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Grazing intensities affect weed seedling emergence and the seed bank in an integrated crop–livestock system

Mauricio Z. Schuster[a,*], Adelino Pelissari[a], Anibal de Moraes[a], S. Kent Harrison[b], R. Mark Sulc[b], Sebastião B.C. Lustosa[c], Ibanor Anghinoni[d], Paulo C.F. Carvalho[e]

[a] Department of Crop Production and Protection, Federal University of Paraná, 1540 Rua dos funcionários Road, Curitiba, PR 80035-060, Brazil
[b] Department of Horticulture and Crop Science, The Ohio State University, 2021 Coffey Road, Columbus, OH 43210-1086, USA
[c] Department of Agronomy, Midwest State University of Paraná, 03 Simeão Camargo Varela de Sá road, Guarapuava, PR 85040-080, Brazil
[d] Department of Soil Science, Federal University of Rio Grande do Sul, Porto Alegre, RS 91540-000, Brazil
[e] Department of Forage Plants and Agrometeorology, Federal University of Rio Grande do Sul, Porto Alegre, RS 91540-000, Brazil

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A B S T R A C T

Integrated crop-livestock systems (ICLS) are widespread worldwide. Although weeds can result in several types of losses, essential information regarding weed seedling emergence and seed banks is lacking in these systems for integrated weed management planning. This study investigated the effects of different grazing intensities (no grazing and grazed swards maintained at 10-, 20-, 30- and 40-cm sward heights) on weed seedling emergence and seed banks in a winter cover crop during the 15th year of an ICLS experiment under no-tillage management in subtropical Southern Brazil. We hypothesized that low grazing intensities would reduce weed interference and weed seed banks size in an ICLS. We determined treatment effects on weed species richness, seed bank population density, and seedling emergence during winter and summer. Higher sward heights in the winter-grazed cover crop reduced the number of weed species, the density of emerged weed seedlings, and the weed seed bank size compared with the non-grazed control. With a sward grazing height of 10 cm, the seed bank contained an average of 3151 seeds m^{-2}, and the weed population densities during the summer and winter were 11.8 and 21.7 plants m^{-2} greater, respectively, compared with the sward grazing height of 40 cm. Fifteen years after adopting low grazing intensities (30- and 40-cm sward heights) in the ICLS, the size of the weed seed bank was reduced by 42.1% compared with the non-grazed treatment. Decreasing the grazing intensity reduced the number of weed species, the density of emerged weed seedlings, and the weed seed bank density; therefore, integrated weed management strategies should consider minimizing grazing intensities in an ICLS.

1. Introduction

Weeds reduce the potential yields of row crops and pastures, and result in an estimated annual loss of US$ 99.2 billion per year in the US, UK, Australia, India, South Africa and Brazil combined (Pimentel et al., 2001). In addition, the increased number of glyphosate-resistant weed species is a primary factor that threatens food security in global agriculture (Busi et al., 2013) and has increased the cost of controlling weeds on farms (Beckie, 2011).

Integrated crop-livestock systems (ICLS) are widespread throughout the world, comprising a total area of approximately 2.5 billion hectares (Keulen and Schiere, 2004). Studies of ICLS have been conducted with regard to production responses (Carvalho et al., 2014), environmental quality (Lemaire et al., 2013), economic viability (Oliveira et al., 2013) and social benefits (Franzluebbers et al., 2014). However, Moraes et al. (2014) published a review of 450 ICLS papers published in 93 journals between 1994 and 2013 and found that although 62% of those papers considered crop components, and only 4% considered weeds, demonstrating a gap in knowledge regarding weed management in ICLS.

Ecology-based integrated weed management in agroecosystems for modern range production depends on the ability to predict the consequences of management activities while understanding the patterns and processes of vegetation (Robertson and Swinton, 2005) and seed bank changes (Davis et al., 2006). Grazing by domestic animals is an important driver of global vegetation

* Corresponding author.
E-mail address: mauricioschus@gmail.com (M.Z. Schuster).

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change (Díaz et al., 2007), and managing grazing intensity is important for understanding the overall dynamics of any ICLS (Kunrath et al., 2014).

The current work investigated the effects of different grazing intensities on weed seedling emergence and seed banks in an ICLS. We hypothesized that reduced grazing intensities would lower weed interference and weed seed banks in an ICLS. We sought to determine whether weed species composition, seedling emergence, and seed bank size change with changing grazing intensity in an ICLS; therefore, we compared the effects of different grazing intensities on those factors during the 15th year of an ICLS experiment under no-tillage management in subtropical Southern Brazil.

2. Materials and methods

2.1. Site and treatment description

The long-term ICLS experiment used for this study was located on a 22-ha field at the Espinilho Farm (Agropecuaria Cerro Coroado) in São Miguel das Missões in Rio Grande do Sul State, Brazil (28°56′12″S latitude, 54°20′52″W longitude, 465 m altitude). This site has a warm humid summer (Cfa) climate according to the Köeppen classification system, with an average temperature of 19 °C and a yearly average precipitation of 1850 mm. The soil is a clayey Oxisol (Rhodic Hapludox; Soil Survey Staff, 1999) that is deep, well-drained and dark red with a clayey texture (540, 270 and 190 g kg^{-1} clay, silt and sand, respectively).

