

## INFLUÊNCIA DE SISTEMAS DE ROTAÇÃO DE SEMENTES DE GRAMÍNEAS FORRAGEIRAS TEMPERADAS NA COMPOSIÇÃO DO BANCO DE SEMENTES INVASORAS NO SOLO<sup>1</sup>

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RESUMO - Em consequência da mudança nas práticas agronômicas nos cultivos de gramíneas perenes para sementes no oeste de Oregon, EUA, sistemas alternativos de rotação estão sendo considerados com a finalidade de reduzir a infestação de plantas invasoras. De um modo geral, inexistem informações dos efeitos de práticas agronômicas alternativas e aplicações de herbicidas na composição do banco de sementes no solo durante esta transição. Seis sistemas alternativos de rotação foram aplicados a partir de 1992 em uma área historicamente cultivada com azevém-perene (*Lolium perenne* L.), para produção de sementes em sistema de monocultura. Parcelas medindo 20x30m, para cada sistema, foram arranjadas em blocos completos, casualizados com quatro repetições. Vinte a trinta amostras de solo foram retiradas de cada parcela em junho de 1997. A composição das espécies de invasoras das amostras de solo foram determinadas em sucessivos ensaios de germinação conduzidos em casa de vegetação. Além da densidade de sementes, índices de heterogeneidade para equitabilidade, riqueza e diversidade de espécies foram determinados. As espécies mais abundantes foram *Juncus buffonius* L. e *Poa annua* L. Mudanças na composição do banco de sementes foram decorrentes dos diferentes herbicidas utilizados nas culturas componentes da rotação. Trigo (*Triticum aestivum* L.) e aveia (*Avena sativa* L.) plantados em cultivo mínimo, na primavera, reduziram a riqueza e a densidade de espécies em comparação com os outros sistemas de rotação de cultura, mas não alterou os índices de equitabilidade e heterogeneidade de espécies. Quando “meadowfoam” (*Limnanthes alba* Hartweg ex Benth.) sucedeu trigo na rotação, a riqueza de espécies não foi afetada, mas equitabilidade e a diversidade diminuíram em comparação com outros sistemas de rotação. “Meadowfoam” sucedendo trevo-branco (*Trifolium repens* L.), o método de estabelecimento (preparo mínimo e convencional do solo) não afetou a densidade, equitabilidade e riqueza de espécies.

Termos para indexação: azevém-perene, espécies invasoras, práticas culturais, produção de sementes, sementes enterradas.

### INFLUENCE OF TEMPERATE GRASS SEED ROTATION SYSTEMS ON WEED SEED SOIL BANK COMPOSITION

ABSTRACT - Due to changing cropping practices in perennial grass seed crops in western Oregon, USA, alternative rotation systems are being considered to reduce weed infestations. Information is generally lacking regarding the effects of alternative agronomic operations and herbicide inputs on soil weed seed bank composition during this transition. Six crop rotation systems were imposed in 1992 on a field that had historically produced monoculture perennial ryegrass (*Lolium perenne* L.) seeds. Each system plot was 20 x 30 m, arranged in a randomized complete block design, replicated four times. Twenty to thirty soil cores were sampled in June 1997 from each plot. The weed species composition of the cores was determined by successive greenhouse grow-out assays. In addition to seed density, heterogeneity indices for species evenness, richness, and diversity

<sup>1</sup> Aceito para publicação em 30.12.2001; parte do Projeto de Pesquisa de Pós-Doutorado realizado pelo primeiro autor no “National Forage Seed Production Research Center”, USDA-ARS, Corvallis, OR.

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were determined. The most abundant species were *Juncus bufonius* L. and *Poa annua* L. Changes in seed bank composition were due to the different herbicides used for the rotation crop components. Compared to the other rotation systems, no-tillage, spring-planted wheat (*Triticum aestivum* L.) and oat (*Avena sativa* L.) reduced overall weed seed density and richness, but did not affect weed species evenness or diversity. When meadowfoam (*Limnanthes alba* Hartweg ex Benth.) succeeded wheat in rotation, weed species richness was unaffected, but evenness and diversity were reduced, compared to the other rotation systems. For meadowfoam in sequence after white clover (*Trifolium repens* L.), crop establishment method (no-tillage and conventional tillage) had no effect on weed seed species density, evenness, or diversity.

Index terms: buried seeds, cropping practices, perennial ryegrass, seed production, weed species.

## INTRODUCTION

The size and composition of the weed seed bank as well as the above-ground flora reflect the impact of past and present weed, crop, and soil management practices (Roberts, 1981; Cardina et al., 1991). In general, large seed banks are associated with arable sites (Fenner, 1995), and its composition is richer than the composition of plants that cover it (Symonides, 1986). The amount of species diversity within seed banks increases by disturbance amount from plowing to disking to no-tillage practices (Feldman et al., 1997).

It is normally assumed that seed banks have clustered (patchy) spatial distributions (Dessaint et al., 1991; Forcella et al., 1992; Boccanelli & Lewis, 1994). Methods including indices of variance-to-mean ratio, Lloyd's mean crowding and Lloyd's patchiness (Dessaint et al., 1991), and Morisita's index (Boccanelli & Lewis, 1994) are used to determine weed aggregation patterns.

