REACTION OF SOYBEAN CULTIVARS

TO WATERLOGGED SOILS

A Thesis

Presented to

The Faculty of the Graduate School

University of Missouri-Columbia

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

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by

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DECEMBER, 2006

The undersigned, appointed by the Dean of the Graduate School, have examined the thesis entitled

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TO WATERLOGGED SOILS

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A candidate for the degree of **Master of Science**

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ACKNOWLEDGEMENTS

The author extended his deepest gratitude and appreciation to God first and foremost for the strength to make this journey. The utmost appreciation goes to Dr. Gene Stevens and Dr. Grover Shannon for the opportunity to earn a graduate degree. Without them, none of this would have been possible. Their generosity is a debt that can never be repaid. Thanks also go to Dr. Allen Wrather and Dr. David Sleper for serving on the author's committee. The guidance, encouragement, and dedication of this group will always serve as a reminder to strive for the best.

Sincere thanks go to the author's former co-workers Holly Wilson, Jeremy Stafford, and Alan Sheckell for all the help throughout the course of this project. Thanks also go to the hourly workers of the Crop Production project at the University of Missouri Delta Center. The help and friendship of these individuals was indispensable during the course of this project. Much appreciation also goes to the members of the Soybean project for their continued help with planting and harvest of these studies. Additional thanks goes to Jake Fisher and the entire staff at the University of Missouri Delta Center for their ongoing support and assistance in these studies.

The author would also like to thank his family for their support and encouragement throughout the course of this degree. Unyielding appreciation goes to his wife, Samantha Rhine, and his son, Trenton, for their support and understanding of his time spent during this task. Thanks also go to the author's father, Gary Rhine, and his mother, Linda Rhine, for the continuing love and support throughout this study. This degree could not have been earned without their encouragement.

TOLERANCE OF SOYBEAN CULTIVARS

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ABSTRACT

Irrigating soybean prior to an extensive rain can result in waterlogged soil that may cause root damage and plant death. Some soybean cultivars tolerate waterlogged soils. The objective of this study was to evaluate tolerance of soybean cultivars to waterlogged soils at different soybean growth stages and flood durations. A selection of maturity group IV soybean cultivars was screened for flood tolerance in the field. Five cultivars were selected for variations in tolerance to waterlogged soil conditions. An experiment was conducted to determine the response of these cultivars to waterlogged soil for 192 h at three growth stages (V5, R1, and R5). The experiment design was a split plot with flood or no flood (main plot) and five cultivars (subplots). A second experiment was conducted to determine the response of these cultivars to flood for 0, 48, 96, 144, and 192 h at the R1 stage of growth. The experimental design was a split plot with times of waterlogged soil (main plot) and cultivars (subplot). A significant interaction was found between cultivars and growth stage flooding when exposed to waterlogged soil. The greatest yield supression from waterlogged soil occurred at the R5 growth stage compared to V5 and R1. Cultivar P94B73 had no significant change in yield from flooding 192 hours at any of thee growth stages compared to no flooding controls. Averaged across years, Delsoy 4710, Manokin, and Mersch-Denver declined in yield by

41% after R5 floods compared to the highest yielding treatments. Cultivars DK 4868 and P94B73 declined in yield by an average of 22% after R5 floods. Soybean yield suppression due to waterlogged soil was least when flood was applied at V5 compared with the R1 and R5 stages of growth. Although soybean leaves turned yellow from V5 flooding, plants were able to recover and produce 2711 to 3387 kg ha^{-1} grain yield compared to 2390 to 3258 kg ha^{-1} non-flooded grain yields. Flood duration had a significant negative effect on soybean yield ($P = 0.0012$). When averaged across years and cultivars, soybean yields declined 310 kg ha^{-1} after being flooded for 192 hours at bloom compared to non-flooded checks. Significant interactions between cultivar and duration were not found.

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INTRODUCTION

In the Mississippi River Delta region of the United States, waterlogged soil often reduces soybean yields. Symptoms of waterlogged soil stress in soybean may include leaf yellowing, reduced root growth, reduced nodulation, stunted growth, defoliation, reduced yields, and plant death (Linkemer et al., 1998; Minchin and Pate, 1975; Oosterhuis et al., 1990; Purcell et al., 1997; Stanley et al., 1980). Waterlogged soil may damage plants directly or indirectly through enhanced plant disease.

One of the known direct effects of flooding on soybeans is reduced root nodulation by nitrogen fixing bacteria. Sallam and Scott (1987) reported that flooding at V1 completely inhibited soybean nodulation. This is due in part to suppressed activity of the enzyme nitrogenase, which is involved in converting nitrogen gas to reduced forms useful to the host plant (Sprent, 1969; Minchin and Pate, 1975). The suppression of nitrogenase has been linked to the lack of oxygen found in flooded conditions. A small amount of oxygen (0.0016 atm) is required for optimal nitrogen fixation (Keister and Rao, 1977). This is one of the main causes for seeing reduced tissue nitrogen concentrations as flood duration increases. If cultivars were able to pull oxygen from the atmosphere by use of aerenchyma cells or other adaptive structural components in the nodules, nitrogen concentrations could possibly remain stable throughout flooding.

