EVALUATION OF BLACK OAT (*AVENA STRIGOSA* SCHREB.) GERMPLASM

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THESIS ABSTRACT

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Black oat has become an important winter cover crop in subtropical and temperate regions. Originating in the northern parts of Spain and Portugal, black oat cultivation has spread to different parts of the globe. Even though different in ploidy level, diploid black oat has been used in many hexaploid common oat (*A. sativa* L.) breeding programs as a donor parent for some desirable characters such as rust resistance. Black oat is an emerging cover crop for the Southeastern US. The only commercially available black oat cultivar in US is 'SoilSaver' released by Auburn University and USDA-ARS-NSDL in 2002. Even though SoilSaver is superior for some traits (e.g. maturity and biomass yield), some traits need further improvement. Over 100 black oat accessions are available from the USDA-ARS Small Grains Germplasm Unit at Aberdeen, Idaho, but a detailed study of this collection is needed before they can be used in a breeding program. The objective of the study was to evaluate the entire USDA-NPGS black oat germplasm collection in the field for morphological traits and maturity and a subset for biomass and grain yield. We used 103 black oat accessions available from USDA and SoilSaver for the morphology and maturity study and 18 accessions selected based on their relative maturity compared to SoilSaver for plot biomass and grain yield trials. Among the 14 response variables measured, 12 were used for the "Canonical Discriminant Analysis" (CDA) in morphology and maturity study. In CDA the first four canonical variates were responsible for 84 % of the total variation and when plotted the first two axes, the accession CIav 9015 was separated farthest from the rest of the accessions. This accession is extremely early maturing, has short culms but long and broad leaves. So we suspect that it may not belong to *Avena strigosa* Schreb., but to some other *Avena* species. Further karyotypic studies may be needed to ascertain our findings in this regard. For the yield trials we compared the biomass and grain yield and test weight of the selected accessions to SoilSaver at a standard seeding rate. None of the tested accessions performed better than SoilSaver at standard seeding rate consistently in all locations. The allelopathy study identified seven accessions having significantly higher radish radicle suppressive ability than SoilSaver.

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I. LITERATURE REVIEW

Introduction

In modern sustainable agricultural systems cover crops occupy a pivotal role in no-tillage and reduced tillage crop management. They are grown to protect and improve the physical and chemical properties of soils. These crops can be utilized for various purposes such as winter cover or green manure, supplemental forage covering periods of shortages for regular crops, living mulch, and as a catch crop. Cover crops may be classified based on their taxonomic status (leguminous or non-leguminous) or growing season (winter *vs*. summer).

Leguminous cover crops currently in use worldwide and those that show potential include white lupin (*Lupinus albus* L.) (Mask et al., 1993; Noffsinger et al., 1998), velvetbean [*Mucuna deeringiana* (Bort) Merr], jackbean [*Canavalia ensiformis* (L.) DC.], jumbie-bean [*Leucaena leucocephala* (Lam.) de Wit], wild tamarind [*Lysiloma latisiliquum* (L.) Benth] (Caamal-Maldonado et al., 2001), crimson clover [*Trifolium incarnatum* L.] and other *Trifolium* species, and hairy vetch [*Vicia villosa* Roth subsp. *villosa*]. Other leguminous crops are not considered cover crops *per se* but play an important role in crop rotations, e.g., alfalfa [*Medicago sativa* L.] and soybean [*Glycine max.* (L.) Merr]. Alfalfa, called the "queen of the forages," is cultivated for forage purposes as well as soil bioremediation (Anonymous, 2000). It was reported that a corn-soybean rotation enhances corn yield without additional nitrogen. (Maloney, 1999).

Another corn-soybean crop rotation study produced corn yields equivalent to the yield produced by the application of 144 kg N ha^{-1} (Omay, 1998). Some of the non-leguminous cover crops used extensively in the southeastern USA are rye (*Secale cereale* L.), wheat (*Triticum aestivum* L.), and oat (*Avena sativa* L.) (Bauer and Reeves, 1999). Non-leguminous cover crops with worldwide importance are black oat (*Avena strigosa* Shreb.) (Ceretta et al*.,* 2002; Federizzi and Mundstock, 2004), white mustard (*Sinapis alba* L. subsp. *alba*), and rapeseed (*Brassica napus* L.) (Weinert et al., 2002).

Benefits of growing cover crops

Cover crops have been a part of agriculture for thousands of years, but they have received the serious attention of many farmers quite recently. Subtropical climates such as the southeastern USA can support plant growth 12 months of the year, provided moisture is available. Yet, the main agronomic crops such as corn (*Zea mays* subsp. *mays*), cotton (*Gossypium hirsutum* L.), and peanut (*Arachis hypogaea* L.) are grown during spring to early autumn. This leaves the ground uncovered for up to eight months of the year, particularly during the winter months with rainfalls in excess of 322 mm month^{-1} (NCDC, 2005) leading to severe erosion.

In the southeastern USA, winter cover crops are essential in conservation tillage systems to protect soils from erosion and for improving soil productivity (Schomberg et al., 2005). They are of particular benefit in colder winter months to prevent the loss of nutrients (Ditsch et al., 1993; Kinyangi et al., 2001). A study conducted at the E.V. Smith Research Center showed that cotton yield was higher in a conservation system than in the conventional system of soil management. (Terra et al., 2005).

Figure 1-1: Erosion in Alabama (http://newdeal.feri.org/library/s25.htm)

Figure 1-2: Erosion in Alabama (http://newdeal.feri.org/library/s24.htm)

Improving Physical Properties of Soil

Cover crops are important in increasing the physical properties of the soil in many ways. Cover crops increase the soil organic carbon (SOC) content (Hermawan and Bomke, 1997; Liua et al., 2005) and dilute acid-extractable polysaccharides (Liua et al., 2005) in the soil. The dilute-acid-extractable polysaccharides act as active binding agents in the soil. The SOC (Hermawan and Bomke, 1997; Liua et al., 2005) and acid-extractable polysaccharides (Liua et al., 2005) increase aggregate stability of the soil, which is expressed as the increase in mean weight diameter (MWD). Winter wheat was found to increase vesicular-arbuscular mycorrhiza (VAM) inoculum potential, soil aggregation and yield of cash crops (Kabir and Koide, 2000). Glomalin, which is a glycoprotein produced by arbuscular mycorrhizal (AM) fungi, is positively correlated with the aggregate stability of the soil. Aggregate stability is measured as resistance to breakdown by wet sieving of air-dried soil samples (Wright and Upadhyaya, 1998). Living cover crop mulches which can reduce the daily maximum soil temperature may have both positive (in tropical conditions) and negative (in temperate conditions) effects on main crop growth (Chassot et al., 2001). Rainfall pattern and/or water availability may be other factors that need to be taken into consideration before starting any conservation system or cover cropping. Stored soil water was found to be reduced slightly after the incorporation of winter cover crops, which necessitates proper water budgeting if planted in arid and semi-arid areas (Mitchell et al., 1999). However, the water storage capacity of the soils was increased by the incorporation of winter cover crops into soil before the next season.

Cover crops can improve water quality by decreasing the amount of pesticides and nutrients percolating from the agricultural fields to the water sources. The reduced seepage of nutrients from agricultural land also reduces microbial contamination of water bodies. Increased phosphorus input can accelerate fresh water eutrophication (Carpenter et al., 1999; Sharpley et al., 2001). Nitrate leaching from the soil is a potential problem for water sources near the agricultural fields (Sainju *et al*., 1998). The leached nitrate can pollute groundwater by precipitation in fall and winter seasons. One of the methods to control nitrate leaching from the crop field is to plant a cover crop with an extensive root system that can translocate the available nitrogen into their roots. In a comparative study for the effectiveness of preventing nitrate leaching, cereal rye (*Secale cereale* L.) was found to be more effective in reducing residual NO_3^- and potential leaching than hairy vetch (*Vicia villosa* Roth) and crimson clover (*Trifolium incarnatum* L.) (Sainju *et al*., 1998). To prevent nitrate leaching effectively, it is important for a cover crop to have an extensive root system. In the experiment conducted by Sainju, the total mini rhizotron root count (MRC; no. roots cm^{-2} soil profile) of cover crops at 0 to 50 cm depth showed a positive correlation to N uptake and a negative correlation to soil NO_3^- concentration. (Sainju et al., 1998). The amount of nitrate leached into water bodies can be controlled by cultivating winter cereal grain cover crops in the field (Staver and Brinsfield, 1998). Soil cover can reduce the amount of pesticides reaching soil during spraying and, thus, can reduce the runoff loss of pesticides and eventual contamination of water bodies. (Silburn et al., 2002).

Cover crops can absorb P from the upper layers of soils and transport it in their roots to subsoil layers. Pea (*Pisum sativum* L. subsp. *arvense*), black oat (*Avena strigosa* Schreb) and narrow leafed lupin (*Lupinus angustifolius* L) were the most efficient cover crops for translocation of soil phosphorus for a 0 to 55 cm depth in oxisol soils. For the 10 to 55 cm depth pea, black oat and narrow leafed lupin were most efficient. Lupin had higher root phosphorus content without P-fertilizer application. This is due to the fact that lupin can absorb phosphorus from soil using specialized proteoid roots if the soil is deficient in phosphorus. These cluster roots release citric acid to mobilize the sparingly available P in the rhizosphere (Neumann et al., 1999). With fertilizer application, common vetch followed by hairy vetch and black oat has the highest content of root P. White lupin has the highest capacity of P accumulation in the aerial parts without P application. In the presence of P fertilizer, black oat accumulated more than 20 kg ha^{-1} of P on the aerial parts. Without P application black oat had the highest root dry matter content among the ten cover crops (*Avena strigosa, Avena sativa, Secale cereale, Pisum sativum* subsp *arvense, Pisum sativum, Vicia villosa, Vicia sativa, Lupinus angustifolius* L.*, Lupinus albus, and Triticum aestivum*) studied (Franchini et al., 2004).

Cover crops may play a role in integrated pest management (IPM) practices by either altering the life cycle of the insect pest or by producing some inhibitory substances. Velvetbean [*Mucuna deeringiana* (Bort) Merr] has a strong inhibitory effect on the gall index of *M. incognita* in the roots of tomato (Caamal-Maldonado et al., 2001). Various cover crops are used to suppress weeds in different parts of the world. The canopy cover produced by the cover crops is important in controlling weeds by photosynthetic suppression. Apart from the cover crop biomass, there are some other factors that are helpful in suppressing weeds effectively, including the quickness in establishment of the cover crop (Barberi and Mazzoncini, 2001) and the ability to demobilize available nutrients from the field in fallow. Fibrous rooted cereal cover crops can scavenge the excess nutrients present in the soil after the harvest of the cash crop and make them available later; thus, this may decrease the weed population. The leguminous cover crops release symbiotic nitrogen to the soil, which decreases the effectiveness of them in suppressing the weeds population. Also, allelopathic chemicals released by the active crop or cover crop residues are important in weed suppression.

A cover crop management system has a clear advantage in weed control compared to the winter fallow system (Reeves et al*.*, 2005). Velvetbean [*Mucuna deeringiana* (Bort)Merr] is used in tropical regions of Mexico to suppress spiny amaranth (*Amaranthus spinosus* L.), smooth pigweed (*A. hybridus* L.), field sandbur (*Cenchrus insertus* M. A. (Curtis), and bitterweed (*Parthenium hysterophorus* L.) (Caamal-Maldonado *et al*., 2001). In a field trial conducted in the northern Guinea savanna of Nigeria, it was shown that velvetbean combined with 40,000 corn plants ha$^{-1,}$ and weeding three times gave higher corn grain yields and efficient weed control than a farmer's control consisting of a single weeding at 4 weeks after planting (WAP) and low corn density. (Chikoye et al*.*, 2004). Even though cover crops can be used to suppress weeds, even cover crops may be considered weedy in certain situations.

The botanical characteristics that predispose a cover crop to become a potential weed are: 1) the ability of the plants to produce seeds at an early stage of its life cycle and continue seed production till the end of its life cycle, 2) the easy shattering of seeds, 3) production of a large number of seeds, 4) high seed dormancy even after long exposure to harsh environmental conditions or no dormancy at all, 5) quick germination and establishment, and 6) the ability to propagate vegetatively. The non-shattering nature of seeds in black oat compared to its wild relatives and the low survival of volunteer seeds in harsh environmental conditions during the summer, where high moisture and high temperature lead to a rapid degradation of seeds without a hard seed coat, reduces the potential threat of black oat as a weed in actual field conditions in southeastern USA.

Allelopathy

The allelopathic effect of a cover crop may negatively affect the crop growth in some cases. The allelopathic effects of some plant residues on the yield parameters of other crops might be reduced by proper tillage and other practices that promote rapid decomposition of the plant materials (Roth et al., 2000). On the other hand it is an efficient method for controlling the weed without chemical application. The allelopathic potential of a cover crop can be estimated by growing the plants in greenhouse conditions and conducting *in-vitro* germination and radicle growth bio-assays using aqueous leachates collected from them at a standard concentration (1%) (Caamal-Maldonado *et al.*, 2001). In velvet bean L-3-(3,4-dihydroxyphenyl) alanine (L-DOPA) is mainly responsible for the allelopathic action (Nishihara *et al.*, 2005). The use of genetic engineering to impart allelopathic potential to cover crops has been a discussion among scientists. Many, however, are skeptical about the effectiveness of such a strategy (Duke *et al.*, 2001). Farmers in Mexico use leguminous species like *Mucuna* spp. and *Canavalia* spp. to control weeds in their fields (Caamal-Maldonado *et al.*, 2001).

BLACK OAT

Biomass Production

Recently black oat (*A. strigosa* Schreb.) has become very important in subtropical and temperate regions as a winter cover crop and forage (Suttie, 2004). In South America black oat is grown on more than 3 million hectares as a cover crop or forage (Federizzi and Mundstock, 2004). It has the potential to produce a considerable amount of biomass in comparison with other non-leguminous or leguminous cover crops. In addition to that, it has many desirable qualities over the other cover crops. In a study conducted by Schomberg et al. (2005) results showed that the biomass production and soil N mineralization dynamics of black oat was similar to crimson clover, indicating the potential of black oat as a cover crop in the southeast USA. The amount of N mineralized in 90 days ($N_{min}90$) measured with *in situ* soil cores was 1.3 to 2.2 times greater following black oat, crimson clover, and oilseed radish than following rye (Schomberg *et al*., 2005). Black oat can be used as a forage crop and produce a comparable dry matter yield to that of ryegrass (*Lolium perenne* L. cv. Kangaroo Valley) and it can also thrive well with other legume forage crops like barrel medic (*Medicago truncatula* L.) (Lowe and Bowdler, 1998). A study conducted at Instituto Agronômico do Paraná IAPAR, Brazil demonstrated the ability of cover crop residues of black oat to decrease manganese toxicity in well-aerated, acid soils by lowering the Mn solubility (Andrade et al., 2002). Another advantage of black oat is the relative ease of field establishment. Black oat only needs N as a top dressing; neither P nor K is needed (Federizzi and Mundstock, 2004). In South America, black oat cultivated for cover crop purpose is desiccated in August

(Federizzi and Mundstock, 2004). Black oat reached maximum biomass at anthesis (8579 kg ha $^{-1}$), while rye (*Secale cereale* L.) and wheat (*Triticum aestivum* L.) continued to increase biomass significantly through soft dough (9497 kg ha $^{-1}$ and 10460 kg ha $^{-1}$, respectively) (Ashford and Reeves, 2003). Therefore, black oat can be terminated at an earlier stage compared to the other two cover crops. Early termination will reduce depletion of the available nutrients and moisture in the field. This is a useful trait since it can be planted as a fall-sown winter cover crop. If the winter is severe it will all be killed so there is no need for the use of herbicides to kill the cover crop. Since black oat has the C_3 photosynthetic pathway for Carbon fixation (Tesar, 1984), it can contain more available NH_4^+ per dry matter mass unit compared to C_4 cover crops such as *Pennisetum glaucum* (Waller, 1979), *Sorghum vulgare* (Waller, 1979), and *Brachiaria decumbens* (Rosolem CA, 2005). Cotton lint yield following black oat was higher than that following rye, even though rye produces more biomass than black oat (Bauer and Reeves, 1999). Even though black oat can thrive well with other cover crops in mixed culture with wheat black oat performs poorer than in monoculture in terms of biomass production (Cousens et al., 2003).

Weed Control

Black oat can suppress the weeds cutleaf evening primrose (*Oenothera laciniata* Hill) and common chickweed (*Stellaria medi*a (L) Vill) (Reeves et al., 2005). In years without any freezing injury, black oat provides better weed control than rye (Reeves *et al.*, 2005). Black oat has a greater inhibitory effect on root elongation of radish than rye suggesting the suitability of black oat as mulch for weed control (Bauer, 1999). Black oat can perform well even in mixtures with other cover crops. Saini et al*.,* (2005) reported a 40% winter weed biomass reduction by mixed covers of lupin (80%) and black oat (20%) preceding corn, but these mixed covers were less effective preceding cotton. Weed biomass produced is less in cotton planted in black oat or rye covers compared to that planted in wheat or fallow covers. Without herbicides, black oat gave greater sickle pod [*Senna obtusifolia* (L.) H. S. Irwin & Barnaby] and palmer amaranth control than rye or wheat, showing the suitability of black oat as an effective cover crop for weed suppression (Patterson et al*.,* 1996).

Management Practices

Black oat has a low C/ N ratio of 34:1 compared to 42:1 for oat and wheat and 45:1 for rye (Bauer and Reeves, 1999). This is desirable for the main crop in regions with high rainfall and temperatures during the growing season because the decomposition of the cover crop residue is slowed down. However, it may also sequester the nitrogen available to the main crop and, hence, application of starter N to the main crop may be warranted (Ceretta et al., 2002). Obviously, the kill date has an effect on biomass yield and available nitrogen and maximizing the days between cover crop establishment and kill is a desirable practice. A delayed kill date of hairy vetch for two weeks can improve N accumulation significantly (from 104 to 113 kg ha^{-1}) (Sainju and Singh, 2001). Using chemicals to kill the cover crop may be advantageous for the following main crop (Vyn et al., 2000). The most effective and economical method to kill black oat at anthesis is the combination of roller and herbicide (88% with roller+paraquat and 91% with roller+glyphosate) (Ashford and Reeves, 2003). The use of a roller also facilitates planting by reducing hairpinning of residue when the planter runs parallel to the roller (Ashford and Reeves, 2003).

There may be a difference in the response of cover crop performance based on the planting date (Bauer and Reeves, 1999). Black oat had higher N concentration than other winter cereals (oat, rye and wheat) for October and November planting dates (Bauer and Reeves, 1999). The date of planting affects the cover crop dry matter yield, N content and C/N ratio (Odhiambo and Bomke, 2001). In a study conducted in Britain, cover crops performed better in terms of dry matter yield and N accumulation if planted in late August compared with late September (Odhiambo and Bomke, 2001). However, the planting date of the cover crop had no influence on cotton lint yield in the southeastern United States (Bauer and Reeves, 1999). Considering all these aspects, black oat, which is widely grown in Brazil and Paraguay as a cover crop, can be used as a winter cover crop in the cotton belt of southeastern USA due to the climatic similarity between these places (Bauer and Reeves, 1999).

Classification and Botany

Black oat (*Avena strigosa* Schreb.) is a member of genus *Avena* of the Aveneae tribe within the Pooideae subfamily of the grass family Poaceae. The Latin binomial is particularly useful in communication because (i) the common name black oat is also sometimes applied to other oat species and (ii) in the English speaking regions of the world *Avena strigosa* Schreb. is referred to by different common names such as bristle oat, sand oat, or small oat. Common names for *A. strigosa* in other languages are avoine rude in French, Rauhhafer and Schwarzhafer in German, and aveia-preta in Portuguese (USDA GRIN Taxonomy 1997).

Avena strigosa can be confused with two closely related diploid species viz. *Avena hispanica* and *Avena brevis.* The conclusive identification can be made with the inspection of the unique strigosa-type lodicules in which the side lobe is larger than that of sativa and fatua type lodicules and is fused partly or almost completely to the conical part of the lodicules above the level of troughing, sometimes near the very tip of the lodicules (Baum, 1977).

Black oat is an annual (Baum, 1977; Legget, 1992) and juvenile growth and flowering stems are either prostrate or erect. The height of flowering stems ranges from 80 to 200 cm. (Legget, 1992). Ligules are obtuse and sometimes pointed (Baum, 1977). Panicles are equilateral and spikelets are short measuring 20 to25 mm long without the awns, each of which consists of two to three florets. The glumes are equal or nearly equal in length (the length may range from 16 to 24 mm) and are non-disarticulating at maturity. Awns inserted at the middle of the lemma and tips of lemmas are bisetulate-biaristulate or sometimes biaristulate only. Lemmas are glabrous or not and sometimes they bear only a few hairs around the point of awn insertion. The palea has 1-2 rows of cilia along the edge of the keel and the back of the palea is often beset with prickles, rarely without. The lodicules are with prickles (Baum, 1977). There is not much information available about the phenological changes other than a brief account given by Baum (1977) regarding the flowering of black oat from June to September and rarely in October.

From very early times black oat has been cultivated for different purposes in different parts of the world. Prior to the 17th century *Avena strigosa* was the most common oat cultivated in Scotland (Murphy and Hoeffman, 1992). Black oat is used as an animal forage, green manure and cover crop and in erosion control (Anonymous). In Brazil much of the fodder oat is *Avena strigosa* rather than *Avena sativa.* (Martinelli, 2004). In Japan *Avena sativa* and *Avena strigosa* are the cultivated fodder oats (Katsura, 2004). *Avena strigosa* Schreb, which formerly was a minor cereal of poor soils, is now grown on a large scale in southern Brazil, Chile, Uruguay and Paraguay (Anonymous, 2004). In southern Brazil, Black oat is cultivated as winter forage, cover crop and for grain production. (Ceretta et al., 2002).

Center(s) of diversity

Coffman (1961) citing Sampson (1954) who in turn cited Tackholm et al. (1941) stated that "What are probably the oldest known oat grains were found in Egypt associated with the remains belonging to the 12th dynasty [2000 to 1788 BC]. Similar grains have been found among Egyptian cereals of the 2nd and 3rd century AD. These Egyptian oats were originally identified as *Avena strigosa*, but Tackholm et al. believe they are either *A. fatua* or *A. sterilis*."

Avena strigosa is distributed in Austria, Belgium, Corsica, Czech Republic, Slovakia, Denmark, Finland, France, Germany, Hungary, Lithuania, Luxemburg, Norway, Portugal, Spain, Sweden, Switzerland, the United Kingdom, and USSR (Baum, 1977). Presently it is grown commercially in South America as a cover crop or for grain to be sown as cover crop (Federizzi and Mundstock, 2004) and to a limited extend in

North America also. Even though black oat was introduced to the United States from Europe, it has become naturalized in California (Magness et al., 1971).The *strigosa* group is seen in vast areas from the Iberian Peninsula, considered to be the center of origin, to the plains of Afghanistan occupying a wide range of ecological niches (Weibull et al., 2005). Black oat is cultivated in France, Belgium, Portugal, Spain, northwest Germany, and Great Britain (Coffman, 1961). Black oat is cultivated in Wales to a limited extent on poor upland soils and to a greater extent in Germany, the United Kingdom, and various parts of Eastern Europe (Baum, 1977). In Latin America the cultivated black oats are introductions from Europe (Federizzi and Mundstock, 2004). A more detailed account of the present geographical distribution of black oat is found in the Flora Europeae (Anonymous).

In many of these regions different cultivars have been developed as a result of cultivation or naturalization. The main black oat cultivars used in Peru are Vilcanota, Mantaro and Pastos (Federizzi and Mundstock, 2004). The United States Department of Agriculture National Germplasm Resources Information Network (USDA-GRIN) lists 121 accessions stored at the National Small Grains Collection (NSGC), Aberdeen, Idaho, of which 119 are available to researchers around the world (http://www.ars-grin.gov/cgi-bin/npgs/html/tax_acc.pl, verified on June 18, 2007).

Cytogenetics

Like the genus *Triticum*, species in the genus *Avena* constitute a polyploid series with a basic chromosome number of x = 7. There are 23 species belonging to the three genome groups with three ploidy levels. All diploid species contain either the A or C genome, the tetraploid species contain the A and C genomes, and the hexaploids have the ACD genomic constitution. Thus, the A and C genomes occur at diploid, tetraploid and hexaploid levels, but the D genome is present at the hexaploid only (Leggett and Markhand, 1995).

Avena strigosa is a diploid species with the A genome and a chromosome number of 2n = 2x = 14 (Baum, 1977; O'Mara, 1961; Thomas, 1992), *Avena strigosa weistii* is another diploid with A_s genome. *A. ventricosa* Bal. ex. Coss is a diploid with C_vC_v and both *A.caudate* Dur. and *A.eriantha* Dur. are diploids with the C_pC_p genome. *A.barbarate* Pott ex Link., *A.abyssinica* Hochst and *A.vavilovania*(Malz.) Mordv. are tetraploids with AABB genomes and *A.murphyi* Ladiz. and *A.maroccana* Gdgr. are tetraploids with AACC genomes. There are six hexaploid species identified with AACCDD genome *viz.* *A.sativa* L., *A.byzantina* C.Koch., *A.sterilis* L., *A. fatua* L., *A. hybrida* Petern., *A.atherantha* Presl., *A.occidentalis* Dur., and *A. trichophylla* C.Koch. (Thomas, 1992).

The C genome is quite different from both the A and D genomes. Based on the Giemsa C-banding technique, it can be seen that the heterochromatin in genome A is located at the telomeres, whereas it is located at the centromeric and interstitial regions in the C genome and is spread throughout the chromosome in the D genome (Linares et al., 1992). The species with A genome have symmetrical chromosomes with low heterochromatin content, whereas those with C genome have asymmetrical heterochromatic chromosomes (Fominaya et al., 1988). Failed attempts to distinguish between the A and D genomes may be an indication of the possible role of A genome as a donor of both A and D genomes of the hexaploid oat. In order to find the role of diploid oat species in the evolution of the hexaploid species, a clear understanding of evolution of various genomes and intergenomic translocations is considered to be significant (Linares et al., 1998).

The cytogenetic map which is a visual representation of chromosomes when stained and examined under a microscope provides valuable information in cytogenetic studies. With the advancement of technology, a high resolution cytogenetic map obtained from Fluorescence *in situ* Hybridization (FISH) has provided important biological information on genome organization and functions. FISH is a molecular cytogenetic technique that can be used to identify and localize the presence or absence of specific DNA sequences on chromosomes. It uses fluorescent probes of desired length and sequence, which hybridize only to the complementary sequences in the chromosomes. The probe is actually a single stranded denatured DNA mixed with a fluorescent dye and it is mixed with the denatured target DNA (combed DNA) for hybridization. The specific tagged sequence can then be visualized using a fluorescence microscope. On the other hand GISH (Genomic *in situ* hybridization) is another molecular cytogenetic technique used to find a genomic relationship among different species or genus. Using this technique chromosomes or genomes from different parents or ancestors can be identified by means of differential hybridization of entire genomic probes.

The highly irregular chromosome pairing in a cross between *A. macroccana* (AACC) and the autotetraploid plant produced by *A. strigosa* Schreb.(A_sA_s) and *A. eriantha* Dur.(C_pC_p) (Legget, 1998) discards the chance that *A. strigosa* and *A. eriantha* participated in the formation of the tetraploid *A. macroccana* (AACC) (Legget, 1998). The low chromosome pairing in a hybrid between *A. strigosa* and *A. insularis* excludes *A. strigosa* as a diploid progenitor of *A. insularis* (Ladizinsky, 1999). A cross between tetraploid *A. abyssinica* and *A. strigosa* can form a triploid (Dilkova *et al*., 2000b). The genome of *Avena longiglumis* is different from the A genome of all other *Avena* species and it is designated as A_l. The total length of the chromosomes of *Avena strigosa* Schreb. is 17 units shorter than that of *Avena longiglumis*, which is equal to the longest arm in the *strigosa* set. This indicates a substantial loss of chromatin material from the *strigosa* group. This may be due to the elimination of acentric fragments due to translocations in the *strigosa* genome rather than a chromatin gain due to duplication in the *Avena longiglumis* genome. The F1 produced from crosses between *Avena longiglumis*, *Avena strigosa* and *Avena hirtula* are sterile due to chromosome incompatibility among themselves. (Rajhathy, 1961).

Avena insularis Ladizinsky was found to be the tetraploid progenitor of the regular oat *Avena sativa* after studying the F1 between these two species. It contains two pairs of satellite chromosomes and one pair of subterminal chromosome more morphologically similar to *Avena magna* than any other tetraploids. However, in *A. magna* three pairs of satellite chromosomes are present. *Avena insularis* Ladizinsky forms pentaploid hybrids with *Avena sativa* but seed set happens only if the *Avena sativa* is used as the female parent; meiosis is irregular in these hybrids. The mean number of chiasmata per cell in the hybrid formed from a cross between *Avena sativa* and *Avena insularis* is higher (88%) than the mean number of chiasmata in hybrids formed from crosses involving *Avena sativa* with other tetraploids such as *Avena magna* (75%), *Avena murphyi* (62%) and *Avena barbata* (42%). This suggested a closer resemblance of *Avena insularis* to *Avena sativa* than any other oat species (Ladizinsky, 1998).

Zhou *et al*. (1999) suggested *Avena sterilis* L. as the putative progenitor of the cultivated hexaploid oat *Avena sativa* L. and *Avena byzantina* C. Koch. based on the cluster analysis of 248 polymorphic RAPD (Random Amplified Polymorphic DNA) markers and the studies of 7C-17 intergenomic chromosomal translocation among the accessions of these three species. They also proposed a dichotomy or divergence in speciation during the period of domestication that leads to the formation of both *Avena sativa* L. and *Avena sterilis* L.

Avena barbarata was introduced to California from Spain during the seventeenth and eighteenth centuries. The gene pool present in California is similar to the present day Spanish gene pool based on allelic and single-locus genotype composition, but different on a multilocus genotype basis. (Garcia et al., 1989).

Avena agardiriana Baum et. Fedak is a recently discovered tetraploid (2n= 4x = 28). Its C-banding pattern revealed that it shows resemblance to A/B/D genomic groups of chromosomes of *Avena* species rather than the C genomic group (Jellen and Gill, 1996). *Avena strigosa, Avena wiestii* and *Avena hirtula* are karyotypically similar with two metacentric, two submetacentric, one subacrocentric, and two morphologically different satellite (SAT) chromosomes (Badaeva et al., 2005).

Pairing inhibitor genes

In allopolyploids such as wheat (*Triticum aestivum*) diploid-like pairing occurs during meiotic division. This means that homologous chromosomes pair as bivalents rather than homoeologous chromosomes pairing as multivalent. Homoeologous are partially homologous chromosomes originating from different ancestral genomic groups.

This mechanism is governed by the gene *Ph1,* which is a *trans*-acting gene affecting centromere-microtubules interaction (Vega and Feldman, 1998). This kind of genetic control of meiotic pairing is observed in other allopolyploids as well, e.g., *Avena sativa* L. and *Festuca arundinacea* (tall fescue) (Jenczewski and Alix, 2004). In wheat another gene (*Ph2*) controlling the pairing of homoeologous chromosomes is present on chromosome 3D, but it is a rather weaker suppresser than *Ph1* (Mello-Sampayo, 1971).

Hexaploid oat has three genomes that might have derived from different ancestral genomes (or three sets of seven chromosome pairs). Each chromosome is capable of pairing with five other related chromosomes, one homologue and four homoeologous, during meiosis, but actually pairs only with the homologous chromosome. This pairing behavior is controlled by pairing control genes (PCG). It is hypothesized that the grass genome might have originated from an ancestor with holocentric chromosomes. Holocentric chromosomes have diffuse centromeres and possess multiple cites for microtubule attachment (Moore, 1998). Newly formed allopolyploids may display homoeologous pairing with multivalent formation resulting in reduced fertility, but as generations advance, the formation of multivalent decreases sharply due to natural selection of plants having more pairing control genes (Jenczewski and Alix, 2004). *Avena barbata* Pott ex Link formed from the polyploidization of Avena *hirtula* Lag. and *Avena wiestii* Steud. complex showing bivalent pairing during meiosis. This shows that the homeologous pairing is suppressed in this tetraploid (Allard *et al*., 1993). Thomas and Rajhathy (1966) observed that initial pairing of chromosomes in an F_2 population of a cross between *Avena abyssinica* Hochst. and *Avena barbarata* took place at early prophase, but desynapsis occurred and was associated with a high incidence of univalents at Metaphase I. They suggested the role of a single recessive gene *ds2* for this pairing control.

Molecular Markers

Even though different plant species are morphologically different, they might have arisen from a common ancestor during the course of evolution. The ubiquitous grass family (Poaceae) is one of the most studied plant groups at all aspects from morphological to molecular level. This family is further divided into six or seven subfamilies with about 40 tribes and 600 to 700 genera (Mathews *et al*., 2000). In order to classify the vast number of grasses, earlier scientists employed the classical approach of studying the morphology of flowering parts and the plant as a whole. Most of the recent studies on grass phylogeny are based on data from chloroplast genomes and a few from the information based on the data from nuclear genomes. The phylogenetic analysis of data obtained from the partial phytochrome B nuclear DNA sequences (nuclear PHYB) is a modern technique in phylogenetic studies (Mathews *et al*., 2000).

The genome co-linearity or synteny among different species is the basis of comparative mapping. Closely related species show convergence in genome structure, whereas distant ones show greater divergence. In a study conducted at Cornell University comparing the oat genome with Triticeae species, rice and maize genomes revealed the conservation of certain regions of homologous segments among these groups *(Deynze et al*., 1995). The integrated grass genome map consists of species of six different tribes and three different subfamilies: viz. Bambusoideae (rice etc), Pooideae (oats and Triticeae) and Panicoideae (Devos and Gale, 1997). In an oat linkage group 134 DNA sequences were assigned to 10 chromosomes associated with the syntenic group using nullisomics of hexaploid oats (Kianian *et al*., 1997).

A genetic linkage map is a useful tool for the localization of qualitative and quantitative traits loci for marker assisted selection and breeding for agronomically important traits. Even though different linkage groups are present in oat species, the correspondence of individual *A. strigosa* chromosomes to these linkage groups or loci is still unknown. Genetic linkage can be explained as the association of genes located on the same chromosomes. In a linkage map, map distance is a statistical estimate of the crossover and physical distance is the number of DNA pairs between two linked genes. Aneuploids are used for linkage mapping because of the ease of assigning the gene families, monomorphic Restriction fragment length polymorphism (RFLP) sequences, and oat linkage groups to chromosomes. Aneuploids can be produced by various techniques such as X-ray irradiation at doses varying from 75r to 600r (Andrews and McGinnis, 1964).

The direct approach for assigning linkage groups to individual chromosomes would be to hybridize genetically mapped RFLP probes to chromosomes. An alternative approach is to directly amplify sequence-tagged site (STS) markers, derived from genetically mapped RFLP clones in the DNA of microdissected chromosomes. Based on the two or four RFLP-derived STS markers, *A. strigosa* chromosomes 2 and 3 were found to be homologous to the oat linkage groups C and E, respectively. Chromosome 7 corresponds to linkage group F and was most probably involved in an *A. strigosa*-specific chromosomal translocation relative to the diploid species *A. atlantica* and *A. hirtula* (Loarce et al*.*, 2002). Based on Amplified fragment length polymorphism (AFLP) and

RAPD dendrograms, *A. prostrata* and *A. longiglumis* have the most divergent A genomes and are considered to be the most ancient, while the A_s (*A. strigosa*) genome is the most recently evolved (Drossou, 2004).