The viable seed fraction in the seed bank is the main source of weed recruitment and infestation in crop fields (Cavers & Benoit, 1989). Reducing the size of weed seed banks has been a long-term goal of weed management strategies, especially for continuously cropped fields (Schweizer & Zimdahl, 1984). Weed seed bank changes occur temporally and by management practices including crop rotation sequences and tillage practices (Chauvel et al., 1989). Tillage practices influence the vertical distribution and density of weed seeds (Buhler, 1995). Limiting the amount and depth of tillage leaves seeds close to the soil surface where most seeds have the ability to germinate and become established (Buhler & Mester, 1991; Yenish et al., 1992; Buhler, 1995).

Crop rotation can disrupt the continuous dominance of specific weeds in a field, decrease the build-up of weed populations, and prevent major shifts in weed species composition (Ball, 1992). However, the lack of rotation crop complexity in a corn and soybean rotation was shown do not

influence weed seed bank composition (Mulugeta & Stoltenber, 1997).

Herbicides to control weeds in different rotation systems are a key component of conservation tillage management (Buhler, 1995). However, single herbicide chemistries rarely control all weed species when applied at selective rates, and repeated crop/herbicide combinations may rapidly shift the composition of weed seed banks (Roberts, 1981). Selective foliar-applied post-emergent herbicides are preferable to soil-applied herbicides for weed management in conservation tillage systems (Lewis, 1985).

Weed seed contaminants are a major problem for maintaining grass seed end-product quality (Schweitzer, 1994). If product purity standards are not met, entire seed lots can be rejected or require recleaning (Churchill et al., 1995). Weed control practices in turf grass and forage seed systems have historically relied on herbicide control methods, but fewer chemicals are available because of withdrawal of registration labels (Mueller-Warrant, 1994). Detection of herbicides in ground-water (Halberg, 1989) and the appearance of herbicide resistant weeds in many rotation systems (Maxwell et al., 1990) necessitate approaches to optimize efficacy when using herbicides (Mulugeta & Stoltenberg, 1997). However, the reduced herbicides inputs and greater reliance on mechanical methods may result in increased weed management problems over time (Mulugeta & Stoltenberg, 1997).

There is a common view that the introduction of no-till crop establishment challenges conventional approaches used to manage weeds in crops. Few reports are available that describe the effects of short-term crop rotations combined with tillage practices on the composition of soil weed seed banks (Feldman et al., 1997). Specifically, there is a lack of information concerning the composition of the prevalent weed seed bank in Willamette Valley, Oregon turf and forage seed rotation systems.

The objective of this research was to determine the impact of six perennial ryegrass rotation system components that differ by rotation sequence and tillage method on soil weed seed species diversity and spatial aggregation.

## MATERIAL AND METHODS

The field experiment was conducted during 1997 to 1998 at the USDA-ARS long-term sustainable grass seed rotation and management systems evaluation area in Linn County (44°35'N latitude and 123°17'W longitude), Oregon, USA. The farm surrounding the research area has been under grass seed production cultivation for decades. A cropping systems project was established on the area in 1992. The soil is Woodburn (fine-silty, mixed, mesic Aquultic Agixeroll) that is poorly drained and normally saturated from late-autumn to early-spring. The climate is typical for humid temperate marine climatic conditions with 800mm of precipitation during the rainfall period, with little or no precipitation during July and August.

Each tillage-crop rotation sequence combination (Table 1) was 20x30m, with each treatment replicated four times and arranged in a randomized complete block design. There were a total of 24 plots at the research site. The CT (conventional-till) system consisted of two passes with a tractor-powered, rear-mounted roto-tiller. A roller mounted behind the roto-tiller compressed the soil with each pass. In the NT (No-till), crops were planted directly into the partially

removed crop residue (approximately 10% of the total above-ground post-harvest phytomass produced by the crop). A conventional double-disk opener planter with modifications was used to plant the crop seeds.

Prescription-based management principles were used to determine when to conduct fertilizer and weed control practices. Standard weed control practices were used for each rotation system, using registered herbicides. Record of the specific herbicides used for the crops harvested in 1997 is given in Table 2. The plots were fertilized according to standard recommendations for each crop.

The soil seed bank was sampled by removing 20 to 30 cores of 5cm diameter by 7cm depth, along two V-shaped pattern transects in each plot, spaced 1m apart. A total of 640 soil cores were collected from all plots. The sampling was done during June 1997, immediately after crop harvest. The soil cores were air-dried in paper bags and stored at approximately 20°C for five months until analyzed for seed content.

The soil cores were broken by hand and ground for two seconds in a grinder (Custom Laboratory Equipment, Orange City, FL). The approximate 250ml of ground soil was added to 325ml of vermiculite (grade #4) and mixed (Burrell Scientific, Pittsburgh) for 30 seconds at 300 shakes min<sup>-1</sup>. The mixed samples were placed in plastic zip-lock-bags with 250ml of dionized water. The hydrated samples were stored in a dark growth chamber (Percival Model E-54, Boone, IA) for 10 days at 5°C to break secondary seed dormancy. After

**TABLE 1. Tillage systems and crop rotation sequences for six perennial ryegrass seed production rotation systems during 1995, 1996, and 1997 at the USDA-ARS sustainable grass seed management systems research area in Linn County, Oregon.**

Management system	System number	Year				
		1995		1996		1997
		Planting season				
		Spring	Autumn	Spring	Autumn	Spring
WC <sub>NT</sub> -MF <sub>NT</sub>	1	WC	WC	WC	MF	MF
WC <sub>CT</sub> -MF <sub>CT</sub>	2	WC	WC	WC	MF	MF
SpWht <sub>NT</sub> -MF <sub>NT</sub>	3	F	F	SpWht	MF	MF
F-WC <sub>NT</sub> WC	4	F	F	WC	WC	WC
PRG <sub>NT</sub> -SpOat <sub>NT</sub>	5	PRG	PRG	PRG	F	SpOat
PRG <sub>NT</sub> -SpWht <sub>NT</sub>	6	PRG	PRG	PRG	F	SpWht