Sullivan et al. (2001) showed that flood duration was positively correlated with leaf tissue Ca, Mg, B, Fe, Cu, and Al, but was negatively correlated with soybean leaf N concentration. In greenhouse beds, soybeans growing in waterlogged soil showed an initial N deficiency and reduced growth rates (Nathanson et al., 1984). However, plants became acclimated to waterlogged conditions and showed improved nodulation and subsequent growth rates.

Root systems need to be able to survive longer under anaerobic soil conditions. Amarante and Sodek (2006) found that waterlogging of soybean roots led to a reduction in xylem glutamine levels, attributed to impaired N_2 fixation. Puiatti and Sodek (1999) suggested a possible alteration in asparagines metabolism underlying changes in amino acid transport in the xylem during waterlogged soil conditions. Nitrogen accumulation in the shoots of nodulated peas and other legumes is slowed by soil waterlogging due to reduced nodulation and nitrogenase activity (Minchin and Pate, 1975). Studies suggest that elevated CO_2 levels in waterlogged soil can inhibit soybean root growth. In a rice paddy rotated to soybean production, topsoil CO_2 following a rainfall increased to 8 kPa of partial pressure, whereas O_2 dropped to a minimum of 7 kPa (Araki, 2006).

Soil waterlogging can also facilitate the growth and infection of diseases such as Phytophthora root rot (*Phytophthora megasperma* Drechs f. sp. *Glycinea*) and Pythium (*Pythium spp.* Pringsh) (Bowers and Russin, 1999). These diseases can cause seed death as well as pre- and postemergence damping off. However, later in the seedling growth susceptible cultivars show yellowing and wilting of leaves. This symptom could often mask what could be taken as a deficiency in N uptake, a common problem in flooded conditions. Schmitthenner (1989) found that severe Phytophthora infections in the seedling stage can result in 100% mortality of susceptible plants. Athow (1985) found that Phytophthora root rot is most prevalent on wet, poorly drained, fine-textured clay soils. Flooding of soil is essential for release and movement of fungal zoospores. (Bowers and Russin, 1999). When flooding occurred following emergence, Kirkpatrick et al. (2006a) found that Pythium pathogenic species caused reductions in soybean plant stands and root discoloration. When flooding occurred at V4 growth stage, soybean root discoloration was observed but at a lower level than flooding at emergence (Kirkpatrick et al., 2006b). These pathogens are an integral part of the damage caused in flooded conditions. However, they are not the sole cause for this damage.

Cultivation of soybean [*Glycine max* (L) Merr.] began approximately 3000 to 4000 years ago in northern China (Hymowitz, 1995). Seed improvements included selection for increased seed size, erect growth habit and reduced seed shattering (Hancock, 2004). Because of the monsoon rainy season in Southeast Asia, farmers probably also selected soybeans that survived the wet soil conditions in the region.

In Australia, Troedson et al. (1989) found that soybean cultivar Fritzroy averaged 38% higher seed yields in continuously saturated soil than with conventional irrigation (60 mm open-pan evaporation). In saturated soil culture, soybean growth rates were enhanced in all plant components including vegetative, reproductive, roots and nodules (Garside et al., 1992).

In Louisiana, 3 to 5 cm of rain per day falling on poorly drained soil was sufficient to reduce soybean growth and seed yield (Linkemer et al., 1998). Arkansas tests with four soybean cultivars showed that soybean grown in saturated soil averaged 40% less seed yields than furrow-irrigated soybean (Purcell et al., 1997). Leaf yellowing following flooding was observed and associated with a lag in N accumulation in soybean plants. The only cultivar that was not reduced by waterlogged soil was Asgrow 6297. Oosterhuis et al. (1990) observed that, within 48 hours of flooding, photosynthesis was reduced 33 and 32% in cv. Essex at V4 and R2 growth stages, respectively. Although seed yields were reduced in both Essex and Forrest cultivars, Forrest was more tolerant than Essex.

Although soybean germplasm used in breeding programs originated from regions accustomed to a monsoon climate during their growing season, many domestic cultivars cannot survive extended periods of flooding. Aerenchyma development in soybean is not commonplace, but can occur in some cultivars. Rapid formation of adventitious roots and aerenchyma between the stem (immediately above the water line), roots and nodules in flooded soybean have been observed (Thomas et al., 2005; Bacanamwo and Purcell, 1999). Weisz and Sinclair (1987) concluded from greenhouse research that soybean nodules can adjust to wide range of rhizosphere oxygen concentrations.

Heatherly and Pringle (1991) found that soybean genotypes differ in their response to soil waterlogging. Shannon et al. (2005) evaluated ten soybean cultivars under waterlogged and non-waterlogged soil conditions. Yield losses from saturated soil conditions at R1 growth stage were 39% for the most tolerant cultivars and 77% for the most sensitive cultivars. VanToai et al. (2001) identified quantitative trait loci (QTL) in isolines associated with soybean tolerance to soil waterlogging. A single QTL linked to marker Sat_064, from the cultivar Archer was associated with improved plant growth and grain yields in waterlogged environments. This marker is close to the *Rps*4 gene for Phytophthora (*Phytophthora sojae* M.J. Kaufmann & J.W. Gerdemann) resistance. But, since the Archer cultivar does not contain the *Rps*4 resistance allele, they concluded that it is not a disease tolerance QTL.