Zhu and Kaeppler (2003) compared the hexaploid oat linkage map produced from a mapping population of a recombinant inbred line derived from the F5:6 lines of a cross 'Ogle/MAM17-5' (OM) to the previous linkage map produced from a mapping population of 'Kanota/Oagle' (Wight et al., 2003). They identified three putative homoeologous groups 5 cM or longer out of the 28 linkage group determined. Group one includes OM7, OM8 and OM18, group two includes OM2 and OM23, and group 3 includes OM13 and OM16. Nine linkage groups identified were homologous to the linkage groups in the KO map. The relevance of the MO mapping population is that it is segregating for a number of agronomically important traits (Zhu and Kaeppler, 2003).

Breeding Programs

Even though black oat has these promising features as a cover crop it has some drawbacks that need to be corrected by the implementation of a proper breeding program. Biomass production of black oat is reduced compared to rye if low night temperature persist for long periods of time (Reeves et al., 2005). This is due to freezing injury. Even though there are six oat-breeding programs active in South America there is no true breeding program in Brazil for *A. strigosa* (Federizzi, 2004). Cold hardiness of black oat needs to be improved through breeding or selection (Schomberg et al., 1995; Bauer 1999). Black oat (*A. strigosa* cv. Saia) was found to be susceptible to root knot nematode (*Meloidogyne marylandi*, *M. javanica* and *M. incognita* in a study in Israel), while *A.*

sativa was resistant or a non-host (Oka et al*.,* 2003). This indicates that we need to concentrate on this aspect also in a breeding program. However another study conducted in Brazil, using five cultivars of black oat demonstrated that all of them are resistant to *Meloidogyne incognita* and *M. paranaensis.* (Moritz et al., 2003). In southeastern USA nowadays reniform nematode (*Rotylenchulus reniformis* Linford & Oliveira) is more problematic than *Meloidogyne*.

A. strigosa has been used in many oat breeding programs to impart disease resistance to cultivated oats as it is an important source of resistance to crown rust (*Puccinia coronata* f. sp. A.e) (Weibull *et al*., 2005). The crown rust resistance gene is a complex with 9 genes involved (Dilkova et al., 2000; Rayapati et al., 1994). The stem rust (caused by *Puccinia graminis* Pers f.sp *avenae* Erikss. and Henn) resistance gene is also present in *Avena strigosa* strains C.D. 3820 and C.I. 3078. The gene is a single dominant gene (Dyck, 1966). However the hybridization incompatibility of the diploid black oat with the natural hexaploid has been a problem. Successful hybridization between *A. strigosa* cv. Saia (2n = 14) and *A. magna* (2n = 28) and the induction of a hexaploid form using colchicine treatment of the triploid hybrid were reported when *A. strigosa* was used as the female parent. However, this hexaploid failed to retain its barley yellow dwarf virus (BYDV) resistance even though it retained its crown rust resistance (Ladizinsky, 2000). For transferring the desirable traits from a diploid to a hexaploid species, the first step is a cross between diploid Avena *strigosa* and a tetraploid such as *Avena abyssinica* to form a triploid. Then, the 6x amphiploid is induced by colchicine treatment of the triploid and it will be hybridized with the hexaploid oat to transfer the desired characteristics. C- banded karyotyping can be used to verify the substitution of the desired gene (Dilkova *et al.*, 2000). According to Forsberg "several barriers to inter-specific gene transfer must be overcome to transfer genes for resistance from diploid species such as *A. strigosa* to *A. sativa*" (Forsberg and Shands, 1969).

Based on the preceding literature review it is clear that cover crops are important for conservation practices and that black oat is a suitable cover crop for the Southeastern USA. The only commercially available black oat cultivar in United States is SoilSaver, released in 2002 by USDA-ARS and The Alabama Agricultural Experiment Station. Even though SoilSaver is superior in many traits like maturity and biomass yield than many other accessions, some traits need to be improved. In order to start a breeding program the foremost important thing needed to be done is the evaluation of available germplasm, since without genetic variation selection for superior characters can not be made. There are 120 accessions of black oat accessions available from 'USDA-ARS Small Grains Germplasm Unit' at Aberdeen, Idaho, but a detailed study of this germplasm collection for maturity and morphology needs to be done before starting a breeding program. The objective of my research is the characterization of the entire USDA-GRIN *Avena strigosa* Schreb. germplasm collection based on reproductive maturity and morphological traits.

References

Allard, R. W., P. Garcia, L. E. Saenz-de-Miera, and M. P. de-la-Vega. 1993. Evolution of multilocus genetic structure in *Avena hirtula* and *Avena barbata*. Genetics 135:1125-1139.

Andrade, E., M. Miyazawa, M. A. Pavan, and E. L.de-Oliveira. 2002. Effect of organic matter on manganese solubility. Brazilian Archives of Biology And Technology 45:17 - 20.

Andrews, G. Y., and R. C. McGinnis. 1964. The artificial induction of aneuploids in *Avena*. Can. J. Genet. Cytol. 6:349-356.

Anonymous. Black Oat [Online]. Available by College of Tropical Agriculture and Human Resources,University of hawai'i at Mānoa http://www2.ctahr.hawaii.edu/sustainag/GreenManures/black_oat.asp.

Anonymous. Flora Europaea [Online]. Available by Royal Botanical Garden Edinburgh http://193.62.154.38/cgi-bin/nph-readbtree.pl/feout?FAMILY_XREF=&GENUS_XREF=Avena&SPECIES_XREF=strigosa&TAXON_NAME_XREF=&RANK= (posted October 25, 2005).

Anonymous. 2004. Perspective for fodder oats, p. 215-220, *In* J.M.Suttie and S.G.Reyynolds, eds. Fodder oats:a world overview, Vol. 33.

Ashford, D. L., and D. W. Reeves. 2003. Use of a mechanical roller-crimper as an alternative kill method for cover crops. American Journal of Alternative Agriculture 18(1):37-45.

Badaeva, E. D., I. G. Loskutov, O. Y. Shelukhina, and V. A. Pukhalsky. 2005. Cytogenetic analysis of diploid *Avena* L. species containing the *As* genome. Russian Journal of Genetics 41:1428-1433.

Barberi, P., and M. Mazzoncini. 2001. Changes in weed community composition as influenced by cover crop and management system in continuous corn. Weed Science 49:491-499.

Bauer, P. J., and D. W. Reeves. 1999. A comparison of winter cereal species and planting dates as residue cover for cotton grown with conservation tillage. Crop Science 39:1824-1830.

Baum, B. R. 1977. Oats: wild and cultivated: A monograph of the genus *Avena* L.(Poaceae), p. 185-193, Vol. 14. Canada department of agriculture, Research Branch,Ontario, Canada.

Caamal-Maldonado, J. A., J. J. Jime´nez-Osornio, A. Torres-Barragan, and A. L. Anaya. 2001. The use of allelopathic legume cover and mulch species for weed control in cropping systems. Agron. J. 93:27-36.

Carpenter, S. R., D.Ludwig, and W.A.Brock. 1999. Management of eutrophication for lakes subject to potentially irreversible change. Ecological applications 9(3):751-771.

Ceretta, C. A., C. J. Basso, J. Diekow, C. Aita, P. S. Pavinato, F. C. B. Vieira*, et al.* 2002. Nitrogen fertilizer split-application for corn in no-till succession to black oats. Scientia Agricola 59:549-554.

Chassot, A., P. Stamp, and W. Richner. 2001. Root distribution and morphology of maize seedlings as affected by tillage and fertilizer placement. Plant and Soil 231:123-135.

Chikoye, D., S. Schulz, and F. Ekeleme. 2004. Evaluation of integrated weed management practices for maize in the northern Guinea savanna of Nigeria. Crop Protection 23:895-900.

Coffman, F. A. 1977. Origin and History, p. 15-40, *In* F. A. Coffman, ed. Oats and Oat Improvement. American Society of Agronomy, Madison.

Cousens, R. D., A. G. Barnett, and G. C. Barry. 2003. Dynamics of competition between wheat and oat. I. Effects of changing the timing of phenological events. Agronomy Journal. 95:1295-1304.

Devos, K. M., and M. D. Gale. 1997. Comparative genetics in the grasses. Plant Molecular Biology 35:3-15.

Dilkova, M., E. N. Jellen, and R. A. Forsberg. 2000. C-banded karyotypes and meiotic abnormalities in germplasm derived from interploidy crosses in *Avena*. Euphytica 111:175-184.

Duke, S. O., B. E.Scheffler, F. E. Dayan, L. A.Weston, and E. Ota. 2001. Strategies for Using Transgenes to Produce Allelopathic Crops. Weed Technology 15:826–834.

Dyck, P. L. 1966. Inheritance of stem rust resistance and other characteristics in diploid oats, *Avena strigosa*. Can. J. Genet. Cytol. 8:444-450.

Fabijanski, S., G. Fedak, K. Armstrong, and I. Altosaar. 1990. A repeated sequence probe for the C genome in *Avena* (Oats). Theor. Appl. Genet. 79:1-7.

Federizzi, L. C., and C. M. Mundstock. 2004. Fodder oats: An overview for South America, p. 37-51, *In* J.M.Suttie and S.G.Reyynolds, eds. Fodder oats:A world overview, Vol. 33. Food and Agriculture organizations of the United Nations.

Fominaya, A., P. Vega, and E. Ferrer. 1988. Giemsa C-Banded Karyotypes of *Avena* Species. Genome 30:627-632.

Franchini, J. C., M. A. Pavan, and M. Miyazawa. 2004. Redistribution of Phosphorus in Soil Through Cover Crop Roots. Brazilian Archives of Biology and Technology. 47:381-386.

Garcia, L. C., C. G. Raetano, A. Justino, and C. Purissimo. 2004. Black-oats (*Avena strigosa* Schreb) control with contact burndown herbicide applied at different carrier volumes, with and without air assistance at sleeve boom sprayer. [Portuguese]. Sociedade Brasileira de Engenharia Agricola (SBEA), Jaboticabal, Brazil 3:758-763.

Hermawan, B., and A. Bomke. 1997. Effects of winter cover crops and successive spring tillage on soil aggregation. Soil & Tillage Research 44:109-120(12).

Jellen, E. N., and B. S. Gill. 1996. C-banding variation in the Moroccan oat species *Avena agadiriana* (2n=4x=28). Theoretical and Applied Genetics 92:726-732.

Jenczewski, E., and K. Alix. 2004. From Diploids to Allopolyploids: The Emergence of Efficient Pairing Control Genes in Plants. Critical Reviews in Plant Sciences 23(1):21-45.

Kabir, Z., and R. T. Koide. 2000. The effect of dandelion or a cover crop on mycorrhiza inoculum potential, soil aggregation and yield of maize. Agriculture, Ecosystems and Environment 78:167-174.

Katsura, M. 2004. Fodder oats in Japan, p. 145-152, *In* J.M.Suttie and S.G.Reynolds, eds. Fodder oats: a world overview, Vol. 33. Food and Agriculture organizations of the United Nations.

Kellogg, E. A. 1998. Relationships of cereal crops and other grasses. Proc. Natl. Acad. Sci.USA. 95:2005-2010.

Kianian, S. F., B. C. Wu, S. L. Fox, H. W. Rines, and R. L. Phillips. 1997. Aneuploid marker assignment in hexaploid oat with the C genome as a reference for determining remnant homoeology. Genome 40(3):386-96.

Ladizinsky, G. 1998. A new species of *Avena* from Sicily, possibly the tetraploid progenitor of hexaploid oats. Genetic Resources and Crop Evolution 45:263-269.

Ladizinsky, G. 1999. Cytogenetic relationships between *Avena insularis* (2n=28) and both *A. strigosa* (2n=14) and *A. murphyi* (2n=28). Genetic Resources and Crop Evolution 46:501-504.

Ladizinsky, G. 2000. A synthetic hexaploid(2n=42) oat from the cross of *Avena strigosa* (2n=14) and domesticated *A.magna* (2n=28). Euphytica 116:231-235.

Legget, J. M. 1992. Classification and speciation in *Avena*. Oat Science and Technology-Agronomy monograph 33:29-51.

Legget, J. M. 1998. Chromasome and genomic relationships between the diploid species *Avena strigosa*, *A.eriantha* and tetraploid *A.maroccana*. Heredity 80:361-363.

Leggett, J. M., and G. S. Markhand. 1995. The genomic identification of some monosomics of *Avena sativa* L. cv. Sun II using genomic in situ hybridization. Genome 38:747-751.

Linares, C., E. Ferrer, and A. Fominaya. 1998. Discrimination of the closely related A and D genomes of the hexaploid oat *Avena sativa* L. Proceedings of National Academy of Science. USA 95:2450–12455.

Linares, C., C. Vega, E. Ferrer, and A. Fominaya. 1992. Identification of C-banded chromosomes in meiosis and the analysis of nucleolar activity in *Avena byzantina* C. Koch cv 'Kanota'. Theoretical and Applied Genetics 83:650-654.

Liua, A., B.L.Mab, and A. A. Bomkec. 2005. Effects of Cover Crops on Soil Aggregate Stability, Total Organic Carbon, and Polysaccharides. Soil Sci. Soc. Am. J. 69:2041-2048.

Loarce, Y., E. Ferrer, G. Kunzel, and A. Fominaya. 2002. Assignment of oat linkage groups to microdissected *Avena strigosa* chromosomes. Theoretical & Applied Genetics 104:1011-1016.

Lowe, K. F., and T. M. Bowdler. 1998. Effects of height and frequecy of defoliation on the productivity of irrigated oats (*Avena strigosa* cv.Saia) and perennial ryegrass (*Lolium perenne* cv. Kangaroo Valley), grown alone or with barrel medic (*Medicago truncatula* cv.Jemalong). Australian Journal of Experimental Agriculture, 28:57-67.

Magness, J. R., G. M. Markle, and C. C. Compton. 1971. Food and feed crops of the United States [Online] http://www.hort.purdue.edu/newcrop/Crops/Oats.html.

Martinelli, J. A. 2004. Oat diseases and their control, p. 197-214, *In* J.M.Suttie and S.G.Reyynolds, eds. Fodder oats: a world overview, Vol. 33.

Mask, P. L., D. W. Reeves, E. v. Santen, G. L. Mullins, and G. E. Aksland. 1993. White Lupin: An Alternate Crop for the Southern Coastal Plain. New crops:277-278.

Mathews, S., R. C. Tsai, and E. A. Kellogg. 2000. Phylogenetic structure in the grass family (Poaceae): evidence from the nuclear gene phytochrome B. Am. J. Bot. 87: 96-107.

Mello-Sampayo, T. 1971. Genetic regulation of meiotic chromosome pairing by chromosome 3D of *Triticum aestivum*. Nat New Biol 230:22-23.

Mitchell, J., D. Peters, and C. Shennan. 1999. Changes in soil water storage in winter fallowed and cover cropped soils. J. Sustainable Agric. 15:19-33.

Moore, G. 1998. To pair or not to pair: chromosome pairing and evolution. Current Opinion in Plant Biology 1:116-122.

Moritz, M. P., G. Simão, and R. G. Carneiro. 2003. Reaction of oat to *Meloidogyne incognita* races 1 and 3, and to *Meloidogyne paranaensis*. Nematologia Brasileira 27(2):207-210.

Murphy, J. P., and L.A.Hoeffman. 1992. The origin, history and production of Oat. Oat science and technology-Agronomy Monograph 33:1-28.

Neumann, G., A. Massonneau, E. Martinoia, and V. Romheld. 1999. Physiological adaptations to phosphorus deficiency during proteoid root development in white lupin. Planta 208:373-382.

Nishihara, E., M. M. Parvez, H. Araya, S. Kawashima, and Y. Fujii. 2005. L-3-(3,4-Dihydroxyphenyl) alanine (L-DOPA), an allelochemical exuded from velvetbean (*Mucuna pruriens*) roots. Plant Growth Regulation 45:113–120.

Noffsinger, S. L., D. E. Starner, and E. v. Santen. 1998. Planting date and seeding rate effects on white lupin yield in Alabama and Virginia. Journal of Production Agriculture 11:100-107.

O'Mara, J. G. 1961. Cytogenetics-The fatuoid and steriloid mutations, p. 112-124, *In* F. A.Coffman, ed. Oats and Oat improvement. Agron. Monogr. 8. ASA, Madison, WI.

Odhiambo, J. J. O., and A. A. Bomke. 2001. Grass and Legume Cover Crop Effects on Dry Matter and Nitrogen Accumulation. Agron. J. 93:299-307.

Ohm, H. W., and G. Shaner. 1992. Breeding Oat for Resistance to Diseases. Oat science and technology-Agronomy Monograph 33:657-698.

Oka, Y., G. Karssen, and M. Mordechai. 2003. Identification, host range and infection process of *Meloidogyne marylandi* from turf grass in Israel. Nematology 5(5): 727-734.

Patterson, M. G., D. W. Reeves, and B. E. Gamble. 1996. Weed management with black oat (*Avena strigosa*) in no-till cotton, p. 1557-1558 *IN* Beltwide Cotton Conf.,January 8-12, 1996 Nashville, TN. National Cotton Council.

Price, A. J., D. W. Reeves, and M. G. Patterson. 2006. Evaluation of weed control provided by three winter cereals in conservation-tillage soybean. Renewable Agriculture and Food Systems 21(3):159-164(6).

Rajhathy, T. 1961. Chromosomal differentiation and speciation in diploid *Avena*. Can. J. Genet. Cytol. 3:372-377.

Rayapati, P. J., J. W. Gregory, M. Lee, and R. P. Wise. 1994. A linkage map of diploid *Avena* based on RFLP loci and a locus conferring resistance to nine isolates of *Puccinia coronata* var. *avenae*. Theoretical and Applied Genetics 89:831-837.

Reeves, D. W., A. J. Price, and M. G. Patterson. 2005. Evaluation of three winter cereals for weed control in conservation-tillage nontransgenic cotton. Weed Technology 19:731-736.

Rosolem CA, C. J., Foloni JSS. 2005. Leaching of nitrate and ammonium from cover crop straws as affected by rainfall. Communications in Soil Science and Plant Analysis 36 (7-8):819-831.

Roth, C. M., J. P. Shroyer, and G. M. Paulsen. 2000. Allelopathy of Sorghum on Wheat under Several Tillage Systems. Agron. J. 92:855-860.

Saini, M., A. J. Price, and E. Van Santen. 2005. Winter Weed Suppression By Winter Cover Crops In A Conservation-Tillage Corn And Cotton Rotation, p. 124-128. In proceedins of the southern conservation tillage systems conferencec, Vol. June 27-29, 2005, Florence, South Carolina.

Sainju, U. M., and B. P. Singh. 2001. Tillage, Cover Crop, and Kill-Planting Date Effects on Corn Yield and Soil Nitrogen. Agron. J. 93:878-886.

Sainju, U. M., B. P. Singh, and W. F. Whitehead. 1998. Cover Crop Root Distribution and Its Effects on Soil Nitrogen Cycling. Agron. J. 90:511–518.

Schomberg, H. H., D. M. Endale, A. Calegari, R. Peixoto, M. Miyazawa, and M. L. Cabrera. 2005. Influence of cover crops on potential nitrogen availability to succeeding crops in a Southern Piedmont soil. Biology and Fertility of Soils 42:299-307.

Sharpley, A. N., R. W. McDowell, and P. J. A. Kleinman. 2001. Phosphorus loss from land to water: integrating agricultural and environmental management. Plant and Soil 237:287-307.

Silburn, D. M., B. W. Simpson, and P. A. Hargreaves. 2002. Management practices for control of runoff losses from cotton furrows under storm rainfall. II. Transport of pesticides in runoff. Aust. J. Soil Res. 40:21-44.

Staver, K., and R. Brinsfield. 1998. Using cereal grain winter cover crops to reduce groundwater nitrate contamination in the mid-Atlantic coastal plain. J. Soil Water Conserv. 53(3):230-240.

Terra, J. A., J. N. Shaw, D. W. Reeves, R. L. Raper, E. van Santen, E. B. Schwab*, et al.* 2005. Soil Management and Landscape Variability Affects Field-Scale Cotton Productivity. Soil Sci. Soc.Am.J. 70:98-107.

Tesar, M. B. 1984. Physiological basis of crop growth and development. American Society of Agronomy Crop Science Society of America, Foundations for modern crop science series. 13:341.

Thomas, H. 1992. Cytogenetics of *Avena*, p. 473-507, *In* H.G.Marshall and M.E.Sorrells, eds. Oat Science and Technology-Agronomy monograph, Vol. 33. American Society of Agronomy, Madison, WI, U.S.A.

Thomas, H., and T. Rajhathy. 1966. A gene for desynapsis and aneuploidy in tetraploid *Avena*. Can. J. Genet. Cytol. 8:506-515.

Van Deynze, A. E., J. C. Nelson, L. S. O'Donoughue, S. N. Ahn, W. Siripoonwiwat, S. E. Harrington*, et al.* 1995. Comparative mapping in grasses. Oat relationships. Mol Gen Genet 249(3):349-356.

Vega, J. M., and M. Feldman. 1998. Effect of the Pairing Gene *Ph1* on Centromere Misdivision in Common Wheat. Genetics 148:1285-1294.

Weibull, J., L. Lyng, J. Bojensen, and V. Rasomavicius. 2005. *Avena strigosa* in Denmark and Lithuania: Prospects for in situ conservation. Plant Genetic Resources Newsletter 131:1 - 6.

Weinert, T. L., W. L.Pan, M. R. Moneymaker, G. S.Santo, and R. G.Stevens. 2002. Nitrogen recycling by nonleguminous winter cover crops to reduced leaching in potato rotations. Agron. J. 943:365-372.

Wight, C. P., N. A. Tinker, S. F. Kianian, M. E. Sorrells, L. S. O'Donoughue, D. L. Hoffman*, et al.* 2003. A molecular marker map in 'Kanota' × 'Ogle' hexaploid oat (*Avena* spp.) enhanced by additional markers and a robust framework. Genome 46:28-47.

Zhou, X., E. N. Jellen, and J. P. Murphy. 1999. Progenitor Germplasm of Domesticated Hexaploid Oat. Crop Sci. 39:1208-1214.

II. MORPHOLOGY AND MATURITY OF BLACK OAT (*AVENA STRIGOSA* SCHREB.)

Abstract

Black oat (*Avena strigosa* Schreb.) is a potential cover crop for the southeastern United States. We evaluated the entire USDA-ARS Germplasm collection for identifying the accessions suitable for cover crop purpose in southeastern US conditions. One hundred four accessions were planted at Shorter, Alabama on a Norfolk sandy loam (coarse-loamy, siliceous, subactive, thermic, Plinthic, Paleudults) during 2003-04 and 2004-05. Agronomic traits and maturity were studied. Relevant traits that can differentiate the accessions identified after the forward stepwise selection procedure (STEPDISC) were used for canonical discriminant analysis (CDA). The first four canonical discriminate variates (CAN) had Eigenvalues ≥ 1 and are responsible for 84 % of the total variation among the entire population for both years. Plotting CAN1 vs. CAN2 differentiated Accession CIav 9015 from all other accessions in this analysis. We speculate that accession CIav 9015 may not be *Avena strigosa* Schreb., the species under consideration, but some other species of *Avena*. Cytogenetic and molecular marker study may be needed for a conclusive identification of this accession. CDA also separated four

accessions from Europe and one from Australia to the extreme right of the first quadrant with high positive values for both CAN1 and CAN2 variates. The accessions studied are significantly different based on individual traits among and within countries and continents. South American accessions are with prostrate habit and are suitable for cover crop purpose in the southeastern US. Accessions from Europe and Australia are late maturing and may not be suitable for the southeastern US condition, but may be suitable for the colder parts where winter kill is employed for the termination of the cover crop.

Introduction

Black oat (*Avena strigosa* Schreb.) is a diploid species with A_s A_s genome and a chromosome number of $2n = 2x = 14$ (Baum, 1977; O'Mara, 1961; Thomas, 1992). Originating in the northern parts of Spain and Portugal (Weibull et al., 2005), black oat has spread to different parts of the globe (Fig. 2-1.) (Baum, 1977; Coffman, 1977; Federizzi and Mundstock, 2004; Weibull et al., 2005). Even though different in ploidy, diploid black oat has been used in many hexaploid common oat (*A. sativa* L.) breeding programs as a donor parent for some desirable characters such as crown rust (Dilkova et al., 2000) and stem rust resistance (Dyck, 1966).

Black oat has become an important winter cover crop in subtropical and temperate regions (Suttie and Reynolds, 2004) and is cultivated on more than 3 million hectares in South America (Federizzi and Mundstock, 2004), especially in southern Brazil (Ceretta et al., 2002). Experiments conducted in the southeastern United States revealed its potential to become a major cover crop in that region (Bauer and Reeves, 1999). Black oat has biomass production and nitrogen dynamics comparable to crimson clover (Schomberg et al., 2005). It also has the potential to be grown as a forage and fodder crop and can thrive well with leguminous forage crops (Katsura, 2004; Lowe and Bowdler, 1998; Martinelli, 2004). Cotton lint yield following black oat was higher than that following rye. Black oat has a low C/ N ratio of 34:1 compared to 42:1 for common oat and wheat and 45:1 for rye (Bauer and Reeves, 1999). Thus the availability of nutrients through degradation of plant residues when used as a cover crop will be faster in black oat than other small grain cover crops. Studies in Brazil revealed black oats also has the potential to decrease manganese toxicity in well aerated acidic soils (Andrade et al., 2002).

The only commercially available black oat cultivar in the United States is ‘SoilSaver’, which was released by Auburn University and USDA in 2002. Even though SoilSaver is superior to other black oat accessions for some traits such as maturity and biomass yield (van Santen, unpublished data, 2005), some traits need further improvement. Over 100 black oat accessions are available from the USDA-ARS Small Grains Germplasm Unit at Aberdeen, Idaho, but a detailed study of this collection is needed before accessions can be used in a breeding program. In this paper we examine the agronomic traits of the entire USDA black oat accessions that are important for use as a cover crop and the potential of these accessions for cover crop purposes in the southeastern United States.

Materials and Methods

SoilSaver and 103 *Avena strigosa* Schreb accessions (Table 2-1) obtained from the USDA-ARS National Small Grains Collection Unit at Aberdeen, ID, USA (http://www.ars-grin.gov/cgi-bin/npgs/html/site.pl?NSGC) were used for the study. Two seeds per cone-tainer (Ray Leach Cone-tainers, Washougal, WA; 2.5 cm diameter by 12 cm depth) were planted in 1:1 sand and PRO-MIX medium (Sun Gro Horticulture Distribution Inc., Bellevue, WA) at the Auburn University Plant Sciences Research Center (PSRC) greenhouse. Approximately 2 weeks after seeding, seedlings were thinned to one per cone-tainer. The seedlings were transplanted on 90 x 90 cm centers at the Field Crops Unit of the E.V. Smith Research Center, Shorter, Alabama (32°24.5'N, 85°57'W) on October 31, 2003, and November 16, 2004. The soil type of the field is a Norfolk sandy loam (coarse-loamy, siliceous, subactive, thermic, plinthic Paleudult). The experimental design was an RCBD with three replicates. Six seedlings were transplanted per year x block x entry combination. Nitrogen was applied during the 3rd week of February of each year at a rate of 36 kg ha^{-1}. Occasional manual and mechanical weeding was done.

Response variables

Twelve traits were measured in this study *viz.* heading date, tiller angle, tiller diameter, tiller length, tiller node number, tiller number, panicle length, panicle node number, flag leaf length and width, seed yield and average seed mass (Table 2-2). Heading date was defined as the day of the year when the first tiller of a given plant had emerged 75% of its length from its leaf sheath. When all the plants in an accession were headed out, the outermost tiller from each plant was removed and observations taken for length and width of flag leaf, tiller and panicle length, tiller and panicle node number and tiller diameter.

The freezing temperature experienced in January 2005 killed many plants in the 2004-05 study, and this resulted in a delayed heading and harvesting dates and lower seed yield. In 2003- 2004 study plants were harvested from mid May to early June, whereas in the 2004-05 study plants were harvested from 10 to 20 June. Tiller angle was measured on one tiller per plant before harvesting using a protractor attached to a wooden ruler. Each plant was harvested separately, dried to reduce the moisture to < 10%, and stored in a paper bag until further processing. The tiller number per plant was counted and tillers were threshed using a belt thresher and cleaned with South Dakota Blower (Seedburo Equipment Co., Chicago, IL) and meshed sieves of different sizes. Total seed yield per plant was determined from cleaned seed and 1000 seed mass from a sample of 50 seeds per plant.

Statistical Analysis

Mixed model methodology as implemented in PROC MIXED of SAS® was used to analyze the data because of observations missing at random. Since the data are not balanced, instead of using simple arithmetic mean, there is the need to use adjusted means (least square means) for optimal representation. The method for variance component estimation is also different for unbalanced data than a balanced one where we can use ANOVA for estimating the variance of the random variable by invoking the Type3 option of PROC MIXED (http://support.sas.com/onlinedoc/913/docMainpage.jsp; verified 9th February 2007); instead in an unbalanced data we need to use "Restricted Maximum Likelihood" (REML) method of variance estimation. The Kenward-Roger method was used for the estimation of degrees of freedom.

For each of the 12 response variables (Table 2-2) we calculated year x accession least squares interaction means listed in Appendix 1.Block within year was the only random effect in the model. Year, accession, and the year x accession interaction were treated as fixed effects. These interaction means were then used in discriminant analysis to investigate multivariate differences among accessions. As a first step PROC STEPDISC (SAS Institute, 1999) procedure was used for stepwise forward selection of quantitative variables discriminating among accessions. This procedure eliminated tiller number and seed yield from other response variables since they had the least canonical correlation among the 12 response variables studied. The 10 selected variables were further analyzed by canonical discriminant analysis (CDA) using PROC CANDISC (SAS Institute, 1999) with accession as class variable.

Unlike fixed and pseudo-random models, where one design matrix is used for the entire model, mixed models use two design matrices say X to describe the fixed effects in the model, and Z to describe the random effects in the model. The fixed effects design matrix X has dimension n * p, where n is the number of observations in the data set and p is the number of fixed effect parameters in the model and Z has dimension n * q, where q is the number of random effect coefficients in the model. In the mixed model analysis, block nested within year was taken as the random factor and interaction means of accession x year were used for further analysis. The analyses of individual traits were based on loadings from CDA.

Results and Discussion

The underlying assumptions of ANOVA are (1) normality of distribution of data within a group with mean μ and standard deviation σ, i.e., the data should be symmetrically distributed. A histogram is a good indicator to check this assumption; (2) homogeneity of variances, which assumes that the variances in different groups of variables are similar. The box and whisker plot can provide a visual estimation of the homogeneity of variance of observations within a group; and (3) independence of observations. The SAS® GLIMMIX procedure (http://support.sas.com/rnd/app/papers/glimmix.pdf; verified February 7, 2007) was used to evaluate these assumptions for all response variables. For each response variable this procedure creates a graph of studentized residuals with four panels: (1) residuals vs. linear predictor, (2) histogram, (3) quantile-quantile plots, and (4) box and whisker plots.

A residual is the difference between the observed value of the variable (Y_i) and the predicted value of the variable $\hat{Y}_i$. Because the variances of the residuals differ, even though the variances of the true errors are equal to each other, it is necessary to do the studentization of the residuals. When the residual is adjusted by dividing it with the standard deviation we call it as a studentized residual.

$\text{Studentized residual} = \frac{\hat{\varepsilon}_i}{\hat{\sigma}\sqrt{1-h_{ii}}}$, where h_{ii} is the ‘leverage’ (a measure of the influence of the i^{th} observation in the matrix) ranges from 0 to 1. The leverage helps to identify the influential observation. Studentized residuals will approximate a normal distribution with mean 0 and variance 1 when residual degrees of freedom for a model get large. The studentization of residuals helped to detect the outliers in each response variable.

Heading date data were long tailed with some extreme values. The heading dates were calculated as the interval between the date of transplanting of the seedling to the field and the date 75% of the panicle had emerged from the leaf sheath. The tiller angle and tiller diameter were normally distributed with few outliers. The tiller length data was distributed within a narrow range with few extreme values. The panicle length and panicle node numbers were normally distributed, but the panicle node number had a narrow distribution. The seed yield residual plot was funnel shaped so that one must assume some kind of trend in the data. The seed yield was much higher in year 2003-04 than 2004-05, the result of the freezing injury experienced in January 2005. The average seed mass is distributed in a very narrow range with some extreme values.

All phenotypic response traits measured had higher values for the year 2003 than 2004 except for the tiller node number, panicle node number and the tiller angle (Table 2-3). The maximum tiller angle remained the same for two years. The average and maximum heading date were more for the 2nd year of the study, likely due to the fact that the plants showed temporary dormancy in growth after exposure to the freezing temperature of January 2005. All other growth parameters like tiller diameter, length, panicle length, flag leaf length and flag leaf width were affected as well by the low temperature but seed yield and seed mass were most affected by freezing injury in 2004-05.

Multivariate analysis

The first four variates from the canonical discriminant analysis all had Eigenvalues ≥1 and were responsible for 84% of the total variation in the entire population (Table 2-4). Heading date (r = 0.72) and tiller node number (r = 0.78) had the highest correlation with CAN 1 and tiller length (r = 0.54), tiller diameter (r = 0.55) and leaf length(r = -0.64) with CAN 2. Tiller angle (r = 0.54) and panicle length (r = -0.59) had highest correlation with CAN3 and tiller angle (r = 0.47), panicle node number (r = 0.59) and leaf width (r = 0.77) with CAN4.

Accession CIav 9015 from Canada was clearly different from all other accessions in this analysis (Fig. 2-2). It is characterized by an extreme early heading date, short tillers with few nodes, yet flag leaves that are longer than most accessions evaluated (Appendix 1). This accession may in fact not belong to *A. strigosa*, the species under consideration, but to another member of the genus *Avena*. Cytogenetic and molecular studies may be needed to confirm the identity of the accession CIav 9015. Because of the large difference caused by a single accession, the relationship among the remaining 103 accessions is severely compressed (Fig. 2-2).

Plotting CAN1 vs. CAN2, separated five accessions grouped together to the first quadrant of the graph with all positive values for CAN1 (tiller node number and heading date) and both positive and negative values for CAN2 (tiller diameter, tiller length and flag leaf length).

While plotting CAN3 vs. CAN4, the separation of accession CIav 9015 is not prominent as in CAN1 vs. CAN2, even though the accession is distinct from all other North American accessions. The five accessions that grouped together in the previous plotting of CAN1 vs. CAN2 are dispersed in second and fourth quadrants while plotting CAN3 vs. CAN4. However the accession PI 306419 from Romania is quite distinct with high positive values for CAN3. This accession is most erect (73^{o}) with a short panicle and high tiller node number. This accession is among the ones that headed very late.