WC<sub>NT</sub>-MF<sub>NT</sub> = No-till (NT) established white clover (WC) followed by meadowfoam (MF); WC<sub>CT</sub>-MF<sub>CT</sub> = Conventional-till (CT) established white clover seed followed by conventional-till established meadowfoam; SpWht<sub>NT</sub>-MF = No-till established spring wheat (SpWht) followed by meadowfoam; F-WC<sub>NT</sub>WC = No-till established white clover after fallow (F) followed by a second seed-year white clover seed crop; PRG<sub>NT</sub>-SpOat<sub>NT</sub> = No-till established perennial ryegrass (PRG) followed by no-till established spring oats (SpOat); PRG<sub>NT</sub>-SpWht<sub>NT</sub> = No-till established perennial ryegrass followed by spring no-till established spring wheat.

**TABLE 2. Herbicides used to control weeds in six grass seed rotation system treatments in 1996 and 1997 at the USDA-ARS sustainable grass seed management systems research area in Linn County, Oregon.**

Management System	Application Date††	Quantity.ha <sup>-1</sup>	Herbicide trade mark†							
			Prism	Basagran	Roundup	Dual	MCPA Amine	Diuron	Goal	Hoelon
WC <sub>NT</sub> -MF <sub>NT</sub>	3.26.96	0.60 kg	x							
	4.3.96	2 l		x						
	4.29.96	0.46 kg	x							
	6.3.96	2 l					x			
	6.3.96	1 l		x						
	10.7.96	6 l			x					
	11.1.96	1.20 kg				x				
	3.24.97	0.60 kg	x							
WC <sub>CT</sub> -MF <sub>CT</sub>	3.26.96	0.60 kg	x							
	4.3.96	2 l		x						
	4.29.96	0.46 kg	x							
	6.3.96	2 l					x		x	
	6.3.96	1 l		x						
	10.7.96	6 l			x					
	11.1.96	1.20 kg				x				
	3.24.97	0.60 kg	x							
SpWht <sub>NT</sub> -MF <sub>NT</sub>	10.19.95	6 l			x					
	3.28.96	6 l			x					
	10.7.96	2 l			x					
	11.1.96	1.2 kg				x				
	2.25.97	0.60 kg	x							
F-WC <sub>NT</sub> WC	10.19.95	4 l			x					
	4.29.96	0.6 kg	x							
	5.6.96	0.6 kg					x			
	6.3.96	1.2 kg					x			
	10.7.96	1 l		x						
	10.7.96	0.60 kg	x							
	2.25.97	0.60 kg	x							
	3.24.97	0.6 kg	x							
PRG <sub>NT</sub> -SpOat <sub>NT</sub>	10.12.95	2.4 kg						x		
	10.12.95	1 l			x				x	
	10.7.96	6 L			x					
	3.24.97	4 l			x					
PRG <sub>NT</sub> -SpWht <sub>NT</sub>	10.19.95	6 l			x					
	3.28.96	6 l			x					
	10.7.96	6 l			x					
	3.24.97	4 l			x					
	4.26.97	5 l								x

† **Prism:** Clethodim: (*E,E*)-(+)-2-[1-[(3-chloro-2-propenyl)oxy] iminol] propyl]; **Basagran:** Bentazon: 3-isopropyl-1*H*-2,1,3-benzothiadiazim-4(3*H*)-one2,2-dioxide; **Roundup:** Glyphosate - *N*-(phosphonomethyl)glycine; **Dual:** Metolachlor - 2-chloro-*N*-(2-ethyl-6-methylphenyl)-*N*-(2-methoxy-1-methylethyl)acetamide; **MCPA amine:** [(4-chloro-*o*-tolyl)oxy] acetic acid (2-methyl-4-chlorophenoxyacetic acid); **Diuron:** 3-(3,4-dichlorophenyl)-1,1-dimethylurea; **Goal:** Oxyfluorfen - 2-chloro-1-(3-thoxy-4-nitrophenoxy)-4-(trifluoromethyl)benzene; **Hoelon:** Diclofop - methyl methyl 2-[4-(2,4-dichlorophenoxy)phenoxy]propanoate.

†† Herbicides with the same date within each rotation system were mixed before spraying.

stratification, each sample was spread in aluminum trays (20x20cm) to a depth of three cm  $\pm$  1 cm depth. The trays were placed at random on greenhouse benches and maintained at 20 $\pm$ 2°C and 18 $\pm$ 2°C (day and night, respectively). Natural light was supplemented with high intensity light (PPF of 170 $\mu$ mol.m<sup>-2</sup>.s<sup>-1</sup>) for 14 hours day<sup>-1</sup>. The samples in the trays were lightly watered daily or when necessary to maintain uniform wetness. Each soil sample was subjected to three cycles of drying for seven days, hydrating, seedling emergence and counting, and soil stirring. Preliminary experiments indicated that three cycles generally depleted the seed bank of readily non-dormant viable seeds, as has been reported by others (Lush, 1988).