Soybean farmers are sometimes apprehensive of irrigating during key periods of crop maturation in fear that precipitation will come shortly after, leaving the soil waterlogged for days at a time and injuring their crop. Because of this threat, many farmers hesitate to make important irrigation applications, also reducing their potential crop yield. Knowing how long soybean cultivars can tolerate flooding is needed for soybean irrigation planning. In Louisiana, Griffin et al. (1988) found that soybeans were more tolerant of waterlogged soils during vegetative growth stages than reproductive stages. They also found that floods during reproductive stages should be removed within two days to avoid significant yield reductions. The objective of this study is to evaluate the tolerance of soybean cultivars to waterlogged soils at varying growth stages and flood durations on upper Mississippi River Delta soils.

MATERIALS AND METHODS

Field Screening of Soybean Cultivars for Reaction to Waterlogged Soil

An experiment was conducted during 2002 – 2004 at the University of Missouri at Hayward (36^{o}N, 89^{o}W) to determine the reaction of select maturity group IV soybean cultivars to waterlogged soil. Seeds were provided from entries in the Missouri Soybean Variety Testing program. The experimental design was a randomized complete block with two replications in 2002 and three replications in 2003 and 2004. The soil was a Sharkey clay (very-fine, smectitic, thermic Chomic Epiaquert). Tests were arranged in replicate hill plots spaced 61 cm in rows and 76 cm between rows. When the majority of cultivars began blooming, plots were flooded and water was allowed to stand for 14 days. The plot area was drained and cultivars were rated for injury after two weeks post flood. Cultivars were visually rated on a 1 to 5 scale where 1 = no apparent injury and 5 = all plants dead (Shannon et. al, 2005).

Manokin, Pioneer Brand 94B73 (P94B73), Merschman Denver RRSTS (Mersch-Denver), Delsoy 4710, and DeltaKing 4868 (DK4868) were selected to determine cultivar reaction to duration of flood at R1 and reaction to flood at various growth stages.

Growth Stage and Flood Duration Experiments

In 2003, field experiments were initiated on a Sharkey clay soil at Hayward and a Tiptonville silt loam soil (fine-silty, mixed, superactive, thermic Oxyaquic Argiudoll) near Portageville (36^{o}N, 90^{o}W). Prior to planting in 2003 and 2004, the fields were tilled, and row beds (76-cm spacing) were formed. The top 10 cm of the beds were harrowed just prior to planting to form a flat-top ridge.

A network of earthen levees to control plot flooding was placed around each main plot. Designated plots were flooded with 2 to 4-cm of water maintained in the furrow of each soybean row. Weed species were controlled with imazaquin, thifensulfuron methyl, fomesafen, and clethodim.

Two field experiments using split plot designs with four replications were employed. In both tests, main plots were four rows wide and 23-m long. Each of the five soybean cultivars was randomly assigned to subplots (3.7-m long) in each main plot. Planting dates were early May each year. After flooding treatments were applied, each soybean cultivar was monitored for reaction to wet soil. Soybean cultivars were allowed two weeks to recover from waterlogging damage. At this time, 20 trifoliate leaves were collected from each plot and digested for nitrogen, potassium, and phosphorus analyses using a modified wet acid dilution procedure (Mills and Jones, 1996). Soybean leaf samples were dried at 100^{o}C, ground, digested with a Hach Digesdahl™ Digestion Apparatus, 115Vac, 50/60 Hz (Hach Company, Loveland, CO) using H_2SO_4 and H_2O_2. Leaf potassium content was tested with a Perkin-Elmer™ (Wellesley, MA) atomic absorption spectrophotometer (Thomas, 1982). Phosphorus and nitrogen was tested colormetrically (Laverty, 1963; Keeney and Nelson, 1982) with a Genesys™ 10 spectrophotometer (Thermo Spectronic, Rochester, NY). In 2003, visual ratings were taken to identify any Phytophthora infestations. The center two rows of each plot were harvested. The seed was weighed and percent moisture was measured to determine yield at 13 % moisture.

Soybean Growth Stage Experiment

Main plots were flooded for eight days (192 hours) at either five trifoliate vegetative stage (V5), full bloom flowering stage (R1), or pod fill (R5). The subplots were the five soybean cultivars mentioned above.

Soybean Flood Duration Experiment

Main plot treatments were flooded at R1 stage for 0, 48, 96, 144, or 192 hours. Subplots were the five soybean cultivars previously listed. The plots were then immediately drained after each treatment.

Statistical Analysis

The statistical analysis of flood duration and growth stage data was performed using Mixed Model procedures of the Statistical Analysis System (SAS, 1997). The Mixed Model procedure provides Type III *F* values but does not provide mean square values for each element within the analysis or the error terms. Mean separation was evaluated though a series of pair-wise contrasts among all treatments (Saxton, 1998). Probability levels greater than 0.05 were categorized as non-significant.