Analysis of individual traits

A variance analysis of the traits identified by canonical discriminant analysis as contributing significantly to the differences among accessions indicated that there were significant differences among continents, countries within continents, and accessions within countries (Table 2-5). For the user searching for suitable accession the practical question arises where to look for such accessions. As indicated earlier, heading date and the number of tiller nodes were traits highly correlated with canonical variate 1 (Table 2-4, Fig. 2-2). As a group, accessions from Australia and Europe matured significantly later than accessions from the Mid-East and North America although individual accessions within geographic region vary greatly in heading date (Table 2-5). Some accessions from Australia and Europe headed very late, in fact too late to be useful for cover crop purposes in the southeastern USA. South American accessions on the average did not differ significantly from Australian and European accessions. Except for accession that headed before the January 2005 freeze (e.g., accession CIav 9015 from Canada) heading date among the accessions was delayed in the second year. For both years heading date was latest for accessions from Australia (data not shown). Heading date has the narrowest and widest range among the accessions from Australia and North America, respectively.

Tiller node number, the second trait with a high correlation to CAN1, was consistent among the accessions from different continents. Accessions from Australia and Europe had higher tiller node numbers, consistent with their later maturity (Table 2-6).

There were no significant differences in tiller node number among the Middle East and the Americas and between North and South America.

Tiller length, tiller diameter, and leaf length were the traits with the highest correlation with canonical variate 2 (Fig. 2-2, Table 2-4). The significance of differences among continents for tiller length (Table 2-7) mirrored those observed for heading date (Table 2-6). The tallest accession came from Australia (PI 83720) and the shortest from North America (CIav 9015). These are also the accessions with the latest and earliest heading date, respectively. The largest range in tiller length was observed among accessions from North America (Table 2-7). Based on tiller length, accessions from North and South Americas were significantly different from that of Mid-East and Europe. For tiller diameter, accessions from Australia were again significantly different from accessions from all other continents. Because of accessions CIav 9015, North America had the largest among accession difference for tiller diameter. The same accession also had the longest leaves, which were 18% (3.6 cm) longer than the leaves of the accession with the second-longest leaves. The trait means discussed thus far CIav 9015 underscore the uniqueness of this accession within the collection evaluated.

Tiller angle (deviation from horizontal) and panicle length had the highest correlation ($r = 0.54$ and -0.59, respectively) with CAN3 (Table 2-4). Tiller angle was fairly consistent between the two years. As a group, South American accessions had the most prostrate growth habit (Table 2-8), although PI 401793 from Spain had the least tiller angle among all accessions studied (data not shown). Tiller angle varied widely within European (50˚), North American (40˚), and South American accessions (45˚). Within country variation for tiller angle among accessions was quite narrow for Brazil and Uruguay with most accessions being quite prostrate (data not shown). This may simply reflect the fact that black oat is primarily used as a cover crop in those countries. Selection for cover crop purposes would tend to favor those accession that exhibit potential to suppress weeds by denying them access to light. Tiller angle among accessions from North America was significantly different from South America. North American accessions as a group also had the largest range among accessions for panicle length (Table 2-8). Based on panicle length accessions from South America is significantly different from Europe and North America.

Panicle node number and leaf width were the discriminating traits most important for CAN4 (Table 2-4, Fig. 2-2). Again accession CIav 9015 from North America was unique with respect to all accessions studied, having the least number of panicle nodes (data not shown). European accession as a group differed from all other continents except Australia (Table 2-9). As a group, Australian accessions had the broadest leaves and were significantly different from all other continents. Mid-eastern accessions not only had the narrowest leaves as a group but also the smallest range among accessions (2.1 mm). The broadest-leaved accession came from Europe (Romania, PI 361912) and the narrowest one is from South America (PI 436108).

Summary and Conclusion

Significant difference can be observed for traits of agronomic importance among and within countries and continents and the reason why these difference exist may be the selection of black oat for different purposes. Late heading European and Australian accessions may not be useful as cover crop in southeastern US conditions, but may be useful in colder parts of the country as winter kill can be used for terminating the crop. Mostly South American accessions are with prostrate habit and are suitable for cover crop purpose in the southeastern US.

The first conclusion that can be drawn from this evaluation is that there is sufficient genetic variation to begin a hybridization and selection program. The second conclusion is that the accession CIav 9015 from Canada may not belong to *A. strigosa* Schreb., the species under consideration, but to another member of the genus *Avena*. Cytogenetics studies may be useful for the conclusive identification of this accession with a doubtful identity. The third conclusion is that some traits like tiller angle are highly heritable. So this evaluation of morphology and maturity is the beginning of future breeding programs and field plot trials of the selected accessions.

References

Andrade, E., M. Miyazawa, M. A. Pavan, and E. L. d. Oliveira. 2002. Effect of organic matter on manganese solubility. Brazilian Archives of Biology And Technology 45:17 - 20.

Bauer, P. J., and D. W. Reeves. 1999. A comparison of winter cereal species and planting dates as residue cover for cotton grown with conservation tillage. Crop Sci. 39:1824-1830.

Baum, B. R. 1977. Oats: wild and cultivated: A monograph of the genus *Avena* L. (Poaceae), p. 185-193, Vol. 14. Canada department of agriculture, Research Branch,Ontario, Canada.

Ceretta, C. A., C. J. Basso, J. Diekow, C. Aita, P. S. Pavinato, F. C. B. Vieira*, et al.* 2002. Nitrogen fertilizer split-application for corn in no-till succession to black oats. Scientia Agricola 59:549-554.

Coffman, F. A. 1977. Origin and History, p. 15-40, *In* F. A. Coffman, ed. Oats and Oat Improvement. American Society of Agronomy, Madison.

Dilkova, M., E. N. Jellen, and R. A. Forsberg. 2000. C-banded karyotypes and meiotic abnormalities in germplasm derived from interploidy crosses in *Avena*. Euphytica 111:175-184.

Dyck, P. L. 1966. Inheritance of stem rust resistance and other characteristics in diploid oats, *Avena strigosa*. Can. J. Genet. Cytol. 8:444-450.

Federizzi, L. C., and C. M. Mundstock. 2004. Fodder oats: An overview for South America, p. 37-51, *In* J.M.Suttie and S.G.Reyynolds, eds. Fodder oats: A world overview, Vol. 33. Food and Agriculture organizations of the United Nations.

Katsura, M. 2004. Fodder oats in Japan, p. 145-152, *In* J.M.Suttie and S.G.Reynolds, eds. Fodder oats: a world overview, Vol. 33. Food and Agriculture organizations of the United Nations.

Lowe, K. F., and T. M. Bowdler. 1998. Effects of height and frequecy of defoliation on the productivity of irrigated oats (*Avena stigosa* cv.Saia) and perennial ryegrass (*Lolium perenne* cv. Kangaroo Valley), grown alone or with barrel medic (*Medicago truncatula* cv.Jemalong). Australian journal of experimental Agriculture, 28:57-67.

Martinelli, J. A. 2004. Oat diseases and their control, p. 197-214, *In* J.M.Suttie and S.G.Reyynolds, eds. Fodder oats: a world overview, Vol. 33.

O'Mara, J. G. 1961. Cytogenetics-The fatuoid and steriloid mutations, p. 112-124, *In* F. A.Coffman, ed. Oats and Oat improvement. Agron. Monogr. 8. ASA, Madison, WI.

Schomberg, H. H., D. M. Endale, A. Calegari, R. Peixoto, M. r. Miyazawa, and M. L. Cabrera. 2005. Influence of cover crops on potential nitrogen availability to succeeding crops in a Southern Piedmont soil. Biology and Fertility of Soils 42:299-307.

Suttie, J. M., and S. G. Reynolds. 2004. Back ground to fodder oats worldwide, p. 1-7, *In* J.M.Suttie and S.G.Reyynolds, eds. Fodder oats: a world overview. Food and Agriculture organizations of the United Nations.

Thomas, H. 1992. Cytogenetics of *Avena*, p. 473-507, *In* H.G.Marshall and M.E.Sorrells, eds. Oat Science and Technology-Agronomy monograph, Vol. 33. American Society of Agronomy, Madison, WI, U.S.A.

Weibull, J., L. Lyng, J. Bojensen, and V. Rasomavicius. 2005. *Avena strigosa* in Denmark and Lithuania: Prospects for in situ conservation. Plant Genetic Resources Newsletter 131:1 - 6.

Table 2-1: Materials used for the morphology and maturity study

		Geographic origin			
NPGS no.	Plant ID	Country	State/Province	Continent	Vernalization
CIav 1782		Russian Federation	Leningrad	Europe	Spring
CIav 2520	26-389	France	Cote-d'Or	Europe	Spring
CIav 2521	26-390	France	Cote-d'Or	Europe	Spring
CIav 2523	26-391	France	Cote-d'Or	Europe	Spring
CIav 2524	26-398	United Kingdom	Wales	Europe	Spring
CIav 2525	26-381	United Kingdom	England	Europe	Spring
PI 78821	Glabrota	Australia	New South Wales	Australia	Spring
PI 83720	C. 3758	Australia	New South Wales	Australia	Unknown
PI 83721	C. 3758	Australia	New South Wales	Australia	Unknown
PI 83722	C. 3593	Australia	New South Wales	Australia	Unknown
PI 83723	C. 3756	Australia	New South Wales	Australia	Unknown
CIav 2894		United States	Washington	North America	Spring
CIav 2920	S 77	United Kingdom	Wales	Europe	Spring
CIav 2921	S 76	United Kingdom	Wales	Europe	Spring
CIav 3214	Reed's No. 590	United States	New York	North America	Spring
PI 111261	CIav 3280	Romania	Cluj	Europe	Spring
CIav 3372	S-171	Unknown		South America	Spring

Table 2-1: (cont.)

PI 131695	5081	Poland	Krakow	Europe	Spring
PI 131640	7513	Poland	Krakow	Europe	Spring
PI 131641	9411	Poland	Krakow	Europe	Spring
PI 131642	9249	Poland	Krakow	Europe	Spring
CIav 4639	Saia	Brazil	Rio Grande do Sul	South America	Facultative
PI 158244	typica	Russian Federation	Smolensk	Europe	Spring
PI 158246	WIR 5201/1	Spain	Lugo	Europe	Winter
PI 274610	Glabrata	Poland		Europe	Winter
PI 287315	Rauhhafer aus Neustadt	Germany		Europe	Winter
PI 291990	Saia 2	Israel		Mid-East	Facultative
PI 291991	Saia 4	Israel		Mid-East	Facultative
PI 292226		Israel	Tel Aviv	Mid-East	Facultative
PI 304557	4659	United Kingdom	Wales	Europe	Spring
PI 436080	353	Chile	Los Lagos	South America	Spring
PI 436082	361	Chile	Los Lagos	South America	Spring
PI 436103	1	Chile	Bio-Bio	South America	Spring
PI 436104	35	Chile	La Araucania	South America	Spring
PI 436105	113	Chile	La Araucania	South America	Spring
PI 436106	117	Chile	La Araucania	South America	Winter

Table 2-1: (cont.)

PI 306419	2582	Romania		Europe	Facultative
PI 361910		Romania	Brasov	Europe	Spring
PI 361911		Romania	Brasov	Europe	Spring
PI 361912		Romania	Brasov	Europe	Spring
PI 401793	*Avena strigosa nuda* 7	United Kingdom		Europe	Spring
PI 401794	*Avena strigosa nuda* 8	United Kingdom		Europe	Winter
PI 436107	146	Chile	Bio-Bio	South America	Spring
PI 436108	197	Chile	La Araucania	South America	Spring
PI 436109	202	Chile	La Araucania	South America	Spring
PI 436110	209	Chile	La Araucania	South America	Spring
PI 436111	218	Chile	La Araucania	South America	Spring
PI 436112	266	Chile	Los Lagos	South America	Spring
PI 436119	355	Chile	Los Lagos	South America	Winter
PI 436120	364	Chile	Los Lagos	South America	Spring
PI 436121	367	Chile	Los Lagos	South America	Spring
PI 436122	394	Chile	Los Lagos	South America	Spring
PI 436124	401	Chile	Los Lagos	South America	Spring
PI 436125	420	Chile	Los Lagos	South America	Spring
PI 436127	425	Chile	Los Lagos	South America	Spring

Table 2-1: (cont.)

PI 436126	423	Chile	Los Lagos	South America	Spring
PI 436130	448	Chile	Los Lagos	South America	Spring
PI 436131	449	Chile	Los Lagos	South America	Spring
PI 436132	454	Chile	Los Lagos	South America	Spring
PI 436133	507	Chile	La Araucania	South America	Spring
PI 436134	509	Chile	La Araucania	South America	Spring
PI 436113	280	Chile	Los Lagos	South America	Spring
PI 436114	302	Chile	Los Lagos	South America	Winter
PI 436115	333	Chile	Los Lagos	South America	Winter
PI 436116	335	Chile	Los Lagos	South America	Winter
PI 436117	346	Chile	Los Lagos	South America	Spring
PI 436118	354	Chile	Los Lagos	South America	Winter
CIav 9019	CD 3642	United Kingdom	Wales	Europe	Winter
CIav 9020	CD 3819	Argentina		South America	Mixed
CIav 9021	CD 3820	Canada	Ontario	North America	Facultative
CIav 9022	CD 3916	Netherlands		Europe	Facultative
CIav 9024	CD 4481	Germany		Europe	Facultative
CIav 9030	CD 7497	Canada	Ontario	North America	Winter
CIav 8089	Autotetraploid of Saia	United States	Pennsylvania	North America	Winter

Table 2-1: (cont.)

CIav 9007	CD 1002	Romania		Europe	Spring
CIav 9011	CD 1025A	Denmark		Europe	Spring
CIav 9012	CD 1576	Bulgaria		Europe	Spring
CIav 9014	CD 2050	Canada	Ontario	North America	Winter
CIav 9015	CD 2108	Canada	Ontario	North America	Winter
CIav 9066	CD 8088	Canada	Ontario	North America	Facultative
CIav 9110	GA 23	Canada	Ontario	North America	Mixed
CIav 9112	GA 33	Canada	Ontario	North America	Spring
CIav 9116	GA 74	Canada	Ontario	North America	Winter
PI 274608	Glabrescens Cambrica	Poland		Europe	Facultative
PI 274609	Oreadensis Arguta	Poland		Europe	Spring
CIav 9031	CD 7497A	Canada	Ontario	North America	Facultative
CIav 9035	CD 7847	Russian Federation	Leningrad	Europe	Facultative
CIav 9038	CD 7853	United Kingdom	Northern Ireland	Europe	Facultative
CIav 9043	CD 7954	Argentina		South America	Winter
CIav 9064	CD 8086	Canada	Ontario	North America	Facultative
CIav 9065	CD 8087	Canada	Ontario	North America	Facultative
PI 158245	WIR 5199	Spain	Lugo	Europe	Spring
PI 158247	WIR 5288/1	Portugal		Europe	Winter

Table 2-1: (cont.)

CIav 5057	C.D. 3686	Russian Federation	Former Soviet Union	Europe	Spring
CIav 5082	C.D. 3381	Uruguay	Colonia	South America	Spring
CIav 6858		Uruguay		South America	Spring
PI 186606	Saia	Brazil	Rio Grande do Sul	South America	Unknown
CIav 6956	C.D. 3820	Canada	Ontario	North America	Facultative
CIav 7010	Saia Selection	Brazil	Rio Grande do Sul	South America	Unknown
CIav 7121	C.D. 1007	Canada	Ontario	North America	Winter
CIav 7122	C.D. 920	Canada	Ontario	North America	Winter
CIav 7280		United States	Maryland	North America	Winter
CIav 8087	5201	Spain		Europe	Facultative
SoilSaver		United States	Alabama	North America	

Table 2-2: Response variables studied

No.	Response variable	Unit
1	Heading date	Julian date
	Tiller	
2	angle	Degree from vertical
3	diameter	mm
4	length	cm
5	node number	count tiller^{-1}
6	number	count plant^{-1}
	Panicle	
7	length	cm
8	node number	count panicle^{-1}
	Flag leaf	
9	length	mm
10	width	mm
11	Seed yield	g plant^{-1}
12	Average seed mass	g 1000 seed^{-1}

Table 2-3: Response variables studied and their range.

No.	Response variable	Unit	Year	Max	Min	Average
1	Heading date	Julian date	2003	195	86	170
			2004	224	29	193
	Tiller					
2	angle	Degree from vertical	2003	73.33	23.33	48.16
			2004	73.33	34.67	54.10
3	diameter	mm	2003	6.78	2.54	4.22
			2004	5.76	1.27	3.71
4	length	cm	2003	147.05	62.19	115.00
			2004	140.02	49.88	96.98
5	node number	count tiller^{-1}	2003	7.73	2.21	4.72
			2004	7.18	2.72	4.29
6	number	count plant^{-1}	2003	48.94	0.17	22.25
			2004	28.46	1	12.04
	Panicle					
7	length	cm	2003	44.13	18.6	30.00
			2004	39.72	15.33	25.84
8	node number	count panicle^{-1}	2003	11.49	4.5	9.11
			2004	10.99	3.37	8.49
	Flag leaf					
9	length	mm	2003	220.04	60.85	108.23
			2004	202.48	62.5	106.94
10	width	mm	2003	1.52	0.34	0.76
			2004	1.21	0.29	0.66
11	Seed yield	g plant^{-1}	2003	51.54	-0.63	8.96
			2004	6.39	-0.14	1.71
12	Average seed mass	g 1000 seed^{-1}	2003	34.8	0	11.84
			2004	25.47	-0.15	12.22

Table 2-4: Loading of Canonical Discriminant Analysis (CDA).

Trait	CAN1	CAN2	CAN3	CAN4
Angle	-0.30	0.10	**0.54**	0.47
Heading	**0.72**	0.22	-0.16	0.01
Tiller length	-0.10	**0.54**	0.18	0.33
Tiller diameter	-0.47	**0.55**	0.06	0.12
Tiller node number	**0.78**	0.15	0.39	-0.11
Panicle length	0.37	0.37	**-0.59**	0.14
Panicle node number	0.20	0.17	0.18	**0.59**
Leaf length	0.00	**-0.64**	0.26	0.38
Leaf width	0.02	-0.06	0.26	**0.77**
Seed mass	-0.40	0.01	0.38	0.31
Eigenvalues	22.59	10.53	8.73	4.04
Cumulative proportion of Eigenvalues	0.41	0.61	0.77	0.84

Table 2-5: Variance analysis of the traits identified by canonical discriminant analysis. These traits are contributing significantly to the differences among accessions among continents, countries within continents, and accessions within countries.

		Tiller				Panicle		Flag leaf	
Source	Heading	angle	diameter	length	node number	length	node number	length	width
					P-values				
Year	0.0001	0.001	0.0002	0.0001	0.0002	0.0001	0.0001	0.9728	0.0001
Continent	0.0001	0.0001	0.0001	0.0001	0.0001	0.0114	0.0005	0.0039	0.0001
Country (Continent)	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Accession (Country*Cont)	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001

Table 2-6: Traits with high correlation to CAN1 among different accessions. CAN 1 is responsible for 41 % of total variation. Pair-wise comparisons identified the significant difference among accessions based on these traits among different continents

				Pair-wise differences and *P*-values				
Continent	Mean	SE	Range	Australia	Europe	Mid-East	North America	South America
Heading date								
Australia	10-May	12.3	27-Apr-28 May		6	25	18	9
Europe	4-May	11.7	5-Mar-13-Jun	0.602		19	12	3
Mid-East	15-Apr	12.7	27-Mar-11-May	<0.001	0.002		-7	-16
North America	22-Apr	11.8	30-Nov-1-Jun	<0.001	<0.001	0.646		-9
South America	1-May	11.7	27-Mar-11-Jun	0.150	0.418	0.018	0.004	
Tiller node number								
Australia	5.6	0.22	4-7		0.94	1.65	1.49	1.36
Europe	4.7	0.20	3-8	<0.001		0.71	0.55	0.42
Mid-East	4.0	0.22	4-4	<0.001	<0.001		-0.16	-0.28
North America	4.1	0.20	2-6	<0.001	<0.001	0.639		-0.12
South America	4.3	0.20	3-6	<0.001	<0.001	0.075	0.218	

Table 2-7: Traits with high correlation to CAN 2 among different accessions. CAN 2 is responsible for 20% of total variation. The significance of differences among continents for tiller length is similar to those observed for heading date (Table 2-6).

				Pair-wise differences and *P*-values				
Continent	Mean	SE	Range	Australia	Europe	Mid-East	North America	South America
Tiller length, cm								
Australia	108	10.5	85-147		-7.64	-9.11	2.19	-0.32
Europe	116	10.3	78-143	0.003		-1.47	9.83	7.32
Mid-East	117	10.5	98-133	0.021	0.969		11.30	8.79
North America	106	10.3	50-132	0.850	<0.001	<0.001		-2.51
South America	109	10.3	66-144	1.000	<0.001	0.002	0.259	
Tiller diameter, mm								
Australia	3.5	0.21	2.9-5.0		-0.42	-1.06	-0.47	-0.77
Europe	4.0	0.19	2.4-7.0	0.001		-0.64	-0.05	-0.35
Mid-East	4.6	0.22	3.9-5.0	<0.001	<0.001		0.59	0.29
North America	4.0	0.19	1.3-6.0	<0.001	0.947	<0.001		-0.3019
South America	4.3	0.19	2.4-6.0	<0.001	<0.001	0.088	<0.001	
Leaf length, mm								
Australia	113	3.5	88-165		4.94	20.63	-3.49	13.16
Europe	108	1.4	61-186	0.645		15.70	-8.43	8.22
Mid-East	93	4.0	85-103	<0.001	0.001		-24.13	-7.47
North America	117	1.9	63-220	0.885	0.001	<0.001		16.65
South America	100	1.3	76-169	0.002	<0.001	0.346	<0.001	

Table 2-8: Traits with high correlation to CAN 3 among different accessions. CAN 3 is responsible for 16 % of total variation. European accessions have broadest range for tiller angle among themselves. Tiller angle among accessions from North America was significantly different from South America.

				Pair-wise differences and *P*-values				
Continent	Mean	SE	Range	Australia	Europe	Mid-East	North America	South America
Tiller angle, º from horizontal								
Australia	56	3.8	43-68		4.92	-3.74	0.63	7.55
Europe	51	3.0	23-73	0.338		-8.67	-4.29	2.63
Mid-East	60	4.3	57-67	0.878	0.064		4.37	11.30
North America	56	3.1	32-73	0.999	0.065	0.702		6.92
South America	49	3.0	27-72	0.035	0.245	0.006	<0.001	
Panicle length, cm								
Australia	30	2.3	24-39		0.56	1.86	0.84	2.04
Europe	29	2.3	21-40	0.790		1.29	0.28	1.47
Mid-East	28	2.3	24-31	0.063	0.131		-1.01	0.18
North America	29	2.3	15-44	0.493	0.882	0.397		1.19
South America	28	2.3	17-35	0.000	<0.001	0.997	0.001	

Table 2-9: Traits with high correlation to CAN 4 among different accessions. CAN 4 is responsible for 7 % of total variation. Pair-wise comparisons identified the significant difference of European accessions from accessions of all other continents except Australia.

				Pair-wise differences and P-values				
Continent	Mean	SE	Range	Australia	Europe	Mid-East	North America	South America
Panicle node number								
Australia	9.2	0.28	8.0-11.0		0.13	0.86	0.77	0.46
Europe	9.1	0.25	7.0-11.0	0.871		0.73	0.64	0.33
Mid-East	8.4	0.29	8.0-9.0	<0.001	<0.001		-0.09	-0.40
North America	8.5	0.26	3.0-11.0	<0.001	<0.001	0.977		-0.31
South America	8.8	0.25	7.0-11.0	0.006	<0.001	0.062	0.001	
Leaf width, mm								
Australia	8.62	0.51	5.9-12.3		1.186	1.84	1.10	1.97
Europe	7.44	0.45	3.1-15.2	<0.001		0.656	-0.081	0.782
Mid-East	6.78	0.53	6.1-8.2	<0.001	0.200		-0.737	0.126
North America	7.52	0.46	3.3-14.2	0.001	0.986	0.139		0.864
South America	6.66	0.45	2.9-12.5	<0.001	<0.001	0.993	<0.001	

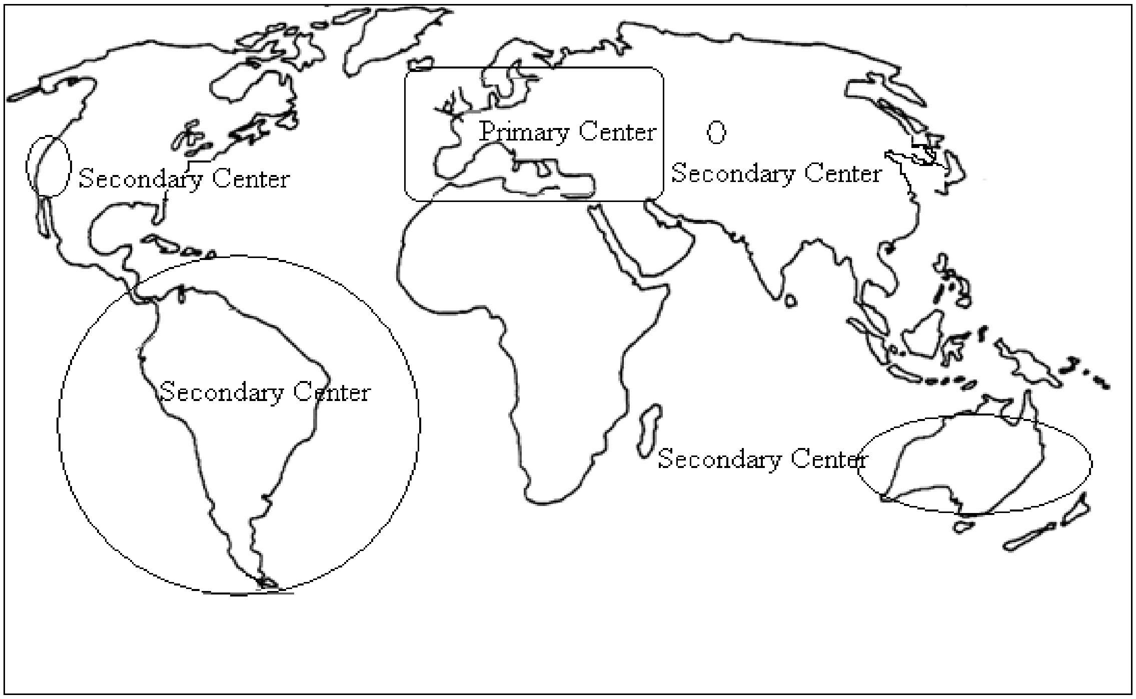

Figure 2-1: Primary (circle) and secondary (rectangle) centers of origin of black oats.

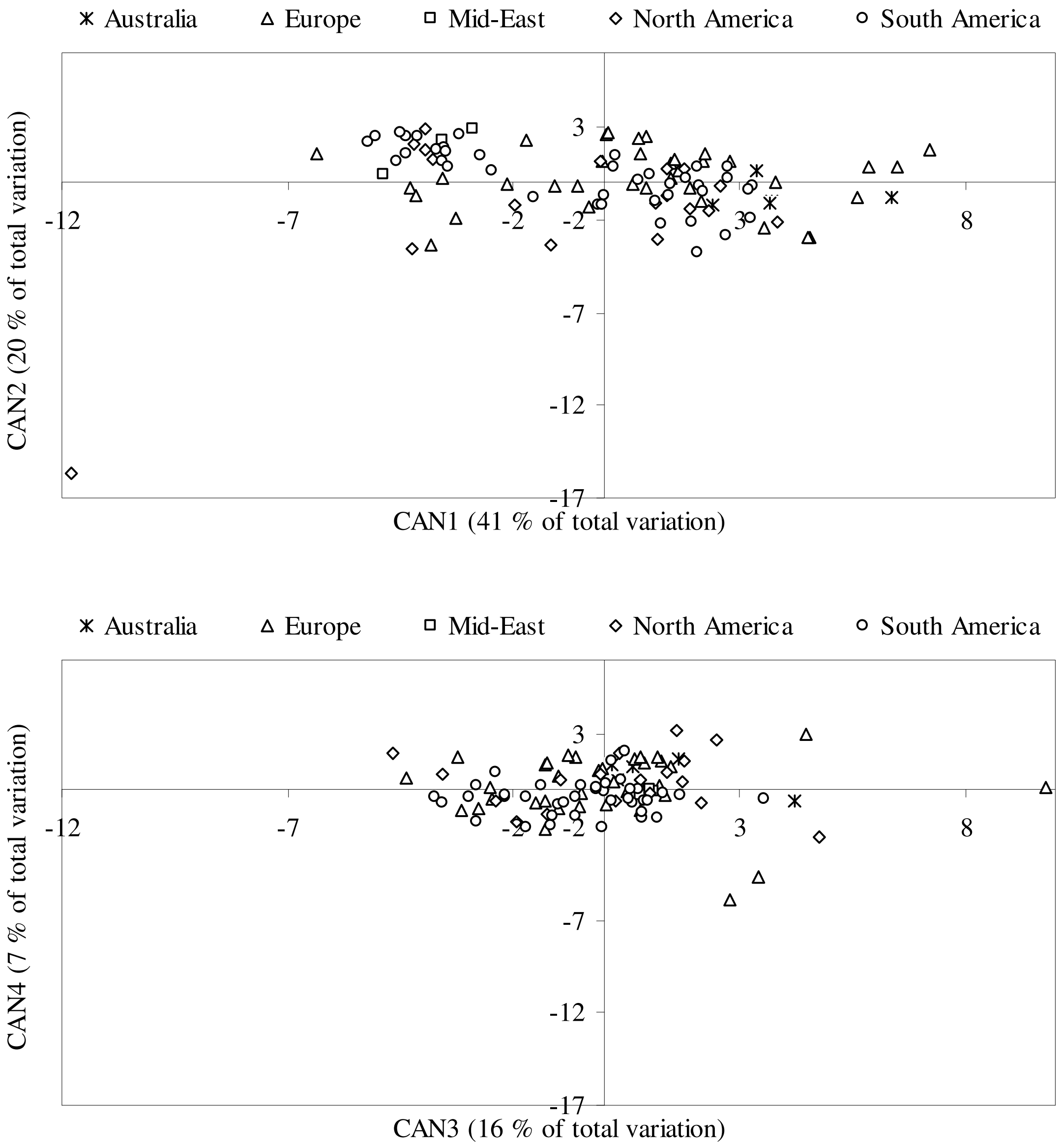

Figure 2-2: Canonical discriminant analysis scatter plot separates the accessions originated in different geographical locations into meaningful groups. In the first panel accession CIav 9015 separated to the extreme left of second quadrant. CAN1 vs. CAN2 separates five accessions to the extreme right of the first quadrant.

III. PLOT TRIALS IN BLACK OAT (*AVENA STRIGOSA* SCHREB.) FOR BIOMASS, GRAIN YIELD AND TEST WEIGHT

Abstract

Even though more than 100 black oat accessions are available from USDA for research purpose the only commercially available black oat cultivar in US is the SoilSaver. In this pioneering study we compared the biomass, grain production and test weight of SoilSaver to the other selected black oat accessions. Eighteen accessions were selected for biomass, grain yield and test weight study based on their relative maturity to that of SoilSaver and the availability of enough seeds from 15 to18 plants. The studies were conducted in 2004-05 and 2006-07. The biomass study was conducted in four locations with two replications in each location and grain yield and test weight study was conducted in two locations in the first year and five locations in the second year with three replicates at each location. Mixed model method by invoking PROC MIXED procedure of SAS® (SAS Institute, Cary, NC) was used for the analysis of variance. The differences of the least squares means of accessions and the SoilSaver control calculated with the 'Dunnett' adjustment gave a clear comparison of the performance of different accessions based on biomass and grain yield and test weight to that of SoilSaver control.

The study revealed the superiority of SoilSaver in biomass and grain yield production, but identified many accessions with higher test weight.

Introduction

Black oat (*A. strigosa* Schreb) has recently emerged as an important winter cover crop and forage crop suitable for subtropical and temperate regions of the world (Suttie and Reynolds, 2004). In South America black oat is grown extensively for cover crop and forage purposes (Federizzi and Mundstock, 2004). It has the potential to produce comparable amount of biomass to other leguminous and non-leguminous cover crops. Biomass production and soil N mineralization dynamics of Black oat are on par with that of crimson clover (Schomberg et al., 2005). A study conducted in Brazil demonstrated the ability of cover crop residues of black oat to decrease the manganese toxicity in well aerated acid soils by lowering the Mn solubility (Andrade *et al.,* 2002). Obviously, the kill date has an effect on biomass yield and nitrogen availability of cover crops and maximizing the window between establishment and kill may increase the biomass production and nutrient accumulation. Delayed kill date of hairy vetch for two weeks improved N accumulation significantly (Sainju and Singh, 2001). Black oat reached maximum biomass at anthesis compared to rye (*Secale cereale L.)*, and wheat (*Triticum aestivum L.*) that continued to increase biomass significantly through soft dough stage (Ashford and Reeves, 2003). Cotton lint yield following black oat was higher than that following rye, even though rye produces more biomass than black oat (Bauer and Reeves, 1999). But low night temperature for a longer period of time has a negative influence on biomass production in black oat compared to rye (Reeves et al., 2005).

Even though more 100 black oat accessions are available from USDA germplasm unit for research purpose the only commercially available black oat cultivar in the United States is ‘SoilSaver’, which was released by Auburn University and USDA in 2002. In this paper we are comparing the biomass production, grain yield and test weight of selected black oat accessions based on the preliminary results from a previous study of the entire USDA black oat accessions for agronomic and morphological traits to that of SoilSaver.

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Materials and Methods

Accessions were selected based on their relative heading date to that of SoilSaver (± 2 weeks) and adequate seed yield from 15-18 plants. The 18 accessions selected have 9 different countries of origin (Brazil, Bulgaria, Canada, Chile, Denmark, Israel, Poland, Romania and United States). For the 2004-05 study the accessions were planted as 5' X 10' row plots on last week of October and first week of November, 2004. The plots were harvested on first week of April, 2005. For the 2004-05 biomass study the entire plot weight was taken in a once-over harvesting scheme when the majority of entries were fully headed. A plot combine was used for grain harvest. Harvested grain was dried to < 10% moisture and cleaned with an Airblast Cleaner (ALMACO Inc., Nevada, Iowa) and meshed sieves of different sizes. For the biomass study the accessions were planted at four locations in Alabama: 1) Plant Breeding Unit (PBU), Tallassee, Alabama, (32°24.5'N, 85°57'W), where the soil type is fine sandy loam, 2) Tennessee Valley Research and Extension Center (TVS), Belle Mina, Alabama (34°41'N, 86°53'W) where the soil type is Decatur silt loam (fine, kaolinitic, thermic, Rhodic, Paleudults.), 3) Wiregrass Research and Extension Center (WGS), Headland (31°21'N, 85°21'. W,) where the major soil type is Dothan sandy loam, and 4) Gulf Coast Research and Extension Center (GCS), Fairhope (30°33' N, 87°81 ' W) where the soil type is Malbis sandy loam. Two replicates were planted in each location for the biomass study. The locations for grain yield and test weight study are 1) Plant Breeding Unit, Tallassee, Alabama and 2) Prattville Agricultural Research Unit (PEF), Prattville, Alabama (32°42' 40" N, 86°44' 38" W) where the major soil type is Lucedale sandy loam. Three replicates were planted in each location for grain yield and test weight studies.