The weed seedlings were identified, counted, and removed with forceps as they emerged until germination ceased. Species identifications were confirmed by growing seedling reference samples to a stage of development that was easily recognized. Reference seedling samples, representative of all identified and unidentified species, were maintained in a herbarium. The assays were conducted between 1 December 1997 and 30 April 1998.

The weed seed species data from the soil cores were logarithmically transformed [ $\log_{10}(x+1)$ ] to adjust for heterogeneity of variance and non-additivity (Mulugeta & Stoltenberg, 1997). Differences among transformed means were separated using Fisher's protected least significant difference test. The treatment means, calculated from log-transformed values, were inversely transformed using the antilogarithm [ $\text{antilog}_{10}(x-1)$ ] for interpretation. The individual weed species differences among the six rotation systems were subjected to analysis of variance.

The density and spatial distribution patterns of the individual weed seeds in the soil cores collected along the sampling transects included: (i) number of seeds; (ii) percentage of cores with seeds; (iii) relative percentage of species (R); (iv) mean number of seeds per core; (v) coefficient of variation (CV) and (vi) Morisita's aggregation index (Johnson & Anderson, 1986; Bocanelli & Lewis, 1994). The PCR-COR software (McCune & Mefford, 1997) was used to calculate the heterogeneity indices: (i) richness (S), (ii) Shannon-Weaver diversity [ $H' = -\sum P_i * \ln(P_i)$ ] and (iii) evenness ( $E = H'/\ln \text{richness}$ ).

Multidimensional scaling and cluster analyses were used to test similarity among the six rotation systems based on the weed seed densities of the four individual replications and means. Multivariate common factor analysis (Norusis, 1994) was used to determine the soil seed bank density relationships based on the 15 most prevalent species among the aggregated

samples. Four factor groupings were produced using factor rotation by the equimax method. Pearson's correlation ( $r$ ) and Spearman's rank correlation ( $r_s$ ) coefficients were used to determine placement of significantly associated species within the factor groupings. Based on the placement of the 15 weed species within the four factor groups, the six rotation system treatments were placed into three groups. Analysis of variance was used to determine differences among three rotation system groups for the six measures of soil seed bank density and spatial distribution. Pearson correlation coefficients were determined among seed bank density and spatial distribution characteristics by individual species, individual species by rotation systems, and heterogeneity indices by the six rotation systems. All results were reported at  $P \leq 0.05$ , unless otherwise stated.

## RESULTS AND DISCUSSION

Weed species characterization - A total of twenty weed species were recorded in the top 7cm of the soil seed bank among all rotation system treatments. The soil seed bank was almost exclusively composed of annual species (Table 3). The only exception was the perennial species was *Lotus corniculatus* L., which occurred at a low density and likely was an introduced contaminant with crop seeds previously sown in the experimental area. The weed flora was dominated by two species, *Juncus bufonius* L. and *Poa annua* L. that represented 59 and 22% of the total seed bank composition, respectively (Table 3). These were also the most abundant species recovered from all samples, being present in 80 and 88% of the soil cores, respectively. The remaining 16 species account only for 19% of the seed bank, of which *Veronica arvensis* L. and *Cerastium viscosum* L. represented 11% of the total. The five least abundant species, *Lupinus* sp., *Solanum nigrum* L., *Oxalis* sp., *Echinochloa crusgalli* (L.) Beauv. and *Lotus corniculatus*, represented only 0.02% of the seed bank and were excluded from the statistical analyses (Dessaint et al., 1991). The species present at this research site are indicative of soils that are saturated from early-winter to early-spring and that have an abundance of *Juncus bufonius* in the soil seed bank (Thompson & Grime, 1979). Normally, this kind of environment contains a high frequency of annual species (Levassor et al., 1990).

The coefficient of variation (CV) and Morisita's index values indicate that the seed bank samples were very different from each other (Table 3). *Juncus bufonius* and *Poa annua* were fairly randomly distributed compared to the very aggregated species such as *Crepis setosa* Hall f. and *Kickxia*

**TABLE 3. The soil seed bank density and spatial distribution characteristics of weeds at the USDA-ARS sustainable grass seed management systems research area in Linn County, Oregon, on the total number of seeds counted in cores from an 8cm depth, percentage of cores with seeds, relative percentage of species (R), the mean number of seeds per core, coefficient of variation (CV) and Morisita's aggregation index. The statistics are the aggregate results from six cropping systems treatments.**

