[a], - 55 mm 'untreated' area[b] 150 hoed (150H), 120 mm SW[a], - 30 mm 'untreated' area[b] 200 hoed (200H), 170 mm SW[a], - 30 mm 'untreated' area except in 2014 with 80 mm 'untreated' area[b] 250 hoed (250H), 220 mm SW[a], - 30 mm 'untreated' area except in 2014 with 45 mm 'untreated' area[b] 300 hoed (300H), 250 mm SW[a], -50 mm 'untreated' area except in 2014 with 95 mm 'untreated' area[b]	1. Crop plants counted at the one-leaf stage (all plots) 2. Weed counts 2 days before hoeing (all plots except 125NH) 3. Weed counts 8–10 days after hoeing (all plots) 4. Weed and crop biomass sampling at crop anthesis in late June (all plots) 5. Crop tiller counts 4–6 days before crop harvest (all plots) 6. Crop harvest mid-August (barley) and late August (wheat) (all plots)

[a] SW = share width. In 2014, SW was 120 mm for 200-mm inter-row spacing and 205 mm for both 250 and 300-mm inter-row spacing.
[b] 'Untreated' area is the inter-row space not directly impacted by the share width.

grown with increased inter-row spacings to make room for the operation of a goosefoot share between crop rows (Jabran et al., 2017). Its principal application is against annual weeds, but it can have some effect against perennials as well (Graglia et al., 2006). It will not eradicate a perennial weed problem since belowground propagules are not directly affected. However, shoot removal will stimulate re-sprouting, which depletes the belowground food reserves. At the same time, translocation of photosynthetic assimilates to roots and rhizomes is interrupted, and overall these effects can impede the regenerative capacity of perennial weeds (Graglia et al., 2006).

Inter-row hoeing for weed control in cereals and other crops grown with narrow inter-row spacing has been the subject of renewed interest in recent years thanks to camera-based automatic steering systems. Vision technology eases the steering task and enables inter-row hoeing with a higher operational capacity as implement width and driving speed can be increased (Jabran et al., 2017). Previous studies on inter-row hoeing in conventionally grown cereals have shown greater effectiveness against problematic weed species such as grasses and tap-rooted species that have an erect growth habit (Melander et al., 2003). Timing of treatment was less crucial with inter-row hoeing than weed harrowing because the cutting action of the shares also controls weeds with more than two or three true leaves. However, weeds growing in the crop rows (intra-row weeds) are not directly impacted by the hoe shares and thus are not controlled unless sideways soil movement causes some soil coverage of the intra-row weeds. Another drawback is a yield penalty of 11–12% associated with the widening of inter-row spacing from the standard 125 mm to 240 mm (Melander et al., 2003). Kolb et al. (2010) achieved improved weed control, yields and profitability using inter-row hoeing in organic spring barley with high infestations of white mustard (*Sinapis alba* L.) in contrast to merely improving crop competition through higher seed rates and spatial arrangement of crop plants. However, inter-row hoeing did not achieve better results at a lower weed infestation level. The study compared just one widened inter-row spacing with the standard spacing (177 mm *versus* 228 mm). There is considerable uncertainty about the optimal combination of inter-row spacing and inter-row hoeing to maximise weed suppression and crop yield. Crop yield and weed control are to some extent inversely related. Wide inter-row spacing means a greater proportion of the surface area can be hoed, which should improve weed control and thus crop yield, but a widening of the inter-space beyond the limits for effective utilisation of the resources can counteract the benefits of weed control, as seen with conventional cereals (Melander et al., 2003). However, moderate widening of the inter-row spacing does not appear to reduce yields of cereals in organic farming that are fertilised with solid or liquid manures, where much of the nitrogen (N) is in organic form and released more slowly (Hiltbrunner et al., 2005). In Danish organic agriculture, NH_4-N rates from slurry applied for spring cereals are typically 100 kg ha^{-1} on dairy farms and around 50 kg ha^{-1} on arable farms without livestock (Bertelsen 2015; personal communication). There has not yet been a thorough investigation of the effect on weed growth and crop yield of interactions between N fertilisation rates and inter-row hoeing at different inter-row spacings.

The objective of this study was therefore to investigate the interaction between inter-row hoeing at different inter-row spacings and N rates in terms of their impact on weed growth and crop yield in organic spring cereals. It was hypothesised that:

- increasing the inter-row space results in greater weed control from inter-row hoeing than smaller spacing
- increasing the N input (50 kg *versus* 100 kg NH_4-N ha^{-1} in animal manure) improves crop growth relative to weed growth from weeds surviving inter-row hoeing
- weed control effects are greater in spring barley than in spring wheat because barley suppresses weeds surviving inter-row hoeing more effectively
- crop yield and quality are unaffected by inter-row spacing in organic farming

2. Materials and methods

2.1. Experimental layout and treatments

In total five experiments were conducted on a sandy loam soil at the Flakkebjerg Research Centre (55°19'N, 11°23'E), Denmark. The factors inter-row spacing with inter-row hoeing and N input were investigated in terms of their impact on crop and weed growth in spring barley (*Hordeum vulgare* L.) and spring wheat (*Triticum aestivum* L.) in organic farming. Table S1 in Supplementary shows the mean temperatures and rainfall during the main growing season (April–July) for each month and year, while Table 1 gives an overview of the crops and years in which they were grown and the experimental factors studied for each combination of crop and year. Spring barley was sown on 2 May 2014, 9 April 2015 and 20 April 2016 using the two-row variety *Evergreen*. Spring wheat, variety *Bittern*, was sown on the same dates as barley in 2015 and 2016. Seed rates were adjusted to target approximately 400 plants m^{-2} for both crops and obtain the same plant density m^{-2} irrespective of inter-row spacing. To achieve this, the seed rate per metre of row was proportionally increased with widening inter-row spacing. The spring cereals were grown according to Danish organic standards. Nutrients were applied as anaerobically-digested slurry at rates