The experiments were repeated in 2006, but this time with more locations for grain yield and test weight studies. The biomass study was conducted at four locations 1) Gulf Coast Research and Extension Center (GCS, 2) Plant Breeding Unit (PBU), 3) Tennessee Valley Research and Extension Center (TVS) and 4) Prattville Agricultural Research Unit (PEF). Two replicates were planted at each location for the biomass study. The grain yield and test weight studies were conducted at five locations of Alabama *viz.* 1) Gulf Coast Research and Extension Center (GCS), 2) Plant Breeding Unit, (PBU) 3) Tennessee Valley Research and Extension Center (TVS), 4) Prattville Agricultural Research Unit (PEF) and 5) Wiregrass Research and Extension Center (WGS). Three replicates were planted at each location for the grain yield and test weight studies. The plots were harvested during the last week of May, 2007 and processed as described earlier.

Statistical Analysis

Mixed model methodology as implemented in PROC MIXED of SAS®(SAS Institute, Cary, NC) was used to analyze the data using a nearest neighbor analysis model. First we calculated the residuals using the Proc Mixed procedure. A residual is the difference between the observed value of the variable (Y_i) and the predicted value of the variable $\hat{Y}_i$. The covtest option in proc mixed produces asymptotic standard errors and Wald *Z*-tests for the covariance parameter estimates. The *Wald Z* is a common likelihood-based statistic, which is computed as the parameter estimate divided by its asymptotic standard error. The asymptotic standard errors are computed from the inverse of the second derivative matrix of the likelihood with respect to each of the covariance parameters. A mean nearest neighbor distance ($\bar{d}$) was calculated by taking the mean of residuals of the four plots surrounding each plot and used in the mixed model analysis using PROC MIXED procedure of SAS® (SAS institute, Cary, NC) for nearest neighbor adjustment. The mean nearest neighbor distance $\bar{d} = \frac{\sum_{i=1}^{N} di}{N}$, where N is the number of points, d_i is the nearest neighbor distance for point *i.* The Kenward-Roger method was used for the estimation of degrees of freedom. For each of the three response variables we calculated least squares interaction means listed in (Tables 3-4, 3-5, 3-6, 3-7 & 3-8). Block within location, mean nearest neighbor distance, location, accession and location x accession interactions were taken as the fixed effects in the model for the 2004-05 study. Block within location, location, accession and location x accession interactions were taken as the fixed effects in the model for the 2006-07 study. The differences of the least squares means of accessions and the SoilSaver control were calculated with the 'Dunnett' adjustment. The Dunnett's test is useful when the only pair-wise comparisons of interest are comparisons with a control. The Dunnett's test is an exact test, because it's family-wise error rate (FWE) is exactly equal to α, for balanced as well as unbalanced one-way designs and hence it reduces the type I error. The yield of SoilSaver at standard seeding rate (90 lbs acre^{-1}) was taken as the reference point or control in this experiment. The difference in least square means with that of the control were plotted for biomass, grain yield and test weight.

Results and Discussion

Biomass Yield

SoilSaver at standard seeding rate (90 lbs acre^{-1}) was used as a control for this evaluation. SoilSaver at standard seeding rate produced 8769 kg ha^{-1}, 11683 kg ha^{-1}, 3997 kg ha^{-1} and 4088 kg ha^{-1} of biomass at Gulf Coast Research and Extension Center, Plant Breeding Unit, Tennessee Valley Research and Extension Center and Wiregrass Research and Extension Center respectively (Table 3-4) during 2004-05 study. Accessions CIav 8089 produced significantly higher biomass yield than SoilSaver at standard seeding rate at Tennessee Valley (*P*= 0.0167) and Wiregrass (*P*=0.001). Accessions PI 111261 except at Wiregrass, CIav 9110 except at Tennessee Valley, and CIav 9112 except at Wiregrass, performed poorer than SoilSaver at standard seeding rate.

During the 2006-07 study SoilSaver at standard seeding rate produced 6562 kg ha^{-1}, 6552 kg ha^{-1}, 1473 kg ha^{-1} and 10433 kg ha^{-1} of biomass at Gulf Coast Research and Extension Center, Plant Breeding Unit, Tennessee Valley Research and Extension Center and Prattville Agricultural Research Unit, respectively (Table 3-5). None of the accessions are significantly different from SoilSaver in biomass production at Gulf Coast Research and Extension Center, Plant Breeding Unit and Prattville Agricultural Research Unit. At Tennessee Valley Research and Extension Center Accession CIav 2520 from France ($P = 0.02$) produced higher biomass yield than the control.

Grain yield

Grain yield was not consistent across the two locations (Plant Breeding Unit, Tallassee, Alabama and Prattville Agricultural Research Unit, Prattville, Alabama) for the 2004-05 study. SoilSaver at standard seeding rate (90 lbs acre^{-1}) was used as a control for this evaluation. SoilSaver at standard seeding rate produced 1013 kg ha^{-1} and 652 kg ha^{-1} grain yield at Plant Breeding Unit (PBU) and Prattville Agricultural Research Unit respectively (Table 3-6). The severe lodging experienced in Prattville was responsible for the low grain production there during 2004-05. Accessions PI 436103, PI 436104 and CIav 7010 performed better than the control in both locations. At PBU, accessions CIav 2520 ($P < 0.001$), CIav 9007 ($P < 0.001$), CIav 9012 ($P < 0.001$) and CIav 9112 ($P = 0.001$) performed poorer than the control and accessions PI 291991 ($P < 0.01$), PI 436103 ($P < 0.001$), PI 436104 ($P = 0.05$), PI 274608 ($P < 0.001$) and CIav 7010 ($P = 0.02$) performed better than the control. At PEF accessions PI 436103 ($P = 0.03$), PI 436104 ($P < 0.001$), PI 436105 ($P = 0.02$), PI 436114 ($P = 0.003$) and CIav 7010 ($P = 0.001$) performed better than the control.

During the 2006-07 study, SoilSaver at standard seeding rate produced 1662 kg ha^{-1}, 1650 kg ha^{-1}, 822 kg ha$^{-1,}$ 1130 kg ha^{-1}, and 344 kg ha^{-1} of grain yield at Gulf Coast Research and Extension Center (GCS), Plant Breeding Unit (PBU), Prattville Agricultural Research Unit (PEF), Tennessee Valley Research and Extension Center (TVS) and Wiregrass Research and Extension Center (WGS) respectively (Table 3-7). During 2006-07 study at GCS accessions PI 274608 ($P = 0.02$) and CIav 9112 ($P = 0.07$) produced significantly lower grain yield than control. At PBU all the accessions except PI 436080 and CIav 9011 differed significantly from SoilSaver in grain production. Among those significantly different accessions, all but SoilSaver_45 (SoilSaver at half the standard seeding rate) produced lower grain yield than SoilSaver at standard seeding rate. At PEF and TVS none of the accessions differ significantly from control. At WGS accession at SoilSaver_45 ($P = 0.01$) produced significantly higher grain yield than control.

Test weight

During the 2004-05 study SoilSaver at standard seeding rate has test weight of 27.5 lbs bu^{-1}and 32.1 lbs bu^{-1} at Plant Breeding Unit (PBU), and Prattville Agricultural Research Unit (PEF), respectively (Table 3-6). Accessions PI 291991, PI 436103, PI 436104, PI 436105, PI 436110, PI 436114, CIav 8089, PI 274608, and CIav 7010 had higher test weight than the control at both locations. Accessions PI 111261 performed poorer than the control at the two locations.

During the 2006-07 study SoilSaver at standard seeding rate had a test weight of 18.6 lbs bu^{-1}, 25.3 lbs bu^{-1}, 25.8 lbs bu$^{-1,}$ 24.1 lbs bu^{-1} and 19.0 lbs bu^{-1} at Gulf Coast

Research and Extension Center (GCS), Plant Breeding Unit (PBU), Prattville Agricultural Research Unit (PEF), Tennessee Valley Research and Extension Center (TVS), and Wiregrass Research and Extension Center (WGS) respectively (Table 3-8). At GCS accession CIav 8089 (P = 0.08) has significantly higher test weight than SoilSaver. Accession PI 436103 (P = 0.06) has significantly lower test weight than SoilSaver. At PEF accessions PI 291991 (P = 0.01), PI 436103 (P = 0.01), PI 436104 (P = 0.01), PI 436110 (P = 0.05), PI 436114 (P = 0.04), CIav 8089 (P = 0.01) and CIav 7010 (P = 0.01) differ significantly from SoilSaver at standard seeding rate. At TVS accessions CIav 2520 ($P < 0.001$), PI 291991 ($P < 0.001$), PI 436103 ($P < 0.001$), PI 436104 ($P < 0.001$), PI 436105 (P = 0.07), PI 436110 ($P < 0.001$), PI 436114 ($P < 0.001$), CIav 8089 ($P < 0.001$), CIav 9007 (P = 0.005), CIav 9110 (P = 0.06), CIav 9112 ($P < 0.001$), PI 274608 (P = 0.012) and CIav 7010 ($P < 0.001$) show significantly higher test weight than SoilSaver at standard seeding rate. At WGS accessions PI291991 ($P < 0.001$), PI 436103 ($P < 0.001$), PI 436104 ($P < 0.001$), PI 436105 ($P < 0.001$), PI 36110 ($P < 0.001$), PI436114 ($P < 0.001$), CIav 8089 ($P < 0.001$), PI 274608 (P = 0.03) and CIav 7010 ($P < 0.001$) has significantly higher test weight than control.

Conclusions

Based on the 2004-05 and 2006-07 study it is found that none of the accessions performed better than SoilSaver in biomass production consistently at all the four locations. None of the accessions performed significantly better than SoilSaver in grain yield production consistently in all locations during 2006-07 study. This evaluation identified many accessions having higher test weight than SoilSaver. Overall SoilSaver performed better than most of the accessions studied in all the aspects.

References

Andrade, E., M. Miyazawa, M. A. Pavan, and E. L. d. Oliveira. 2002. Effect of organic matter on manganese solubility. Brazilian Archives Of Biology And Technology 45:17 - 20.

Ashford, D. L., and D. W. Reeves. 2003. Use of a mechanical roller-crimper as an alternative kill method for cover crops. American Journal of Alternative Agriculture 18(1):37-45.

Bauer, P. J., and D. W. Reeves. 1999. A comparison of winter cereal species and planting dates as residue cover for cotton grown with conservation tillage. Crop Science 39:1824-1830.

Federizzi, L. C., and C. M. Mundstock. 2004. Fodder oats: An overview for South America, p. 37-51, *In* J.M.Suttie and S.G.Reyynolds, eds. Fodder oats: A world overview, Vol. 33. Food and Agriculture organizations of the United Nations.

Reeves, D. W., A. J. Price, and M. G. Patterson. 2005. Evaluation of three winter cereals for weed control in conservation-tillage nontransgenic cotton. Weed Technology 19:731-736.

Sainju, U. M., and B. P. Singh. 2001. Tillage, Cover Crop, and Kill-Planting Date Effects on Corn Yield and Soil Nitrogen. Agron. J. 93:878-886.

Schomberg, H. H., D. M. Endale, A. Calegari, R. Peixoto, M. Miyazawa, and M. L. Cabrera. 2005. Influence of cover crops on potential nitrogen availability to succeeding crops in a Southern Piedmont soil. Biology and Fertility of Soils 42:299-307.

Suttie, J. M., and S. G. Reynolds. 2004. Back ground to fodder oats worldwide, p. 1-7, *In* J.M.Suttie and S.G.Reyynolds, eds. Fodder oats: a world overview. Food and Agriculture Organizations of the United Nations.

Table 3-1: Materials used for the Biomass and grain yield studies

		Geographic origin		
NPGS no.	Plant ID	Country	State/Province	Continent
CIav 2520	26-389	France	Cote-d'Or	Europe
CIav 7010	Saia Selection	Brazil	Rio Grande do Sul	South America
CIav 8089	Autotetraploid of Saia	United States	Pennsylvania	North America
CIav 9007	CD 1002	Romania		Europe
CIav 9011	CD 1025A	Denmark		Europe
CIav 9012	CD 1576	Bulgaria		Europe
CIav 9110	GA 23	Canada	Ontario	North America
CIav 9112	GA 33	Canada	Ontario	North America
CIav 9116	GA 74	Canada	Ontario	North America
PI 111261	CIav 3280	Romania	Cluj	Europe
PI 274608	Glabrescens Cambrica	Poland		Europe
PI 291991	Saia 4	Israel		Mid-East
PI 436080	353	Chile	Los Lagos	South America
PI 436103	1	Chile	Bio-Bio	South America
PI 436104	35	Chile	La Araucania	South America
PI 436105	113	Chile	La Araucania	South America
PI 436110	209	Chile	La Araucania	South America
PI 436114	302	Chile	Los Lagos	South America
SoilSaver		United States	Alabama	North America

Table 3-2: Variance analysis of the biomass, grain yield and test weight studies of 2004-05 studies

Source	Biomass				Grain yield		Test weight	
	GCS	PBU	TVS	WGS	PBU	PEF	PBU	PEF
	--*P*-value---							
Rep	0.0002	0.0045	0.8761	0.2346	0.0601	0.0079	0.0053	0.0001
Nearest neighbor distance	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Accession	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001

Table 3-3: Variance analysis of the biomass, grain yield and test weight studies of 2006-07 studies

	Biomass		Grain yield		Test weight	
Location	Rep	Accession	Rep	Accession	Rep	Accession
		.------------------------------*P P* value----------------------------				
GCS	0.004	0.237	0.335	0.000	0.000	0.147
PBU	0.026	0.797	0.260	0.000	0.001	0.531
TVS	0.563	0.004	0.004	0.025	0.511	0.000
PEF	0.031	0.213	0.276	0.028	0.765	0.000
WGS	-	-	0.443	0.008	0.060	0.000

Table 3-4: LS means of biomass study 2004-05 at four locations. 1) Gulf Coast Research and Extension Center, Fairhope 2) Plant Breeding Unit, 3) Tennessee Valley Research and Extension Center, and 4) Wiregrass Research and Extension Center.

Accession	GCS		EVS		TVS		WGS	
	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE
SoilSaver_90	8769	174	11683	375	3997	133	4088	94
As_016	7067	250	8653	524	2843	187	3803	133
As_028	9566	248	11199	526	4505	187	4179	136
As_031	8188	247	13436	524	3834	188	4756	109
As_033	8974	249	10638	526	4688	188	4362	109
As_034	9568	249	11260	524	4638	188	4497	112
As_035	9514	247	9913	537	4734	188	4374	133
As_046	7618	247	10360	524	4836	187	4189	112
As_063	10788	250	11144	525	4370	209	4304	134
As_074	8926	247	12014	524	4873	188	5117	135
As_075	7238	249	12338	524	2802	187	3456	133
As_076	7954	250	10140	525	3025	188	2871	143
As_077	6574	248	10172	526	3740	188	4373	137
As_081	7745	247	8674	525	3728	188	3303	134
As_082	7373	247	8705	524	3154	188	3693	133
As_083	8004	248	10828	524	3580	188	3463	133
As_084	10385	247	12053	527	4150	190	4549	133
As_099	8606	247	11783	524	4947	187	4623	133
SoilSaver_45	9320	248	10790	524	3288	188	4221	134

Table 3-5: LS means of biomass study 2006-07 at four locations. 1) Gulf Coast Research and Extension Center, Fairhope 2) Plant Breeding Unit, Tallassee, 3) Prattville Agricultural Research Unit and 4) Tennessee Valley Research and Extension Center.

Accession	GCS		PBU		PEF		TVS	
	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE
SoilSaver_90	6562	971	6552	1846	10433	1366	1473	104
CIav 2520	6807	971	5567	1846	11010	1366	2005	104
PI 111261	6270	971	7624	1846	9414	1366	1314	104
PI 291991	7279	971	6951	1846	12690	1366	1447	104
PI 436080	6527	971	9458	1846	11387	1366	1571	104
PI 436103	6656	971	10211	1846	10124	1366	1489	104
PI 436104	6401	971	5773	1846	13049	1366	1509	104
PI 436105	6199	971	7347	1846	12896	1366	1448	104
PI 436110	7935	971	8265	1846	9229	1366	1536	104
PI 436114	7960	971	5314	1846	11461	1366	1564	104
CIav 8089	7536	971	6071	1846	9312	1366	1400	104
CIav 9007	7107	971	9781	1846	9841	1366	1356	104
CIav 9011	3957	971	8509	1846	8638	1366	1514	104
CIav 9012	7264	971	9273	1846	10173	1366	1249	104
CIav 9110	5947	971	8260	1846	6600	1366	1157	104
CIav 9112	4571	971	7919	1846	9666	1366	1657	104
CIav 9116	6673	971	10168	1846	10486	1366	1278	104
PI 274608	4194	971	8313	1846	11790	1366	1319	104
CIav 7010	7142	971	6562	1846	12423	1366	1687	104
SoilSaver_45	5150	971	8145	1846	8822	1366	1767	104

Table 3-6: LS means of grain yield and test weight study 2004-05 at 1) Plant Breeding Unit, and 2) Prattville Agricultural Research Unit.

	Grain yield				Test weight			
	PBU		PEF		PBU		PEF	
Accession	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE
SoilSaver_90	1013	73	652	91	27.5	0.4	32.1	0.4
As_002	488	85	652	91	24.9	0.4	37.9	0.6
As_016	738	85	1089	140	25.2	0.4	28.9	0.8
As_028	1675	84	392	138	36.3	0.4	37.1	0.6
As_031	1147	84	468	137	24.7	0.4	31.6	0.8
As_033	1490	85	480	137	39.0	0.4	38.5	0.6
As_034	1353	84	1199	137	37.9	0.4	39.8	0.6
As_035	1175	84	1571	137	37.1	0.4	37.1	0.6
As_046	1353	84	1227	137	36.8	0.4	36.9	0.6
As_063	1154	84	949	137	35.1	0.4	37.6	0.6
As_074	1240	84	1325	137	35.9	0.4	36.3	0.6
As_075	555	85	986	137	24.3	0.4	31.4	0.6
As_076	921	84	266	137	27.1	0.4	30.8	0.6
As_077	563	73	867	138	24.8	0.4	31.2	0.8
As_081	709	84	671	169	24.9	0.4	28.8	0.6
As_082	513	104	543	137	23.5	0.5	29.6	0.8
As_083	720	85	724	170	23.7	0.4		
As_084	1447	73	783	137	31.7	0.4	35.8	0.6
As_099	1381	73	1392	137	36.9	0.4	37.5	0.6
SoilSaver_45	1080	84	949	138	26.8	0.4	31.5	0.6

Table 3-7: LS means of grain yield study 2006-07 at five locations. 1) Gulf Coast Research and Extension Center, Fairhope 2) Plant Breeding Unit, Tallassee 3) Prattville Agricultural Research Unit and 4) Tennessee Valley Research and Extension Center 5) Wiregrass Research and Extension Center.

	GCS		PBU		PEF		TVS		WGS	
Accession	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE
SoilSaver_90	1662	142	1650	80	822	164	1130	227	344	144
CIav 2520	1661	142	748	80	850	164	1567	227	259	144
PI 111261	1410	142	800	80	712	164	1043	227	246	144
PI 291991	1142	142	421	80	1343	164	1553	227	554	144
PI 436080	1933	142	1475	80	857	202	776	227	893	144
PI 436103	1424	142	193	80	1113	164	1640	227	724	144
PI 436104	1469	142	277	80	1301	164	1696	227	518	178
PI 436105	1670	142	665	80	1097	164	1768	227	527	144
PI 436110	1386	142	247	80	1177	164	1337	227	535	144
PI 436114	1202	142	282	80	1091	164	1303	227	576	144
CIav 8089	1394	142	257	80	1331	164	1690	227	773	144
CIav 9007	1567	142	924	80	771	164	1341	227	570	144
CIav 9011	1415	142	1360	80	698	164	1073	227	360	144
CIav 9012	1123	142	879	99	811	164	984	227	379	144
CIav 9110	1406	142	859	80	720	164	687	227	285	144
CIav 9112	1082	142	710	80	846	164	1260	227	269	144
CIav 9116	1368	142	790	80	790	164	773	227	304	144
PI 274608	962	142	282	80	1053	164	987	227	462	144
CIav 7010	1253	142	317	80	1316	164	1251	227	517	144
SoilSaver_45	1979	142	1655	80	658	164	1067	227	1116	144

Table 3-8: LS means of test weight study 2006-07 at five locations. 1) Gulf Coast Research and Extension Center, Fairhope 2) Plant Breeding Unit, Tallassee, 3) Prattville Agricultural Research Unit and 4) Tennessee Valley Research and Extension Center 5) Wiregrass Research and Extension Center.

	GCS		PBU		PEF		TVS		WGS	
Accession	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE
SoilSaver_90	18.6	2.3	25.4	1.1	25.8	2	24.1	0.9	19.1	0.6
CIav 2520	20.2	2.3	24.4	1.1	30.3	2	30.7	0.9	20.9	0.8
PI 111261	19.1	2.3	24.7	1.1	27.1	2	25.7	0.9	19.7	0.8
PI 291991	22.8	2.3	23.3	1.1	36.1	2	32.3	0.9	27.6	0.6
PI 436080	18.5	2.3	24.0	1.1	25.8	2.5	23.2	0.9	20.0	0.6
PI 436103	22.7	2.3	19.8	1.4	36.6	2	33.7	0.9	26.2	0.6
PI 436104	23.2	2.3	23.6	1.4	37.0	2	34.3	0.9	27.5	0.8
PI 436105	21.8	2.3	23.7	1.1	32.6	2	28.0	0.9	26.4	0.6
PI 436110	23.0	2.3	22.4	1.4	34.5	2	34.7	0.9	27.8	0.6
PI 436114	22.9	2.3	23.6	1.1	34.8	2	34.5	0.9	27.8	0.6
CIav 8089	28.1	2.3	23.4	1.4	36.0	2	32.9	0.9	27.8	0.6
CIav 9007	20.2	2.3	24.6	1.1	28.9	2	29.3	0.9	21.3	0.8
CIav 9011	18.7	2.3	24.7	1.1	25.6	2	24.8	0.9	19.5	0.6
CIav 9012	23.5	2.3	23.8	1.4	27.3	2	26.7	0.9	20.5	0.6
CIav 9110	24.0	2.3	22.3	1.1	25.6	2	28.0	0.9	20.2	0.6
CIav 9112	19.0	2.3	22.6	1.1	28.6	2	30.9	0.9	21.7	0.8
CIav 9116	23.3	2.3	23.3	1.1	26.2	2	26.6	1.1	20.3	0.6
PI 274608	20.3	2.3	23.3	1.4	29.7	2	28.8	0.9	21.9	0.6
CIav 7010	27.8	2.3	25.0	1.1	36.0	2	32.3	0.9	25.0	0.6
SoilSaver_45	18.5	2.3	24.6	1.1	18.1	2	23.7	0.9	19.7	0.6

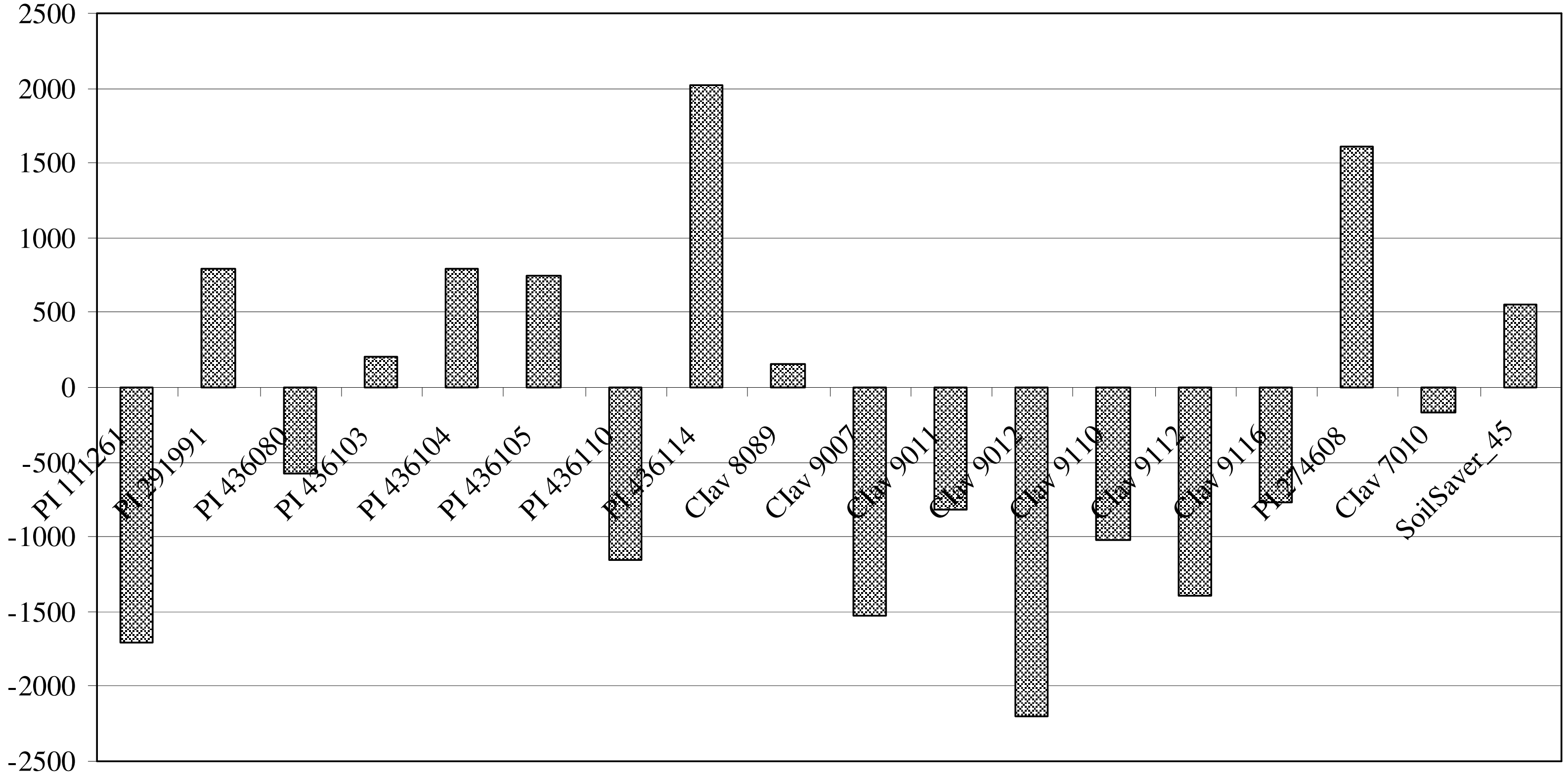

Figure 3-1: Biomass study 2004-05 at Gulf Coast Research and Extension Center, Fairhope. The biomass yield of SoilSaver at standard seeding rate is 8769 kg ha^{-1} with a SED of 174.

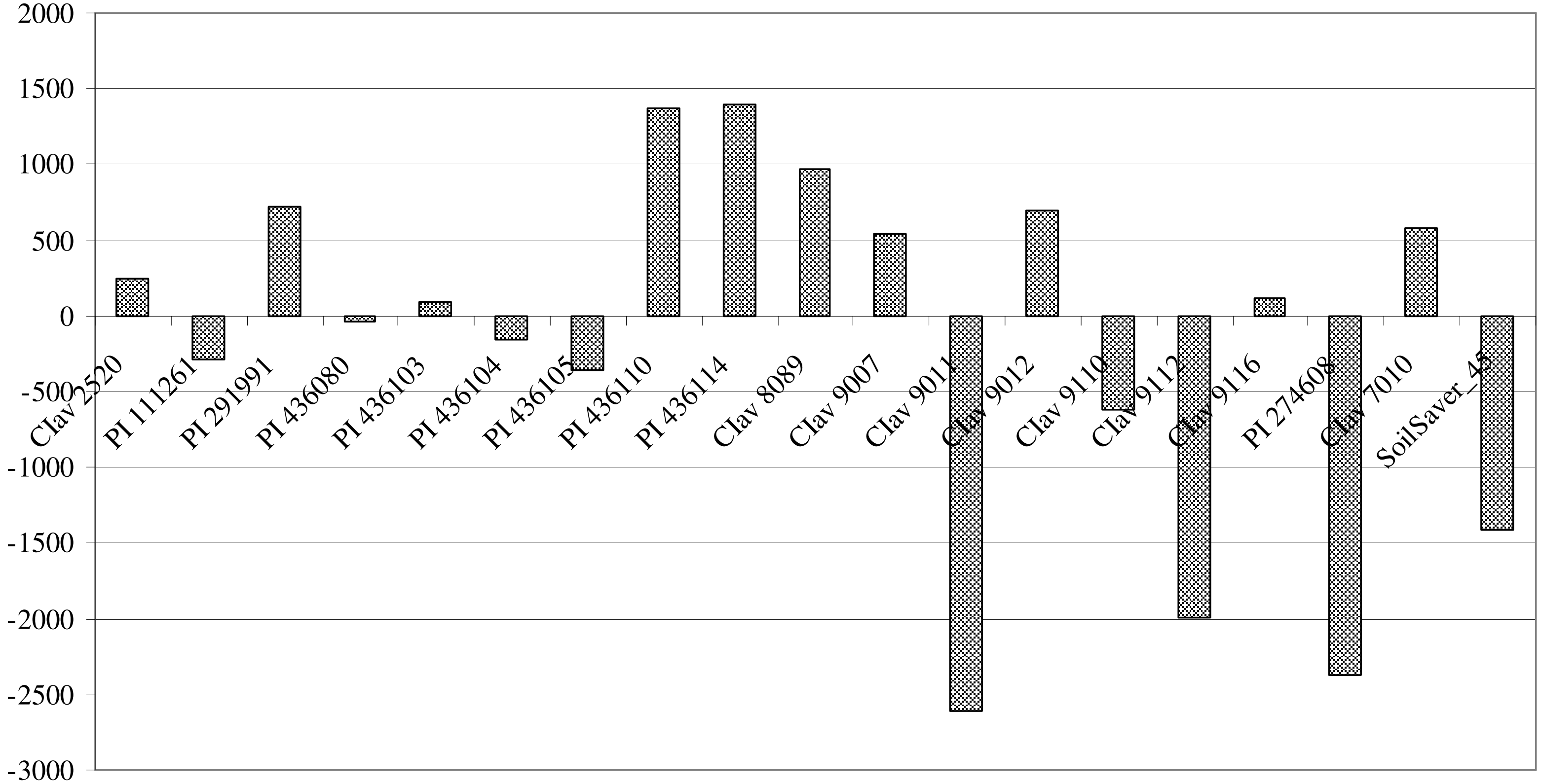

Figure 3-2: Biomass study 2006-07 at Gulf Coast Research and Extension Center, Fairhope. The biomass yield of SoilSaver at standard seeding rate is 6562 kg ha^{-1} with a SED of 971.

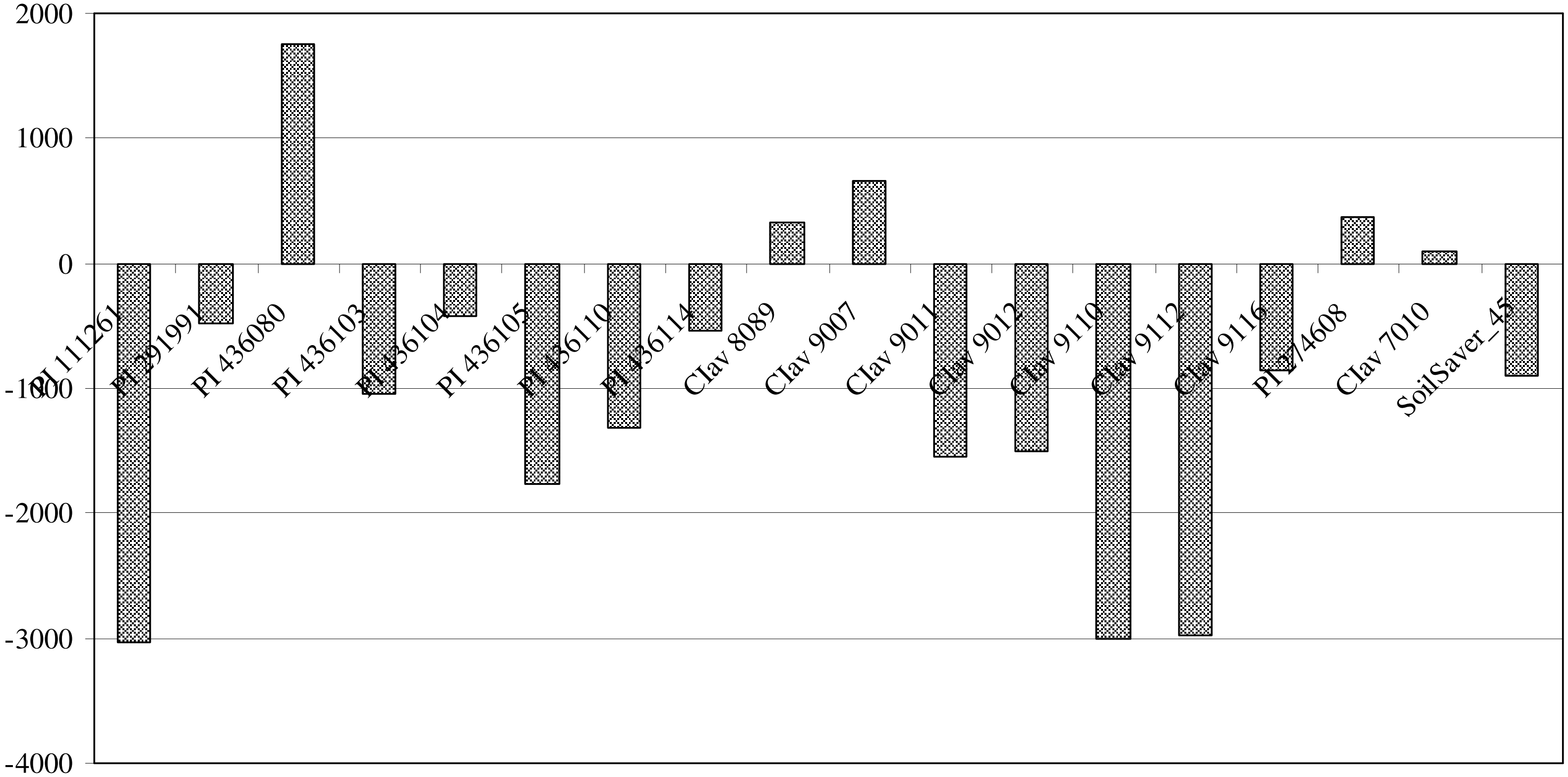

Figure 3-3: Biomass study 2004-05 at Plant Breeding Unit, Tallassee, Alabama. The biomass yield of SoilSaver at standard seeding rate is 11683 kg ha^{-1} with a SED of 374.

