WEED SEEDBANK COMMUNITY CHANGES ON THE WISCONSIN INTEGRATED CROPPING SYSTEMS TRIAL (WICST): 1992-2004.

H. Kümmel[1], J. Doll[2], J. Posner[2], J. Hedtcke[3], A. Cook[4]

INTRODUCTION

Weed seedbanks are the viable seeds present in the soil, and its surface. Seedbanks consist of both recent and older seeds shed; so, the soil weed seedbank can be regarded as the 'memory' of a weed community. The seedbank influences both the weed populations that occur in a field and the success of weed management strategies (Iowa State university 1996). Changes in weed community and weed seedbank size occur as time passes. Dekker (1999) explains that species once present may be replaced, or reduced due to the arrival of more competitive intra-specific variants, variable weather and crop management practices. He emphasizes however, that changes in the environment (especially wet or dry seasons that reduce weed control efficacy), and agricultural activities are the two most important factors influencing multiple year changes in the soil seedbank. A number of authors have shown for example, that crop rotation alone (Buhler et al. 2001; Forcella et al. 1988; Hill 1989; Schreiber 1992), tillage systems alone (Cardina et al. 1991; Mulugeta and Stoltenberg 1997), cultivations (Roberts and Dawkins 1967), crop rotation *and* tillage (Cardina et al. 2002), cropping systems (Davis et al. 2005), and weed management (Roberts and Chancellor 1986) are all important practices impacting seedbanks on arable land.

With agronomic systems, the seedbank itself is the primary source of annual weeds (Dekker 1999). Therefore, tracking the changes in weed seedbank composition can help one understand and evaluate the long-term effects of alternative cropping systems. Iowa State University's study of agricultural fields found that the weed seedbank density in the north central Corn Belt ranges from 2,100 to 580,000 seeds/m² (Iowa State University 1996). Forcella et al. (1992) in a study centered on Minnesota and Wisconsin found that the range in seed bank density in crop fields was between 1,500 seed/m² to 22,000 seed/m². These weed seedbanks are composed of many species, but 70 to 90% of the total seeds are from few dominant species. A second group comprising 10 to 20% of the total seedbank is generally made of species adapted to the geographic area, but not to current production practices. A final small percentage of the total seeds include recalcitrant seeds from previous seedbanks, newly introduced species, and seeds of previous crops (Buhler 1997).

Long-term studies of weed seedbanks are necessary however, to understand cropping management effects on seedbanks. This is because, for example, tillage systems require from 4 to 10 years to reach equilibrium in yield, weed populations, and soil characteristics (cited in Cardina et al. 1991). In addition, Roberts and Dawkins (1967) found that improvements in estimating seed bank could be achieved by sampling the same time of the year in successive years (cited in Dekker 1996).

Seedbanks have been estimated using: 1) seedling emergence, also called tray method (Forcella et al. 1992, 1997; Hill et al. 1989; Roberts and Dawkins 1997; Mulugeta and Stoltenberg 1997a, 1997b); 2) direct extraction from the soil called as extraction method (Buhler et al. 2001; Schreiber 1992); and 3) seedling emergence from undisturbed cores called core

[1] Undergraduate student, independent project (699), UW-Madison, Agronomy Dept.
[2] Professor, UW-Madison, Agronomy Dept.
[3] Research specialist, UW-Madison, Agronomy Dept.
[4] Graduate student, UW-Madison, Agronomy Dept.

method (Forcella and Sparrow 1996). All three approaches have its pros and cons. While, seedling emergence may under estimate the weed seed density due to unknown quantities of dormant seeds remaining in the soil, extraction of seeds directly from the soil may over estimate the weed seed density due to the difficulty in judging seeds viability and fitness (Dekker 1999). There have been also some studies conducted to evaluate and/or compare methods to predict weed seedling populations from the soil seedbank. Forcella and Sparrow (1996) found that the three methods (extraction, trays germination and core methods) were essentially equivalent in variability and in predictability of seedling populations. They report that the main difference between methods was the time and effort required to complete the procedure. While the seed extraction method required the most effort, and the core method over the standard tray method required minimum sample manipulation. However, in general Forcella and Sparrow found that the emergence percentage was lower from the core method that from the tray method (Forcella and Sparrow 1996). A second issue in estimating weed seed density is how to soil sample. Kropac (1966) and Roberts (1970) each reported that it is better to take large numbers of smaller soil samples rather than relatively smaller numbers of lager samples (cited in Dekker 1996).

The goal of this study was to compare the effect of six different cropping systems over a 14-year period on:

- Weed seed density;
- The weed seed community; and,
- To statistically test the hypothesis developed at the onset of the Wisconsin Cropping Systems Trial (WICST) at ARL UW- Research Station trial in 1990.

MATERIAL AND METHODS

The Wisconsin Cropping Systems Trial (WICST) started in 1989 and consists of three grain, and three forage cropping systems. (See **Table 1**) The fields were in a dairy rotation (a-a-c) with manure for the previous 20 years. The weed seedbank at the trial has been monitored annually since 1989 by counting weed seedlings that germinate in soil collected from selected plots early in the spring. Seeds include seeds (fertilized ripened ovule of a flowering plant) and fruits, but not vegetative propagules or spores.

Dr Jerry Doll initially conducted the sampling protocol and data collection and the results are available in an earlier WICST report (WICST Technical Report #8 1997-1998). Initially (1989-1992) three subsamples of soil per plot, each consisting of ten 0.75in. diameter cores and 6 in. deep were taken. In 1994 six subsamples of ten 0.75in. diameter cores and 6 in. deep were taken. Since 1995 four subsamples of soil per plot, each consisting of eight 0.75in. diameter cores and 6 in. deep are taken. This results in approximately 1.0 to 1.3 lb of soil per subsample. The soil is then mixed with an equal weight of silica sand, placed in 8 X 12-in. plastic trays with small holes in the bottom (giving a 0.75- to 1-inch soil depth). Trays are then placed on capillary mat on a greenhouse bench and subirrigated every other day, or daily when necessary. As seeds germinate, the seedlings are identified, counted and removed. After the first flush of seedlings is counted, the soil is let to dry completely, remixed and returned to the trays for another germination cycle. Three cycles of weed seed germination are conducted from May to September, and when all germination observations are completed, the number of seedlings per square meter is calculated for each system as follow:

$\leq$ 1995 when tray sample was made of 10 cores: # plants / tray * 350.849 = weed seed /m²

$\geq$1997 when tray sample was made of 8 cores: # plants / tray * 438.56 = weed seed /m².

Currently, the sampling strategy is to sample all plots in the spring following the corn phase because this helps to standardize the results since corn is a common crop in 5 of the 6 systems. The permanent pasture and continuous corn system are sampled every year. For this report the weed seedbank density results from 2004 for the 6 cropping systems were compared to the baseline data from 1991 for CS1 and CS6, and 1992 for the other four systems. The plots were sampled on March , 2004. The design of the trial is a randomized complete block with four replications for each of the six systems. In total, there are 14 plots per repetition to cover each phase of the 6 cropping systems and the individual plots are 0.73 acres in size. Each sampled plot had 3 subsamples (germination trays) for the baseline years and 4 subsamples (germination trays) for 2004. The data was analyzed with PROC MIXED (SAS 8.2). Analysis of variance and test for normality were performed on the total weed density data. Years and repetitions were considered random, and cropping systems as fixed effects. In addition to PROC MIXED, which gives a preliminary test of the average effect of the sources of variation (i.e. system, block, block (sample)), linear comparisons were used to provide a more detailed assessment of the factors influencing weed seed density.

RESULTS AND DISCUSSION

I) EVOLUTION OF WEED SEED NUMBERS

Viable seeds of 9 broadleaf weed species were found, and they were: red root pigweed (Rrpw), common lambsquarter (Colq), velvetleaf (Vele), shepard's purse (Shpu), smartweed (Smwe), eastern black nightshade (Blns), broadleaf plantain (BdPlntn), dandelion (Dali), white cockle (Whco), and others (O_Bdlf). The viable seeds of grass weeds found were giant foxtail (Gift), green foxtail (Grft), yellow foxtail (Yeft), fall panicum (Fapa), barnyard grass (Bygr), large crabgrass (Lacg), and others (O_Grs). In all six systems, the total weed seedbank density decreased since 1992. (See **Table 2a**) Except for the rotational grazing plots, the reserves of viable seed in the soil are typically dominated by one or two species in each system. Total viable seedbank densities found ranged from 2,000 to 13,000 seed /m² in the earlier years of 1991-92 and 600 to 10,000 seed /m² in 2004. These numbers are toward the lower range found in the Iowa State studies (1996) and are similar to Forcella et al. (1992) findings in Wisconsin and Minnesota. Weed seedbanks densities are categorized into population categories: **low** (< 4,300 seeds/m²), **moderate** (4,301- 8,600 seeds/m²), **high** (8,601 – 12,900 seeds /m²), and **severe** (> 12,901 seeds/m²) (WICST Report #8).

In the continuous corn cropping system (**CS1**), which receives conventional rates of herbicides and tillage, the weed seedbank decreased 66% since 1991 (currently 600 seeds/m²). The plots sampled and analyzed in 2004 were established in a low to moderate weed seed density area to begin with (WICST Uniformity Year Report 1989). The 2004 data shows that the weed seed density in this high input, low diversity system is considerably less than when the system was last sampled in 1998. Completion of the data analysis from the 2005 sampling on these plots will allow us confirm this reduction in weed seed load. Cardina et al. (1991) compared weed seed density in three locations following 25-26 years of continuous corn and found that the weed seed density under minimum tillage (chisel plow) ranged from 4,800 to 400 seeds/m², similar to our findings.

