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Tillage and establishment system effects on annual ryegrass seed crops

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ABSTRACT

Annual ryegrass [*Lolium perenne* L. ssp. *multiflorum* (Lam.) Husnot] seed crops have been produced on some Oregon farms continuously for decades without rotation of crops or farming practices. The objective of the study was to determine the effects of tillage and establishment systems on 'Gulf' annual ryegrass seed crops over a 9-year period. Six systems were employed: (i) continuous conventional tillage (CT), (ii) continuous no-till (NT), (iii) NT/CT cycle alternate year tillage (NT/CT), (iv) volunteer/CT cycle alternate year tillage (Vol/CT), (v) burn and NT/CT cycle alternate year tillage (Burn + NT/CT), and (vi) volunteer/NT/CT cycle with tillage every 3rd year (Vol/NT/CT). Environment × system interaction effects governed seed production characteristics. Three seed yield environments were observed during the 9 years: high, intermediate, and low. High yield environments had higher temperatures (+1.2 °C) and lower precipitation (−48 mm) in April–June than in low yield environments. Across environments, yields were greatest with Burn + NT/CT, CT, and Vol/NT/CT and lowest with NT. Stability analysis revealed that Burn + NT/CT, CT, and Vol/NT/CT systems produced up to 40% greater yields than the mean of all systems in low yield environments. Yield variation among systems was high in low yield environments. Increasing tillage frequency from zero in NT to once every other year in NT/CT boosted yields so that they were equivalent to CT. Yield differences among systems were attributable to seed number. Moderate tillage frequency and occasional residue removal are required to produce the best long-term seed yields in annual ryegrass.

1. Introduction

Annual ryegrass [*Lolium perenne* L. ssp. *multiflorum* (Lam.) Husnot] seed crops are grown on wet, poorly drained soils in western Oregon's Willamette Valley because few other crops are adapted to these conditions (Young and Barker, 1997; Hart et al., 2011). Western Oregon's climate is classified as a Mediterranean warm summer type (Csb) and is marked by dry summers and mild, wet winters (Peel et al., 2007). Annual precipitation in the region is 1015 mm, with 90% recorded between October and April. Annual ryegrass seed crops are grown on an average 51,543 ha each year in Oregon making it one of the state's most important grass seed crops. Oregon accounts for nearly 100% of US production of annual ryegrass seed and 77% of global production for this widely used forage and turf grass (NASS, 2016; IHSG, 2007).

Annual ryegrass has been among the most stable of the state's grass seed crops over the past 40 years and as such is an important contributor to the economic welfare of Oregon seed producers. But this stability and need for a crop on wet, low productivity soils means that annual ryegrass has been grown in some fields continuously for decades without rotation. The long-term influences of continuous cropping of annual ryegrass seed crops have not been examined nor have any long-term management practices been evaluated to date in annual ryegrass seed production. This situation is markedly different from wheat (*Triticum aestivum* L.) and other grain crops where there have been many studies on the impacts of long-term employment of agronomic practices on crop productivity (Hammel, 1995; López-Bellido et al., 1996; Hernanz et al., 2014).

Tillage and establishment systems for annual ryegrass seed production have evolved over time with changes in post-harvest residue management practices. Residue management is one of the most important practices in the production of cool-season grass seed crops (Chastain et al., 2011). Historically, annual ryegrass seed producers have used field burning as an inexpensive means to remove crop residue remaining after seed harvest and prior to preparation of the field for the next annual ryegrass crop (Young and Barker, 1997). Legislative action ended the practice of field burning in the region because of public concern over air quality and as a consequence, seed growers have been

Abbreviations: BBCH, Biologische Bundesanstalt, Bundessortenamt und CHemische Industrie; CT, conventional tillage; NT, no-till; NT/CT, cycle alternate year NT and CT; Vol/CT, volunteer/CT cycle alternate year tillage; Burn + NT/CT, burn and NT/CT cycle alternate year tillage; Vol/NT/CT, volunteer/NT/CT cycle with tillage every 3rd year

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searching for new approaches to management of annual ryegrass seed crops. Establishment of annual ryegrass seed crops with no-tillage planting was successful when following removal of the previous annual ryegrass crop residues by field burning (Burn + NT). However, the most common alternative non-thermal residue management system involves flail chopping of the straw and stubble, and then using conventional tillage (CT) to incorporate residues before preparation of the seed bed for planting the next crop.

Some annual ryegrass seed producers are reluctant to adopt the CT alternative system and have instead chosen to produce seed from plants that have volunteered from shattered seed lost during harvest of the previous crop (Vol). Volunteer cropping works for seed production of annual ryegrass when the seed is not produced under the seed certification system and the seed is sold as uncertified annual ryegrass. The Vol system has lower cost than CT because it forgoes seed bed preparation with tillage and has the added benefit of reducing soil erosion (Young and Barker, 1997). A key to success of the Vol system is the creation of rows with herbicides to reduce stand density, thereby increasing seed yield (Young et al., 1997, 1998).

The objective of this study was to determine the long-term effects of tillage and establishment systems on seed production of annual ryegrass over a 9-year period.