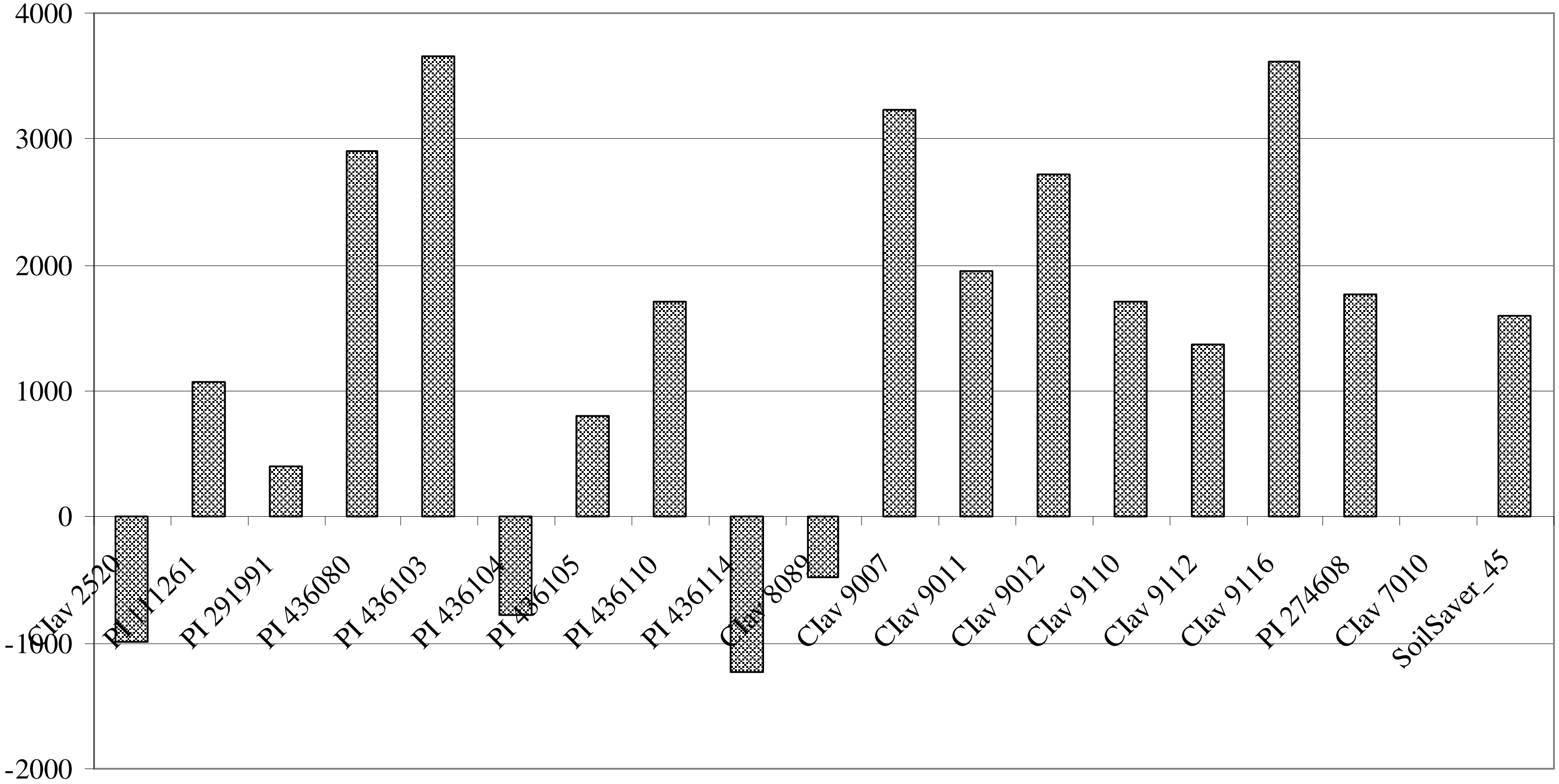

Figure 3-4: Biomass study 2006-07 at Plant Breeding Unit, Tallassee, Alabama. The biomass yield of SoilSaver at standard seeding rate is 6552 kg ha^{-1} with a SED of 1846.

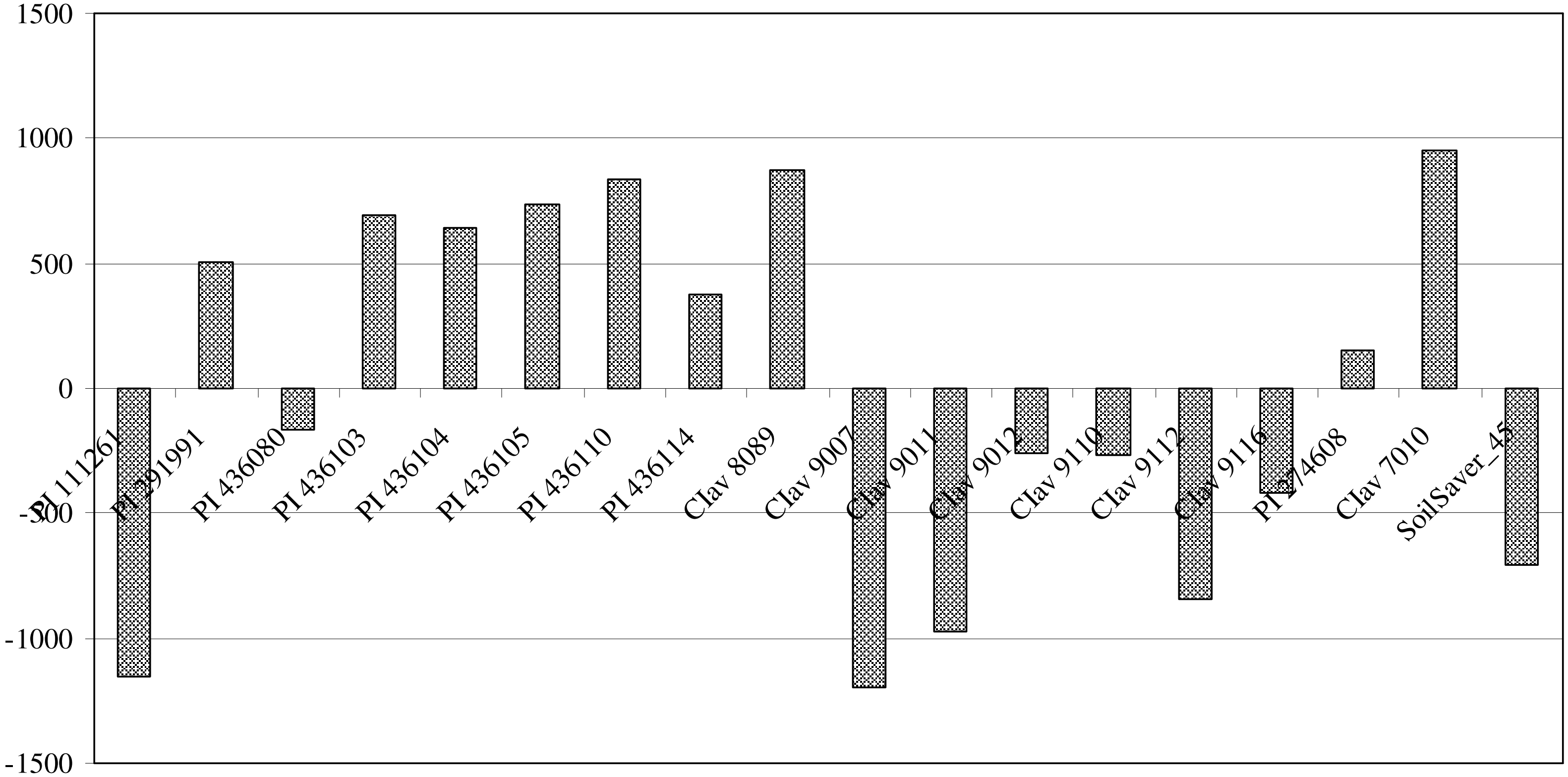

Figure 3-5: Biomass study 2004-05 at Tennessee Valley Research and Extension Center, Belle Mina. The biomass yield of SoilSaver at standard seeding rate is 3997 kg ha^{-1} with a SED of 133

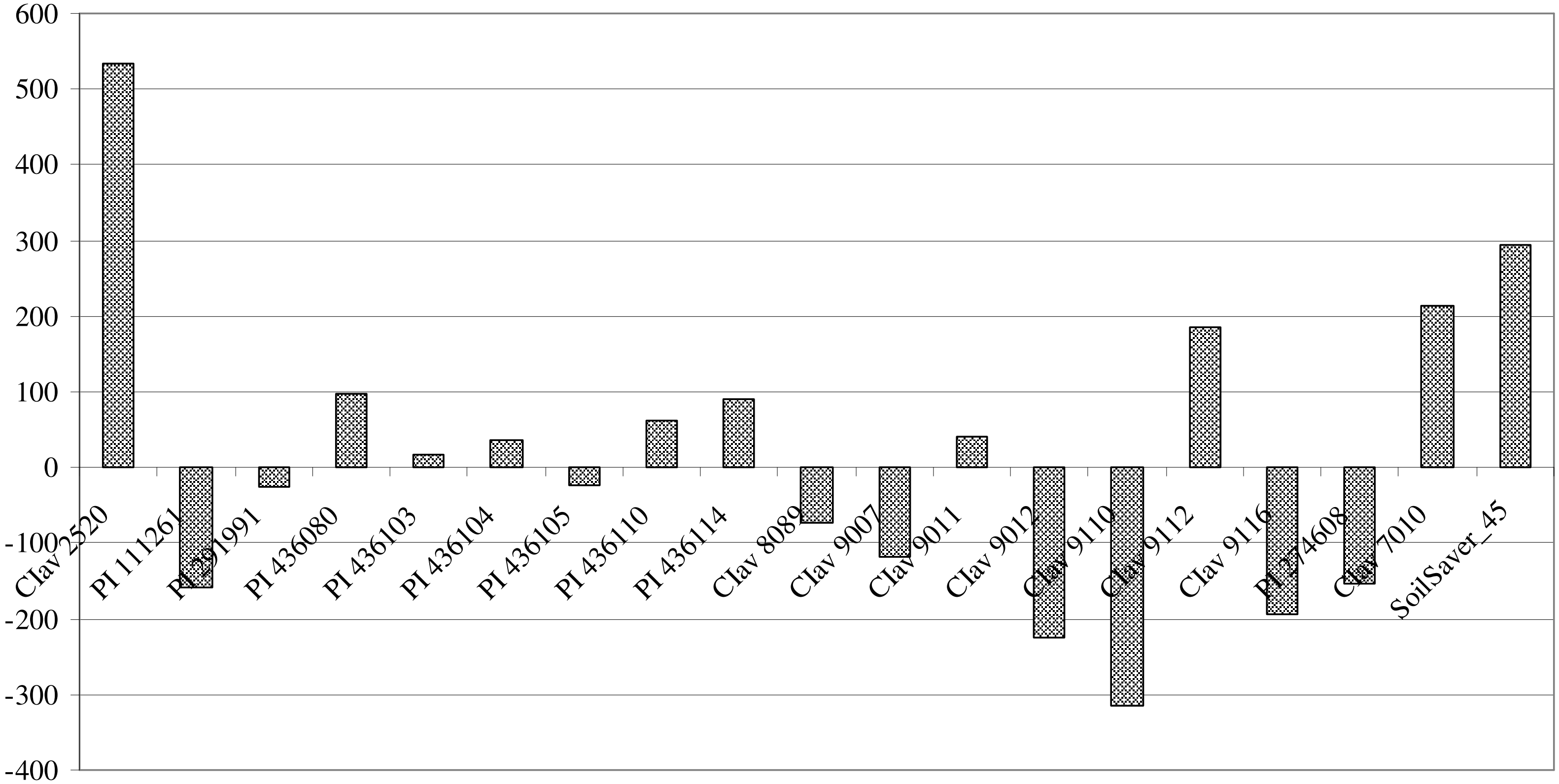

Figure 3-6: Biomass study 2006-07 at Tennessee Valley Research and Extension Center, Belle Mina. The biomass yield of SoilSaver at standard seeding rate is 1473 kg ha^{-1} with a SED of 104.

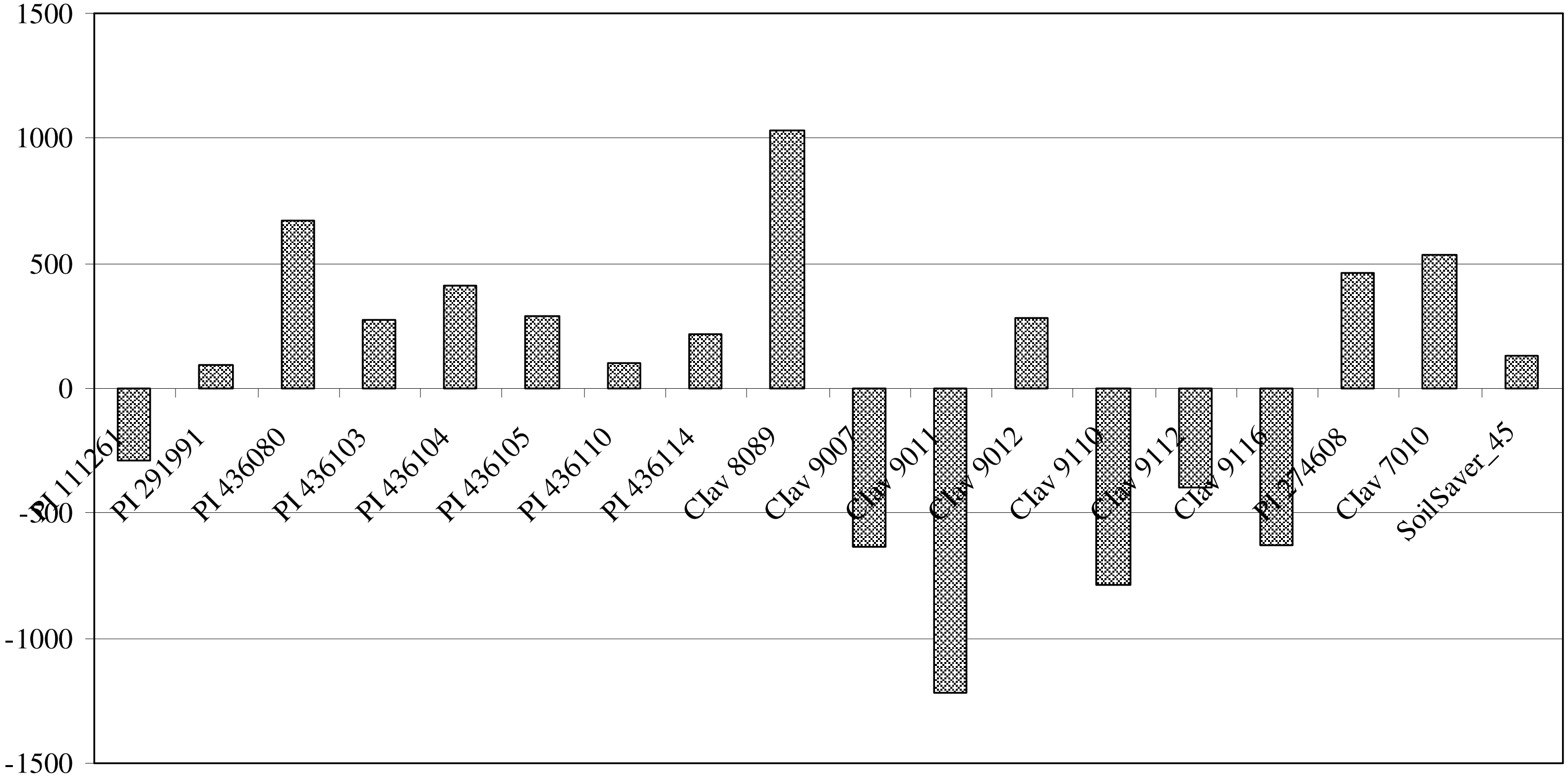

Figure 3-7: Biomass study 2004-05 at Wiregrass Research and Extension Center, Headland. The biomass yield of SoilSaver at standard seeding rate is 4088 kg ha^{-1} with a SED of 94.

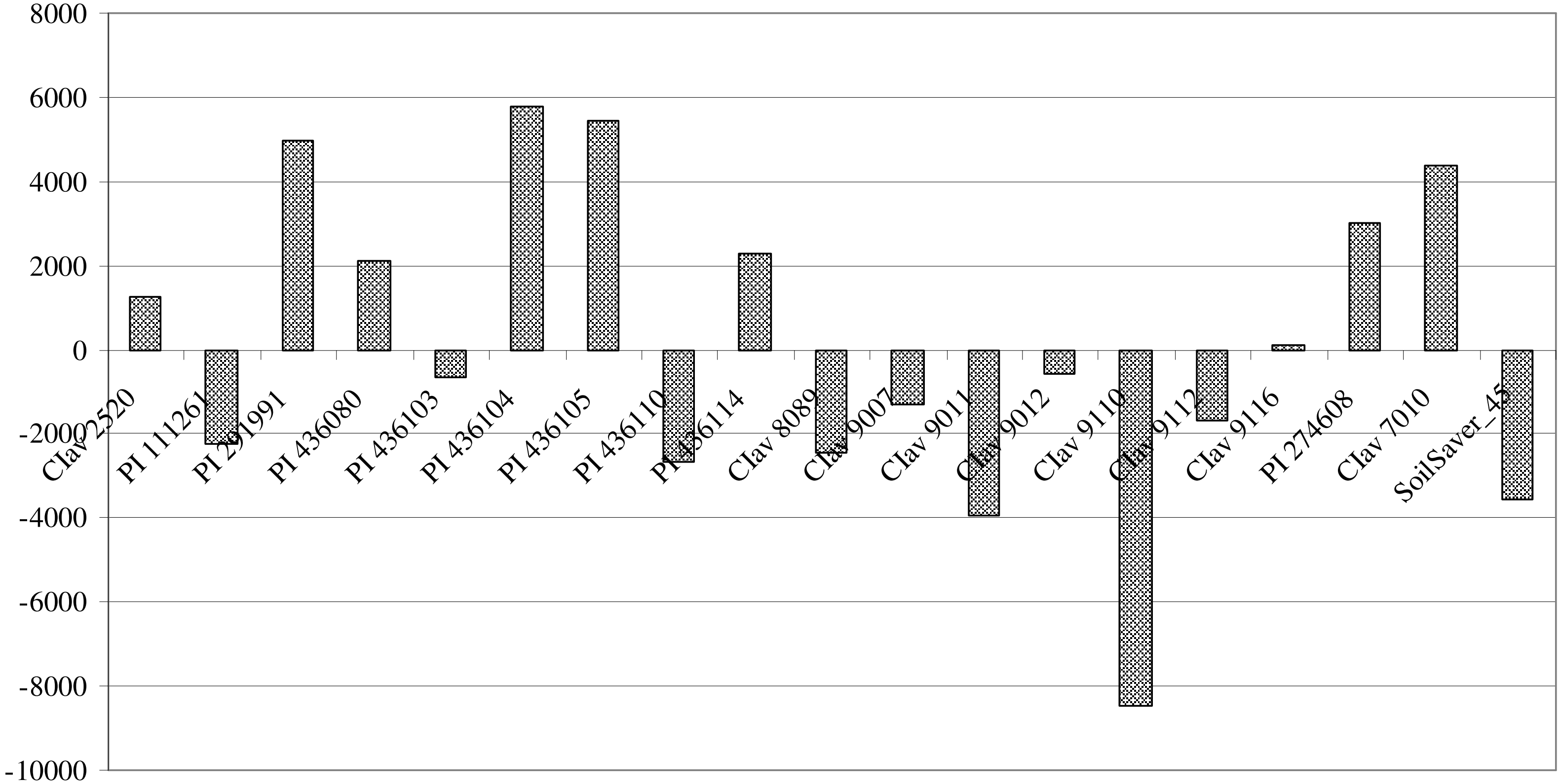

Figure 3-8: Biomass study 2006-07 at Prattville Agricultural Research Unit. The biomass yield of SoilSaver at standard seeding rate is 10433 kg ha^{-1} with a SED of 1366.

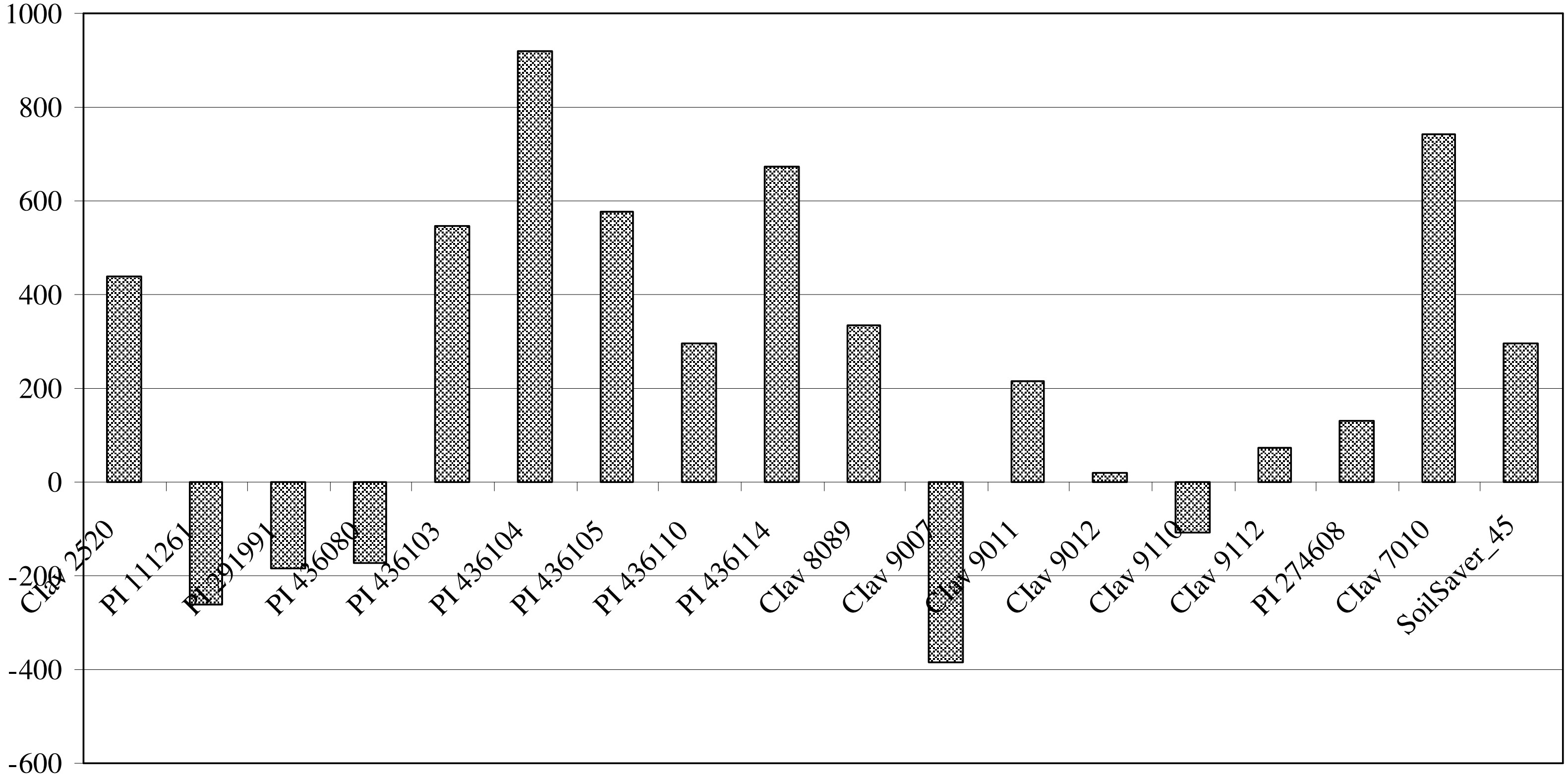

Figure 3-9: Grain yield study 2004-05 at Prattville Agricultural Research Unit, Prattville, Alabama. The grain yield of SoilSaver at standard seeding rate is 652 kg ha^{-1} with a SED of 91.

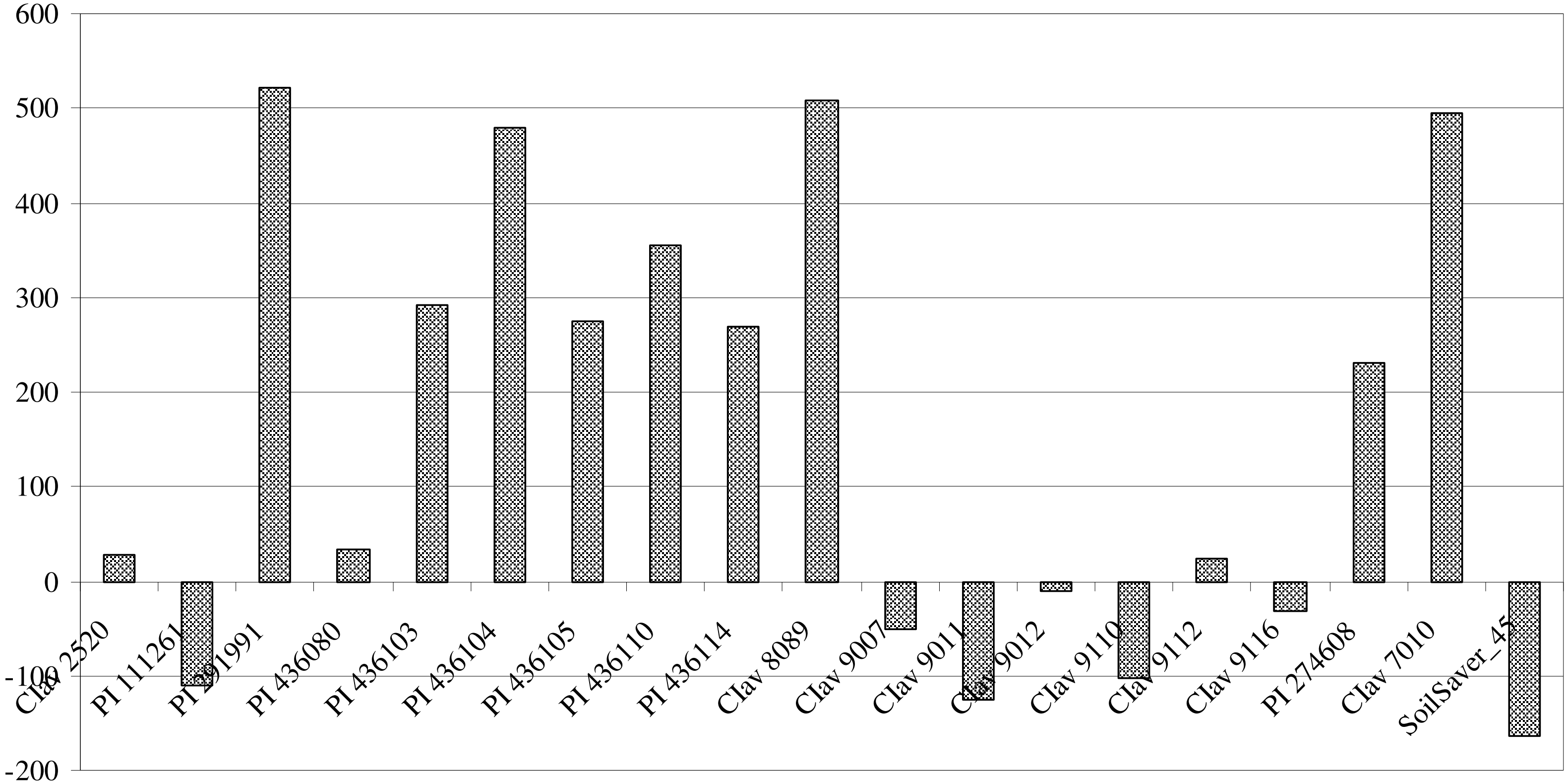

Figure 3-10: Grain yield study 2006-07 at Prattville Agricultural Research Unit, Prattville, Alabama. The grain yield of SoilSaver at standard seeding rate is 822 kg ha^{-1} with a SED of 164.

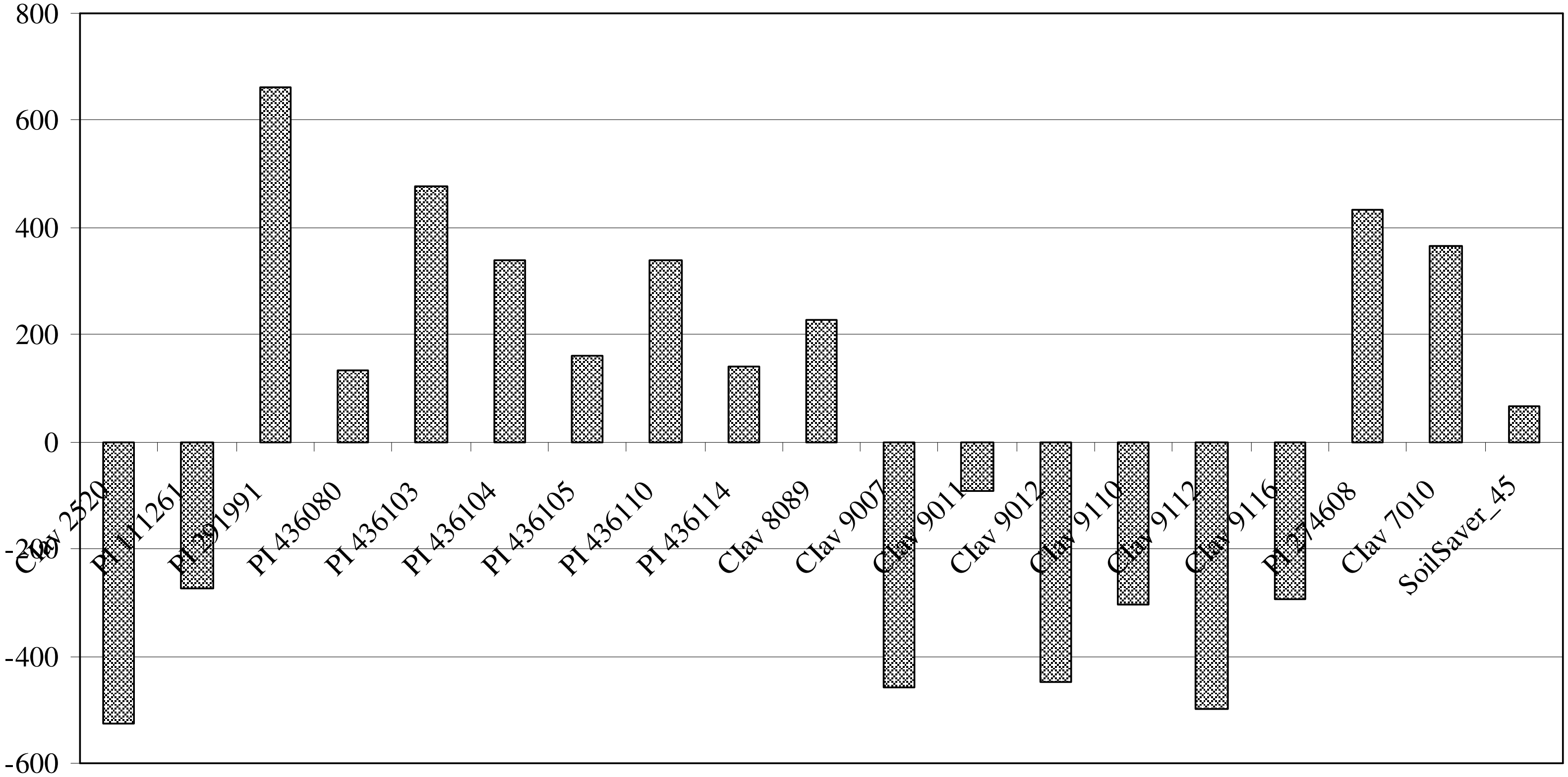

Figure 3-11: Grain yield study 2004-05 at Plant Breeding Unit, Tallassee, Alabama. The grain yield of SoilSaver at standard seeding rate is 1013 kg ha^{-1} with a SED of 73.

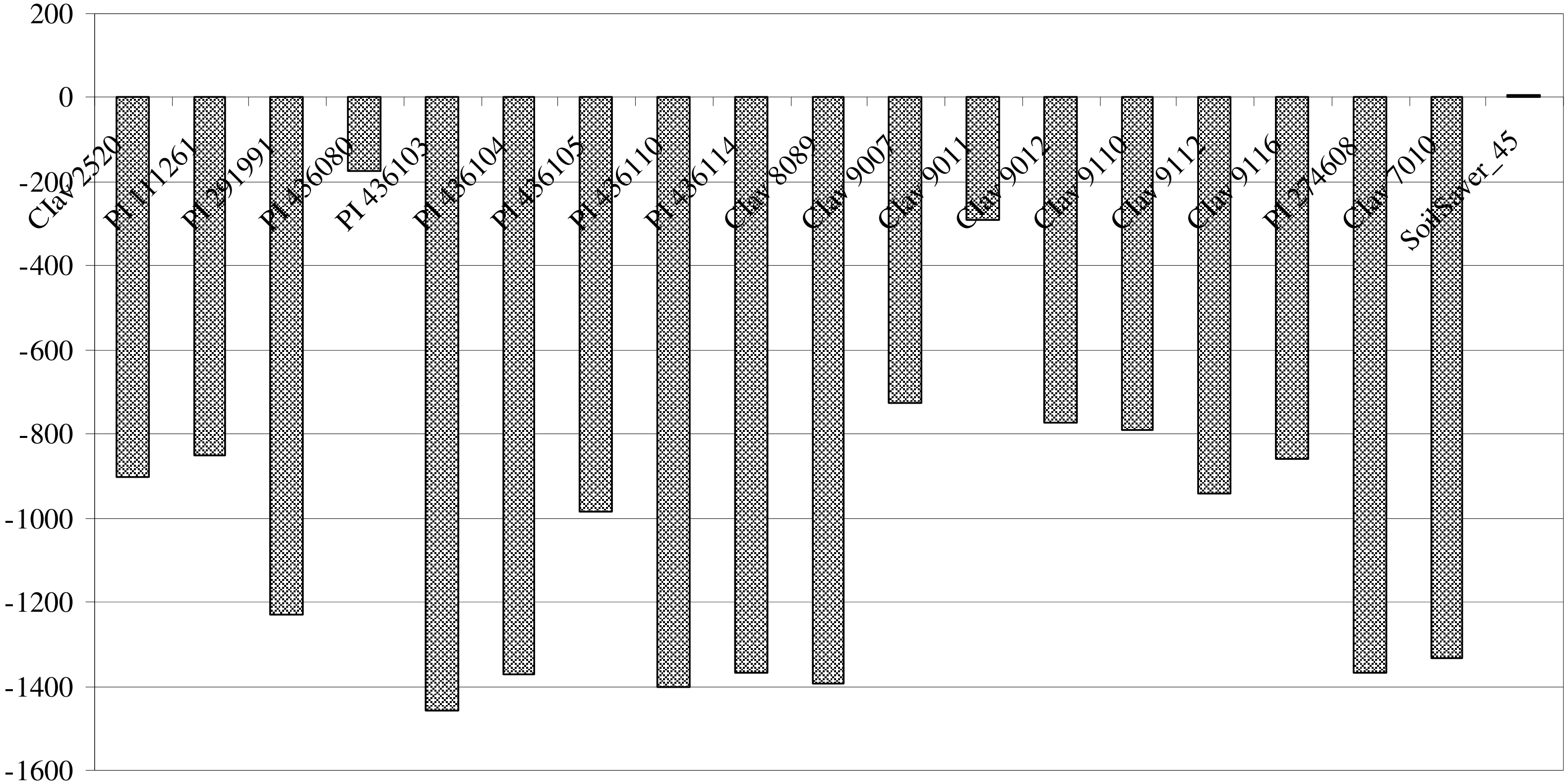

Figure 3-12: Grain yield study 2006-07 at Plant Breeding Unit, Tallassee, Alabama. The grain yield of SoilSaver at standard seeding rate is 1650 kg ha^{-1} with a SED of 80.