RESULTS AND DISCUSSION

Field trials showed a significant year by cultivar interaction (P = 0.0015) based on visual injury ratings in 2002, 2003 and 2004 (Table 1). When years were analyzed separately, cultivars showed significant differences in injury to waterlogged soil in 2002 and 2003. In 2004, cultivars showed no significant differences based on visual observation. All cultivars showed signs of injury. This injury ranged from moderate tolerance to severe intolerance (Table 2). Pioneer 94B73 had the most consistent flood tolerance ratings across years. Mersch – Denver RRSTS rated well in 2002, and Armor 44 – R4 had the best tolerance rating in 2003. However, neither cultivar was consistent across all three years. Ratings for Manokin and Delsoy 4710 are not shown because these cultivars were dropped from the Missouri Soybean Variety Testing program after 2002. In 2002, Manokin rated 1.5, while Delsoy 4710 rated a 5.0 flood injury.

Soybean Flood Duration Experiment

Analysis of variance indicated year, soil, duration of flood, and cultivar significantly affected soybean yield at the $\alpha = 0.1$ level (Table 3). In 2004, the Sharkey clay soil produced different results from the rest of the test environments. The magnitude of soybean yield suppression from flooding on the Sharkey clay soil in 2004 was much greater than in 2003 at the same location. This is due to an excess of rainfall after the R1 growth stage. Immediately after flood termination, an accumulation of 72.39 mm of rainfall occurred on test plots in Hayward, Missouri from June 30 to July 6 (Data not shown). Plots remained under flooded conditions for more than 7 d after planned flood termination. This illustrates one of the difficulties of conducting flood tolerance research in the humid region when precipitation cannot be controlled.

Cultivar yield response to flooding on Tiptonville silt loam soil in 2003 and 2004 was similar to Sharkey clay in 2003 (Table 4). An interaction between cultivar and duration was not significant at the test locations. However, the main effect of duration on yields was significant. When analyzed separately for mean separation, yields of Delsoy 4710 were not significantly different from each other at any flood duration either year. P94B73 also followed this same pattern (Table 4). Yields of DK 4868 were significantly different in 2003 on both soils. The combined means of all cultivars were also analyzed, and no significant differences were found between treatments within cultivars, with the exception of DK 4868 (Table 4). Yields of P94B73, Manokin, and DK 4868 on the silt loam in 2003 and 2004, along with the clay in 2003 increased following 24 h of flooding and, in some cases, the 48 h flood durations, only to decrease in yield at longer durations. Delsoy 4710 and Mersch-Denver declined linearly at the 24 h flood duration at these same locations and years. Yield responses for all cultivars on the clay soil in 2004 drastically declined at every flood duration (Figure 1). All cultivars were injured when extended soil waterlogging occurred. The magnitude of yield loss differed between cultivars, indicating some degree of tolerance or intolerance.

Tissue nutrient content

Analysis of variance was calculated for soybean leaf N, P, and K contents following soil waterlogging at R1 stage. Analysis of clay 2004 tissue N, P and K concentrations were not included because of extended soil waterlogging. Results from tissue phosphorus and potassium showed no significant main effects of flood duration, soil, years, or interactions between the factors (Table 5). Averaged across flood durations, leaf P content was 0.23 g kg^{-1} and K content was 1.41 g kg^{-1} (Table 6). The effect of flood duration on leaf N was highly significant ($P<0.0001$). Cultivar effect on leaf N was not significant ($P = 0.12$). A significant interaction among soil types, duration and cultivar was not found for leaf N.

A significant interaction was found between soil type (clay and silt loam) and flood duration for leaf N (Table 5). Sharkey clay soils have poor internal drainage with slow surface runoff and permeability (Pettry and Switzer, 1996**)**. According to the Natural Resource Conservation Service, the Tiptonville silt loam is classified with moderate internal drainage (Soil Survey Staff, 1971). On the Sharkey clay soil, leaf N content decreased numerically as flood duration increased (Table 6). Soybean plants in control (not flooded) plots on the Tiptonville silt loam soil did not contain significantly more leaf N than flooded treatments.

Averaged across sites, Mersch-Denver and Delsoy 4710 showed a linear decline in leaf N as flood duration increased. Manokin, P94B73, and DK4868 increased in leaf N up to 48 h of flood, then decreased in a quadratic response to flood duration compared to no flooding controls. The short-term flooding in the 48 h treatment probably had a positive irrigation effect by soaking the soybean rooting zone and helping reduce water stress to the soybean plants. Manokin, P94B73, and DK 4868 then declined in a quadratic pattern over increased flood durations. Overall, P94B73 plants produced the highest leaf N content, averaging 18 to 40% higher than other cultivars tested. This may indicate that P94B73 roots were more suitable for nitrogen fixation symbiosis than other cultivars under flooded conditions. Another possibility is that that P94B73 began translocating leaf N to pods later in the season than the other Group IV cultivars.