Species	Bayer code	Seed bank characteristic					
		Density				Spatial distribution	
		Number of seeds (n)	Percentage of cores (%)	R (%)	Mean (n)	CV (%)	Morisita's index
<b>Monocotyledenous</b> .....							
- <i>Juncus bufonius</i> L.	IUNBU	40827	80.00	59.451	63.792	171.82	3.93
- <i>Poa annua</i> L.	POAAN	15244	87.97	22.198	23.819	175.25	4.02
- <i>Digitaria sanguinalis</i> (L.) Scop.	DIGSA	2582	34.22	3.760	4.034	325.40	11.33
- <i>Panicum capillare</i> L.	PANCA	1087	26.88	1.583	1.698	376.35	14.57
- <i>Festuca myuros</i> L.	VLPMY	327	11.88	0.476	0.511	494.06	23.49
- <i>Echinochloa crusgalli</i> (L.) Beauv.	ECHCG	2	0.31	0.003	0.003	1787.45	‡
<b>Dicotyledenous</b> .....							
- <i>Veronica arvensis</i> L.	VERAR	4635	39.84	6.749	7.242	311.04	10.52
- <i>Cerastium viscosum</i> L.	CERGL	3035	22.81	4.419	4.742	572.10	33.48
- <i>Gnaphalium palustre</i> Nutt.	GNAPA <sup>†</sup>	367	15.00	0.534	0.573	602.38	35.58
- <i>Cardamine oligosperma</i> Nutt.	CAROL <sup>†</sup>	196	10.47	0.285	0.306	675.42	43.50
- <i>Sonchus asper</i> (L.) Hill	SONAS	93	10.63	0.135	0.145	352.32	6.58
- <i>Kickxia elatine</i> (L.) Dumort	KICEL	74	3.28	0.108	0.116	1269.80	155.44
- <i>Senecio vulgaris</i> L.	SENVU	72	8.59	0.105	0.113	415.92	9.51
- <i>Crepis setosa</i> Hall f.	CVPSE	57	2.81	0.083	0.089	1579.12	243.01
- <i>Trifolium dubium</i> Sibth.	TRFDU	48	5.00	0.070	0.075	668.02	32.91
- <i>Daucus carota</i> L.	DAUCA	15	1.72	0.022	0.023	903.42	42.67
- <i>Lupinus</i> sp.	-	4	0.63	0.006	0.006	1261.94	‡
- <i>Solanum nigrum</i> L.	SOLNI	3	0.47	0.004	0.005	1458.31	‡
- <i>Oxalis</i> sp.	-	3	0.47	0.004	0.005	1458.31	‡
- <i>Lotus corniculatus</i> L.	LOTCO	2	0.31	0.003	0.003	1787.45	‡

<sup>†</sup> Codes are not necessarily reported in Weed Science Society of America (1984).

<sup>‡</sup> Number of seeds observed too few to calculate Morisita's index.

*elatine* (L.) Dumort. Morisita's indices that equal 1 have random spatial distribution patterns (Johnson & Anderson, 1986). Aggregated patterns have been observed in old-field systems (Bigwood & Inouye, 1988; Boccanelli & Lewis, 1994), as well as in cultivated systems (Benoit et al., 1989; Dessaint et al., 1991; Forcella et al., 1992). *Sonchus asper* (L.) Hill and *Senecio vulgaris* L. were the most evenly distributed dicotyledonous species among all samples, and had relatively low Morisita's index values (Table 3).

Generally high CV values were observed for all weed species (Table 3), and the CV was correlated with Morisita's index ( $r = 0.94, \leq 0.0001$ ). In addition, the percentage of soil cores that contained a weed species was seed density dependent ( $r = 0.82, \leq 0.0001$ ). Other systems have reported

that the CV was seed density dependent (Forcella et al., 1992) and that aggregation and density were inversely proportional (Dessaint et al., 1991). In this experiment, both CV and aggregation were not associated with weed seed density ( $r = -0.43$  and  $-0.26$ , respectively). This may be the result of the greater number of species present in our systems compared to others (Forcella et al., 1992).

**Rotation system effects** - The soil seed bank size and species composition among rotation system treatments was differentially affected by crop sequence history and the associated herbicide applications (Table 4). Multidimensional scaling (MDS) and cluster analyses classified the six rotation systems into three groupings: (i) WC<sub>NT</sub>-MF<sub>NT</sub> and WC<sub>CT</sub>-MF<sub>CT</sub> (Group-A); (ii) SpWht<sub>NT</sub>-MF<sub>NT</sub> and F-WC<sub>NT</sub> WC (Group-B);

**TABLE 4. Soil seed bank composition to 8cm depth in six rotation systems at the USDA-ARS sustainable grass seed management systems research area in Linn County, Oregon.**

Species Bayer code <sup>†</sup>	Rotation system					
	WC <sub>NT</sub> -MF <sub>NT</sub>	WC <sub>CT</sub> -MF <sub>CT</sub>	SpWht <sub>NT</sub> -MF <sub>NT</sub>	F-WC <sub>NT</sub> WC	PRG <sub>NT</sub> -SpOat <sub>NT</sub>	PRG <sub>NT</sub> -SpWht <sub>NT</sub>
	seeds m <sup>-2</sup>					
<b>Monocotyledonous</b> .....						
- IUNBU	23992ab <sup>‡</sup>	21876 b	44257a	7815 c	103 e	234 d
- POAAN	12822a	11454ab	1743 c	1474 c	3907abc	3341 bc
- DIGSA	16 bc	5 c	60 b	2889a	740a	76 b
- PANCA	1 b	1 b	14 b	12 b	852a	342a
- VLPMY	164a	191a	12 b	3 bc	0 c	0 c
<b>Dicotyledonous</b> .....						
- VERAR	1551ab	1392ab	3564a	309 b	1 c	3 c
- CERGL	4549a	1098a	55 b	76 b	0 c	0 c
- GNAPA	114ab	57 b	55 b	201a	2 d	21 c
- CAROL	3 b	3 b	21 b	15 b	17 b	241a
- SONAS	18	19	10	42	50	16
- KICEL	6ab	6ab	3ab	22a	0 b	0 b
- SENVU	2	3	34	39	3	19
- CVPSE	3ab	3ab	3ab	22a	0 b	0 b
- TRFDU	49a	29a	5 b	22a	0 c	0 c
- DAUCA	3	8	0	1	1	2
<b>Total</b> <sup>§</sup>	49203a	38725 a	52722a	13931 b	6208 bc	5092 c

<sup>†</sup> Bayer code definitions are the same as given in Table 2.