2. Materials and methods

2.1. Experimental design and plot maintenance

Field trials were conducted at the Oregon State University Hyslop Farm (44°40′ N, 123°11′36″ W) near Corvallis, Oregon from 2005 to 2014. The soil at the experimental site was a Woodburn silt loam (fine-silty, mixed, superactive, mesic, Aquultic Argixeroll). The previous grown crop for the two years prior to the start of the trials at the experimental site was 'Gulf' annual ryegrass. The experimental design was a randomized complete block with three replications of the following six tillage and crop establishment systems and combinations: (i) continuous conventional tillage (CT), (ii) continuous no-till (NT), (iii) NT/CT cycle alternate year tillage (NT/CT), (iv) volunteer/CT cycle alternate year tillage (Vol/CT), (v) burn and NT/CT cycle alternate year tillage (Burn + NT/CT), and (vi) volunteer/NT/CT cycle with tillage every 3rd year (Vol/NT/CT).

Crop residue (straw and stubble) was flail-chopped with a flail mower to at least 5 cm above the soil surface after seed harvest in each year but not removed from plots except in the Burn + NT treatment where residues were not flailed prior to burning. The Burn treatment was conducted by igniting the crop residue, which produced a steady uniform burn to the soil surface. Conventional tillage involved primary tillage by moldboard plow followed by disking and other secondary tillage operations needed to produce a seedbed. Crop residues were incorporated into the soil by the CT treatments. The depth of plowing in CT ranged from 20 to 25 cm.

'Gulf' annual ryegrass was used in planting CT and NT treatments in the late September to mid-October period each year depending on weather conditions. The seeding rate for CT and NT treatments was 19 kg ha^{-1} and row spacing was 18 cm. In the volunteer treatment (Vol), seed shed from the previous crop (Gulf annual ryegrass) was the source of seed for the stand in each year. Since stand density in the Vol treatment was high, rows were created in the stand by row-spray removal of approximately 70% (18 cm out of every 25 cm) of the crop stand with glyphosate [*N*-(phosphonomethyl) glycine] applied at 3.9 L ha^{-1} (Young et al., 1997). This was accomplished by use of a shielded spray system so that the remaining 30% (7 cm) of the crop stand was not sprayed. No tillage was done in the volunteer treatment. Each tillage and establishment system plot measured 7.6 m × 38.1 m.

A pre-plant application of 36 kg N ha^{-1} as a dry mixture of urea, monoammonium phosphate, ammonium sulfate, and muriate of potash (16-16-16-6) was made uniformly across all treatments by using a tractor-mounted Gandy orbit-air fertilizer spreader in each year (late September to mid-October). Spring applications of N were made as dry granular urea (46-0-0) at 163 kg N ha^{-1} in March of each year as is the standard practice for annual ryegrass seed crops in the region (Hart et al., 2011).

Volunteer annual ryegrass plants are a genetic contaminant and considered weeds in certified annual ryegrass seed production. These volunteer plants were controlled in NT treatments with an application of glyphosate at a 1.7 L ha^{-1} rate. Annual bluegrass (*Poa annua* L.) weeds were controlled after the crop was established with applications of ethofumesate (2-ethoxy-2,3-dihydro-3,3-dimethyl-5-benzofuranyl methanesulfonate) at a 1.12 kg ai ha^{-1} rate in November or December of each year. Bromoxynil (3,5-dibromo-4-hydroxybenzonitrile) and MCPA [(4-chloro-2-ethylhexylphenoxy) acetic acid] were applied at 0.53 kg ae ha^{-1} rates in March of each year to control broadleaved weeds.

2.2. Soil sampling and analysis

The soil was sampled to a depth of 20 cm in 2005 prior to implementation of tillage and establishment treatments (baseline), and at the end of the trials in 2014. Soil samples were analyzed for total N, P, K, soil C, organic matter, and pH (Gavlak et al., 2003). Soil C was determined by the Dumas combustion method (Jones and Case, 1990) using an automated LECO CNS-2000 macro analyzer (LECO Corporation, St. Joseph, MI). Soil C was considered equivalent to soil organic carbon since soil pH was 5.8 or lower. Soil pH was determined by using a pH electrode on 2:1 soil:water suspension. Soil organic matter was determined by loss on ignition.

2.3. Seed yield and yield components

Plots were harvested in late June to early July of each year by swathing when the seed moisture content reached approximately 400 g kg^{-1}. A commercial swather, modified for small plots, was used to harvest plots into windrows for drying in the field. A plot combine was used to thresh seed in mid-July when seed moisture in the swath had decreased to 120 g kg^{-1}. Harvested seed yield was measured directly in the field with a sub-sample (100 g each) being collected for further analysis in the laboratory. Sub-samples were cleaned to marketable seed yield quality standards (99% annual ryegrass seed as required by Oregon Seed Certification) by using a laboratory size Clipper M-2B (A.T. Farrell, Saginaw, MI) air-screen cleaner. Cleanout from the seed conditioning process was used to calculate clean seed yield. Samples to determine seed weight were hand cleaned using screens and a blower prior to counting. For each plot, two 1000-seed samples were counted with an electronic counter (Old Mill model 850-2, San Antonio, TX), weighed, and averaged. Seed number m^{-2} was calculated by dividing the clean seed weight m^{-2} by the individual seed weight. Harvest index was calculated in 2014 as the ratio of clean seed yield to above-ground biomass at taken at BBCH 80 (seed maturation).

2.4. Statistical analysis

Analysis of variance was conducted to test tillage and establishment system, year, and interaction effects on seed yield, seed weight, seed number, and cleanout by using PROC GLM from SAS (SAS Institute, 2009). Tillage and establishment system effects on soil characteristics and harvest index in 2014 were also analyzed by using ANOVA. All source terms in the ANOVA models were considered to be fixed effects and none of the data were transformed prior to or after analysis. Treatment means were separated by Fisher's protected LSD values at the 5% level of significance.

Stability analysis was conducted to assess seed yield stability of tillage and establishment systems across environments (year and system