In drought tolerance evaluations, cultivars with better relative yield ranking in drought environments than in non-drought environments are usually considered to be the most tolerant (Sneller and Dombek, 1997). If the same logic is applied to soil waterlogging tolerance tests, Delsoy 4710 would be rated highly tolerant. Linear regression showed no significant yield loss across flood durations for Delsoy 4710 on three moderate waterlog environments (silt loam 2003, 2004, and clay 2003; Table 4). But, Delsoy 4710, which has performed well in cultivars trials in the region, yielded one of the lowest overall among the five cultivars. The two highest yielding cultivars, DK 4868 and P94B73, followed a polynomial regression curve over flood durations. These cultivars increased in yield up to 96 hours of flooding without causing any soil waterlogging yield reduction. Cultivars Manokin and Mersch-Denver decreased linearly in yield as flood duration increased, showing little or no yield increase from short-term flood irrigation.

Soybean Growth Stage Experiment

Similar to the flood duration experiment, analysis on growth stage yields was separated into two categories. The Tiptonville silt loam tests in 2003 and 2004 along with the 2003 data from the Sharkey clay series were pooled from the Sharkey clay tests in 2004 due to an interaction between year, soil, cultivar, and growth stage found in the analysis of variance on yield (Table 7). Growth stage results from the Sharkey clay in 2004 are not shown because of water stood in furrows longer at bloom than at V5 or R5 because of rainfall and poor internal drainage.

Mean separation was conducted on tissue N, P, and K across years to determine any differences within cultivars at various growth stages (Table 8). Tissue N concentration was significantly different for DK 4868 at the R1 growth stage flood compared to the control. Tissue N was not significantly different at any other growth stage for any cultivar. No significant differences were found in leaf N for any cultivar at V5 and R5. Leaf P levels were significantly higher in control plots compared to flood treatments at V5 in cultivars DK 4868 and Mersch – Denver. Delsoy 4710 control plots were significantly higher in leaf P than flooded plots at R1. At R5, Mersch – Denver flood plots had significantly higher leaf P than controls. Tissue K concentrations were significantly different at V5 for Delsoy 4710, DK 4868, and Manokin, however the flood treatments had higher leaf K than the controls. At R1, tissue K content was significantly higher in control plots than in flooded plots in cultivar Delsoy 4710. No significant differences were found for leaf K at R5 floods compared to non-flood treatments. Cultivar P94B73 showed no statistical difference between flood and non-flood treatments for N, P, or K contents.

A significant interaction was found between cultivars and growth stage flooding. For each cultivar, the highest yielding flood growth stage treatment was either V5 or the control (Table 9). Leaves of most plants in plots flooded at V5 turned either pale green or yellow in color after one week. But, unless a plant was killed by flooding, all cultivars were able to fully recover from vegetative flooding. The greatest yield loss occurred when plants were flooded at the R5 (pod fill) growth stage. This confirms the work done by Griffin et al. (1988) which found that soybeans were more tolerant of waterlogged soils during vegetative growth stages than reproductive stages. Yield response at bloom stage was usually intermediate between flooding at V5 and R5 growth stages. Cultivars DK 4868 and Manokin yielded significantly less during R5 floods compared to control plots. Delsoy 4710 and Mersch-Denver yielded significantly higher when flooded at V5 than without flooding. Compared to V5 flooding treatments for Delsoy 4710 and Mersch-Denver, R5 floods caused yields to significantly decrease. P94B73 produced the highest numerical yield of any cultivar flooded at R5. P94B73 also had no significant change in yield over any flooding treatments including controls (Table 9).

Field Observations

Field notes and digital images were recorded in the fields from the root systems of cultivars after flooding. These were compared to soybean roots in control plots and roots from a legume weed species in the area that grow naturally under flooded conditions in rice fields. We found several Manokin cultivar plants contained spongy, white roots after eight days of flooding. The same thick, spongy root system was observed on healthy coffeeweed (*Sesbania herbacea*) plants growing in water in a levee ditch. When flood tolerant plants come under flooding stress, some plants species such as coffeeweed develop aerenchyma cells in order to transfer oxygen from the plant canopy down to the roots (Kawase, 1981). If soybeans were to develop these cells in the latter portion of the flood, the plants would begin to collect oxygen again, increasing their limiting factor in a flooded situation. Although aerenchyma cells in soybean roots are not typical, our observations showed it is possible.

Field ratings for diseases were made in 2003 determine whether Phytophthora or Pythium incidence was increased by soil waterlogging. No signs of either disease were recorded.

CONCLUSIONS

Evaluations of flood timing and duration on injury to five soybean cultivars showed that soil type was a significant factor. In 2004 on Sharkey clay, a soil with poor internal drainage, all plots except the control produced low yields. Rainfall occurred several consecutive days after we completed the flooding bloom growth stage treatments at this location.

Under normal rainfall conditions (loam 2003, 2004 and clay 2003), flooding for 192 h at V5 vegetative stage did not cause significant yield reductions. All cultivars were able to fully recover and yield comparably with control plots. When flooded at full bloom, most moderately tolerant and intolerant cultivars showed significant yield suppression compared to controls. This flood caused an influence on the flowering capabilities of these cultivars, reducing the total number of available flowering positions to make full pods. When floods occur at the pod fill (R5) growth stage, there was even less time for the plants to recover from waterlogging stress. In cultivars with lower tolerance, and even those that have shown considerably high tolerance, 192 h floods at the R5 growth stage can cause significant damage to yield. At this point in the soybeans growth, most of the energy produced from photosynthesis is consumed filling pods with seed.