<sup>‡</sup> Means of species and totals are antilogarithm transformations ( $\text{antilog}_{10}(x-1)$ ) of the original data that were transformed using the logarithm transformation because of the non-normal distributions. Means followed by the same letter across tillage systems are not significantly different at  $P = 0.05$  according to Fisher's protected least significance difference test.

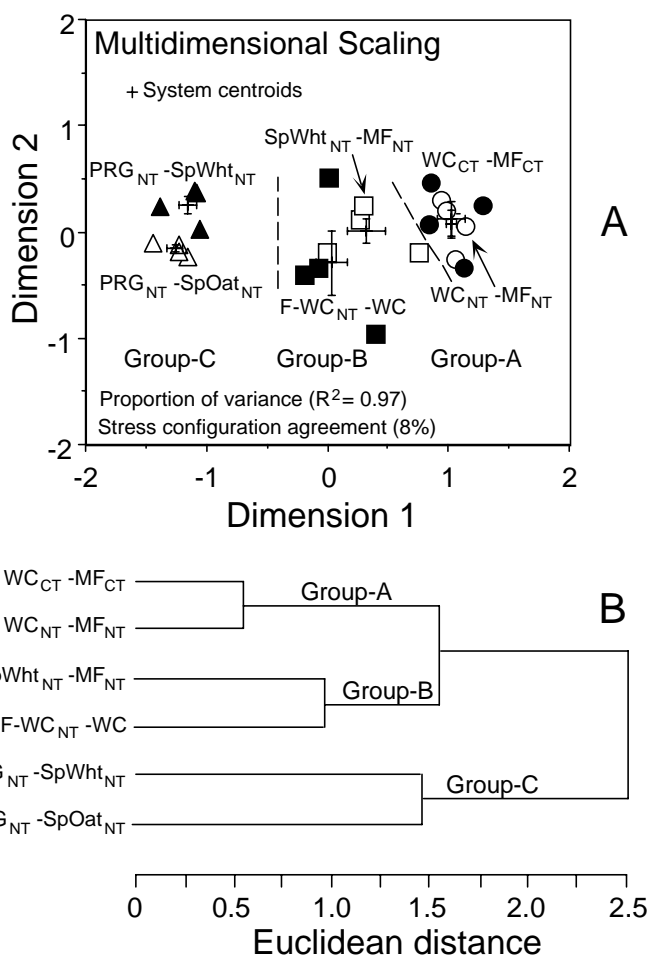
<sup>§</sup> Total represents the effects of cropping system differences. Orthogonal contrast can be made to differentiate the effects of crop component and disturbance treatment differences.

(iii) PRG<sub>NT</sub>-SpOat<sub>NT</sub> and PRG<sub>NT</sub>-SpWht<sub>NT</sub> (Group-C), based on the density of the soil seed bank constituents (Figure 1). Between the MDS and cluster analysis methods, there was strong support for groupings of the respective rotation systems into Groups 1 and 3. The two rotation systems in Group-A only differed by establishment of the meadowfoam crop, and the two systems in Group-C by kind of spring-planted cereal (wheat and oats). The aggregation of the two systems into Group-B was not as assured as with the other two groups based on the MDS method (Figure 1A), probably because of the difference in kinds of crops that composed the rotation sequence.

Relationship of species density and heterogeneity with rotation system groups - The Group-A meadowfoam-after-white clover seed rotation systems had the same soil seed bank richness, evenness, and diversity indices (Table 5), and had generally similar species densities (Table 4). Crop sequence (Table 1), and thus the similarity of herbicide management (Table 2), appeared to be the cause for this

similarity, with no effect resulting from the utilization of conventional and no-tillage establishment methods. This may have been due to the relatively few years that no-till management has been employed at the site. This is contrary to reports that even moderate disturbance increased species diversity (Rykiel, 1985). In other longer-term system comparisons, the number of species found in no-tillage management were either greater or the same as in conventional tillage (Cardina et al., 1991).

The Group-B rotation systems (SpWht-MF<sub>NT</sub> and F-WC<sub>NT</sub>WC) had different crop sequence histories, but shared nearly the same species composition (Table 4). The Group-B systems had similar richness, but differed in evenness and diversity, with the SpWht-MF<sub>NT</sub> system having lower E and H' than all of the six systems (Table 5). The low E value for SpWht-MF<sub>NT</sub> may be due to the dominance of *Juncus bufonius* in this system, compared to the other five systems. The F-WC<sub>NT</sub>WC system had more *Digitaria saguinalis* (L.) Soop.



**FIG. 1.** (A) Multidimensional scaling (MDS) of the density of 15 weed species in the soil seed bank of six perennial ryegrass seed production rotation systems. The range of observations are for four replicate blocks. The symbol + represents the centroid of each rotation system with the standard error of the mean for the first and second MDS dimension. The crop rotation systems are defined in Table 1. (B) Cluster analysis of the mean densities of the six rotation systems based on seed species density.

than the SpWht-MF<sub>NT</sub> system. Because diversity was directly associated with evenness ( $r = 0.88, \leq 0.05$ ), SpWht-MF<sub>NT</sub> also had the lowest H' index value. The high weed seed densities in the meadowfoam systems (both systems in Group-A and SpWht-MF<sub>NT</sub> in Group-B) may be due to poor weed control of early germinating species in late-winter or early-spring because of a sole reliance on the herbicide Prism for post-emergence control.