Before 1993, gallery forest and natural pasture covered the experimental area. The area was converted into no-tillage cropland in 1993, and from 1993 to 2001 soybeans (*Glycine max* (L.) Merr.) were grown during the summer, and black oats (*Avena strigosa* Schreb.) were grown during the winter. Since 2001, a soybean-beef cattle ICLS experiment was established with two seasons: (1) the winter season with cattle grazing a cover crop from May to November; and (2) the summer season with soybean crops from December to May.

During the winter season, black oat (cv. "Iapar 61") was sown (45 kg ha^{-1}) with naturally reseeding Italian ryegrass (*Lolium multiflorum* Lam. cv."common") to form a mixed winter pasture system; the ryegrass heads out and drops seed at the end of each winter grazing cycle and establishes itself each year by self-seeding, which is the common practice in ICLS in the region (Neto et al., 2014). Grazing was forage-based in a continuous stocking system with steers weighing approximately 200 kg (crossbred Angus, Hereford and Nellore) that entered the pasture system when the aboveground forage mass was approximately 1.5 ton ha^{-1} of dry matter (approximately 25 cm sward height).

The treatments consisted of different grazing intensities during the winter season that were determined by pasture vegetation sward height. Sward heights of 10-, 20-, 30- and 40-cm (G10, G20, G30 and G40, respectively) were considered in addition to a reference non-grazed (NG) treatment. All treatments were organized in a randomized complete block design with three replications, with experimental units ranging from 0.8 to 3.2 ha. Sward heights for each treatment, which corresponded to grazing intensity (stocking), were controlled with variable stocking with put-and-take steers that were added or removed from the plot as required. The experimental unit size varied across treatments to achieve the desired sward height with the desired minimum number of three test animals. Sward heights were measured every 14 days using the sward stick method, using a graduated measurement stick with a sliding marker. The sward height recorded was the height at which the first forage leaf blade contacted as the marker as it was lowered into the canopy. Approximately 100 readings (points) were taken randomly in each experimental unit. The grazing period was approximately 110 days; for more details see Kunrath et al. (2014).

At the end of the winter season (mid-November), the pasture was desiccated with glyphosate (1750 g a.i. ha^{-1}), chlorimuron-ethyl (37 g a.i. ha^{-1}, used for the first 11 years) and saflufenacil (35 g a.i. ha^{-1}, used for the past 4 years). The early desiccation (2–4 week before sowing) was necessary for residue management and facilitation of no-tillage soybean seeding (Bolliger et al., 2006). In mid-December of each year, soybeans were sown with the cultivar "Iguaçu" for the first three years and with "Nidera RR" (a transgenic glyphosate-resistant cultivar) in the remaining years. Soybeans were sown in rows spaced 45 cm a part at a seeding rate of 45 seeds m^{-2}. Post-emergent herbicide was applied in mid-January (chlorimuron-ethyl 37 g a.i. ha^{-1} and clethodim 100 g a.i. ha^{-1} in the first three years and glyphosate at 1400 g a.i. ha^{-1}in the remaining years), and insecticides and fungicides were applied following agronomic recommendations. Soybeans were harvested in May each year.

2.2. Seed bank sampling and seed tray maintenance

Soil samples were collected from the central area of each plot, where 56 soil cores were taken from the top 5-cm layer.

Seed banks were sampled before summer crop seeding in November 2014, which marked the beginning of year 15 of the ICLS experiment described above. Soil samples were collected manually along four 56-m transects in each experimental unit using a steel 4.2-cm diameter probe, and 56 soil cores were extracted from the top 5 cm of the central area of each plot. The four transects were laid out in the "XX" pattern described by Wiles and Schweizer (2002) to ensure an adequate spatial distribution of weed seed bank sampling. Along the transects, two soil cores were collected at 8-m intervals and combined into one 56-core composite sample for each experimental unit.

All soil samples were processed to remove stones and root fragments, then spread in 44 × 38-cm plastic trays and placed in a greenhouse for 12 months beginning in November 2014. Soil moisture was maintained in the trays using regular sub-irrigation. The seedling emergence method (Thompson et al., 1997) was used to quantify the readily germinable seeds (not taking into account dead or dormant seeds) in the soil seed bank (Ma et al., 2012). During the seed tray maintenance, the lowest temperature was 0 °C, and the maximum temperature was 38 °C.

Emerged seedlings were periodically identified, counted and removed from the plastic trays. Seedling identification was conducted as described by Kissmann and Groth (1997) and Lorenzi (2006). A two-week drought period was imposed in May 2015 to break seed dormancy (De Cauwer et al., 2010). At the end of the drought period, the soil in the trays was stirred and sub-irrigation was reactivated. After the seedling emergence ceased, the samples were stirred and placed in a room at 4 °C for three weeks before being subjected to alternating temperatures of 15 and 4 °C for one-week intervals and then returned to the greenhouse (Cardina et al., 2002). This process was repeated until no additional seedlings emerged.

2.3. Field weed seedling sampling

In each experimental unit in the field, weed seedling emergence was quantified into two seasons: at the end of grazing (November in 2014 and 2015) and during soybean cropping before post-emergent herbicide application (mid-January in 2015 and 2016). The emerged weed seedlings were identified and counted within 50 × 50 cm quadrats placed at 14-m intervals in the central area of each experimental unit and distributed along four 56-m transects laid out in the "XX" pattern described previously. We calculated the