Research with five soybean cultivars demonstrated that short-term flood irrigation can be done without reducing soybean yields. In flood duration experiments, DK 4868 and P94B73 produced higher yields than other cultivars in extended waterlogged soils.

Cultivar Delsoy 4710 showed no difference in yield between the control and 192 h flood duration treatment. However, since Delsoy 4710 in control plots yielded low compared to other cultivars, at 192 h it still remained the lowest yielding cultivar in the experiment. This suggests that using yield loss compared to the control for ranking waterlogging tolerance in soybean may be misleading.

Visual injury ratings from screening work showed no complete tolerance to soil waterlogging by any of the tested maturity group IV soybean cultivars. However, some differences were found in flood tolerance between cultivars that could be useful in a soybean breeding program. In the future, plant introductions should be studied as sources of increased flood tolerances in future cultivars.

TABLES OF OBSERVED AND DERIVED PARAMETERS

Table 1. Summary of analysis of fixed effects of year, flood duration, and cultivar on visual ratings of flood injury.

Effect †	Pr > F
Year (Y)	0.0175
Cult (C)	<.0001
Y x C	0.0015

† Years were 2002 though 2004, flood duration was 14 d, and cultivars were a list of maturity group IV cultivars from the Missouri Soybean Variety Testing Program.

Table 2. Reaction of maturity group IV soybean cultivars to waterlogged soil for 14 d in clay soil during 2002 – 2004.

	Visual ratings of flood injury (1 to 5) †		
Cultivar‡	2002§	2003	2004
Armor 44-R4	3.7 cdef	1.5 a	2.0 a
Armor 47-G7	4.2 efghi	2.5 abc	2.0 a
ASGROW AG4201	4.7 hij	3.0 bcde	2.7 a
ASGROW AG4403	4.7 hij	3.7 cde	2.0 a
ASGROW AG4603	4.7 hij	2.5 abc	3.3 a
Delta Grow 4860RR	4.5 ghij	3.3 bcde	2.7 a
Delta King DK4461RR	4.3 fghij	3.0 bcde	2.0 a
Delta King DK4763RR	4.3 fghij	3.5 cde	2.0 a
Delta King DK4868RR	4.0 defgh	3.0 bcde	1.7 a
Delta Pine DP 4933 RR	3.8 defg	4.3 e	2.7 a
Dyna Gro DG3443NRR	4.7 hij	2.0 ab	2.7 a
Excel Brand 8499NRR	4.8 ij	4.0 de	2.7 a
FFR 4922RR	4.5 ghij	4.0 de	3.0 a
Golden Harvest H-4368RR	3.7 cdef	4.0 de	2.0 a
Hornbeck HBK R4820	3.8 defg	2.5 abc	2.3 a
Mersch. Austin RR	3.8 defg	3.0 bcde	2.7 a
Mersch. Dallas RR	3.5 bcde	3.7 cde	2.7 a
Mersch. Denver RRSTS	2.0 a	3.5 cde	3.0 a
Mersch. Phoenix IIIRR	3.3 bcd	3.5 cde	2.7 a
MFA Morsoy RT 4201N	4.8 ij	4.3 e	2.7 a
MFA Morsoy RT 4480N	3.5 bcde	2.5 abc	2.3 a
MFA Morsoy RT4731N	3.7 cdef	3.0 bcde	2.7 a
Pioneer 94B73	1.8 a	2.3 abc	2.3 a
Pioneer 94B74	2.8 b	2.3 abc	2.0 a
Progeny 4401RR	3.7 cdef	2.3 abc	2.0 a
Progeny 4910	3.0 bc	2.0 ab	2.3 a
Southern Cross Aaron	3.5 bcde	2.0 ab	2.7 a
Southern Cross Silas	4.2 efghi	2.7 abcd	2.3 a
Southern Cross Titus	3.3 bcd	3.0 bcde	2.3 a
UniSouth USG 7440nRR	5.0 j	3.3 bcde	2.3 a
UniSouth USG 7499nRR	5.0 j	4.3 e	2.7 a
Willcross RR2432N	4.0 defgh	4.0 de	2.7 a

† Rated 1 to 5 with 1 = no injury, 5 = all plants dead.

‡ Only cultivars tested all thee years (2002 – 2004) are shown.

§ Within columns, visual ratings followed by the same letter were not significantly different at the 0.05 level.

Table 3. Summary of analysis of fixed effects of year, soil, flood duration, and cultivar on soybean grain yield (kg ha^{-1}).

Effect	Pr > F
Year (Y) †	0.0187
Soil (S) ‡	<.0001
Y x S	0.0075
Duration (D) §	0.0012
Y x D	0.0099
S x D	0.4032
Y x S x D	0.0254
Cultivar (C) ¶	<.0001
Y x C	0.0010
S x C	<.0001
Y x S x C	0.0163
C x D	0.2266
Y x C x D	0.2716
S x C x D	0.9045
Y x S x C x D	0.0941

† Years were 2003 and 2004.

‡ Soils were clay and loam.

§ Flood durations were 0, 48, 96, 144, 192.

¶ Cultivars were Delsoy 4710, Delta King 4868, Manokin, Mersch-Denver, and Pioneer 94B73.