The Group-C systems, which were comprised of the two spring-planted cereals that were planted without tillage and which followed winter fallow applications of glyphosate, had

**TABLE 5.** Species richness (S), evenness (E) and Shannon-Weaver diversity (H') heterogeneity indices for soil seed bank measurements taken from the USDA-ARS sustainable grass seed management systems research area in Linn County, Oregon.

Rotation system <sup>†</sup>	Species heterogeneity indices		
	S <sup>‡</sup>	E	H'
WC <sub>NT</sub> -MF <sub>NT</sub>	11.25 a <sup>§</sup>	0.45 a	1.20 a
WC <sub>CT</sub> -MF <sub>CT</sub>	11.25 a	0.42 a	1.01 a
SpWht <sub>NT</sub> -MF <sub>NT</sub>	12.00 a	0.21 b	0.53 b
F-WC <sub>NT</sub> -WC	12.75 a	0.49 a	1.24 a
PRG <sub>NT</sub> -SpOat <sub>NT</sub>	7.50 b	0.49 a	0.97 a
PRG <sub>NT</sub> -SpWht <sub>NT</sub>	8.25 b	0.47 a	0.99 a

<sup>†</sup> Rotation system abbreviations same as given in Table 1.

<sup>‡</sup> The larger the values of S, E, and H' the greater diversity.

<sup>§</sup> Means within columns followed by the same letters are not different at P = 0.05 according to Fisher's protected least significant difference test.

the lowest total soil seed bank densities of all systems (Table 4), in addition to the lowest species richness (Table 5). The PRG-SpOat<sub>NT</sub> system had a total seed bank size greater than the PRG-SpWht<sub>NT</sub> system, but was similar to the F-WC<sub>NT</sub>-WC system. The PRG-SpWht<sub>NT</sub> system had one post-emergence application of the selective herbicide Hoelon and PRG-SpOat<sub>NT</sub> did not (because of lack of crop tolerance). The Group-C systems also had equal heterogeneity indices, but the amount of species richness was less than that in WC<sub>NT</sub>-MF<sub>NT</sub> and WC<sub>CT</sub>-MF<sub>CT</sub>.

**Relationship of individual weed species densities and their associations with rotation system groups** - The individual weed species composition of the soil seed bank was differentially affected by the different rotation systems (Table 4). Multivariate common factor analyses classified the individual weed species based on the Pearson correlation among weed seed densities of the six rotation systems (Table 6). Those species that did not have significant factor loadings based on Pearson correlation coefficients were classified by their Spearman rank correlation coefficients. This approach provided insight into which species were the cause of the group classifications of the rotation systems (Figura 1). Factor-1 contained those weed species that were associated with Group-A rotations systems (WC<sub>NT</sub>-MF<sub>NT</sub> and WC<sub>CT</sub>-MF<sub>CT</sub>). Factor-2 contained weed species that were associated with Group-B (SpWht-MF<sub>NT</sub> and F-WC<sub>NT</sub>-WC). Factor-3 weed species were associated with the rotation systems in Group-C (PRG-SpWht<sub>NT</sub> and PRG-SpOat<sub>NT</sub>).



**TABLE 6. Common factor analysis rotated loading values and weed species classification with three multivariate group classifications of six rotation systems based on the soil seed bank densities of 15 weed sampled in 1997 at the USDA-ARS sustainable grass seed management systems research area in Linn County, Oregon. Species factor loadings in double-line boxes are correlated according to Pearson's  $r$  and single-line boxes according to Spearman's  $r_s$  at  $P = 0.05$ .**

Species Bayer code <sup>†</sup>	Factor-1 (Group-A) <sup>‡</sup>	Factor-2 (Group-B)	Factor-3 (Group-C)	Factor-4
	Rotated factor loading values			
POAAN	0.981	-0.174	0.056	0.056
VLPMY	0.964	-0.049	0.213	0.056
TRFDU	0.869	0.393	0.185	0.125
CERGL	0.775	0.024	0.180	0.085
DAUCA	0.715	-0.102	-0.022	-0.089
SENVU	-0.699	0.601	0.336	-0.194
KICEL	0.024	0.987	-0.045	0.117
CVPSE	-0.159	0.976	-0.076	0.105
GNAPA	0.152	0.965	0.096	0.073
DIGSA	-0.345	0.838	-0.362	0.219
PANCA	-0.383	-0.563	-0.674	0.276
VERAR	-0.001	-0.101	0.980	0.174
IUNBU	0.112	-0.020	0.976	0.185
SONAS	-0.252	0.238	-0.742	0.573
CAROL <sup>§</sup>	-0.299	-0.267	-0.271	-0.835
Variance explained (%)	31.5	30.5	22.5	8.8

<sup>†</sup> Bayer code definitions are the same as given in Table 2.

<sup>‡</sup> Group classifications of the six rotation systems are based on the results shown in Figura 1.

<sup>§</sup> This species is independent of the three rotation system classification groups.

*Juncus bufonius* which had the greatest seed density of all species, was favored by the three meadowfoam systems, but was nearly eliminated in two winter-fallow systems (PRG-SpOat<sub>NT</sub> and PRG-SpWh<sub>NT</sub>). The high potential densities of *J. bufonius* at this research site were due to the saturated soil conditions from winter until early-spring with rapid growth and high seed production in late-spring (Popai et al., 1995). *Veronica arvensis* responded similarly to the rotation systems as *J. bufonius*. ( $r = 0.99$ ;  $\leq = 0.0001$ ), with great soil seed bank reduction by the two cereal rotation systems.