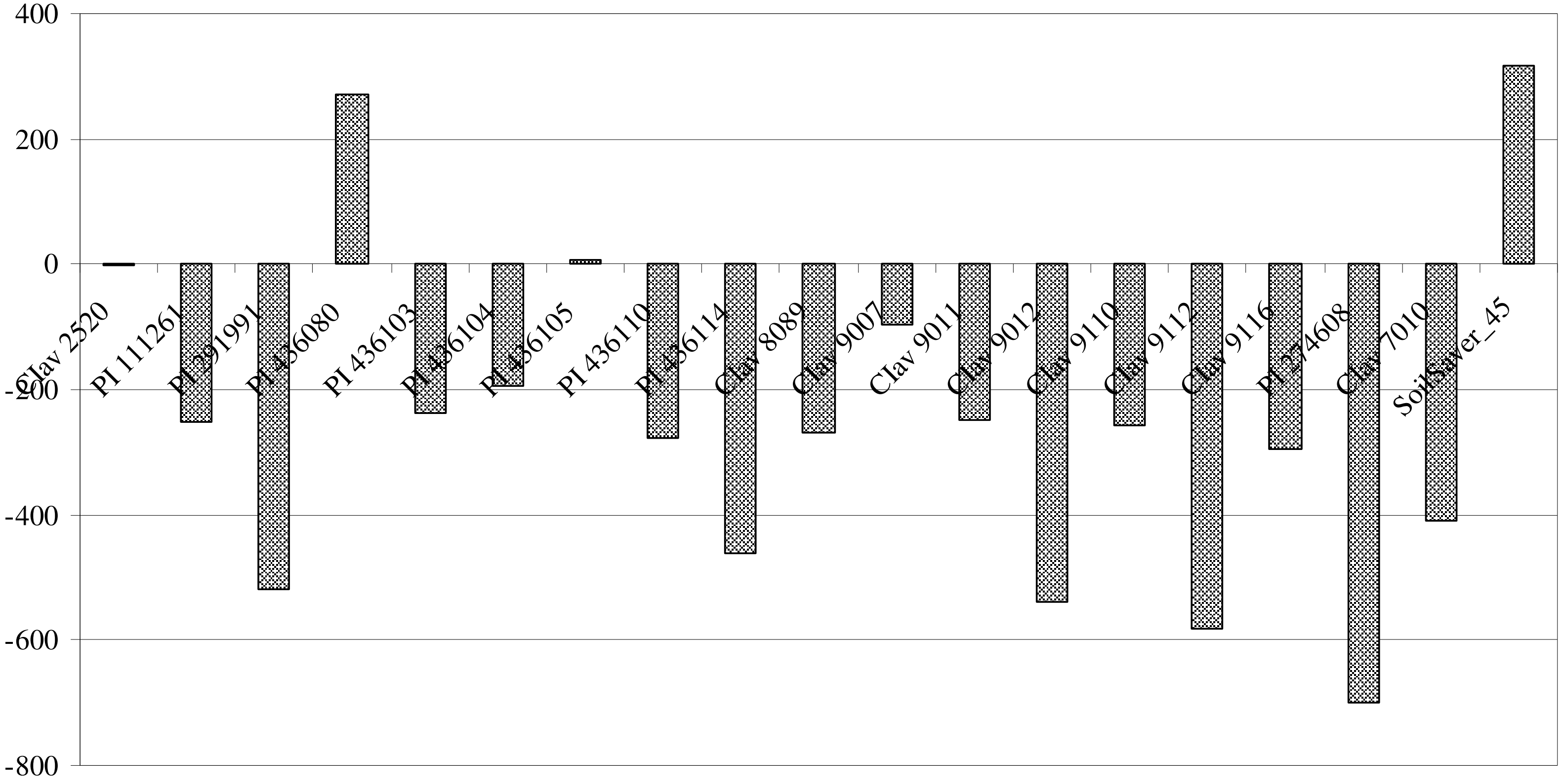

Figure 3-13: Grain yield study 2006-07 at Gulf Coast Research and Extension Center, Fairhope. The grain yield of SoilSaver at standard seeding rate is 1662 kg ha^{-1} with a SED of 142.

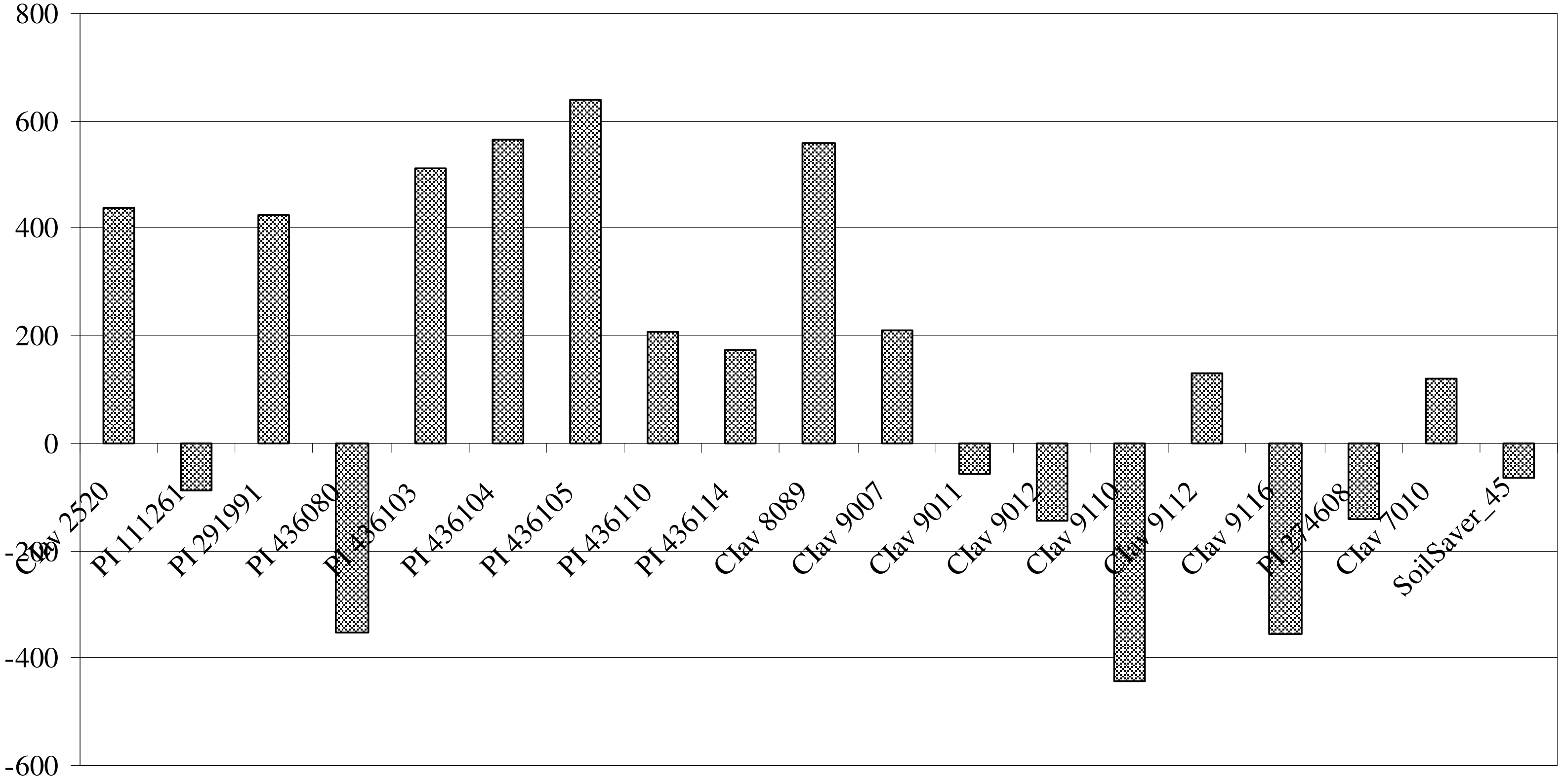

Figure 3-14: Grain yield study 2006-07 at Tennessee Valley Research and Extension Center, Belle Mina. The grain yield of SoilSaver at standard seeding rate is 1130 kg ha^{-1} with a SED of 227.

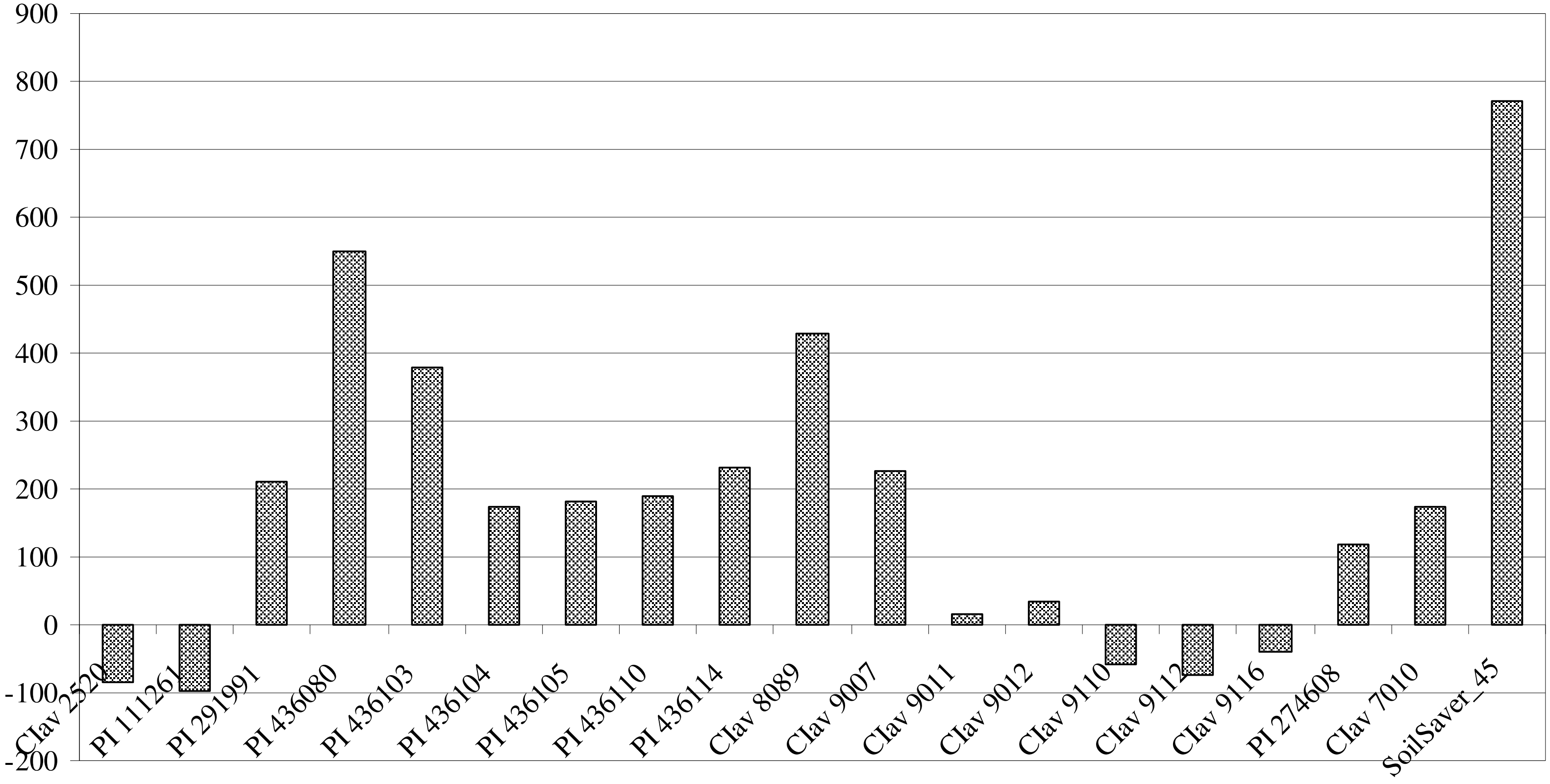

Figure 3-15: Grain yield study 2006-07 at Wiregrass Research and Extension Center, Headland. The grain yield of SoilSaver at standard seeding rate is 344 kg ha^{-1} with a SED of 144.

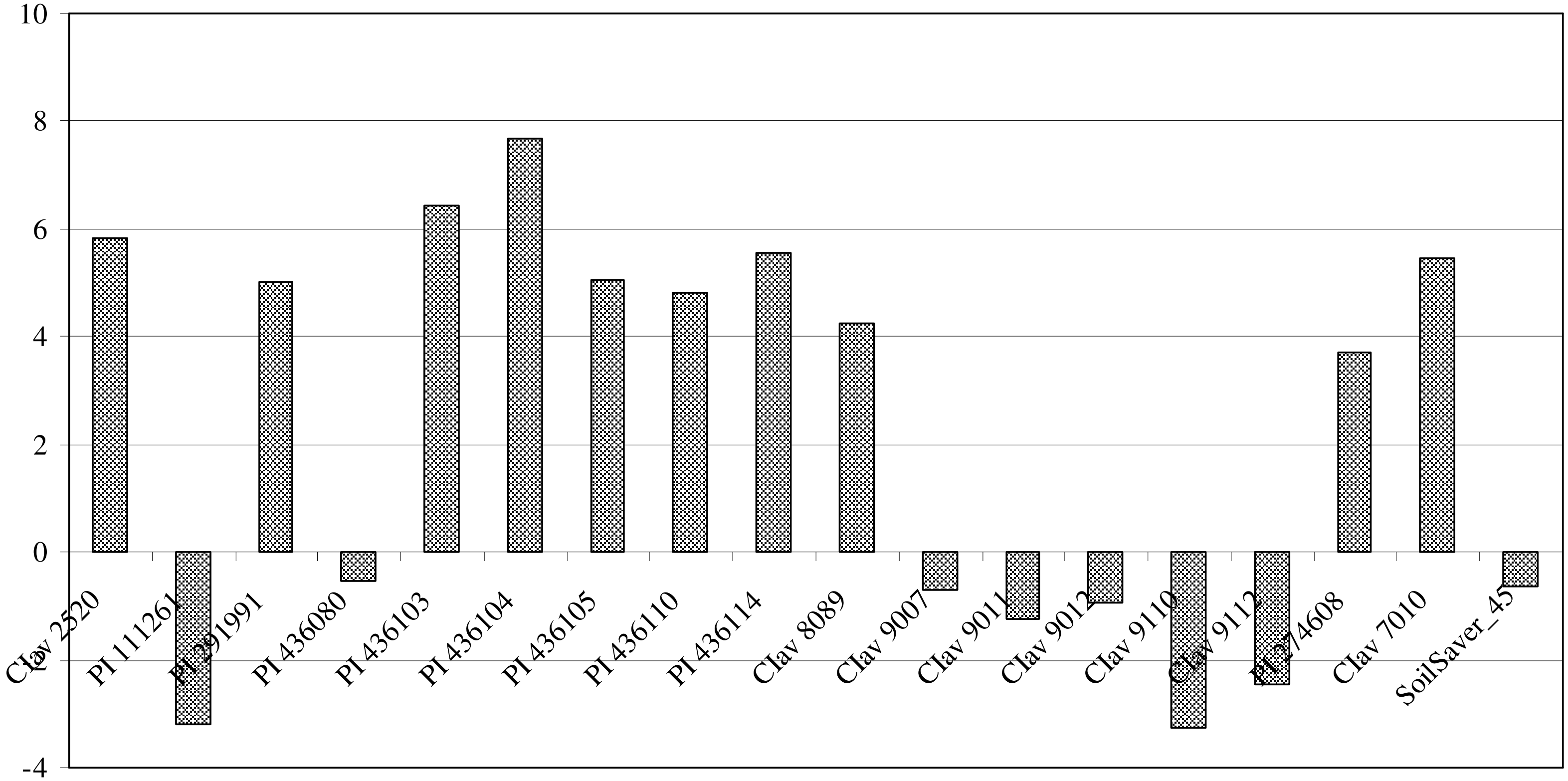

Figure 3-16: Test weight study 2004-05 at Prattville Agricultural Research Unit, Prattville. The grain yield of SoilSaver at standard seeding rate is 32.1 lbs bu^{-1} with a SED of 0.4.

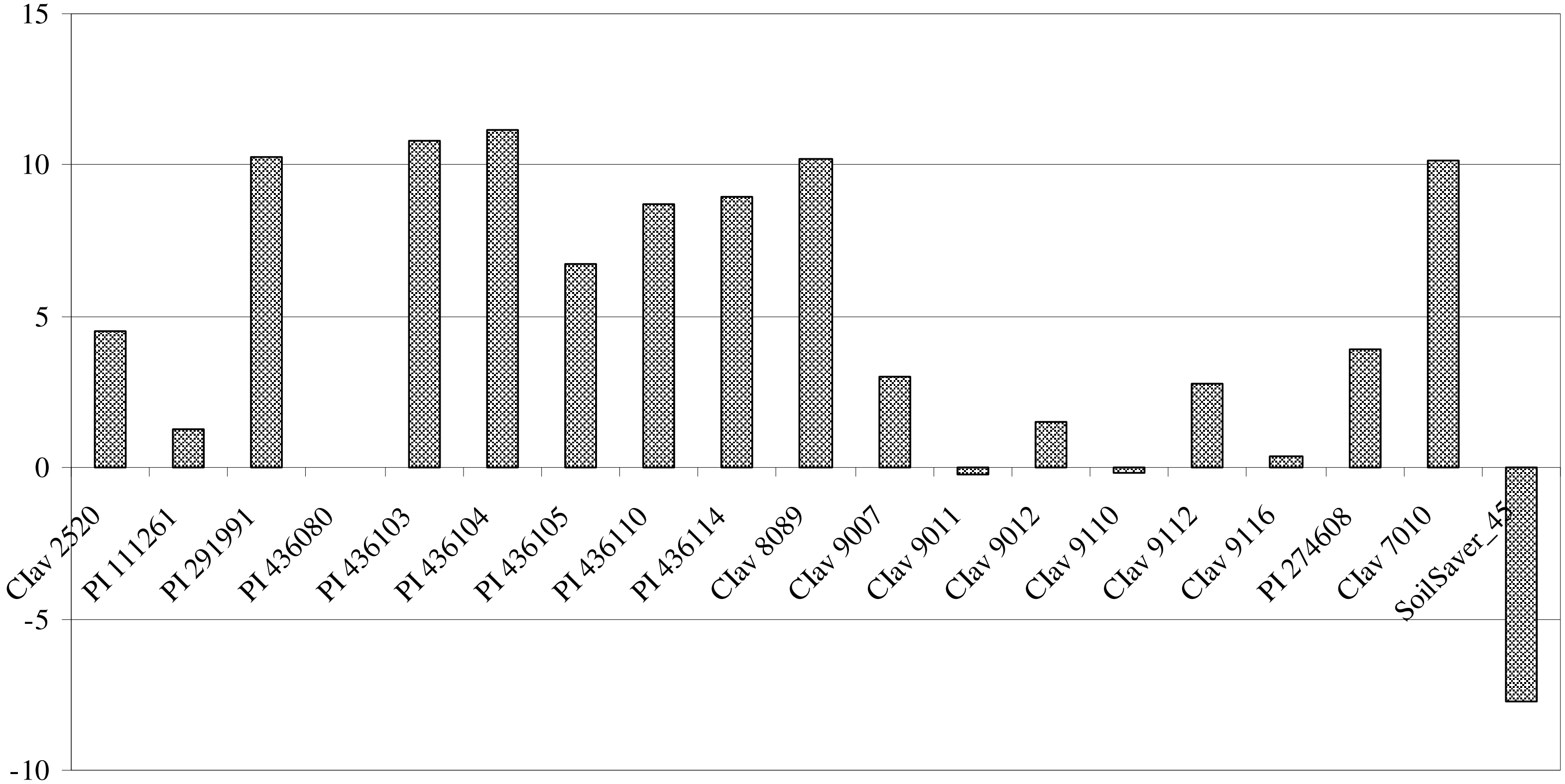

Figure 3-17: Test weight study 2006-07 at Prattville Agricultural Research Unit, Prattville. The grain yield of SoilSaver at standard seeding rate is 25.8 lbs bu^{-1} with a SED of 2.3

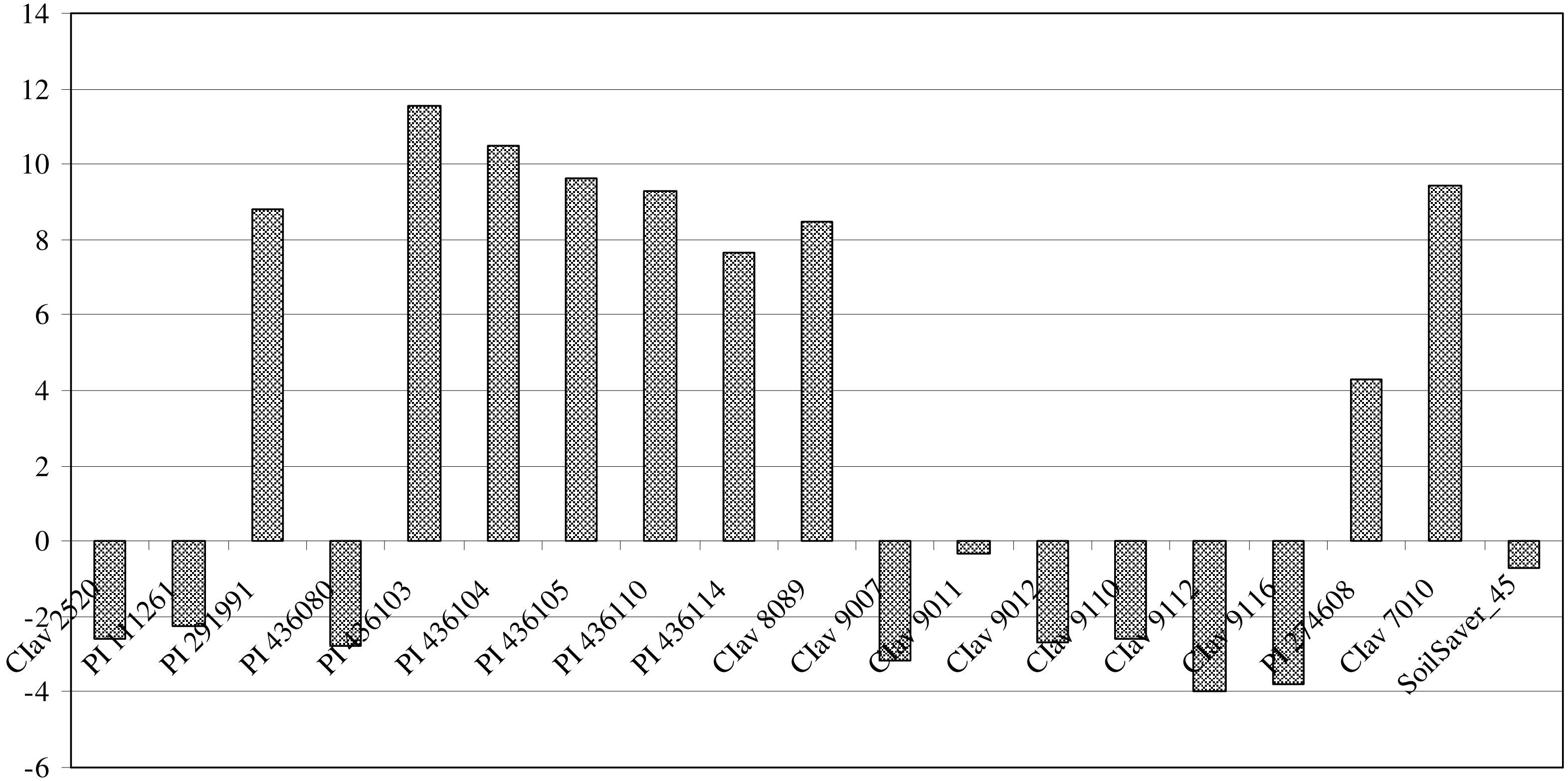

Figure 3-18: Test weight study 2004-05 at Plant Breeding Unit, Tallassee. The grain yield of SoilSaver at standard seeding rate is 27.5 lbs bu^{-1} with a SED of 0.4.

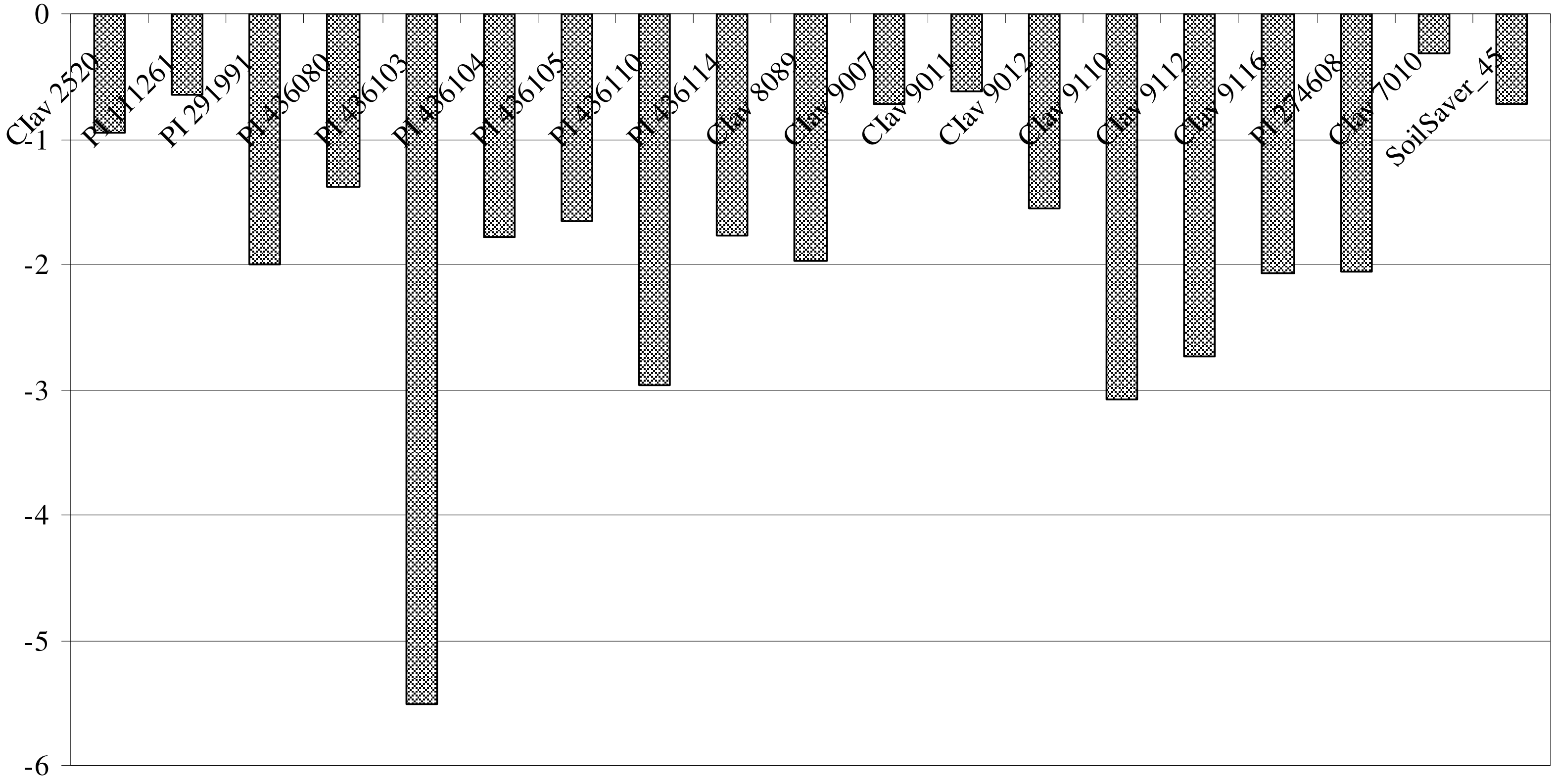

Figure 3-19: Test weight study 2006-07 at Plant Breeding Unit, Tallassee. The grain yield of SoilSaver at standard seeding rate is 25.3 lbs bu^{-1} with a SED of 1.1.

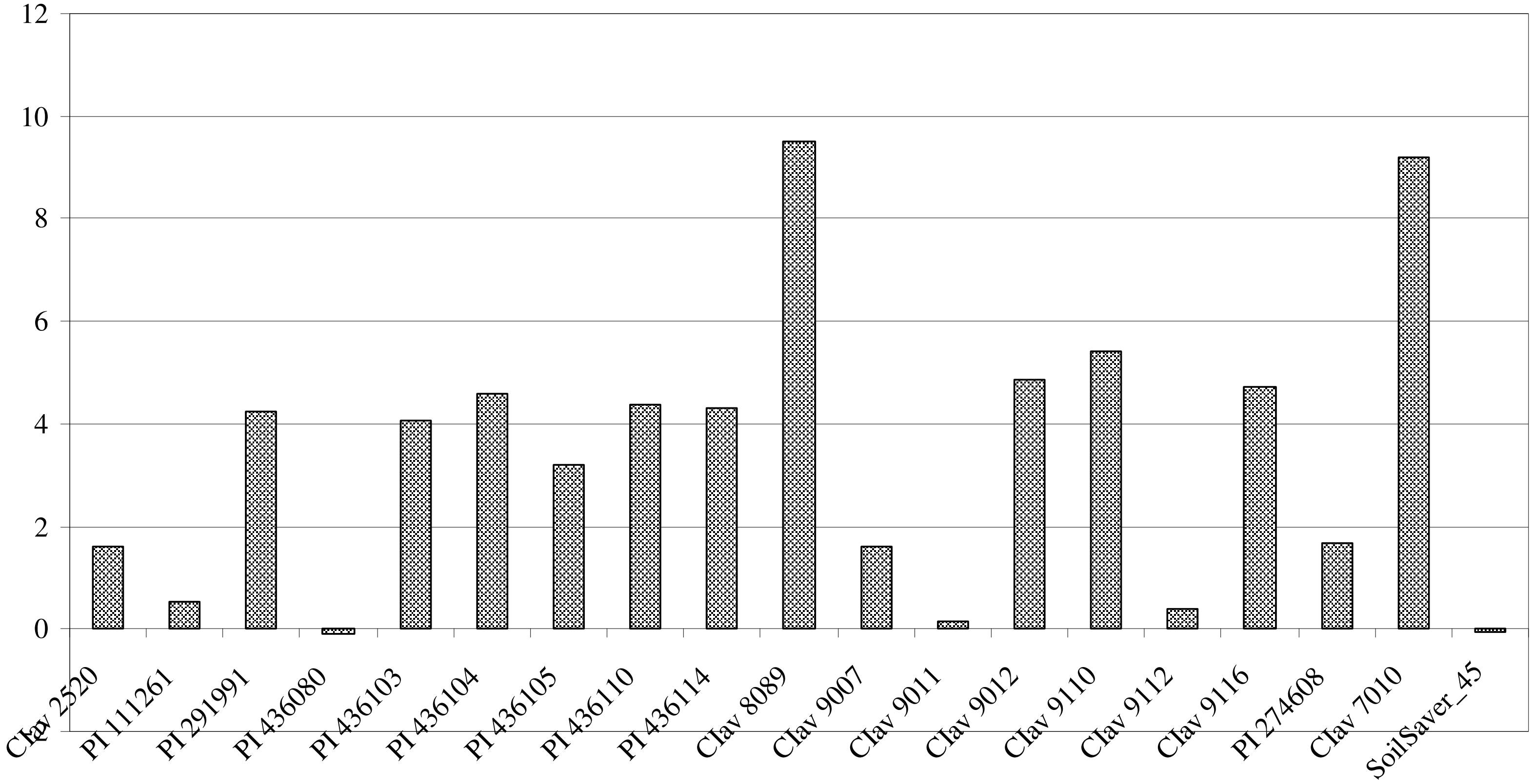

Figure 3-20: Test weight study 2006-07 at Gulf Coast Research and Extension Center, Fairhope. The grain yield of SoilSaver at standard seeding rate is 18.6 lbs bu^{-1} with a SED of 2.3.

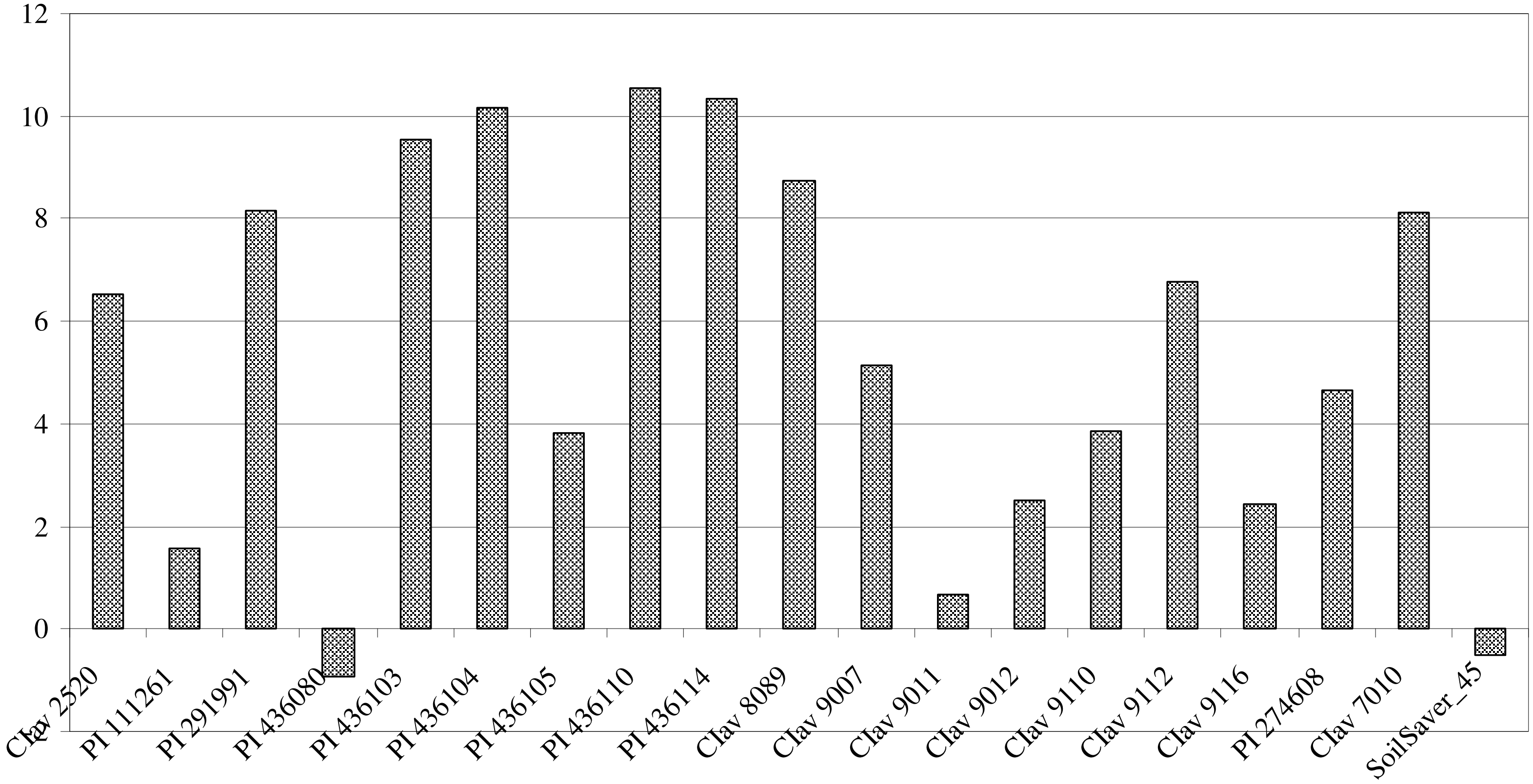

Figure 3-21: Test weight study 2006-07 at Tennessee Valley Research and Extension Center, Belle Mina.. The grain yield of SoilSaver at standard seeding rate is 24.1 lbs bu^{-1} with a SED of 0.9.