The weed seedbank in the no-till (**CS2**) cropping system had decreased by 60% since 1992 (2,400 seeds/m²). The weed seed density is low, and even though the total weed seed

density is quite variable from year to year, it has been decreasing over time. Weed seed density declined sharply from 5,838 seed/m² in 1998 to 2412 seed/m² in 2004. The decline may be due to changes in weed management. In 1998 we switched from Asgrow 1900 using glyphosate only as a pre emergence herbicide to Asgrow 2301 using glyphosate pre and post emergence.

The organically managed grain system **CS3** has the lowest decrease in weed seedbank density over time among all the systems in WICST. The weed seed density was high in 1992 and after 13 years it decreased 18% maintaining high weed seed density (9,300 seeds/m²). Total weed seed density decreased by 55% from 1992 to 1995. However, the total weed seed density is increasing steadily since 1995.

In the conventional forage system **CS4** the weed seedbank density is low and it has been steadily decreasing over time (1,650 seeds/m²). The use of herbicide in the corn and alfalfa establishment phase's plus intensive management of the forage phases has proved effective again weed encroachment. The major weak link in this system is the openings in the sod, created by winterkill. The total weed seed density in this forage system decreased 74% since 1992.

The weed seedbank density in the organic forage **CS5** decreased 77% since 1992 (3,000 seeds/m²) changing from moderate to low. However, visual observations show that quack grass, which is not counted in the germination trays, is building up in CS5.

The weed seedbank density at the rotational grazing plots (**CS6**) is low, and decreased 60% since 1991 to 1,700 seeds.m². Reducing the stocking rate on the paddocks plus a timely schedule of clipping and hay making in early spring and late fall has increased the competitiveness of the pastures to weed development since 1996.

The weed management regime in the high input, low diversity systems (CS1) and (CS4), seems to successfully hold steady or even decrease the total weed seed density over time. Meanwhile, it appears that weed control is more challenging in the low input, high diversity systems, especially CS3. Still, our findings are optimistic. For instance, when studying weed seedbank dynamics in three organic farming cropping systems, Teasdale et al. (2004) found that seedbank populations in different organic cropping systems tended to "fluctuate within a range that was considerably higher than the initial levels." Their study compared the weed seedbank of a 2 yr corn-soybean, 3 yr corn-soybean-wheat/fallow and a 4yr corn-soybean-wheat-red clover/orchard grass hay rotations using the tray method sampling the systems following the corn phase also.

Davis et al. (2005) analyzed the effects of cropping systems in the weed seedbank in four systems: conventional (CONV), no-till (NT), reduced input (RI) and organic (ORG). The long-term project started in 1990 at Michigan State University's Biological Station and from 1990 to 1993 the CONV and NT systems were in corn-soybean crop sequence and RI and ORG systems were in corn-soybean- wheat/underseed with red clover crop sequence. After 1993 CONV and NT were switched to the same rotation as RI and ORG. The moldboard plow was used as primary tillage for CONV, RI and ORG systems. The seed densities found in ARL are well bellow the ones found in their study. He reports that the weed seed density after 12 years were 22,600, 21,780, 29,350, and 18,540 seed/m² in CONV, NT, RI, ORG respectively. Similarly to our findings, they found that high input systems (CONV, NT) and low input systems (RI, ORG) changed in similar manner over time. Although, they found that the weed seed density in the ORG system was slightly lower than the other systems (Davis et al. 2005).

In the early years of 91 and 92, system as a fixed effect did not significantly effect weed seed density. This was expected because all the plots were managed similarly for the 10 years

before 1989. However, the test shows that cropping system significantly affects the total weed seedbank density after 13 years (see **Table 2b**).

II) Changes in weed community

Ratio of broadleaves to grasses

As can be seen in **Table 3**, the proportion of broadleaf to grasses was fairly constant in continuous corn (CS1), green gold alfalfa (CS4), and the rotational grazing (CS6). Whereas the proportion of broadleaves grew in importance in the no-till corn/soybean rotation (CS2), the proportion of grasses increased in the two organic rotations (CS3 & CS5).

Tillage effects weed seedbank due to several factors as depth distribution, abundance, and species composition of seeds in soil (Cardina et al. 2002). However, seed depth in the soil seems to be the most important factor (Buhler 1995). No-till systems favors emergences of small-seeded annual broadleaf and annual grasses that are adapted to germinate well near the surface (Buhler 1995). In no-tillage systems over 60% of all the weed seeds are located in the upper 1–4 cm of soil where most germination occurs and establishment is favored (Buhler 1995; Buhler 1997; Mulugeta and Stoltenberg 1997). In the wet spring years of 1996, 1998, 2000 and 2001 the moisture level on the soil surface may had favored broadleaf seed germination and the number of broadleaf weeds established, consequently the number of escape seeds increased.

It appears that grass control is more challenging in the organic systems, especially CS3. Our hypothesis is that in CS3 the grass seedbank started to increase heavily in wet spring years especially in the corn phase (WICST 7th report). WICST data has shown that when May and June rainfall exceeds 10 inches, organic corn yields are severely impacted due poor mechanical weed control resulting in heavy weed pressure (Baldock et al in press). Indeed, the climate data shows that there were wet springs in 1996, 1998, 2000 and 2001 reducing mechanical weed control performance and providing ideal conditions for late emergence and consequent weed seed production (WICST Report #7). Likewise, Teasdale et al. (2004) found that seedbanks in organic systems tend to rise the following years when a high abundance of weeds generated high seed inputs.

Weed Community Analysis

In continuous corn (**CS1**), redroot pigweed and common lambsquarters dominated the broadleaf seed bank (74%) and fall panicum (60% of the grasses species), and foxtails were the predominant grasses. The 2004 data reveals that common lambsquarters still composes 34% of the broadleaf weed seed community, but pigweed seeds decreased its percentage among broadleaves from 34% to 12%. Curiously, the winter annual shepherd's purse which was present in 1991 at 12% of the broadleaf weed seeds wasn't detected in 2004, and the summer annual eastern black nightshade increased from 2% in 91 to 24% of the broadleaves weed seed community in 2004. The data in 2004 showed species not found in 91 like large crabgrass, and barnyard. Fall panicum wasn't found in 2004 samples; however, 40% of the grass seedlings were not identified due to a hot weekend when they wilted and died before identification. Maybe, fall panicum seedlings, which aren't as drought tolerant as large crabgrass and barnyard, were the first to die. (See **Appendix II**)

Even though the plots sampled in 2004 for **CS2** were initially located in moderate to high grass weeds areas, the grass weed seedbank density decreased from composing 22% of the seedbank in 1992 to 7% in 2004. The grass weed community changed from a diverse and

proportional mixture of foxtails, fall panicum, barnyard and large crabgrass to a seedbank composed primarily of large crabgrass (49%). Among the broadleaf seeds community, common lambsquarters was the dominant specie, and still is. (More than 50% of the broadleaf seeds detected in the soil weed seedbank. Broadleaves composed 78% of the seedbank in 1992 and in 2004, represented 93% of the seed bank. (See **Appendix II**)

The organic grain system (**CS3**) broadleaf seed community doesn't show any major changes in its composition. Common lambsquarters represents 70% of the broadleaf weed seed community just as it did in 1992. Other summer annuals such as redroot pigweed and eastern black nightshade still comprise relatively the same percentage of the broadleaf seedbank compared to the 1992 baseline data. However, there is a clear shift from broadleaf weeds to grass weeds in the seedbank after 1995. (See **Figure 1**) The grass community was composed of 50% of fall panicum and 41% of a mix of yellow, green and giant foxtails. Today, 72% of the grass community is composed by giant foxtail. (See **Appendix II**) Indeed, Buhler and Daniel (1988); Buhler and Oplinger (1990) and Johnson et al. (1989) reported that the most troublesome change in annual weed populations is the increase in summer annual grasses such as giant foxtail (cited in Buhler, 1995).

There may be several reasons for such a shift in the weed seed community in cropping system 3. First, as mentioned above the climate data shows that there were wet springs in 1996, 1998, 2000 and 2001 reducing mechanical weed control performance and providing ideal conditions for late emergence and consequent weed seed production (WICST Report #7). Second, in addition to the weather, the tillage system used in CS3 and CS5 (chisel plow) may be giving the weeds a higher chance to succeed. It had been reported by Buhler (1995) and Mulugeta and Stoltenberg (1997) that giant foxtail density is greater under reduced chisel plow than under moldboard plow. Thirdly, we have found that wheat and red clover "sod" phase hasn't been very effective for weed control, allowing many foxtail plants to go to seed. Lastly, it has been observed in the past seasons that the giant foxtail escapes from poor past weed control is vigorously growing in the soybean phase and the within-row weeds do not get buried by the cultivator and go to seed.

Many researchers observed that indeed, the seedbank can increase rapidly following a year of poor weed control because many weed species are prolific seed producers (Iowa State University 1996). In addition, a species that produces seed population with individuals that each has different germination requirements is even more likely to succeed (Dekker 1996). Giant foxtail according to Dekker, possess a very wide range of germination requirements when shed from the parent plant, and this heterogeneity arises from many sources in an individual plant, including the type of tiller the panicle appears on, the position of the seed in the panicle, and the position of the seed on the fascicle in the panicle (Dekker 1996). While it is true that weed seed densities can rapidly increase if plants are allowed to produce seeds, weed seed densities can also greatly be reduced if seed production is eliminated by a few years.