*Poa annua* had the greatest seed density of all treatment in the WC<sub>NT</sub>-MF<sub>NT</sub> and WC<sub>CT</sub>-MF<sub>CT</sub> systems. However, the introduction of winter chemical-fallow system in conjunction with white clover seed production (F-WC<sub>NT</sub>-WC) or following perennial ryegrass seed production (PRG<sub>NT</sub>-SpOat<sub>NT</sub> and PRG<sub>NT</sub>-SpWh<sub>NT</sub>), greatly reduced its density. *Poa annua* has become a problematic grassy weed in perennial ryegrass seed production systems since the exclusion of thermal post-harvest residue management (Mueller-Warrant, 1994). Rotation systems that include winter chemical-fallow components

appeared to be effective weed management strategies to reduce the size of *P. annua* seed banks.

The soil seed bank density responses of *Festuca myuros* L., *Trifolium dubium* Sibth. and *Cerastium viscosum* were similar to *Poa annua* ( $r = 0.96, 0.81, \text{ and } 0.83$ ;  $\leq = 0.002, 0.06, \text{ and } 0.04$ , respectively). These three weeds may form an association of weeds with *P. annua*, but may respond independently in their response to different rotation systems because of their elimination from the PRG-SpOat<sub>NT</sub> and PRG-SpWh<sub>NT</sub> systems. *Poa annua* seed densities were greatly reduced in the cereal systems, so this may indicate that its response is still in transition. The response of *Senecio vulgaris* was inversely related to that of *P. annua* ( $r = -0.78$ ;  $\leq = 0.07$ ), and may become a problematic weed in those systems that are able to have *P. annua* control.

The summer annual grass *Panicum capillare* L. had the greatest soil seed bank densities in the PRG-SpOat<sub>NT</sub> and PRG-SpWh<sub>NT</sub> systems (Group-C). This was probably due to later germination time after the spring chemical-fallow application of glyphosate than the winter and spring annuals

germinate, thus escaping the effect of the herbicide application. *Digitaria sanguinalis* (L.) Scop. had its greatest density in the PRG-SpOat<sub>NT</sub> (Group-C) and F-WC<sub>NT</sub> WC (Group-B) rotation systems, probably because hoelon herbicide is not used in the spring oat system and summer annual grasses germinate after the period of winter grass control in white clover seed rotation component. *Gnaphalium palustre* Nutt. and *Kickxia elatine* are summer annual dicotyledonous species with similar responses to the different rotation systems ( $r = 0.95$ ;  $\leq 0.003$ ) that had the greatest soil seed bank densities in the WC<sub>NT</sub>-MF<sub>NT</sub>, WC<sub>CT</sub>-MF<sub>CT</sub> (Group-A) and F-WC<sub>NT</sub> WC (Group-B) systems. The seedlings of both species probably also escaped the effects of winter- and spring-applied herbicides because of their late germination time, compared to other species (Medeiros & Steiner, unpublished data, 1998). The reduction in *G. palustre* and *K. elatine* in PRG-SpOat<sub>NT</sub> and PRG-SpWht<sub>NT</sub> was possibly due to the combined competition effects from perennial ryegrass the prior year in the rotation sequence, as well as the competition from spring-planted cereals. These two summer annual grass species have independent niche responses to the six rotation systems, as indicated by the lack of correlation among their seed bank densities ( $r = -0.04$ ;  $\leq 0.94$ ). Similarly, *Panicum capillare* was not associated with *G. palustre* and *K. elatine* ( $r = -0.63$  and  $-0.51$ ;  $\leq 0.18$  and  $0.30$ , respectively). *Crepis setosa* responds to the rotation systems similarly as *G. palustre* and *K. elatine*, but was among the least abundant species in the total seed bank. This species does not appear to have the potential to become a problematic weed for grass seed rotation systems. The soil seed bank responses for *Digitaria sanguinalis* and *K. elatine* were similar ( $r = 0.87$ ;  $\leq 0.03$ ).

The species *Sonchus asper*, *Senecio vulgaris* and *Daucus carota* L. were unaffected by the six rotation system treatments and all had relatively low factor loading values (Table 6). *Cardamine oligosperma* Nutt. increased in PRG-SpWht<sub>NT</sub>, but was present at relatively low seed densities in all treatments. There were also no correlation among *C. oligosperma* and any other weed species and appears that this is a non-problematic weed in these grass seed rotation systems.

## CONCLUSIONS

- ♦ The weed flora recorded among all rotation system treatments was almost annual species, dominated by *Juncus bufonius* L. and *Poa annua* L.;

- ♦ high and low seed species densities were associated with random and aggregation seed distribution patterns, respectively;
- ♦ the characteristic of the soil seed bank among rotation system treatments was differentially affected by crop sequence history and the associated herbicide applications;
- ♦ rotation systems that included winter chemical-fallow system in conjunction with white clover seed production or, spring oat or wheat following perennial ryegrass seed production, greatly depressed the *Poa annua* L. density;
- ♦ there is a clear indication that rapid changes in weed seed bank size and composition can occur in different perennial ryegrass seed rotation systems.

## ACKNOWLEDGMENTS

The authors thank W. Gavin, B. Robinson and C. Reid for technical assistance. Thanks also to G. Mueller-Warrant M. Wilson for suggestions regarding field sampling strategies. This research was supported by a grant from the Oregon Department of Agriculture Alternatives to Field Burning research program, Grant No. 9302 012-1 and by CAPES, Brasil.

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