Table 4. Reaction of group IV soybean cultivar yields to waterlogged soil for varying durations averaged across Tiptonville silt loam soil in 2003 and 2004 and Sharkey clay in 2003.

		Soybean grain yields†			
		Tiptonville silt loam		Sharkey clay	
Cultivar	Flood duration	2003	2004	2003	Mean
		----------------------kg ha^{-1}	----------------------		
Delsoy 4710	0	2999 a	2716 a	2349 a	2594 a
	48	3636 a	2463 a	2689 a	2929 a
	96	3299 a	2232 a	2337 a	2623 a
	144	2718 a	2282 a	2286 a	2429 a
	192	3037 a	2229 a	2666 a	2644 a
Delta King 4868	0	3636 b	4176 a	1712 b	3175 ab
	48	4086 a	4670 a	2966 ab	3907 a
	96	4049 ab	4383 a	3330 a	3921 a
	144	3505 abc	2938 a	2222 ab	2888 b
	192	2812 c	4287 a	2354 ab	3151 ab
Manokin	0	4086 a	3576 a	2542 a	3401 a
	48	3336 ab	4336 a	2957 a	3543 a
	96	3130 b	3476 a	2347 a	2984 a
	144	3130 ab	3218 a	2391 a	3032 a
	192	2905 b	3970 a	2013 a	2963 a
Mersch-Denver	0	3505 a	3636 a	1894 a	3012 a
	48	3393 a	3520 a	1609 a	2841 a
	96	3224 a	3022 ab	2141 a	2796 a
	144	3224 a	2147 b	1901 a	2424 a
	192	3186 a	2742 ab	1952 a	2627 a
Pioneer 94B73	0	3561 a	3318 a	2870 a	3250 a
	48	3711 a	3414 a	3026 a	3384 a
	96	3786 a	3890 a	2700 a	3459 a
	144	3393 a	2854 a	2300 a	2849 a
	192	3149 a	3260 a	2623 a	3011 a

† Yield values within a column and cultivar followed be different letters were not significantly different at an α-level of 0.05.

Table 5. Summary of analysis of fixed effects of soil, flood duration, and cultivar on nitrogen, phosphorus, and potassium tissue concentrations (g kg^{-1}) †.

Effect	Pr > F		
	N	P	K
Soil (S) †	0.1521	<.0001	0.7466
Duration (D) ‡	<.0001	0.0006	0.0126
S x D	<.0001	0.1173	0.1467
Cultivar (C) §	0.1218	0.8529	0.1951
S x C	0.3088	0.5996	0.0896
C x D	0.5097	0.1978	0.9979
S x C x D	0.7389	0.1539	0.5692

† Soils were clay and loam.

‡ Flood durations were 0, 48, 96, 144, 192.

§ Cultivars were Delsoy 4710, Delta King 4868, Manokin, Mersch-Denver, and Pioneer 94B73.

Table 6. Soybean leaf N, K, and P content two weeks after flooding with five durations on Sharkey clay and Tiptonville silt loam soils averaged across cultivars and years‡.

Flood Duration	Leaf Content †		
	N ‡	P	K
h	--------g kg^{-1} --------		
Sharkey clay			
0	4.68 a	0.20 a	1.59 a
48	3.23 b	0.22 a	1.42 b
96	2.78 b	0.19 ab	1.30 b
144	3.08 b	0.20 a	1.35 b
192	2.81 b	0.18 b	1.32 b
Tiptonville silt loam			
0	2.77 a	0.30 a	1.43 a
48	2.85 a	0.27 a	1.46 a
96	2.92 a	0.27 a	1.38 a
144	2.76 a	0.23 b	1.44 a
192	2.56 a	0.23 b	1.38 a

† Within soil types, soybean leaf contents followed by the same letter were not significantly different at an α-level of 0.05.

‡ Nutrient contents were averaged across Delsoy 4710, Delta King 4868, Manokin, Mersch-Denver, Pioneer 94B73 cultivars in 2003 and 2004.

Table 7. Summary of analysis of fixed effects of year, soil, growth stage, and cultivar on grain yield (kg ha^{-1}) †.

Effect	Pr > F
Year (Y) †	0.0699
Soil (S) ‡	0.0001
Y x S	0.7433
Growth stage (G) §	0.0067
Y x G	0.0003
S x G	0.0833
Y x S x G	0.7068
Cultivar (C) ¶	<.0001
Y x C	0.0207
S x C	0.0024
Y x S x C	0.3757
C x G	0.0017
Y x C x G	0.4524
S x C x G	0.8893
Y x S x C x G	0.0853

† Years were 2003 and 2004.

‡ Soils were clay and loam.

§ Growth stages were V5, R1, and R5.

¶ Cultivars were Delsoy 4710, Delta King 4868, Manokin, Mersch-Denver, and Pioneer 94B73.

Table 8. Effect of flooding at V5, R1, and R5 soybean growth stages on nitrogen, phosphorus, and potassium in soybean leaves.