The conventional forage system (**CS4**) maintained the proportion of 90% broadleaves to 10% grasses comparing 1992 to 2004 data. The only change in the weed seed community since 1992 is the presence of initially not detected white cockle seeds. (Currently it composes 20% of the broadleaf community). White cockle is commonly found in alfalfa and probably it got in the field with the manure applied. (See **Appendix II**)

The weed seedbank in **CS5**, the other organically managed system, is 77% lower than it was in 1992. However, grass weed seeds represent a higher percentage of the total weed seeds than it did in 1992. Initially, the system weed seeds were composed of 86% of broadleaves and

14% of grasses. Currently, grasses represent 40% of the total weed seeds in the soil seedbank. The broadleaf weed seed community became much more diverse. There were four detected broadleaves species in 1992 against nine species detected in 2004. The broadleaves community is dominated by common lambsquarters and redroot pigweed by 73%, but also contains yellow wood sorrel, dandelion, velvetleaf, shepherd's purse, black nightshade and smartweed. This is probably due to the use of manure in this system. (See **Appendix II)**

Comparing the two organically managed cropping systems we find that CS3 is presenting a much more problematic weed control. Because they are managed similarly (chemical free, chisel plow as primary tillage, cultivation as the main weed control, and delayed planting of the row crops into a "stale seedbed"), it seems likely that the longer alfalfa rotation in CS5 is providing a better "sod" phase to smother weeds than is the wheat/red clover phase in CS3. Foxtail is emerging throughout summer and setting seed with the onset of the fall.

The weed seedbank density at the rotational grazing plots (**CS6**) is low and the proportion of broadleaf weed seeds to grass weed seeds in 2004 is still basically the same. The broadleaf weed community, which was dominated by common lambsquarter and redroot pigweed, is now more diverse and balanced. This isn't surprising since constantly disturbed agricultural sites are normally dominated by a few species in contrast to not disturbed sites like grasslands. To our advantage, one of the broadleaf weed specie to increase its presence from 1% to 10% at the CS6 sites was dandelion, which is considered palatable forage. Another change in the weed seed community is the increase in white cockle seeds, which is a common weed of pastures. All the weed community changes in CS6 have been positive so far. For example, eastern black nightshade seed density has decreased since 1991. Eastern black nightshade contains glycoalkaloid solanine and can cause gastrointestinal irritation and its vegetative parts and fruit can poison all classes of livestock (Stubbendieck et al. 2003). (see **Appendix II**)

III) Hypothesis testing with linear contrasts

We have been collecting the density and diversity of weed species to be able to compare the effects of cropping systems in weed seedbank and species shifts hoping to test the following hypotheses:

Cash Grain Systems

Ho: Weed seed numbers: with herbicides as part of the program, there will be fewer escapes and weed seed numbers will decrease more rapidly in the high input grain systems than in mechanical weed control systems (CS1&CS2 < CS3).

Results: As can be seen in **Table 4,** although total weed seed number was not different among the three systems at the beginning of the trial, by spring 2004 CS3 had significantly more weed seeds than CS1 and CS2. Thus our hypothesis was confirmed and there is better weed control in the chemical systems than in the organic grain system.

Ho: Weed shifts: annual grasses will increase in proportion under continuous corn (CS1) in comparison to more diverse CS2 and CS3.

Results: Annual grasses increased in proportion under continuous corn (CS1), organic grain (CS3), organic forage (CS5), and rotational grazing (CS6). However, CS3 and CS5 had a greater increase in the proportion of annual grasses than CS1. (See Table 3)

Forage Systems

Ho: Weed seed numbers**:** due to the longer sod phase, more intensive forage harvesting schedule, and use of herbicides on the corn, weed seed numbers will be lower in CS4 than CS5.

Results: As can be seen in **Table 4**, similar to the cash grain contrasts, the high input CS4 had fewer weed seeds than the organic CS5 system. However, the difference was not as marked (only at 10% probability) as with the cash grain comparison (.01 % probability) CS4 and CS5 didn't present any difference in total weed seedbank density in 1992. In contrast, CS4 < CS5 regarding grasses seedbank density in 2004. (See **Table4**)

Cash Grain and Hay Systems vs. Rotational Grazing

Ho: Weed seed numbers: due to the grazing clipping regime and no-tillage, it is expected that the rotational grazing (CS6) system will have the lower weed seed numbers that the systems including annual crops (CS1 thru CS5 > CS6).

Results: As can be seen in **Table 4,** CS6 has indeed a lower total weed seed density when compared to the average of the other five systems. It is surprising to note that agronomically CS1 is almost the complete opposite of CS6, and yet CS1 has the lowest actual weed seed density (603 vs. 1,727 seeds/m²) among all the systems in 2004. (See **Table 4**).

CONCLUSION

The long-term cropping systems trial (WICST), conducted in the UW-research station at in Arlington, Wisconsin shows that cropping systems significantly affect weed seed density over time. The results show that in all six systems, for the plots sampled in 2004, the total weed seed density decreased over time. Initially weed seed densities ranged from 2,000 seed /m² to 13,000 seed /m² in, while recent data reveals weed seed densities ranging from 600 seed /m² to 10,000 seed /m². Except for CS3, all the other cropping systems show low weed seed density (< 4,300 seeds/ m²). Shifts in the ratio of broadleaves to grasses were only important in the two organic systems (increased proportion of grasses in CS3 and CS5) and in the no-till corn-soybean rotation (increased proportion of broadleaves).

It is observed that CS3 weed community clearly shifted from a system dominated by broadleaf weeds to a system dominated by grass weeds. The community shift may have occurred due to environmental, tillage and crop rotation effects. Wet springs in 1996, 1998, 2000 and 2001 made cultivation challenging and weeds had a chance to shed seeds, especially in the corn phase of the rotation. Also, the chisel plow may not be aggressive enough to bury the weed seeds under the favorable germination increasing weed emergence. Consequently, more weeds have a change to succeed and boost the weed seedbank. Furthermore, the forage rotation in CS3 may not be long enough to smother the weeds and avoid new seeds to enter the seedbank. Thus, organic grain farmers may choose to use the moldboard plow instead of chisel plow if erosion is not a problem in their land and/or have a longer hay crop into the organic corn and soybean rotations in order to minimize opportunities for rapid buildup of the seedbank.

On the whole, the hypothesis that over the years the weed seed density in CS1 and CS2 would be lower than CS3 due to herbicide usage is supported by the linear contrast among the systems. Also the hypothesis that over time CS4 would have a lower weed seed density than CS5 due to the fact that CS4 has not only a longer forage rotation phase, but also uses herbicides is supported by our data. The other hypothesis that ultimately CS6 would have the lowest weed seed density of all systems is not supported by the data yet. However, CS6 presents a more balanced broadleaf community than it did back in 1991. The weed seed community in CS6 isn't categorized by a few dominant species, but by various proportionally represented species. With fewer disturbances than the other systems, CS6 doesn't present as much space for opportunistic annual weeds to get established. In addition, annual weeds do not have the chance to go to seed because of the frequent grazing by the heifers.

The trends over time of the weed seedbank due to differences in cropping systems will be strengthened when 2005 data is analyzed and the plots in a different phase of the rotation will be compared to their baseline data.

Table 1- Cropping weed and nutrient management summary by system.

Cropping System	Weed management	Nutrient management
(CS1) Conventional corn "Continuous corn" *corn*	*conventional rates of herbicides *cultivation when needed *conventional tillage[1]	*Recommended rates of fertilizers
(CS2) No-till "No-till corn" *corn – soybeans*	*reduced rates of herbicides in corn followed by cultivation *conventional rates of herbicides in soybean phase until 1998 when glyphosate- resistant soybeans were adopted	*Recommended rates of fertilizers in the corn phase.
(CS3) Organically managed "Organic grain" *corn – soybeans – winter wheat/red clover*	*primary[1] and secondary tillage [2] *delayed planting *rotary hoeing and cultivation * no herbicides	*green manure plowed down before corn planting
(CS4) Conventional forage "Green gold alfalfa" *corn – alf – alf – alf*	*full rates of herbicides and cultivation in the corn phase Recommended rates of herbicide with alfalfa seeding *last alfalfa crop is killed with fall-applied glyphosate *conventional tillage[1]	*cattle manure application 20t/a in fall prior to corn planting and again before the alfalfa seeding phase
(CS5) Organically managed "Organic forage" *corn – oats/peas/alf – alf*	*delayed planting *rotary hoeing and cultivation *last alfalfa crop is chisel plowed *no herbicides	*green manure *cattle manure 15t/a prior to the corn and oat/pea/alf phases
(CS6) Rotational grazing "Rotational grazing"	*intensive rotational grazing by dairy heifers *spot herbicide application for thistles	*cattle manure deposited directly on the paddocks

[1] shank, disc chisel

[2] mulch master, field digger, soil finisher, cultivator and/or disc.

Table 2a - Mean of total weed seed/m2 in the spring following corn (n=4).

	91	**92**	**93**	**94**	**95**	**96**	**97**	**98**	**04**
CS1	1,784	2,222	2,866	1,842		3,860	2,686	3,947	603
CS2	5,162	6,140		11,373		2,916		5,838	2,412
CS3		11,257			5,087			6,387	9,319
CS4		6,286				2,149			1,645
CS5		12,894			3,004			2,357	2,988
CS6	4,356				4,144	6,513			1,727

Table 2b – Total weed seed ANOVA of 6 systems initially and in 2004.

Effect	Num DF	F Value	Pr > F
System initially (91-92)	5	11.01	0.2247
System in 2004	5	31.17	<. 0001

Table 3 – Percentage of broadleaf to grass of total weed seed per system.