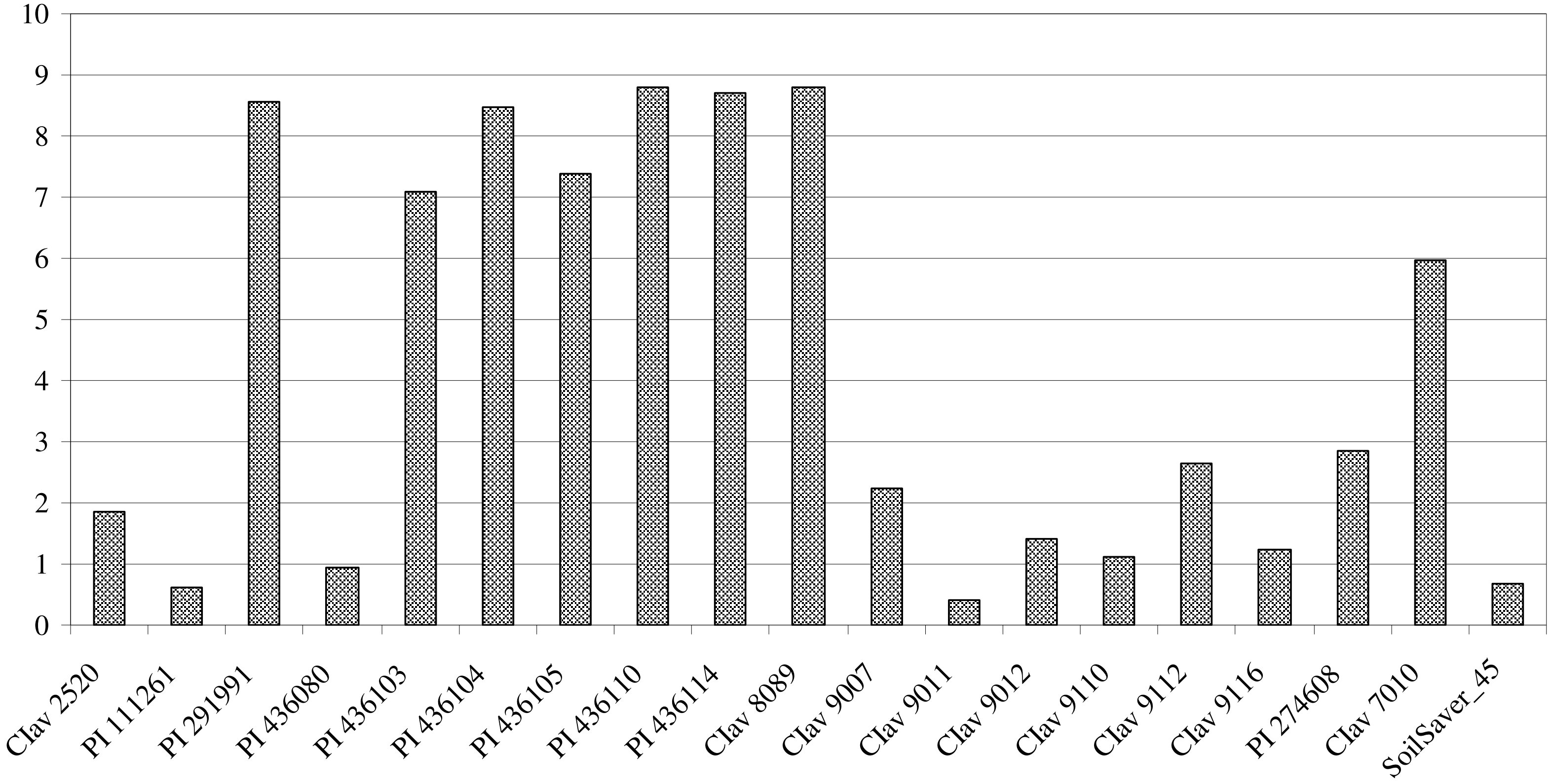

Figure 3-22: Test weight study 2006-07 at Wiregrass Research and Extension Center, Headland. The grain yield of SoilSaver at standard seeding rate is 19 lbs bu^{-1} with a SED of 0.6.

IV. ALLELOPATHY OF BLACK OAT (*AVENA STRIGOSA* SCHREB.) ACCESSIONS

Abstract

Black oat (*Avena strigosa* Schreb.) has been considered to have allelopathic potential in suppressing weedy species in the crop field when grown as a cover crop. Various bio-assays have been used by many researchers in screening plant species based on their allelopathic potential. In this study we compared the allelopathic potential of eighteen black oat accessions and SoilSaver using the modified Pederson bio-assay. All the black oat accession and SoilSaver performed better than the control in suppressing radicle elongation of pre-germinated radish (*Raphanus sativus* L.) seedlings. Accession CIav 2520 expressed the maximum suppression of radicle elongation of the indicator species. .

Introduction

Black oat has been found to be effective in suppressing different weeds in field condition (Price et al., 2006; Reeves et al., 2005), and this may be due to the release of allelopathic chemicals to the soil. The allelopathic potential of a cover crop can be estimated by in-vitro germination and radicle growth bio-assay of the target species using aqueous leachates collected from the donor species at a standard 1% concentration (Caamal-Maldonado et al., 2001). Earlier researchers used the aqueous leachates from seeds (Cope, 1982), roots (Peters, 1968) or stems on a germination paper to test the germination of the indicator species, but Carlson et al (1983) used the extract agar medium for testing germination. Carlson et al (1983) took only the germination percentage data, which were transformed with arcsine square root transformation in order to equalize among treatment variances. Cope (1982) measured the root length of the leguminous species and shoot length of the grassy species to assess allelopathic potential. According to Pederson (1986) the germination using extract agar is more precise than using germination paper since the germination of indicator species on a germination paper may not be even. He also suggested that root length measurement will give better indication of allelopathic effects than the germination method. But some times the dormancy that varies differently among different seeds is a problem in bio-assay and may result in higher experimental error, but the use of pre-germinated seeds will reduce experimental error (Ben-Hammouda et al., 1995; Wardle et al., 1993; Wu et al., 2001). Even though the germination bio-assay is a good way to test the allelopathic effects of donor plants, some researchers argue that findings of the extract screening bioassay may not be extrapolated to real agronomic situation because the allelopathic interactions may be different in crop fields (Romeo and J.D.Weidenhamer, 1999). But as a preliminary way to select the allelopathic potential of a given species, researchers use germination bio-assay extensively. In this study we used a modified method of Pederson (Pederson, 1986) described by Stoll et al (2006) for the screening of black oat accessions for their allelopathic potential.

Materials and Methods

Eighteen black oat accessions and SoilSaver were selected based on the results of a previous study of morphology and maturity of black oat (Table 3-1). The entire evaluation for allelopathic potential was repeated three times. Seeds were sown in 7.6 L plastic containers in 1:1 sand and PRO-MIX medium (Sun Gro Horticulture Distribution Inc., Bellevue, WA) at the Auburn University Plant Sciences Research Center (PSRC) greenhouse and watered daily. Thirty seeds were sown and thinned to 15 seedlings per container after emergence. Three replicattes were planted on 1) last week of December, 2006, 2) third week of January and 3) first week of April 2007. Aboveground biomass was harvested by cutting at soil level 5 weeks after planting, shredded into 15 mm pieces and mixed well. From each sample 10 g plant material was soaked in 50 mL of distilled water in opaque plastic containers. Extracts were filtered after 24 hours using coffee filters into another plastic container and 20 ml of filtered extracts were transferred into separate test tubes. As a control we used 20 mL of distilled water instead of filtered plant extract. Agar medium (12g L^{-1}) was prepared by autoclaving the granulated agar (12 g) mixed with distilled water (1 L) at 121 °C for 15 minutes. The medium was cooled down to 50 °C, mixed with the filtered extract in the test tubes, transferred into Petri plates (15 x 100mm) and allowed to solidify. Radish seeds (*Raphanus sativus* L.) pre-germinated for 24 hours with a radicle length < 2 mm were planted at 5 seedlings/ Petri-plate, sealed with parafilm and kept in dark around 22 °C. The response variable was the radicle lengths 48 h post placement.

We calculated the mean radicle length per Petri plate and analyzed the data using a mixed models approach as implemented in SAS Proc Mixed. Treatment (18 accessions and SoilSaver plus untreated control) was the sole fixed effect and run run x trt effects were considered to be random effects. Accession means were compared to either the untreated control or SoilSaver using Dunnett's test.

Result and Discussion

Accessions CIav 2520, PI 111261, PI 291991, PI 436103, PI 436104, PI 436105 and PI 436110 have significantly greater radicle suppressive ability of the indicator species than SoilSaver. Accession CIav 2520 showed the most radicle suppressive ability among all accession studied. Even though this screening based on bioassay is an indication of the effectiveness of black oat in suppressing weed growth, in real crop field the interaction of different factors may play their role, influencing the actual expression of the allelopathic potential. Also quantification of the allelopathic chemicals using chromatographic method may give more precise information about the antagonistic chemicals present in these accessions.

References

Ben-Hammouda, M.R.J. Kremer, H.C. Minor, and M.Sarwar. 1995. A chemical basis for the differential allelopathic potential of sorghum hybrids on wheat. J. Chem. Ecol. 21:775-786.

Caamal-Maldonado, J.A., J.J. Jime´nez-Osornio, A. Torres-Barragan, and A.L. Anaya. 2001. The use of allelopathic legume cover and mulch species for weed control in cropping systems. Agron. J. 93:27-36.

Carlson, J.R., R.L. Ditterline, J.M. Martin, D.C. Sands, and R.E. Lund. 1983. Alfalfa seed germination in anitibiotic agar containing NaCl. Crop.Sci. 23:882-885.

Cope, W.A. 1982. Inhibition of germination and seedling growth of eight forage species by leachates from seeds. Crop Sci. 22:1109-1111.

Fay, P.K., and W.B. Duke. 1977. An assessment of allelopathic potential in *Avena* germplasm. Weed science 25:224-228.

Pederson, G.A. 1986. White clover seed germination in agar containing tall fescue leaf extracts. Crop Sci. 26:1248-1249.

Peters, E.J. 1968. Toxicity of tall fescue to rape and birdsfoot trefoil seeds and seedlings. Crop Sci. 8:650-653.

Price, A.J., D.W. Reeves, and M.G. Patterson. 2006. Evaluation of weed control provided by three winter cereals in conservation-tillage soybean. Renewable Agriculture and Food Systems 21(3):159-164(6).

Reeves, D.W., A.J. Price, and M.G. Patterson. 2005. Evaluation of three winter cereals for weed control in conservation-tillage nontransgenic cotton. Weed Technology 19:731-736.

Romeo, J.T., and J.D.Weidenhamer. 1999. Bioassay for allelopathy in terrestrial plants, p. 179-211, *In* K. F. Haynes and J. G. Millar, eds. Methods in chemical ecology. Kluwer Academic Publishing, Boston.

Stoll, M.E., A.J. Price, and J.R. Jones. 2006. Cover crop extract effects on radish radicle elongation, p. 184-186 Southern Conservation Systems Conference, Amarillo TX.

Wardle, D.A., K.A. Nicholson, and A. Rahman. 1993. Influence of plant age on allelopathic potential of nodding thistle(*Carduus nutans* L.) against pasture grasses and legumes. Weed research 33:69-78.

Wu, H., J. Pratley, D. Lemerle, T. Haig, and M. An. 2001. Screening methods for the evaluation of crop allelopathic potential. Botanical Review 67(3):403-415.

Table 4-1: The allelopathic potential of different black oat accessions in comparison to SoilSaver.

Treatment	Country of origin	Radicle elongation	P > 0 (Dunnett's) vs. Control	P > 0 (Dunnett's) vs. SoilSaver
		---- mm ----		
Control		65.6		
PI 274608	Poland	25	<0.0001	1.000
CIav 9116	Canada	23.8	<0.0001	0.962
SoilSaver	United States	22.5	<0.0001	
CIav 8089	United States	22.2	<0.0001	1.000
CIav 9112	Canada	21.7	<0.0001	0.473
CIav 7010	Brazil	21.3	<0.0001	0.436
PI 436114	Chile	20.6	<0.0001	0.999
CIav 9007	Romania	20	<0.0001	0.472
CIav 9012	Bulgaria	19.4	<0.0001	0.163
CIav 9011	Denmark	19.3	<0.0001	0.394
CIav 9110	Canada	19.3	<0.0001	0.268
PI 436080	Chile	19.1	<0.0001	0.161
PI 111261	Romania	17.3	<0.0001	0.015
PI 436110	Chile	17.1	<0.0001	0.021
PI 291991	Israel	16.8	<0.0001	0.002
PI 436103	Chile	16.1	<0.0001	0.002
PI 436105	Chile	15.3	<0.0001	0.0005
PI 436104	Chile	14.8	<0.0001	<0.0001
CIav 2520	France	14.3	<0.0001	<0.0001
	SE	3.7		

Appendix 1. Year x accession least squares interaction means.

				Tiller									
Year	NPGS no.	Heading	SE	Angle	SE	Diameter	SE	Length	SE	Node number	SE	Number	SE
2003	CIav 1782	120	5.03	26.67	5.95	2.76	0.24	107.54	4.34	5.33	0.22	29.39	3.49
2004	CIav 1782	138	5.03	69.62	10.24	2.36	0.42	94.37	8.27	5.20	0.41	5.01	4.80
2003	CIav 2520	105	5.03	50.00	5.95	4.40	0.23	132.62	4.34	5.21	0.22	28.59	3.49
2004	CIav 2520	136	5.03	53.00	5.95	3.56	0.26	123.42	4.65	5.60	0.23	9.17	3.49
2003	CIav 2521	120	5.03	48.33	5.95	3.53	0.24	140.69	4.34	6.01	0.22	30.67	3.49
2004	CIav 2521	137	5.03	49.67	5.95	3.24	0.26	123.54	4.65	5.71	0.23	15.20	3.67
2003	CIav 2523	116	5.03	41.67	5.95	3.60	0.42	106.88	8.29	5.32	0.41	25.50	3.49
2004	CIav 2523	141	5.03	47.67	5.95	3.57	0.30	84.86	5.55	4.21	0.28	6.09	4.19
2003	CIav 2524	122	5.03	43.33	5.95	3.64	0.25	133.48	4.48	5.28	0.23	29.22	3.49
2004	CIav 2524	136	5.03	65.47	7.26	2.77	0.38	100.83	7.41	4.50	0.37	13.48	6.36
2003	CIav 2525	120	5.03	45.00	5.95	3.03	0.24	122.40	4.21	5.94	0.21	40.00	3.49
2004	CIav 2525	139	5.03	57.34	7.26	3.25	0.48	105.71	9.53	6.06	0.47	7.31	5.42
2003	PI 78821	120	5.03	53.33	5.95	2.93	0.24	124.81	4.34	6.26	0.22	28.61	3.49
2004	PI 78821	147	5.03	43.33	5.95	4.29	0.27	85.33	5.04	7.18	0.25	5.53	3.58

Appendix 1. Year x accession least squares interaction means.

				Tiller									
Year	NPGS no.	Heading	SE	Angle	SE	Diameter	SE	Length	SE	Node number	SE	Number	SE
2003	PI 83720	117	5.03	58.33	5.95	4.55	0.27	147.05	5.05	6.06	0.25	32.67	3.49
2004	PI 83720	138	5.03	68.34	7.26	2.96	0.33	91.79	6.28	4.40	0.31	6.63	5.41
2003	PI 83721	120	5.03	65.00	5.95	3.11	0.25	117.29	4.48	5.52	0.23	28.89	3.49
2004	PI 83721	138	5.03	65.67	5.95	3.61	0.31	106.69	5.88	4.93	0.29	11.33	3.49
2003	PI 83723	120	5.03	51.67	5.95	3.90	0.23	112.80	4.09	5.58	0.21	22.56	3.49
2004	PI 83723	141	5.03	53.33	5.95	2.78	0.27	90.55	5.04	5.11	0.26	13.12	3.78
2003	CIav 2894	127	5.03	50.00	5.95	3.70	0.30	98.34	5.55	4.66	0.28	10.89	3.49
2004	CIav 2894	139	5.03	40.05	10.24	2.05	0.35	54.67	6.76	3.50	0.33	2.36	4.80
2003	CIav 2920	120	5.03	41.67	5.95	3.51	0.27	107.44	4.83	4.59	0.24	21.94	3.49
2004	CIav 2920	139	5.03	52.67	5.95	3.49	0.31	92.77	5.88	4.37	0.29	8.06	3.49
2003	CIav 2921	122	5.03	46.67	5.95	4.32	0.25	126.20	4.48	6.15	0.23	23.72	3.49
2004	CIav 2921	140	5.03	53.33	5.95	3.05	0.30	99.25	5.55	5.10	0.28	12.89	3.78
2003	CIav 3214	107	5.03	38.33	5.95	4.41	0.28	106.71	5.28	4.76	0.26	24.33	3.49
2004	CIav 3214	137	5.03	48.67	5.95	3.42	0.24	96.88	4.34	4.28	0.22	12.06	3.49

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Appendix 1. Year x accession least squares interaction means.

				Tiller									
Year	NPGS no.	Heading	SE	Angle	SE	Diameter	SE	Length	SE	Node number	SE	Number	SE
2003	PI 111261	103	5.03	65.00	5.95	4.07	0.23	141.46	4.09	4.89	0.21	35.61	3.49
2003	CIav 3372	132	5.03	31.67	5.95	4.38	0.48	109.60	9.53	5.27	0.47	3.44	3.49
2004	CIav 3372	151	5.03	48.33	5.95	3.35	0.80	67.18	16.45	4.14	0.81	2.02	4.37
2003	PI 131695	85	5.03	68.33	5.95	4.45	0.23	127.39	3.98	3.83	0.20	31.00	3.49
2004	PI 131695	127	5.03	60.97	7.26	3.48	0.28	103.32	5.28	4.17	0.26	11.81	4.20
2003	PI 131640	85	5.03	56.67	5.95	4.78	0.23	127.72	3.98	3.67	0.20	25.89	3.49
2004	PI 131640	116	5.03	55.67	5.95	4.30	0.24	103.84	4.21	3.33	0.21	11.72	3.49
2003	PI 131641	86	5.03	58.33	5.95	4.81	0.25	134.30	4.34	3.89	0.22	35.16	3.58
2004	PI 131641	109	5.03	57.33	5.95	4.41	0.24	109.05	4.21	3.62	0.21	20.28	3.49
2003	PI 131642	85	5.03	56.67	5.95	5.00	0.23	107.87	4.09	3.65	0.21	27.22	3.49
2004	PI 131642	113	5.03	40.00	5.95	3.79	0.26	86.50	4.65	3.29	0.23	5.78	3.49
2003	CIav 4639	89	5.03	50.00	5.95	5.28	0.23	132.83	3.98	4.33	0.20	34.67	3.49
2004	CIav 4639	111	5.03	56.67	5.95	5.07	0.24	117.25	4.21	4.25	0.21	20.89	3.49
2003	PI 158244	120	5.03	38.33	5.95	3.20	0.26	122.77	4.65	6.39	0.24	27.83	3.49

Appendix 1. Year x accession least squares interaction means.

				Tiller									
Year	NPGS no.	Heading	SE	Angle	SE	Diameter	SE	Length	SE	Node number	SE	Number	SE
2004	PI 158244	139	5.03	65.47	7.26	2.50	0.28	95.61	5.27	4.97	0.26	7.65	4.37
2003	PI 158246	132	5.03	23.33	5.95	5.11	0.48	112.36	9.53	4.65	0.47	2.94	4.20
2004	PI 158246	152	5.03	39.84	7.26	4.14	0.35	90.70	6.78	3.41	0.34	4.60	4.57
2004	PI 274610	140	5.03	54.84	7.26	2.76	0.31	89.83	5.88	4.24	0.29	8.82	5.07
2003	PI 287315	116	5.03	33.33	5.95	3.09	0.24	124.45	4.21	5.12	0.21	35.00	3.49
2004	PI 287315	131	5.03	58.33	5.95	2.93	0.25	112.52	4.48	5.13	0.23	25.65	3.58
2003	PI 291990	91	5.03	56.67	5.95	4.78	0.23	132.89	3.98	4.22	0.20	30.50	3.49
2004	PI 291990	130	5.03	58.00	5.95	4.90	0.27	111.34	5.04	4.34	0.25	16.26	3.67
2003	PI 291991	92	5.03	60.00	5.95	4.60	0.23	125.75	4.09	4.12	0.21	30.94	3.49
2004	PI 291991	119	5.03	61.67	5.95	4.66	0.23	107.99	4.09	3.99	0.21	16.72	3.49
2003	PI 292226	85	5.03	66.67	5.95	4.75	0.24	127.27	4.21	3.63	0.21	32.94	3.49
2004	PI 292226	108	5.03	57.67	5.95	3.87	0.26	97.64	4.65	3.70	0.23	13.73	4.04
2003	PI 304557	120	5.03	46.67	5.95	6.78	0.80	116.17	16.45	5.90	0.81	4.00	3.49
2004	PI 304557	139	5.03	52.33	5.95	4.13	0.25	106.08	4.48	4.16	0.23	7.66	3.78

Appendix 1. Year x accession least squares interaction means.

				Tiller									
Year	NPGS no.	Heading	SE	Angle	SE	Diameter	SE	Length	SE	Node number	SE	Number	SE
2003	PI 436080	102	5.03	33.33	5.95	3.98	0.23	114.68	4.09	4.63	0.21	22.11	3.49
2004	PI 436080	136	5.03	45.33	5.95	3.33	0.24	113.11	4.34	4.18	0.22	19.89	3.58
2003	PI 436082	134	8.71	35.00	5.95	5.01	0.48	74.69	9.53	4.32	0.47	0.61	3.49
2004	PI 436082	136	5.03	48.97	7.26	3.85	0.38	79.96	7.40	3.97	0.37	1.00	5.08
2003	PI 436103	92	5.03	63.33	5.95	4.63	0.24	130.34	4.21	4.31	0.21	28.61	3.49
2003	PI 436104	95	5.03	61.67	5.95	4.97	0.24	122.89	4.34	3.88	0.22	26.56	3.49
2004	PI 436104	111	5.03	56.00	5.95	3.43	0.23	101.44	3.98	3.94	0.20	14.61	3.49
2003	PI 436105	94	5.03	55.00	5.95	4.85	0.24	137.21	4.21	4.75	0.21	35.50	3.49
2004	PI 436105	112	5.03	55.00	5.95	4.68	0.24	112.55	4.21	4.12	0.21	28.46	3.78
2003	PI 436106	91	5.03	53.33	5.95	4.58	0.23	133.46	4.09	4.36	0.21	35.22	3.49
2004	PI 436106	112	5.03	55.33	5.95	4.53	0.23	107.28	4.09	3.70	0.21	22.80	3.58
2003	PI 306419	122	5.03	61.67	5.95	5.06	0.48	120.73	9.53	7.73	0.47	2.28	3.49
2004	PI 306419	151	5.03	73.33	5.95	3.79	0.58	112.55	11.66	6.97	0.57	1.47	4.04
2003	PI 361910	122	5.03	53.33	5.95	4.62	0.48	97.07	9.53	5.06	0.47	6.00	3.49
2004	PI 361910	150	5.03	52.33	5.95	3.83	0.42	140.02	8.29	4.88	0.41	14.89	3.91

Appendix 1. Year x accession least squares interaction means.

				Tiller									
Year	NPGS no.	Heading	SE	Angle	SE	Diameter	SE	Length	SE	Node number	SE	Number	SE
2003	PI 361912	117	5.03	60.00	5.95	5.68	0.48	106.60	9.53	4.61	0.47	5.94	3.49
2004	PI 361912	150	5.03	61.33	5.95	5.10	0.35	86.64	6.78	4.92	0.34	4.42	4.04
2003	PI 401793	134	5.03	23.33	5.95	3.91	0.35	115.32	6.77	7.67	0.33	31.17	3.49
2004	PI 401793	158	5.03	34.67	5.95	3.64	0.58	100.55	11.66	6.47	0.57	6.57	3.67
2003	PI 401794	134	5.03	46.67	5.95	3.43	0.38	102.72	7.40	6.99	0.37	13.85	4.20
2004	PI 401794	163	5.03	43.00	5.95	2.67	0.33	80.09	6.28	5.71	0.31	12.56	4.04
2004	PI 436107	140	5.03	42.33	5.95	4.15	0.24	93.99	4.34	4.06	0.22	11.06	3.49
2003	PI 436108	107	5.03	31.67	5.95	3.60	0.35	91.26	6.78	3.88	0.34	10.72	3.49
2004	PI 436108	136	5.03	49.67	5.95	2.35	0.24	89.83	4.34	4.08	0.22	14.56	3.49
2003	PI 436109	88	5.03	71.67	5.95	4.85	0.24	124.04	4.21	3.69	0.22	27.78	3.49
2004	PI 436109	112	5.03	50.33	5.95	5.64	0.23	111.23	4.09	3.65	0.21	15.28	3.49
2003	PI 436110	92	5.03	60.00	5.95	4.68	0.24	144.09	4.21	4.75	0.21	40.39	3.49
2004	PI 436110	112	5.03	55.33	5.95	5.19	0.25	107.69	4.34	3.88	0.22	26.44	3.49
2003	PI 436111	89	5.03	63.33	5.95	4.61	0.23	112.22	3.98	4.39	0.20	39.78	3.49
2004	PI 436111	116	5.03	56.67	5.95	3.70	0.24	102.52	4.34	3.66	0.22	28.04	3.67

Appendix 1. Year x accession least squares interaction means.

				Tiller									
Year	NPGS no.	Heading	SE	Angle	SE	Diameter	SE	Length	SE	Node number	SE	Number	SE
2003	PI 436112	134	6.16	45.00	5.95	3.80	0.48	106.09	9.53	5.04	0.47	3.48	4.04
2004	PI 436112	161	6.16	52.34	7.26	3.49	0.38	76.78	7.43	4.34	0.37	2.90	4.57
2003	PI 436119	127	5.03	26.67	5.95	4.21	0.33	105.34	6.27	5.30	0.31	11.09	4.20
2004	PI 436119	151	5.03	37.67	5.95	3.85	0.25	87.63	4.48	4.63	0.23	7.39	3.49
2003	PI 436120	125	5.03	48.33	5.95	4.11	0.48	93.60	9.53	3.94	0.47	8.83	3.49
2004	PI 436120	151	5.03	49.33	5.95	3.11	0.28	72.98	5.27	4.59	0.26	11.58	3.67
2003	PI 436121	125	5.03	36.67	5.95	3.99	0.31	97.58	5.88	5.12	0.29	14.00	3.49
2003	PI 436122	127	5.03	26.67	5.95	4.67	0.42	112.36	8.26	5.26	0.41	0.87	4.37
2004	PI 436122	134	5.03	65.00	5.95	3.16	0.30	119.99	5.55	4.20	0.28	17.61	3.91
2003	PI 436124	125	5.03	51.67	5.95	4.10	0.30	109.87	5.55	5.54	0.28	21.11	3.49
2004	PI 436124	147	5.03	48.00	5.95	3.26	0.25	80.38	4.48	4.88	0.23	12.52	3.90
2003	PI 436125	122	5.03	35.00	5.95	4.35	0.42	92.49	8.27	4.43	0.41	8.44	3.49
2004	PI 436125	137	5.03	51.00	5.95	3.73	0.25	99.88	4.48	4.23	0.23	12.58	3.78
2003	PI 436127	120	5.03	53.33	5.95	4.07	0.30	119.93	5.55	5.68	0.28	24.94	3.49
2004	PI 436127	148	5.03	52.33	5.95	3.68	0.28	91.30	5.27	4.60	0.26	13.77	3.58

Appendix 1. Year x accession least squares interaction means.

				Tiller									
Year	NPGS no.	Heading	SE	Angle	SE	Diameter	SE	Length	SE	Node number	SE	Number	SE
2003	PI 436126	131	6.16	35.10	7.26	4.40	0.42	86.13	8.27	4.99	0.41	0.17	3.49
2004	PI 436126	156	5.03	47.00	5.95	3.34	0.35	77.15	6.77	4.14	0.33	2.75	3.91
2003	PI 436130	134	5.03	45.00	5.95	3.58	0.31	96.60	5.88	5.76	0.29	14.17	3.49
2004	PI 436130	149	5.03	56.00	5.95	2.97	0.24	83.86	4.34	5.52	0.22	16.18	3.67
2003	PI 436131	131	6.16	33.33	5.95	3.68	0.48	120.60	9.53	5.61	0.47	9.39	3.49
2004	PI 436131	161	5.03	38.33	5.95	2.74	0.48	65.86	9.53	3.58	0.47	3.95	3.67
2003	PI 436132	122	5.03	45.00	5.95	3.97	0.31	112.04	5.88	5.60	0.29	25.89	3.49
2004	PI 436132	137	5.03	44.33	5.95	2.99	0.31	83.18	5.88	4.20	0.29	9.74	4.80
2004	PI 436133	159	5.03	53.00	5.95	2.96	0.33	67.03	6.29	4.39	0.31	2.92	3.78
2003	PI 436134	127	5.03	35.00	5.95	4.00	0.38	125.96	6.28	4.74	0.31	4.06	3.49
2004	PI 436134	150	5.03	35.67	5.95	2.96	0.30	70.06	4.48	3.78	0.23	5.06	3.58
2003	PI 436113	109	5.03	35.00	5.95	4.52	0.38	94.22	7.41	3.25	0.37	7.33	3.49
2004	PI 436113	139	5.03	49.67	5.95	3.47	0.25	81.49	4.48	3.47	0.23	9.95	3.67
2003	PI 436114	95	5.03	53.33	5.95	4.43	0.23	133.00	3.98	4.22	0.20	37.22	3.49
2004	PI 436114	111	5.03	57.33	5.95	5.29	0.23	105.11	3.98	3.67	0.20	23.72	3.49

Appendix 1. Year x accession least squares interaction means.

				Tiller									
Year	NPGS no.	Heading	SE	Angle	SE	Diameter	SE	Length	SE	Node number	SE	Number	SE
2003	PI 436115	125	5.03	35.00	5.95	4.04	0.38	84.62	7.41	4.07	0.26	3.94	3.49
2004	PI 436115	151	5.03	42.33	5.95	3.51	0.26	72.87	4.65	3.66	0.23	5.55	3.58
2003	PI 436116	114	5.03	31.67	5.95	4.85	0.38	94.80	7.41	3.40	0.37	4.80	3.49
2004	PI 436116	124	5.03	50.33	5.95	3.36	0.27	90.83	4.64	4.06	0.24	8.83	3.58
2003	PI 436117	86	5.03	65.00	5.95	4.96	0.23	127.17	3.98	4.22	0.20	33.28	3.58
2004	PI 436117	112	5.03	55.67	5.95	4.80	0.23	105.87	4.09	3.82	0.21	18.39	3.49
2003	PI 436118	107	5.03	30.00	5.95	4.60	0.31	96.35	5.89	3.73	0.29	18.26	4.20
2004	PI 436118	135	5.03	46.67	5.95	3.40	0.25	84.69	4.48	4.17	0.23	12.61	3.49
2003	CIav 9019	120	5.03	28.33	5.95	4.32	0.27	124.51	5.03	5.49	0.26	19.00	3.49
2003	CIav 9020	89	5.03	51.67	5.95	4.67	0.23	137.61	3.98	4.78	0.20	38.83	3.49
2004	CIav 9020	112	5.03	56.67	5.95	4.57	0.24	111.11	4.21	3.68	0.21	12.78	3.49
2003	CIav 9021	88	5.03	55.00	5.95	4.87	0.23	131.00	3.98	4.33	0.20	43.00	3.49
2004	CIav 9021	128	5.03	61.67	5.95	4.33	0.26	96.35	4.65	3.20	0.23	18.11	3.49
2003	CIav 9022	113	5.03	61.67	5.95	3.55	0.31	132.30	5.89	5.07	0.47	34.33	3.58
2004	CIav 9022	136	5.03	72.00	5.95	2.98	0.24	109.79	4.21	4.42	0.21	23.45	3.67

Appendix 1. Year x accession least squares interaction means.

				Tiller									
Year	NPGS no.	Heading	SE	Angle	SE	Diameter	SE	Length	SE	Node number	SE	Number	SE
2003	CIav 9024	122	5.03	48.33	5.95	3.88	0.24	126.60	4.34	5.53	0.22	28.06	3.49
2004	CIav 9024	141	5.03	67.00	5.95	3.00	0.28	95.71	5.27	5.27	0.26	5.88	3.67
2003	CIav 9030	127	5.03	50.00	5.95	3.34	0.31	96.83	5.88	4.87	0.29	9.44	3.49
2004	CIav 9030	137	5.03	73.33	5.95	4.18	0.27	100.65	4.83	4.56	0.24	18.17	3.49
2003	CIav 8089	92	5.03	61.67	5.95	4.66	0.23	132.11	4.09	4.30	0.21	37.00	3.49
2004	CIav 8089	111	5.03	61.33	5.95	5.49	0.23	111.00	4.09	3.65	0.21	26.17	3.49
2003	CIav 9007	106	5.03	71.67	5.95	4.43	0.23	142.78	3.98	4.72	0.20	41.17	3.49
2004	CIav 9007	132	5.03	68.67	5.95	3.60	0.25	129.49	4.48	4.70	0.23	12.56	3.49
2003	CIav 9011	105	5.03	68.33	5.95	4.20	0.23	140.56	4.09	4.70	0.21	39.89	3.49
2004	CIav 9011	136	5.03	61.00	5.95	3.41	0.27	126.39	4.83	4.91	0.24	14.08	3.58
2004	CIav 9012	135	5.03	70.00	5.95	3.67	0.25	136.44	4.48	5.22	0.23	19.88	3.67
2003	CIav 9014	108	5.03	50.00	5.95	5.30	0.31	122.47	5.88	4.89	0.29	8.11	3.49
2004	CIav 9014	144	5.03	56.67	5.95	4.04	0.30	103.72	5.55	4.51	0.28	9.21	3.67
2003	CIav 9015	25	5.03	73.33	5.95	2.54	0.25	62.19	4.48	2.21	0.23	12.28	3.49
2004	CIav 9015	-32	5.03	65.32	10.24	1.27	0.38	49.88	7.41	2.72	0.37	2.03	5.84

Appendix 1. Year x accession least squares interaction means.