		Soybean Tissue Nutrient Content								
		V 5†			R1			R5		
	Flood	N	P	K	N	P	K	N	P	K
	h	g kg^{-1}								
Delsoy 4710	0	3.28 a	0.33 a	1.78 b	1.69 a	0.26 a	1.30 a	2.00 a	0.26 a	1.17 a
	192	3.34 a	0.31 a	2.08 a	1.40 a	0.20 b	1.09 b	2.20 a	0.25 a	1.17 a
DK4868	0	3.68 a	0.33 a	1.73 b	1.81 a	0.24 a	1.22 a	1.78 a	0.25 a	1.18 a
	192	3.15 a	0.28 b	2.03 a	1.32 b	0.23 a	1.39 a	1.98 a	0.26 a	1.15 a
Manokin	0	3.11 a	0.29 a	1.64 b	1.53 a	0.27 a	1.21 a	2.20 a	0.24 a	1.07 a
	192	3.08 a	0.29 a	1.94 a	1.37 a	0.26 a	1.29 a	1.70 a	0.25 a	1.09 a
Mersch-Denver	0	2.79 a	0.32 a	1.80 a	1.48 a	0.20 a	1.29 a	1.33 a	0.22 b	1.41 a
	192	3.00 a	0.26 b	1.83 a	1.42 a	0.24 a	1.37 a	1.87 a	0.26 a	1.34 a
P94B73	0	2.57 a	0.31 a	1.48 a	1.74 a	0.25 a	1.35 a	1.23 a	0.22 a	1.17 a
	192	3.57 a	0.30 a	1.69 a	1.47 a	0.23 a	1.31 a	2.37 a	0.24 a	1.02 a

† Values with different letters following control and flooded (192 h) in same column and cultivar were significantly different at α-level of 0.05.

Table 9. Effect of flooding five cultivars 192 h at three growth stages on grain yield (kg ha^{-1}) averaged across loam and clay soils in 2003 and loam soil in 2004 at Portageville and Hayward, Missouri.

Cultivar	Growth Stage	Yield †	
		kg ha^{-1}	
Delsoy 4710	Check	2557	b
	V5	3387	a
	R1	2192	b
	R5	2037	b
DK 4868	Check	3127	a
	V5	2957	ab
	R1	3437	a
	R5	2385	b
Manokin	Check	3258	a
	V5	2711	ab
	R1	2474	bc
	R5	1984	c
Mersch-Denver	Check	2390	bc
	V5	3121	a
	R1	2661	ab
	R5	1837	c
P94B73	Check	3035	a
	V5	3009	a
	R1	2663	a
	R5	2428	a

† Within cultivars, soybean yields followed by the same letter were not significantly different at an α-level of 0.05.

PLOTS OF THE DATA

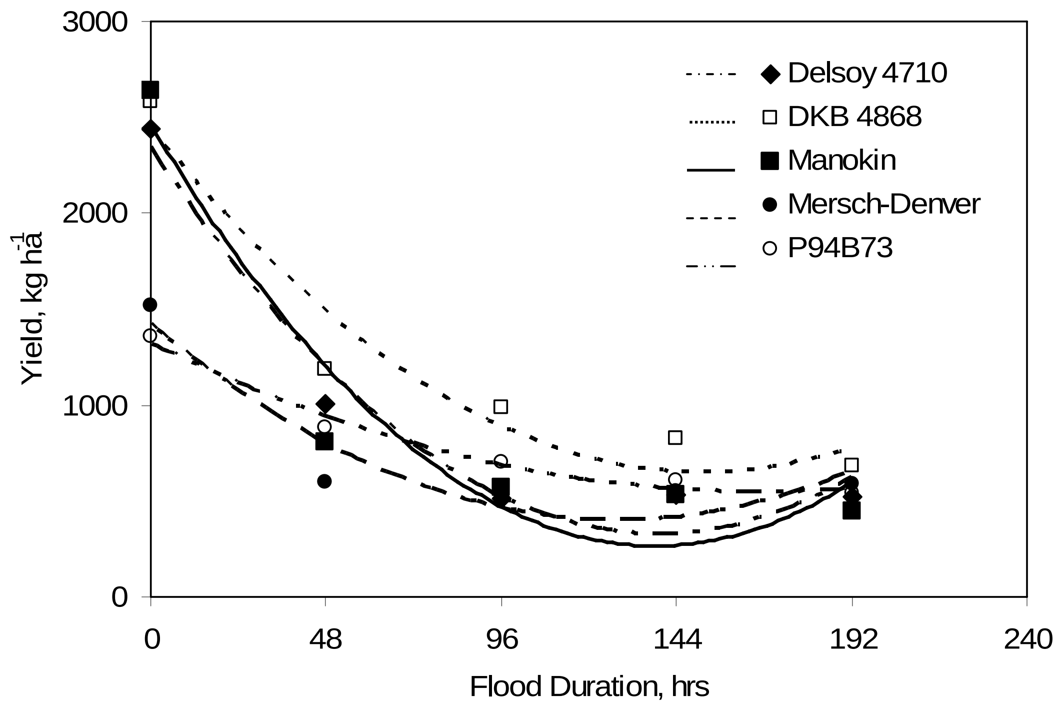

Figure 1. Effect of duration of water flooding on yield of five group IV soybean cultivars grown on a Sharkey clay soil in 2004 at Hayward, Missouri.

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