	1991-1992	**2004**	**From 1991-2 to 2004**
Cropping System	**% Broadleaf / %Grass**	**%Broadleaf / %Grass**	**% Grass**
CS1	84 / 16	77 / 23	From 16% to 23% = 7%
CS2	78 / 22	93 / 7	
CS3	88 / 12	18 / 82	From 12% to 82% = 70%
CS4	90 / 10	90 / 10	
CS5	86 / 14	60 / 40	From 14% to 40% = 26%
CS6	75 / 25	68 / 32	From 25% to 32% = 7%

Table 4- Linear Contrasts

Ho: CS1&CS2<CS3

	Baseline 91/92			2004		
Total seeds	**df**	**p>F**	**Means**	**df**	**p>F**	**Means**
2) CS1, 2 (conv. grains) vs.			4,181			1,508
CS3 (org grain)	1	0.1338	11,256	1	<.0001	9,319

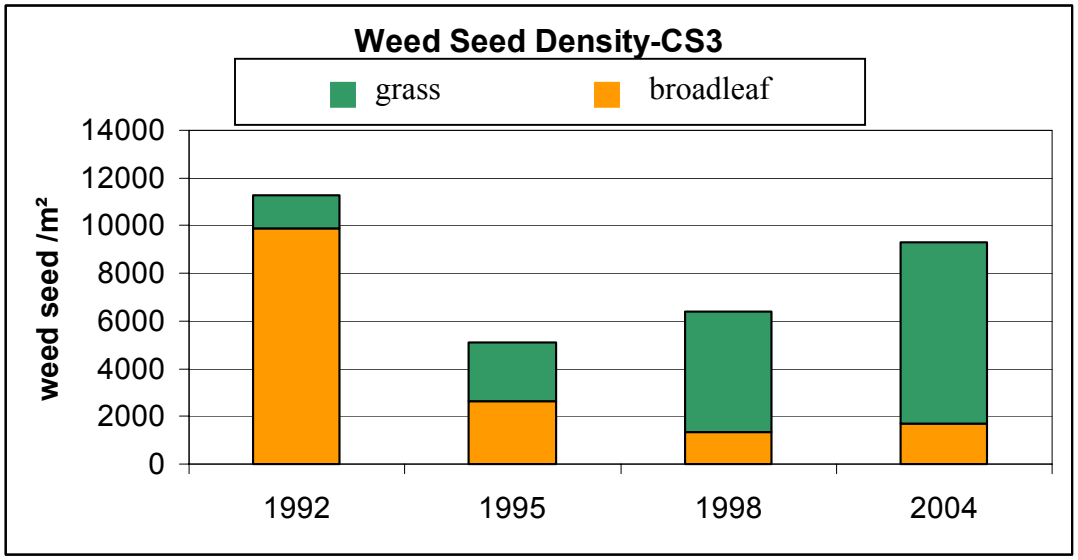
Ho: Total weed seed in CS4 < CS5

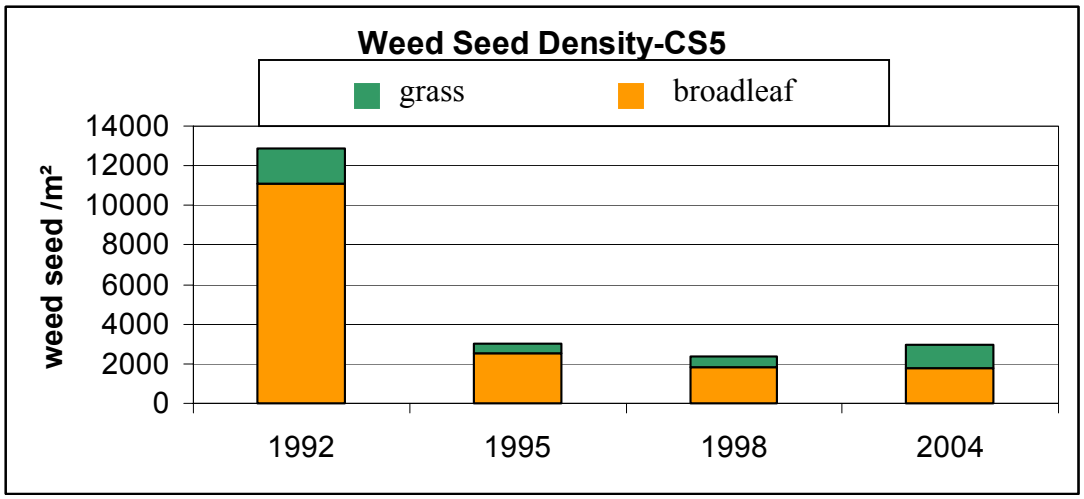
Total seeds	**df**	**p>F**	**Means**	**df**	**p>F**	**Means**
4) CS4 (forage) vs. CS5			6,286			1,645
(org forage)	1	0.1642	12,894	1	0.0952	2,988

Ho: Total weed seed in CS1 thru CS5 > CS6

Total seeds	**df**	**p>F**	**Means**	**df**	**p>F**	**Means**
2) CS1,5 (sys w/ Corn) vs.			7,760			3,393
CS6 (sys w/out Corn)	1	0.2405	4,356	1	0.0082	1,727

Figure 1 – CS3 and CS5 total weed seed density divided into grass and broadleaf species.





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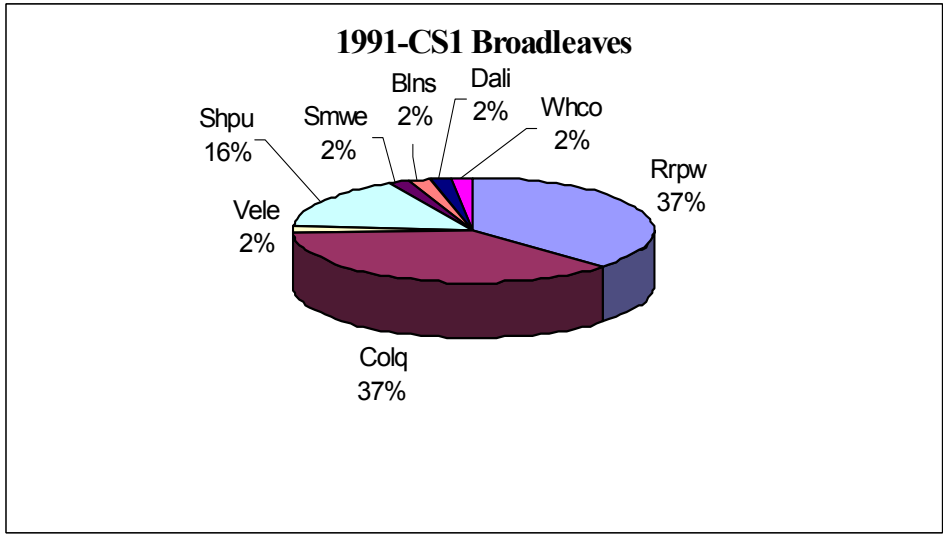
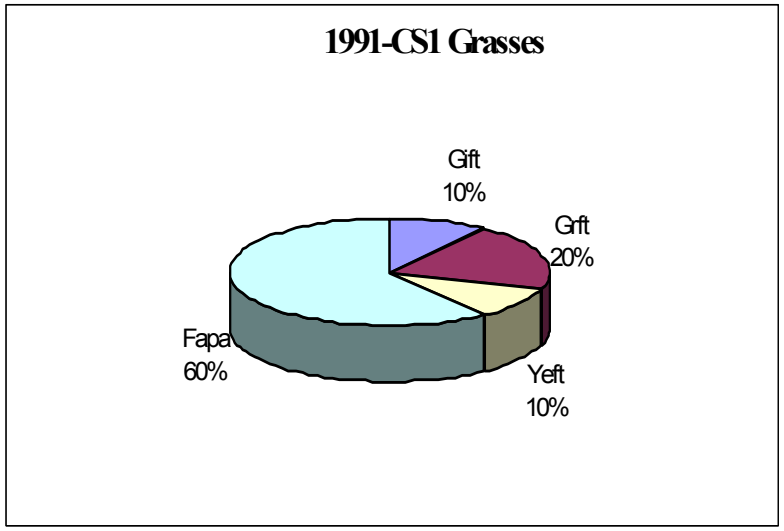
Appendix I- Summary of linear contrasts to determine the influence of agricultural management practices on weed seedbank (1991/92 - 2004)

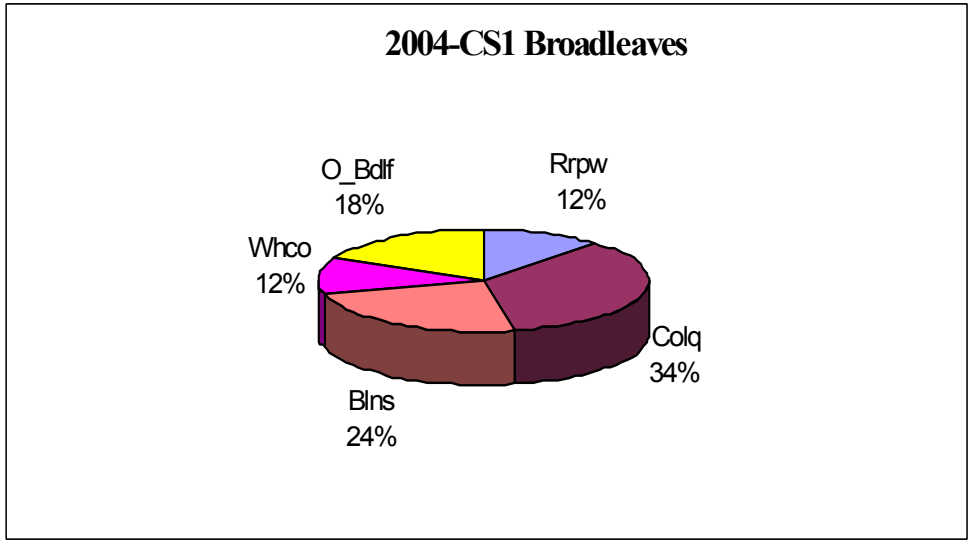
	Baseline 91/92			2004		
Total seeds	**df**	**p>F**	**Means**	**df**	**p>F**	**Means**
1) CS3 (org grain) vs. CS5 (org forage)	1	0.5200	11,256 12,894	1	<.0001	9,319 2,988
2) CS1,5 (sys w/ Corn) vs. CS6 (sys w/out Corn)	1	0.2405	7,760 4,356	1	0.0082	3,393 1,727
3) CS4, 5 (hay forages) vs. CS6 (pasture)	1	0.1788	9,590 4,356	1	0.3952	2,316 1,727
4) CS4 (forage) vs. CS5 (org forage)	1	0.1642	6,286 12,894	1	0.0952	1,645 2,988
5) CS1 (C corn) vs. CS2 (no-till Corn)	1	0.2665	2,222 6,140	1	0.0255	603 2,412
6) CS2 (no-till grain) vs. CS6 (no-till forage)	1	0.4928	6,140 4,356	1	0.3919	2,412 1,727
7) CS1, 3 (grains) vs. CS4, 5 (forages)	1	0.2250	6,539 9,590	1	0.0007	4,111 2,316
8) CS1, 2 (grains) vs. CS3 (org grain)	1	0.1338	4,181 11,256	1	<.0001	1,508 9,319