				Tiller									
Year	NPGS no.	Heading	SE	Angle	SE	Diameter	SE	Length	SE	Node number	SE	Number	SE
2003	CIav 9066	131	6.16	31.67	5.95	3.73	0.38	126.85	7.43	4.83	0.37	1.44	3.49
2004	CIav 9066	151	5.03	45.69	7.26	4.38	0.31	90.76	5.88	3.49	0.29	4.60	5.41
2003	CIav 9110	105	5.03	70.00	5.95	4.03	0.24	126.61	4.34	4.81	0.23	33.61	3.49
2004	CIav 9110	137	5.03	66.34	7.26	3.32	0.31	103.88	5.88	4.40	0.29	12.19	4.04
2003	CIav 9112	110	5.03	70.00	5.95	3.35	0.35	116.34	6.80	4.40	0.34	39.33	3.49
2004	CIav 9112	139	5.03	65.00	5.95	2.99	0.27	111.24	4.83	5.07	0.24	12.83	3.49
2003	CIav 9116	105	5.03	73.33	5.95	4.05	0.24	116.33	4.34	4.36	0.23	48.94	3.49
2004	CIav 9116	136	5.03	70.67	5.95	3.59	0.27	125.48	4.83	4.83	0.24	20.89	3.67
2003	PI 274608	103	5.03	58.33	5.95	5.01	0.26	140.47	4.65	4.35	0.23	37.11	3.49
2004	PI 274608	120	5.03	54.67	5.95	4.69	0.23	107.40	4.09	4.05	0.21	18.78	3.49
2003	PI 274609	85	5.03	43.33	5.95	5.14	0.23	108.50	3.98	3.78	0.20	26.28	3.49
2003	CIav 9031	117	5.03	43.33	5.95	4.48	0.38	79.24	7.41	4.44	0.37	4.78	3.49
2004	CIav 9031	143	5.03	65.67	5.95	3.90	0.26	80.75	4.64	4.07	0.23	4.00	3.49
2003	CIav 9035	114	5.03	43.33	5.95	3.28	0.80	84.17	16.45	3.90	0.81	7.06	3.49
2004	CIav 9035	131	5.03	47.00	5.95	4.84	0.25	94.07	4.48	3.57	0.23	10.50	3.49

Appendix 1. Year x accession least squares interaction means.

				Tiller									
Year	NPGS no.	Heading	SE	Angle	SE	Diameter	SE	Length	SE	Node number	SE	Number	SE
2003	CIav 9038	114	5.03	38.33	5.95	5.03	0.58	78.17	11.66	4.40	0.57	2.78	3.49
2004	CIav 9038	152	5.03	47.00	5.95	4.37	0.30	100.13	5.55	4.35	0.28	6.76	4.04
2003	CIav 9043	120	5.03	38.33	5.95	3.99	0.31	130.42	5.89	5.76	0.29	27.39	3.49
2004	CIav 9043	136	5.03	56.47	7.26	3.31	0.28	100.14	5.28	4.94	0.26	9.59	4.57
2003	CIav 9064	65	5.03	53.33	5.95	2.95	0.23	100.95	4.21	3.62	0.21	24.94	3.49
2004	CIav 9064	119	5.03	63.47	7.26	2.70	0.27	88.50	5.27	2.81	0.25	3.98	4.20
2003	PI 158247	86	5.03	66.67	5.95	4.46	0.23	139.89	3.98	3.83	0.20	38.39	3.49
2004	PI 158247	113	5.03	68.67	5.95	5.76	0.24	113.65	4.34	3.19	0.22	13.29	3.67
2003	CIav 5057	109	5.03	28.67	5.95	4.41	0.31	119.54	5.89	4.93	0.29	12.44	3.49
2004	CIav 5057	146	5.03	36.67	5.95	3.47	0.27	93.21	5.03	4.26	0.25	5.92	4.04
2003	CIav 5082	89	5.03	60.00	5.95	4.66	0.23	128.80	4.09	3.94	0.21	34.13	3.58
2004	CIav 5082	115	5.03	54.67	5.95	5.37	0.24	105.31	4.34	3.65	0.22	17.80	3.58
2004	CIav 6858	112	5.03	57.67	5.95	5.58	0.23	106.52	4.09	3.52	0.21	19.21	3.58
2003	PI 186606	85	5.03	53.33	5.95	4.98	0.24	121.40	4.21	4.25	0.21	24.56	3.49
2004	PI 186606	109	5.03	56.00	5.95	5.22	0.23	106.89	3.98	3.67	0.20	19.17	3.49

Appendix 1. Year x accession least squares interaction means.

				Tiller									
Year	NPGS no.	Heading	SE	Angle	SE	Diameter	SE	Length	SE	Node number	SE	Number	SE
2003	CIav 6956	88	5.03	46.67	5.95	4.82	0.23	123.34	4.09	4.30	0.21	26.22	3.49
2004	CIav 6956	112	5.03	54.67	5.95	5.60	0.24	112.93	4.21	3.75	0.21	18.83	3.49
2003	CIav 7010	94	5.03	55.00	5.95	4.79	0.24	127.15	4.21	4.19	0.21	28.97	3.49
2004	CIav 7010	116	5.03	58.33	5.95	3.97	0.26	97.23	4.64	3.46	0.23	18.01	3.67
2003	CIav 7121	120	5.03	43.33	5.95	3.10	0.26	111.90	4.65	5.01	0.23	23.02	3.49
2004	CIav 7121	137	5.03	52.34	7.26	2.82	0.38	105.05	7.41	5.54	0.37	8.27	4.37
2003	CIav 7122	122	5.03	33.33	5.95	3.44	0.24	105.81	4.34	4.28	0.22	22.72	3.49
2004	CIav 7122	139	5.03	54.97	7.26	2.46	0.28	92.78	5.28	3.92	0.26	12.82	4.37
2003	CIav 7280	85	5.03	63.33	5.95	5.12	0.23	126.50	3.98	4.33	0.20	27.78	3.49
2004	CIav 7280	109	5.03	57.67	5.95	4.78	0.23	112.47	4.09	3.87	0.22	20.39	3.49
2003	CIav 8087	105	5.03	38.33	5.95	4.75	0.35	105.21	6.77	4.69	0.33	9.33	3.49
2004	CIav 8087	150	5.03	43.33	5.95	4.58	0.28	103.41	5.27	4.77	0.26	2.34	4.19
2003	SoilSaver	102	5.03	36.67	5.95	4.48	0.25	105.88	4.49	3.89	0.23	14.39	3.49
2004	SoilSaver	112	5.03	48.67	5.95	4.29	0.23	96.64	4.09	4.05	0.21	15.89	3.49

Appendix 1. Year x accession least squares interaction means.

		Panicle				Flag leaf				Seed			
Year	NPGS no.	Length	SE	Node number	SE	Length	SE	Width	SE	Yield	SE	Mass	SE
2003	CIav 1782	29.82	1.14	9.40	0.29	112.94	7.87	0.77	0.06	2.11	2.28	11.00	1.29
2004	CIav 1782	26.54	2.16	9.73	0.57	110.80	15.15	0.90	0.12	-0.14	2.73	6.92	2.87
2003	CIav 2520	33.08	1.14	9.60	0.29	108.60	7.40	0.97	0.06	14.95	2.28	8.85	1.18
2004	CIav 2520	28.09	1.22	9.38	0.31	92.94	8.45	0.69	0.07	0.88	2.28	8.59	1.57
2003	CIav 2521	27.94	1.14	9.53	0.29	83.33	8.14	0.85	0.07	6.81	2.28	10.64	1.25
2004	CIav 2521	25.59	1.22	9.01	0.31	94.34	8.45	0.69	0.07	3.43	2.28	7.32	1.38
2003	CIav 2523	23.86	2.49	8.51	0.57	82.03	15.19	0.64	0.12	7.38	2.28	13.09	1.21
2004	CIav 2523	24.94	1.46	8.55	0.38	109.88	10.12	0.70	0.08	0.46	2.28	11.65	2.22
2003	CIav 2524	31.34	1.18	9.50	0.30	113.24	8.15	0.87	0.07	4.86	2.28	10.46	1.33
2004	CIav 2524	26.39	1.94	9.56	0.51	113.89	13.57	0.75	0.11	1.43	2.73	8.91	2.48
2003	CIav 2525	33.16	1.11	10.25	0.28	110.42	7.63	0.91	0.06	6.73	2.28	10.56	1.21
2004	CIav 2525	27.13	2.49	10.36	0.65	88.33	17.47	0.73	0.14	0.31	2.73	10.23	2.86
2003	PI 78821	29.35	1.14	9.46	0.29	89.47	7.87	0.67	0.06	2.99	2.28	9.61	1.25
2004	PI 78821	31.93	1.32	7.73	0.34	149.73	9.61	1.07	0.08	0.43	2.28	17.12	2.03

Appendix 1. Year x accession least squares interaction means.

		Panicle				Flag leaf				Seed			
Year	NPGS no.	Length	SE	Node number	SE	Length	SE	Width	SE	Yield	SE	Mass	SE
2003	PI 83720	39.47	1.33	10.81	0.34	115.11	9.63	0.93	0.08	5.85	2.28	11.16	1.21
2004	PI 83720	26.09	1.64	9.28	0.43	101.03	11.47	0.59	0.09	0.51	2.73	8.18	2.22
2003	PI 83721	27.80	1.18	9.64	0.30	88.01	8.15	0.82	0.07	4.94	2.28	10.06	1.29
2004	PI 83721	32.14	1.54	8.28	0.40	164.59	10.74	0.86	0.09	1.98	2.28	17.58	1.76
2003	PI 83723	30.44	1.08	9.59	0.28	114.19	7.40	0.92	0.06	2.43	2.28	10.08	1.18
2004	PI 83723	23.96	1.38	8.92	0.34	105.42	9.17	0.75	0.07	1.27	2.28	7.06	1.50
2003	CIav 2894	26.14	1.46	10.22	0.38	97.68	10.12	0.57	0.08	1.49	2.28	6.78	1.50
2004	CIav 2894	15.33	1.77	7.00	0.46	62.50	12.37	0.33	0.10	0.35	2.73	4.83	3.51
2003	CIav 2920	27.68	1.27	9.58	0.33	74.71	8.78	0.46	0.07	2.34	2.28	9.88	1.33
2004	CIav 2920	28.34	1.54	9.12	0.40	94.32	10.74	0.56	0.09	1.03	2.28	10.32	1.76
2003	CIav 2921	31.93	1.18	10.29	0.30	114.47	8.14	0.84	0.07	1.82	2.28	8.73	1.38
2004	CIav 2921	26.94	1.46	8.11	0.38	106.32	10.12	0.76	0.08	2.27	2.28	9.58	1.76
2003	CIav 3214	25.63	1.39	9.39	0.36	75.31	9.63	0.67	0.08	4.65	2.28	9.15	1.18
2004	CIav 3214	21.99	1.14	8.94	0.29	75.34	8.14	0.48	0.07	2.35	2.28	10.24	1.29

Appendix 1. Year x accession least squares interaction means.

		Panicle				Flag leaf				Seed			
Year	NPGS no.	Length	SE	Node number	SE	Length	SE	Width	SE	Yield	SE	Mass	SE
2003	PI 111261	34.43	1.08	9.06	0.28	93.39	7.20	0.92	0.06	19.73	2.28	9.69	1.18
2003	CIav 3372	29.04	2.49	9.99	0.65	122.86	17.47	0.76	0.14	0.61	2.54	10.34	4.95
2004	CIav 3372	17.10	4.29	8.06	1.13	105.36	30.22	0.49	0.23	-0.02	2.33	9.55	4.95
2003	PI 131695	29.50	1.05	8.56	0.27	116.22	7.20	0.71	0.06	21.88	2.28	16.70	1.18
2004	PI 131695	24.86	1.39	7.69	0.36	94.41	9.62	0.59	0.08	1.83	2.73	16.27	1.88
2003	PI 131640	33.39	1.05	8.78	0.27	137.95	7.40	0.90	0.06	17.03	2.28	14.01	1.18
2004	PI 131640	25.29	1.11	8.57	0.28	104.72	8.44	0.62	0.07	1.78	2.28	13.61	1.33
2003	PI 131641	32.60	1.14	8.80	0.29	132.86	7.40	0.86	0.06	24.84	2.33	17.01	1.29
2004	PI 131641	26.98	1.11	8.81	0.28	127.45	7.63	0.98	0.06	1.83	2.28	13.43	1.39
2003	PI 131642	30.61	1.08	9.69	0.28	141.93	7.63	0.69	0.06	11.78	2.28	14.61	1.21
2004	PI 131642	25.09	1.22	9.23	0.31	104.66	8.78	0.65	0.07	0.60	2.28	11.73	1.66
2003	CIav 4639	30.06	1.05	8.83	0.27	90.17	7.20	0.78	0.06	24.34	2.28	16.65	1.21
2004	CIav 4639	28.34	1.11	9.13	0.29	118.34	7.63	0.98	0.06	5.13	2.28	14.89	1.21
2003	PI 158244	33.62	1.22	10.46	0.31	150.77	8.45	0.71	0.07	8.65	2.28	10.84	1.38

Appendix 1. Year x accession least squares interaction means.

		Panicle				Flag leaf				Seed			
Year	NPGS no.	Length	SE	Node number	SE	Length	SE	Width	SE	Yield	SE	Mass	SE
2004	PI 158244	25.28	1.38	9.69	0.36	111.77	10.12	0.46	0.08	0.56	2.28	9.40	2.03
2003	PI 158246	34.10	2.49	10.99	0.65	149.11	21.38	0.85	0.17	0.00	2.73	0.00	0.00
2004	PI 158246	27.53	1.77	9.47	0.46	145.47	12.39	0.67	0.10	-0.08	2.73	11.78	2.48
2004	PI 274610	28.16	1.54	10.62	0.40	114.44	10.74	0.68	0.09	0.34	2.28	9.05	2.03
2003	PI 287315	28.23	1.11	9.25	0.28	79.43	7.87	0.62	0.06	5.98	2.28	10.93	1.18
2004	PI 287315	26.35	1.18	9.78	0.30	97.94	8.45	0.48	0.07	3.89	2.28	10.20	1.38
2003	PI 291990	30.56	1.05	8.78	0.27	89.19	7.40	0.82	0.06	13.41	2.28	15.09	1.21
2004	PI 291990	26.41	1.32	8.35	0.34	88.51	9.17	0.67	0.07	2.93	2.28	14.64	1.50
2003	PI 291991	30.20	1.08	8.65	0.28	90.39	7.40	0.67	0.06	14.71	2.28	13.52	1.18
2004	PI 291991	24.08	1.08	8.62	0.28	84.77	7.63	0.61	0.06	3.29	2.28	16.26	1.29
2003	PI 292226	30.85	1.11	8.31	0.28	101.79	8.14	0.65	0.07	26.18	2.28	18.20	1.21
2004	PI 292226	24.21	1.22	7.54	0.31	102.88	8.45	0.65	0.07	1.18	2.28	15.60	1.38
2003	PI 304557	30.65	4.29	11.00	1.13	157.35	30.22	0.76	0.23	0.00	2.28	0.00	0.00
2004	PI 304557	24.69	1.18	7.72	0.30	96.79	8.45	0.58	0.07	0.71	2.28	13.98	1.88

Appendix 1. Year x accession least squares interaction means.

		Panicle				Flag leaf				Seed			
Year	NPGS no.	Length	SE	Node number	SE	Length	SE	Width	SE	Yield	SE	Mass	SE
2003	PI 436080	33.20	1.08	9.41	0.28	88.37	7.40	0.72	0.06	8.65	2.28	10.28	1.18
2004	PI 436080	31.04	1.14	8.53	0.29	109.39	7.87	0.49	0.06	3.83	2.28	12.95	1.33
2003	PI 436082	26.43	2.49	10.66	0.65	109.37	17.47	0.52	0.14	0.03	2.28	3.11	3.50
2004	PI 436082	25.18	1.94	9.19	0.51	111.73	13.54	0.60	0.11	-0.11	2.73	0.24	4.95
2003	PI 436103	30.24	1.11	9.00	0.28	92.74	7.63	0.63	0.06	14.91	2.28	14.18	1.21
2003	PI 436104	30.01	1.14	8.87	0.29	97.10	7.87	0.65	0.06	16.30	2.28	12.98	1.33
2004	PI 436104	23.33	1.05	7.56	0.27	84.17	7.20	0.52	0.06	1.35	2.28	13.89	1.33
2003	PI 436105	30.60	1.11	9.07	0.29	76.23	7.87	0.82	0.06	17.54	2.28	14.15	1.21
2004	PI 436105	25.14	1.11	7.81	0.28	95.39	7.63	0.71	0.06	4.02	2.28	16.39	1.29
2003	PI 436106	30.02	1.08	8.76	0.28	78.86	7.40	0.61	0.06	12.54	2.28	15.99	1.18
2004	PI 436106	23.49	1.08	7.62	0.28	78.57	7.40	0.49	0.06	3.09	2.28	15.86	1.21
2003	PI 306419	38.96	2.49	8.01	0.65	135.14	17.47	0.91	0.14	0.31	2.28	19.42	1.88
2004	PI 306419	39.72	3.04	6.98	0.80	132.87	21.41	1.00	0.17	0.75	2.73	23.54	2.86
2003	PI 361910	23.96	2.49	9.67	0.65	98.81	17.47	0.81	0.14	1.83	2.28	15.71	1.88
2004	PI 361910	37.43	2.17	9.21	0.57	134.28	15.18	0.86	0.12	1.99	2.28	13.70	1.88

Appendix 1. Year x accession least squares interaction means.

		Panicle				Flag leaf				Seed			
Year	NPGS no.	Length	SE	Node number	SE	Length	SE	Width	SE	Yield	SE	Mass	SE
2003	PI 361912	31.71	2.49	7.99	0.65	139.52	17.47	1.52	0.14	4.17	2.28	23.23	1.50
2004	PI 361912	28.64	1.77	6.70	0.46	186.19	12.39	1.21	0.10	0.84	2.28	22.07	2.48
2003	PI 401793	27.95	1.77	9.34	0.46	126.82	12.38	0.39	0.10	0.14	2.28	5.15	2.22
2004	PI 401793	21.22	3.04	7.98	0.80	85.37	21.41	0.30	0.17	0.00	2.28	0.24	4.95
2003	PI 401794	22.49	1.94	8.20	0.51	87.64	13.54	0.34	0.11	-0.25	2.73	4.13	4.95
2004	PI 401794	22.29	1.65	7.72	0.43	80.88	11.48	0.30	0.09	0.08	2.28	3.95	2.48
2004	PI 436107	26.27	1.14	9.26	0.29	95.13	7.87	0.63	0.06	0.60	2.28	11.62	1.66
2003	PI 436108	27.06	1.77	8.16	0.46	88.01	12.39	0.51	0.10	0.99	2.28	7.02	1.44
2004	PI 436108	25.09	1.14	7.67	0.29	77.41	7.87	0.29	0.06	2.05	2.28	13.83	1.44
2003	PI 436109	29.61	1.11	8.63	0.28	92.33	7.63	0.64	0.06	14.41	2.28	15.89	1.25
2004	PI 436109	26.58	1.08	8.63	0.28	112.45	7.40	0.79	0.06	3.70	2.28	15.86	1.29
2003	PI 436110	31.43	1.11	9.25	0.28	92.54	7.87	0.84	0.06	28.38	2.28	15.33	1.18
2004	PI 436110	28.63	1.14	9.21	0.29	120.21	7.87	1.05	0.06	6.38	2.28	15.16	1.21
2003	PI 436111	29.06	1.05	9.18	0.28	90.11	7.20	0.67	0.06	32.95	2.28	15.49	1.29
2004	PI 436111	25.14	1.14	9.06	0.29	85.20	7.87	0.57	0.06	5.62	2.28	12.72	1.25

Appendix 1. Year x accession least squares interaction means.

		Panicle				Flag leaf				Seed			
Year	NPGS no.	Length	SE	Node number	SE	Length	SE	Width	SE	Yield	SE	Mass	SE
2003	PI 436112	27.39	2.49	9.33	0.65	97.51	17.47	0.73	0.14	0.62	2.63	14.36	4.95
2004	PI 436112	23.30	1.94	10.46	0.51	98.16	13.61	0.41	0.11	0.02	2.73	22.93	2.49
2003	PI 436119	30.36	1.64	10.43	0.43	80.25	11.46	0.53	0.09	0.19	2.73	11.13	2.48
2004	PI 436119	23.78	1.18	8.64	0.30	106.19	8.14	0.53	0.07	0.92	2.40	8.87	2.03
2003	PI 436120	34.04	2.49	7.66	0.65	169.11	21.38	1.25	0.17	1.98	2.28	13.71	1.44
2004	PI 436120	29.37	1.38	7.90	0.36	163.83	9.61	0.80	0.08	1.05	2.28	16.49	1.76
2003	PI 436121	33.56	1.54	8.50	0.40	163.03	10.73	0.89	0.09	1.87	2.28	15.09	1.44
2003	PI 436122	28.46	2.16	10.00	0.56	108.97	15.13	0.59	0.12	0.02	2.83	9.47	2.03
2004	PI 436122	25.90	1.46	7.77	0.38	99.67	10.12	0.79	0.08	2.02	2.28	14.49	1.76
2003	PI 436124	25.79	1.46	9.89	0.38	109.06	10.12	0.56	0.08	1.88	2.28	7.21	1.50
2004	PI 436124	22.41	1.18	9.08	0.30	84.48	8.14	0.41	0.07	1.48	2.33	7.87	1.76
2003	PI 436125	28.69	2.16	10.75	0.57	97.23	15.15	0.56	0.12	1.38	2.28	11.04	2.03
2004	PI 436125	26.80	1.18	8.72	0.30	93.19	8.14	0.66	0.07	1.41	2.28	12.77	1.76
2003	PI 436127	30.05	1.46	9.00	0.38	113.18	10.13	0.75	0.08	4.71	2.28	6.77	1.38
2004	PI 436127	23.17	1.38	8.80	0.36	94.68	10.12	0.40	0.08	0.96	2.28	8.62	1.66

Appendix 1. Year x accession least squares interaction means.

		Panicle				Flag leaf				Seed			
Year	NPGS no.	Length	SE	Node number	SE	Length	SE	Width	SE	Yield	SE	Mass	SE
2003	PI 436126	29.53	2.16	11.49	0.57	100.49	15.15	0.47	0.12	0.00	2.28	0.00	0.00
2004	PI 436126	27.52	1.77	9.32	0.46	103.17	12.38	0.49	0.10	0.08	2.28	10.66	3.50
2003	PI 436130	23.67	1.54	7.88	0.40	120.96	10.73	0.79	0.09	0.78	2.28	18.14	1.50
2004	PI 436130	22.47	1.14	7.46	0.29	137.00	7.87	0.73	0.06	1.12	2.33	25.47	1.38
2003	PI 436131	29.04	2.49	9.99	0.65	104.19	17.47	0.56	0.14	0.50	2.28	34.80	2.22
2004	PI 436131	20.86	2.49	6.63	0.65	113.28	21.40	0.61	0.17	0.00	2.28	-0.15	4.95
2003	PI 436132	27.54	1.54	9.50	0.40	112.96	10.73	0.64	0.09	1.48	2.28	7.11	1.44
2004	PI 436132	24.81	1.54	8.60	0.40	87.45	10.74	0.48	0.09	0.02	2.28	9.43	3.50
2004	PI 436133	21.09	1.65	7.99	0.43	114.16	11.49	0.74	0.09	0.00	2.28	-0.09	4.95
2003	PI 436134	31.14	1.64	10.28	0.43	89.16	10.74	0.58	0.09	0.11	2.28	12.36	4.95
2004	PI 436134	21.99	1.18	8.92	0.30	99.26	8.14	0.49	0.07	0.04	2.28	7.85	1.88
2003	PI 436113	27.90	1.94	8.60	0.51	124.60	15.15	0.68	0.12	0.34	2.28	8.04	1.66
2004	PI 436113	24.32	1.18	8.99	0.30	91.94	8.45	0.55	0.07	0.41	2.28	11.08	1.57
2003	PI 436114	29.50	1.05	9.06	0.27	82.24	7.63	0.57	0.06	24.44	2.28	13.65	1.21
2004	PI 436114	24.97	1.05	8.36	0.28	89.59	7.87	0.71	0.06	3.47	2.63	15.55	1.21

Appendix 1. Year x accession least squares interaction means.

		Panicle				Flag leaf				Seed			
Year	NPGS no.	Length	SE	Node number	SE	Length	SE	Width	SE	Yield	SE	Mass	SE
2003	PI 436115	31.78	1.38	8.50	0.36	156.83	13.56	0.86	0.11	0.00	2.28	12.29	4.95
2004	PI 436115	22.71	1.22	9.53	0.31	102.63	8.45	0.61	0.07	0.02	2.28	7.88	2.86
2003	PI 436116	35.19	1.94	8.99	0.51	133.97	13.57	0.97	0.11	-0.63	2.73	8.62	1.88
2004	PI 436116	25.21	1.22	8.77	0.31	101.79	8.44	0.72	0.07	0.45	2.28	12.71	1.66
2003	PI 436117	29.33	1.05	9.11	0.27	94.30	7.63	0.73	0.06	17.02	2.33	15.94	1.18
2004	PI 436117	23.91	1.08	8.37	0.28	102.86	7.40	0.73	0.06	2.85	2.28	15.56	1.44
2003	PI 436118	29.76	1.54	9.87	0.40	128.05	10.75	0.74	0.09	1.59	2.28	8.26	1.33
2004	PI 436118	22.62	1.18	10.08	0.30	84.63	8.15	0.51	0.07	0.78	2.28	11.62	1.44
2003	CIav 9019	25.04	1.32	8.82	0.34	107.42	8.78	0.89	0.07	0.43	2.28	11.28	1.38
2003	CIav 9020	32.44	1.05	8.94	0.27	100.47	7.63	0.67	0.06	28.67	2.28	15.75	1.18
2004	CIav 9020	25.26	1.11	8.25	0.28	92.33	7.87	0.65	0.07	2.29	2.28	14.73	1.44
2003	CIav 9021	30.33	1.05	9.39	0.27	92.33	7.20	0.74	0.06	23.64	2.28	16.20	1.21
2004	CIav 9021	25.15	1.22	7.91	0.31	109.15	9.17	0.81	0.08	4.27	2.28	16.15	1.44
2003	CIav 9022	36.20	2.49	8.35	0.65	98.21	10.75	1.00	0.09	6.86	2.28	9.60	1.25
2004	CIav 9022	26.55	1.11	8.26	0.29	85.83	7.63	0.51	0.06	2.09	2.28	9.49	1.29

Appendix 1. Year x accession least squares interaction means.

		Panicle				Flag leaf				Seed			
Year	NPGS no.	Length	SE	Node number	SE	Length	SE	Width	SE	Yield	SE	Mass	SE
2003	CIav 9024	29.07	1.14	8.93	0.29	74.07	7.87	0.55	0.06	4.06	2.28	11.38	1.25
2004	CIav 9024	24.78	1.38	9.59	0.36	81.88	10.13	0.59	0.08	0.39	2.28	19.76	1.66
2003	CIav 9030	29.81	1.54	6.87	0.40	152.15	10.73	1.13	0.09	1.29	2.28	17.01	1.44
2004	CIav 9030	34.27	1.27	8.82	0.33	183.75	8.79	0.99	0.07	1.53	2.28	21.90	1.76
2003	CIav 8089	29.73	1.08	8.94	0.28	86.67	7.63	0.74	0.06	21.14	2.28	13.89	1.18
2004	CIav 8089	27.43	1.08	8.50	0.28	91.45	7.40	0.85	0.06	6.39	2.28	14.92	1.18
2003	CIav 9007	34.17	1.05	8.89	0.27	99.89	7.20	0.93	0.06	28.23	2.28	10.43	1.18
2004	CIav 9007	29.06	1.18	9.71	0.30	85.05	8.14	0.64	0.07	3.43	2.28	9.98	1.33
2003	CIav 9011	35.95	1.08	8.88	0.28	112.05	7.63	0.97	0.06	27.29	2.33	9.90	1.18
2004	CIav 9011	28.93	1.32	8.83	0.33	93.97	9.17	0.75	0.07	3.22	2.28	9.52	1.38
2004	CIav 9012	31.38	1.18	9.50	0.30	86.48	8.14	0.65	0.07	4.68	2.28	10.56	1.38
2003	CIav 9014	44.13	1.54	8.75	0.40	146.96	9.17	1.42	0.07	3.35	2.28	11.27	1.38
2004	CIav 9014	36.08	1.46	7.76	0.38	200.55	10.13	1.04	0.08	1.35	2.28	18.46	1.66
2003	CIav 9015	18.60	1.18	4.50	0.30	220.04	8.78	0.72	0.07	6.24	2.28	16.86	1.33
2004	CIav 9015	17.70	1.94	3.37	0.51	171.31	17.47	0.51	0.14	0.62	3.77	13.22	4.95

Appendix 1. Year x accession least squares interaction means.

		Panicle				Flag leaf				Seed			
Year	NPGS no.	Length	SE	Node number	SE	Length	SE	Width	SE	Yield	SE	Mass	SE
2003	CIav 9066	36.42	1.94	9.79	0.51	123.07	13.60	1.24	0.11	0.00	2.28	6.79	3.50
2004	CIav 9066	28.80	1.54	10.99	0.43	122.34	10.73	0.51	0.09	0.33	2.84	7.87	3.51
2003	CIav 9110	37.73	1.14	9.13	0.29	113.42	7.40	0.91	0.06	16.48	2.28	9.44	1.21
2004	CIav 9110	31.08	1.54	8.26	0.40	104.20	10.74	0.47	0.09	1.63	2.28	9.07	2.03
2003	CIav 9112	36.65	1.78	8.16	0.46	141.35	12.44	0.95	0.10	12.53	2.28	9.02	1.18
2004	CIav 9112	29.59	1.27	8.16	0.33	125.08	8.78	0.65	0.07	2.21	2.28	12.89	1.57
2003	CIav 9116	35.13	1.14	9.47	0.29	123.33	7.63	0.95	0.06	30.97	2.28	9.51	1.18
2004	CIav 9116	31.79	1.27	9.75	0.33	98.24	8.78	0.58	0.07	4.56	2.28	10.26	1.50
2003	PI 274608	35.52	1.22	10.00	0.31	141.79	8.80	0.99	0.07	31.96	2.28	15.73	1.38
2004	PI 274608	27.64	1.08	9.00	0.28	134.63	7.40	0.87	0.06	2.34	2.28	13.53	1.44
2003	PI 274609	31.06	1.05	10.78	0.27	143.72	7.20	0.68	0.06	13.07	2.28	14.33	1.18
2003	CIav 9031	25.36	1.94	7.99	0.51	128.05	13.57	0.79	0.11	1.81	2.28	19.75	1.66
2004	CIav 9031	26.21	1.22	7.69	0.31	202.48	8.44	0.89	0.07	1.12	2.28	20.75	1.57
2003	CIav 9035	21.65	4.29	10.00	1.13	68.35	30.22	0.46	0.23	0.37	2.28	7.47	1.57
2004	CIav 9035	27.77	1.18	8.43	0.30	125.67	7.87	0.79	0.06	0.76	2.28	12.94	1.58

Appendix 1. Year x accession least squares interaction means.

		Panicle				Flag leaf				Seed			
Year	NPGS no.	Length	SE	Node number	SE	Length	SE	Width	SE	Yield	SE	Mass	SE
2003	CIav 9038	21.15	3.05	11.00	0.80	60.85	21.41	0.46	0.17	0.05	2.28	11.70	2.87
2004	CIav 9038	26.65	1.46	8.34	0.38	85.55	10.12	0.48	0.08	0.12	2.28	11.23	1.88
2003	CIav 9043	32.45	1.54	9.76	0.40	113.99	10.75	0.82	0.09	1.84	2.28	8.57	1.25
2004	CIav 9043	27.50	1.39	8.57	0.36	116.23	9.63	0.74	0.08	0.75	2.73	5.41	1.76
2003	CIav 9064	30.35	1.11	5.56	0.28	126.93	7.87	0.66	0.06	4.99	2.28	12.28	1.25
2004	CIav 9064	24.81	1.32	5.36	0.34	122.33	9.17	0.62	0.07	0.21	2.73	11.02	2.48
2003	PI 158247	28.50	1.05	8.11	0.27	120.74	7.63	0.73	0.06	51.54	2.28	19.60	1.18
2004	PI 158247	27.89	1.11	7.93	0.30	116.02	8.45	1.13	0.07	3.07	2.28	15.87	1.29
2003	CIav 5057	31.30	1.54	10.25	0.40	108.20	10.75	0.69	0.09	1.18	2.28	6.91	1.38
2004	CIav 5057	27.17	1.32	9.09	0.34	87.60	9.17	0.49	0.07	0.20	2.28	14.05	2.22
2003	CIav 5082	30.54	1.08	8.94	0.28	105.07	7.40	0.76	0.06	17.82	2.28	16.33	1.21
2004	CIav 5082	25.81	1.14	8.59	0.29	118.09	8.45	0.78	0.07	2.83	2.28	16.37	1.38
2004	CIav 6858	25.20	1.11	8.37	0.28	91.77	7.63	0.69	0.06	3.30	2.28	16.62	1.29
2003	PI 186606	28.86	1.11	8.87	0.28	85.24	7.63	0.62	0.06	11.86	2.28	14.36	1.21
2004	PI 186606	22.84	1.05	7.65	0.28	87.71	7.63	0.59	0.06	4.79	2.28	16.55	1.29

Appendix 1. Year x accession least squares interaction means.

		Panicle				Flag leaf				Seed			
Year	NPGS no.	Length	SE	Node number	SE	Length	SE	Width	SE	Yield	SE	Mass	SE
2003	CIav 6956	29.73	1.08	9.06	0.28	94.33	7.20	0.63	0.06	10.19	2.28	16.03	1.29
2004	CIav 6956	26.89	1.11	8.44	0.28	100.58	7.63	0.80	0.06	3.48	2.28	15.58	1.21
2003	CIav 7010	29.85	1.11	9.00	0.28	93.83	7.40	0.64	0.06	12.06	2.28	12.35	1.21
2004	CIav 7010	24.48	1.22	8.08	0.33	104.41	8.44	0.76	0.07	2.04	2.28	14.77	1.38
2003	CIav 7121	32.08	1.22	9.23	0.31	111.72	8.45	0.74	0.07	3.72	2.28	10.96	1.38
2004	CIav 7121	28.17	1.94	9.98	0.51	124.49	13.57	0.68	0.11	0.79	2.73	9.88	2.22
2003	CIav 7122	27.66	1.14	9.60	0.29	80.12	8.14	0.70	0.07	3.28	2.28	9.31	1.25
2004	CIav 7122	25.18	1.39	9.57	0.36	86.61	9.63	0.62	0.08	1.51	2.73	10.07	1.58
2003	CIav 7280	31.39	1.05	9.00	0.27	88.96	7.63	0.61	0.06	13.50	2.28	13.59	1.18
2004	CIav 7280	25.50	1.05	8.44	0.27	108.72	7.20	0.81	0.06	5.22	2.28	15.55	1.18
2003	CIav 8087	25.36	1.77	9.50	0.46	86.75	12.38	0.68	0.10	1.54	2.28	9.54	1.66
2004	CIav 8087	25.48	1.38	9.54	0.38	115.13	9.61	0.73	0.08	0.06	2.28	15.01	2.22
2003	SoilSaver	28.31	1.18	9.33	0.33	117.11	8.15	0.63	0.07	5.02	2.28	9.96	1.29
2004	SoilSaver	25.41	1.08	9.76	0.28	114.52	7.63	0.69	0.06	1.12	2.28	13.28	1.50