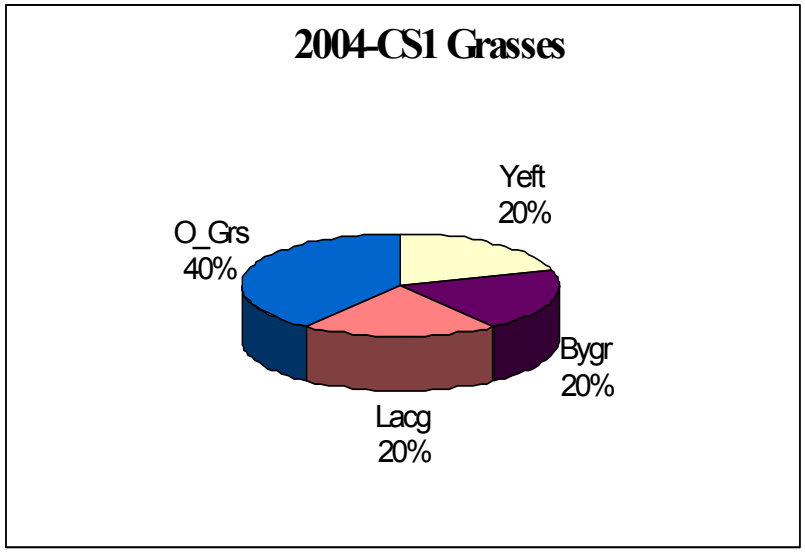
	Baseline 91/92			2004		
Broadleaf seeds	**df**	**p>F**	**Means**	**df**	**p>F**	**Means**
1) CS3 (org grain) vs. CS5 (org forage)	1	0.6078	9,911.50 11,052	1	0.8223	1,672.06 1,781.63
2) CS1,5 (sys w/ Corn) vs. CS6 (sys w/out Corn)	1	0.2244	6,666.15 3,274.50	1	0.3548	1,529.53 1,178.81
3) CS4, 5 (hay forages) vs. CS6 (pasture)	1	0.1708	8,347.33 3,274.50	1	0.2864	1,630.97 1,178.81
4) CS4 (forage) vs. CS5 (org forage)	1	0.1842	5,642.92 11,052	1	0.5374	1,480.31 1,781.63
5) CS1 (C corn) vs. CS2 (no-till Corn)	1	0.3260	1,929 4,795	1	0.0005	466.06 2,247.56
6) CS2 (no-till grain) vs. CS6 (no-till forage)	1	0.5183	4,795 3,274.5	1	0.0310	2,247.56 1,178.81
7) CS1, 3 (grains) vs. CS4, 5 (forages)	1	0.2262	5,545.13 8,347.33	1	0.5917	1,461.89 1,630.97
8) CS1, 2 (grains) vs. CS3 (org grain)	1	0.1336	3,362.29 9,911.5	1	0.4564	1,356.81 1,672.06
Grass seeds	**df**	**p>F**	**Means**	**df**	**p>F**	**Means**
1) CS3 (org grain) vs. CS5 (org forage)	1	0.3329	1,345 1,842.17	1	<.0001	7,647.38 1,206.00
2) CS1,5 (sys w/ Corn) vs. CS6 (sys w/out Corn)	1	0.9764	1,093.55 1,081.83	1	0.0059	1,863.93 548.31
3) CS4, 5 (hay forages) vs. CS6 (pasture)	1	0.7165	1,242.71 1,081.83	1	0.7935	685.28 548.31
4) CS4 (forage) vs. CS5 (org forage)	1	0.0221	643.25 1,842.17	1	0.0873	164.56 1,206.00
5) CS1 (C corn) vs. CS2 (no-till Corn)	1	0.0433	292.42 1,344.92	1	0.9638	137.13 164.56
6) CS2 (no-till grain) vs. CS6 (no-till forage)	1	0.6073	1,344.92 1,081.83	1	0.5258	164.56 548.31
7) CS1, 3 (grains) vs. CS4, 5 (forages)	1	0.4524	994.12 1,242.71	1	<.0001	2,649.69 685.28
8) CS1, 2 (grains) vs. CS3 (org grain)	1	0.2375	818.67 1,345.00	1	<.0001	150.84 7,647.38

Appendix II - Weed community analysis for CS1 from 1991 to 2004.

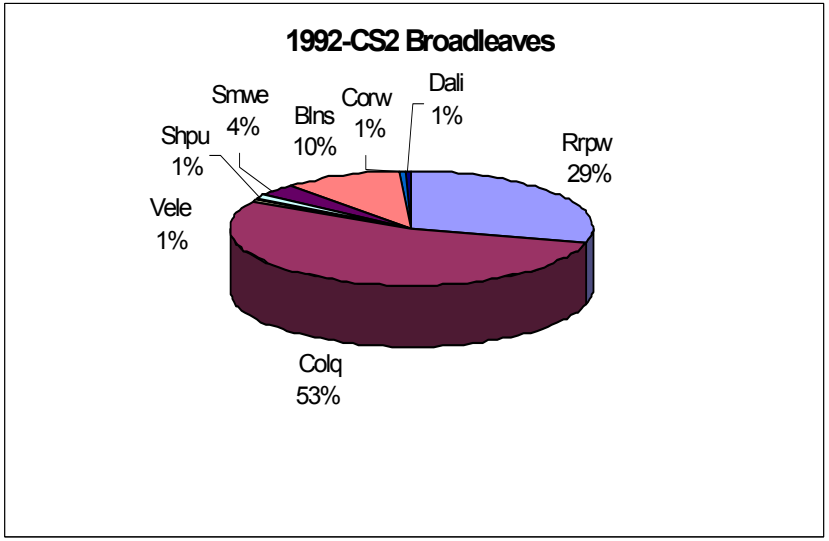


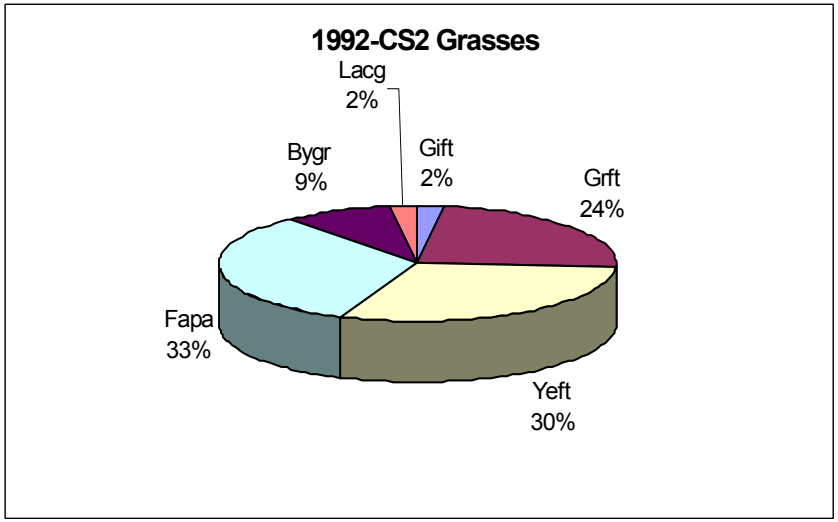


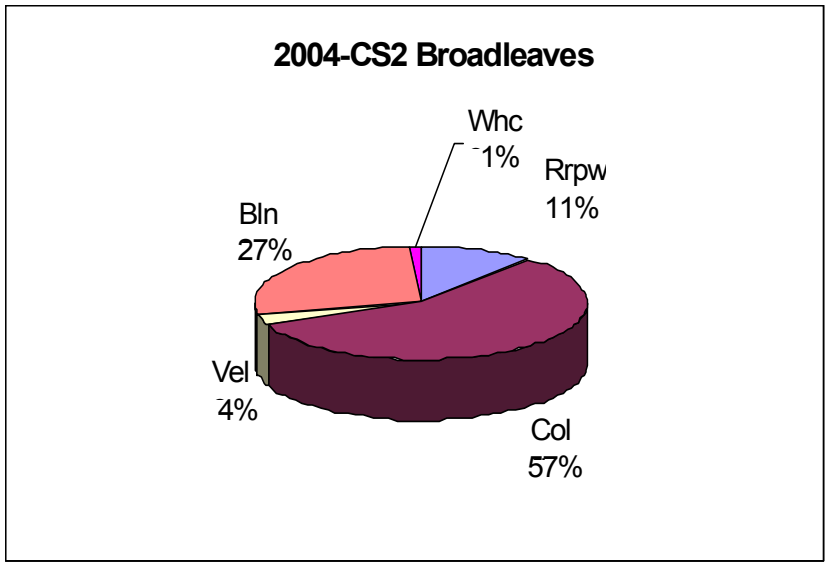


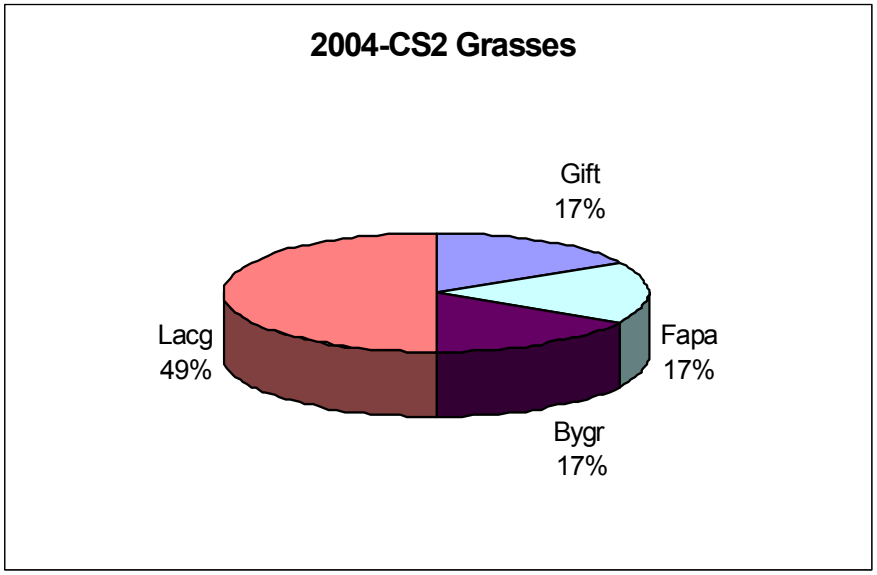


Weed community analysis for CS2 from 1992 to 2004.

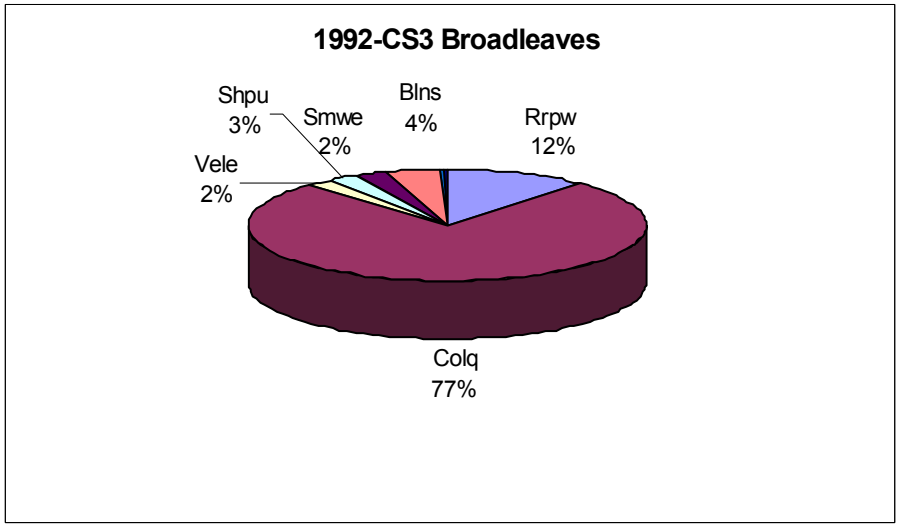


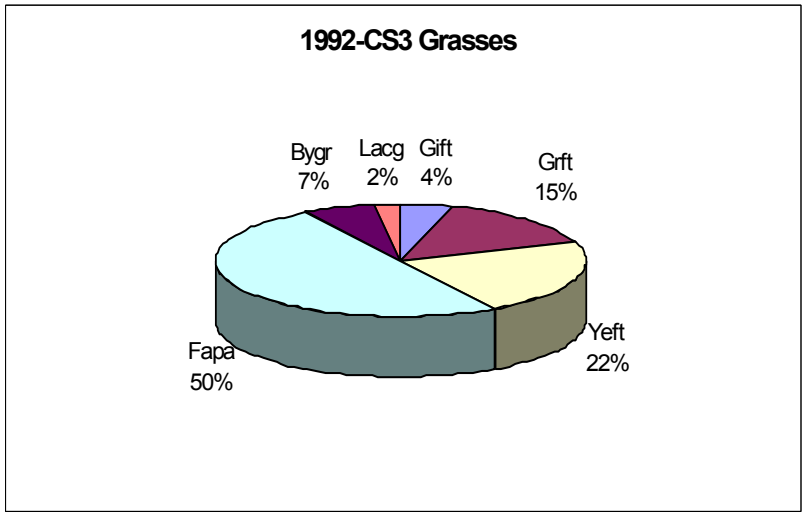


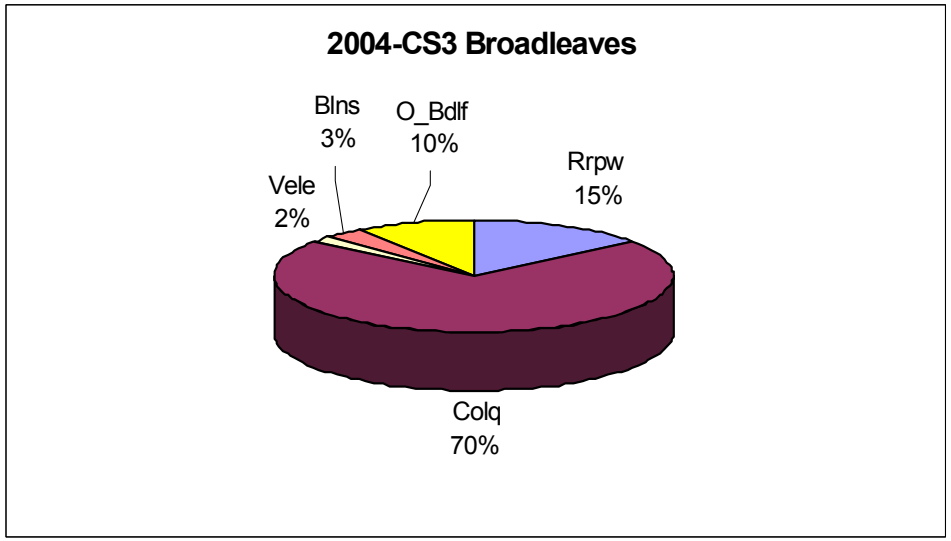


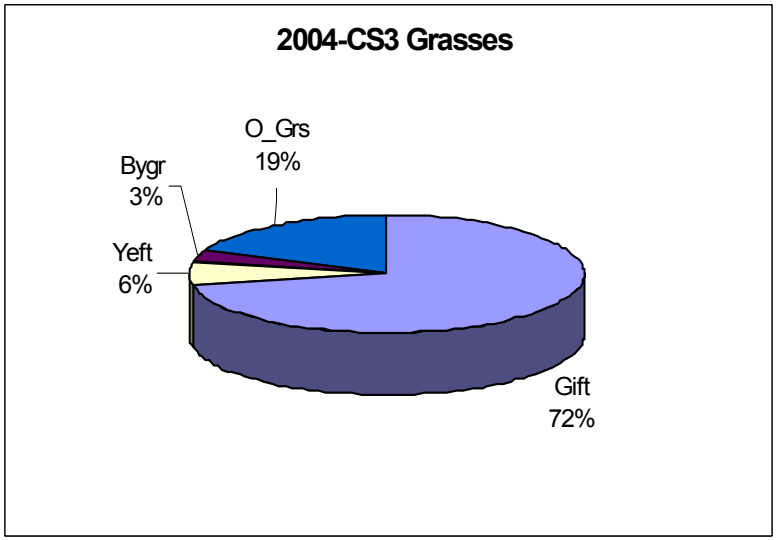


Weed community analysis for CS3 from 1992 to 2004.

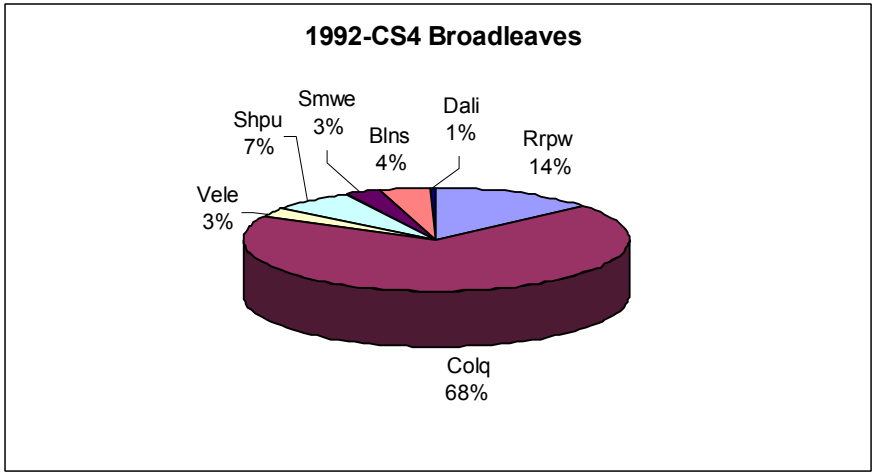


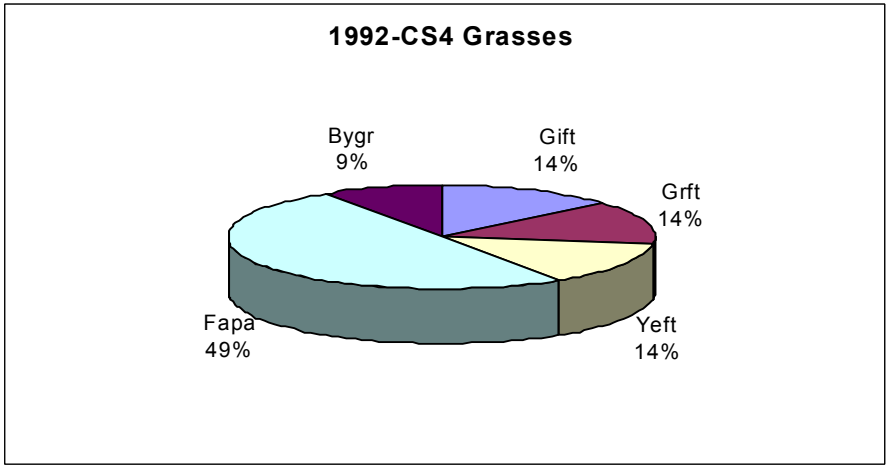


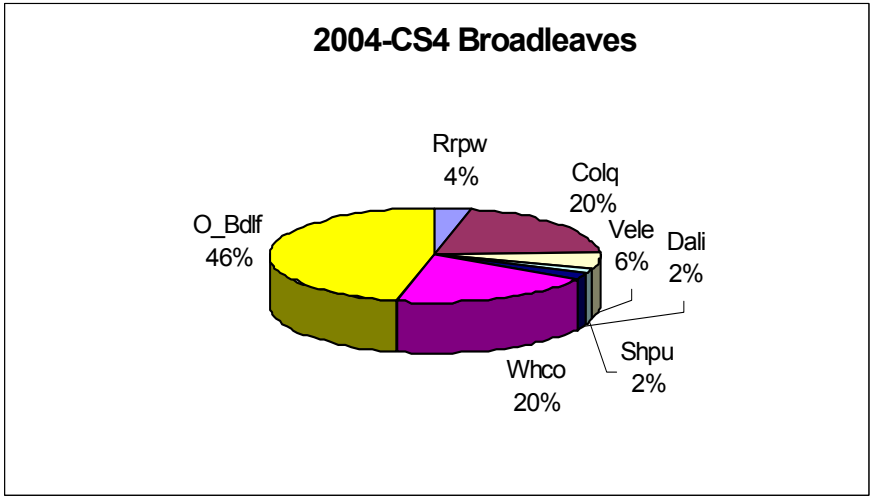


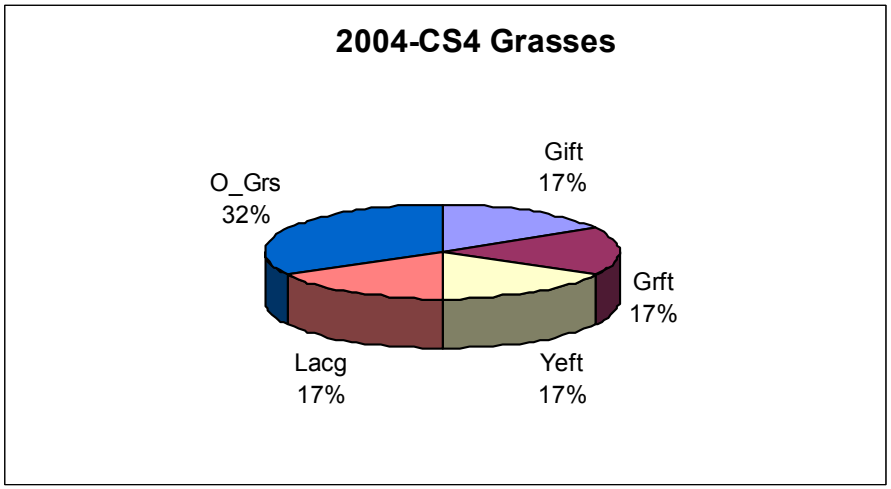


Weed community analysis for CS4 from 1992 to 2004.

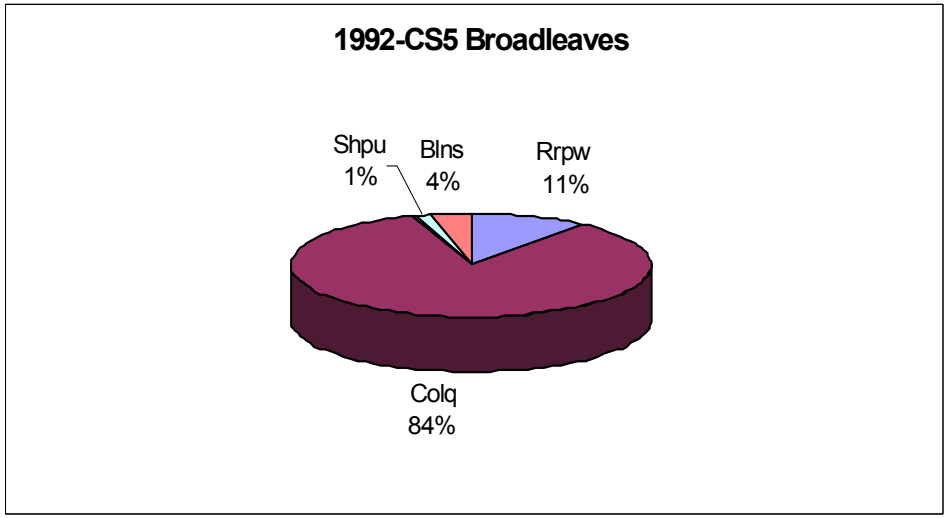


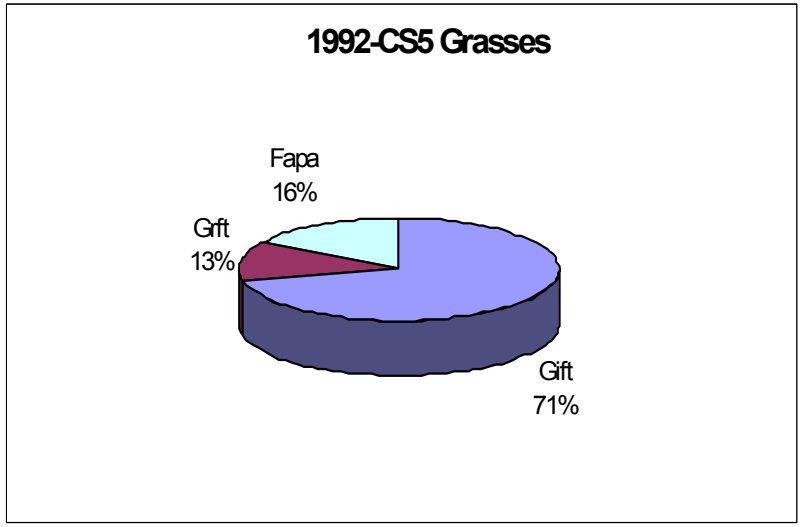


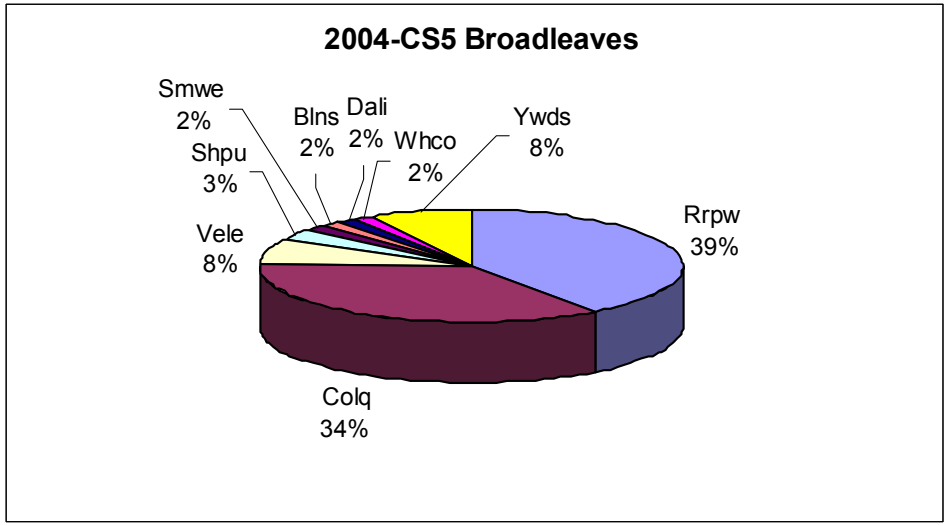


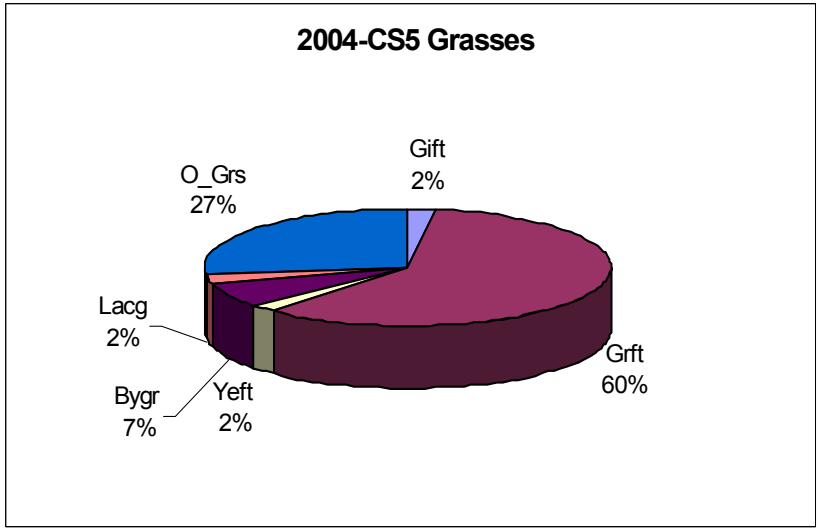


Weed community analysis for CS5 from 1992 to 2004.

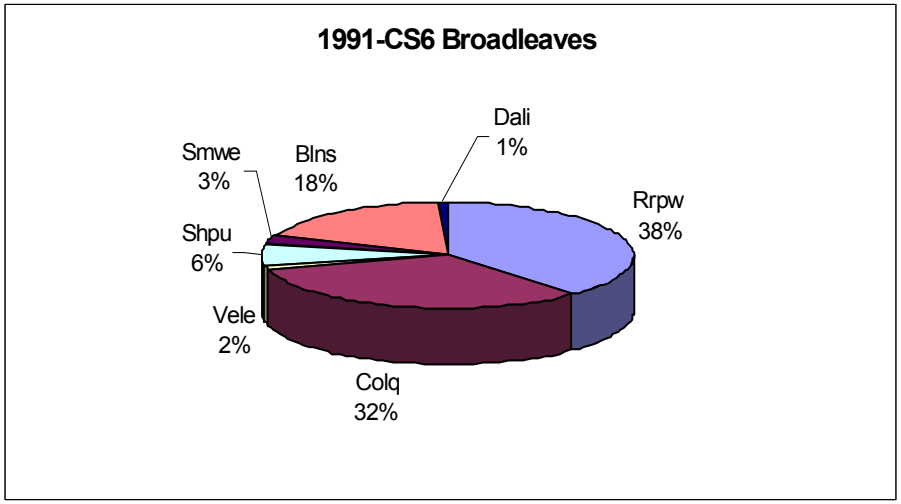


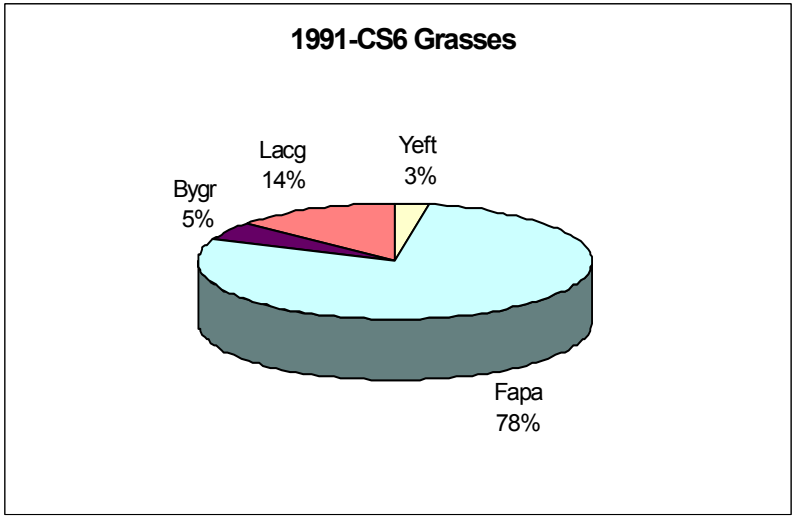


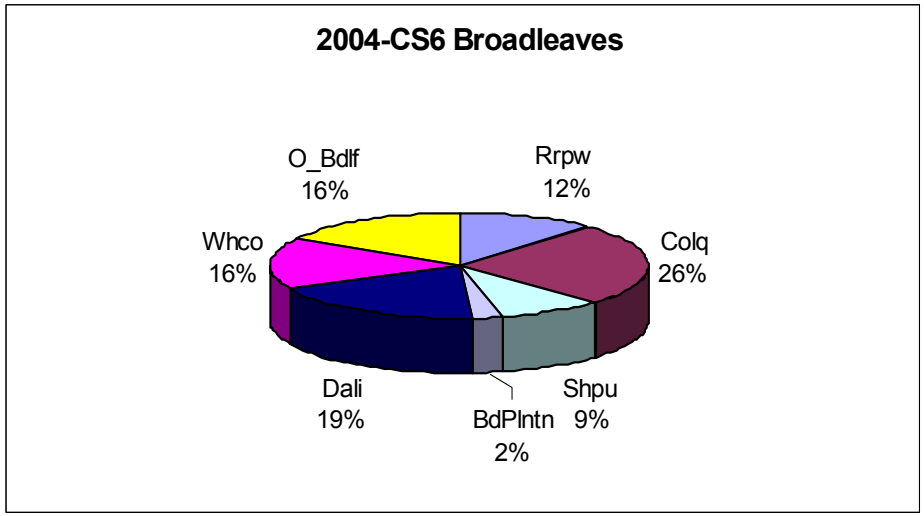


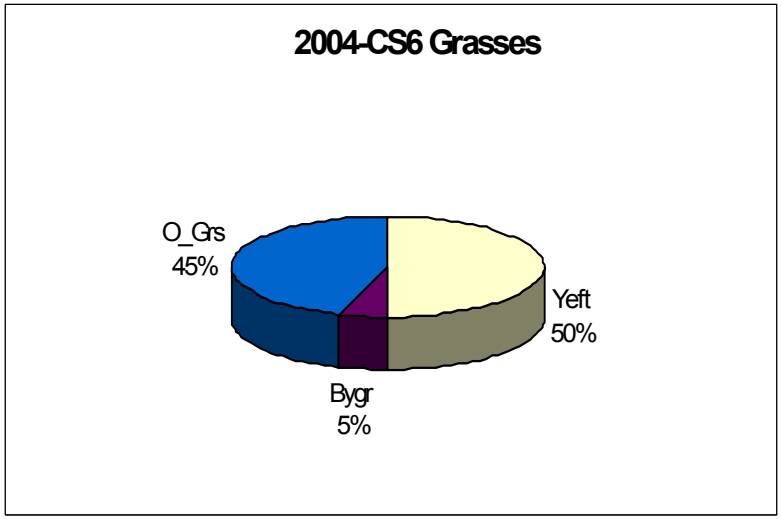


Weed community analysis for CS6 from 1991 to 2004.









Appendix III- Weed seedbank changes in WICST at ARL from 1990 to 2004.

trt		90	91	92	93	94	95	96	97	98	.....	04
1	Seeds/m^2	C 4,823	C 1,787	C 2,218	C 2,864	C 1,841	C	C 3,827	C 2,821	C 3,951		C 603
	% brdlf	86	84	87	86	81	--	92	97	79	.....	77
	% grass	14	16	13	14	49	--	8	3	21		23
2	Seeds/m^2	FC	S 1,548	C	S 2,312	C	S 3,043	C	S 2,247	C		C
	% brdlf	--	70	--	86	--	93	--	95	--	.....	--
	% grass	--	30	--	14	--	7	--	5	--		--
3	Seeds/m^2	S 4,613	C 5,162	S 6,140	C	S 11,366	C	S 2,871	C	S 5,828		S 2,409
	% brdlf	75	73	78	--	88	--	96	--	88	.....	93
	% grass	25	27	22	--	12	--	4	--	12		7
4	Seeds/m^2	FC	FC	S 11,247	W/Rc	C 7,677	S5,130	W/Rc	C	S 6,376		Sb 9,312
	% brdlf	--	--	88	--	64	51	--	--	21	.....	18
	% grass	--	--	12	--	36	49	--	--	79		82
5	Seeds/m^2	S 2,215	W 2,935	C 9,613	S 9,140	W	C	S 3,645	W	C		C
	% brdlf	68	80	85	83	--	--	95	--	--	.....	--
	% grass	32	20	15	17	--	--	5	--	--		--
6	Seeds/m^2	FC	S 7,559	W	C 11,602	S 10,807	W	C	S 13,990	W		W
	% brdlf	--	88	-	67	43	--	--	13	--	.....	--
	% grass	--	12	--	33	57	--	--	87	--		--
7	Seeds/m^2	A 5,075	A 2,839	A	C	A 2,570	A	A	C	A 3,258		A
	% brdlf	82	81	--	--	93	--	--	--	57	.....	
	% grass	18	19	--	--	7	--	--	--	43		
8	Seeds/m^2	FC	A 3,097	A	A	C 12,301	A 3,720	A	A	C		A
	% brdlf	--	59	--	--	99	96	--	--	--	.....	--
	% grass	--	41	--	--	1	4	--	--	--		--
9	Seeds/m^2	FC	FC	A 6,280	A	A	C 2,925	A 2,258	A	A		A 1,645
	% brdlf	--	--	90	--	--	94	83	--	--	.....	90
	% grass	--	--	10	--	--	6	17	--	--		10
10	Seeds/m^2	FC	FC	FC 7,742	A 2,892	A	A	C 4,011	A 1,893	A		C
	% brdlf	--	--	93	88	--	--	60	86	--	.....	--
	% grass	--	--	7	12	--	--	40	14	--		--
11	Seeds/m^2	Oa 4,774	A 8,118	C 7,441	Oa 3,645	A	C 4,205 77	Oa 2,301	A	C		C
	% brdlf	82	64	91	95	--	23	63	--	--	.....	--
	% grass	18	36	9	5	--		37	--	--		--
12	Seeds/ft^2	FC	Oa 5,871	A	C 5,441	Oa 4,968	A	C 6,355	Oa 4,269	A		A
	% brdlf	--	82	--	88	86	--	57	58	--	.....	--
	% grass	--	18	--	12	14	--	43	42	--		--
13	Seeds/ft^2	FC	FC	Oa12,882	A	C 3,452	Oa 3,000	A	C	Oa 2,355		Oa 2,990
	% brdlf	--	--	86	--	90	83	--	--	77	.....	60
	% grass	--	--	14	--	10	17	--	--	23		40
14	Seeds/ft^2	P 4,151	P 4,312	P	P	P	P 4,118	P 6,462	P	P		P 1,720
	% brdlf	82	75	--	--	--	89	73	--	--	.....	68
	% grass	18	25	--	--	--	11	27	--	--		32