ABSTRACT

REAGAN, CASEY JAMES. Against the Tide: Evaluating Yield and Visual Response of Southern Soybean Germplasm to Flooding in North Carolina. (Under the direction of Dr. Thomas E. Carter, Jr.).

Soybean [*Glycine max* (L.) Merrill] growers in eastern North Carolina (NC) often face flooding as a result of excessive rainfall, such as that from Hurricane Matthew in 2016. The effects of prolonged waterlogging on soybean can include weak root development, spindly plants, and ultimately, a decrease in yield. Despite the economic consequences of flooding and waterlogging, yield response of soybean genotypes to flooding has not been quantified well in NC. To fill this research gap, we investigated the flooding response of a diverse array of soybean genotypes in four separate experiments at the Tidewater Research Station in Plymouth, NC in 2016 and 2017. Flood treatments were imposed by building berms around replicated blocks of genotypes and filling the berms with approximately 15 cm of water for about 7 days. In Experiments I and II, 32 genotypes of maturity groups (MG) IV and V and 24 genotypes of MG VI through VIII were subjected to flooding stress during early reproductive stages and then evaluated for visual response and seed yield. In Experiments III and IV, 40 genotypes of MG IV and V and 45 genotypes of MG VI through VIII were subjected to flooding during vegetative growth and early reproductive stages and were rated for visual appearance beginning two weeks after stress was alleviated, employing 1-row plots. Flooding stress during the reproductive growth stage reduced seed yield more than 50% on average as compared to control plots. Genotypic rankings of visual ratings were only slightly affected by timing of flooding (vegetative vs. reproductive). Significant genotypic differences in flooding response were observed for visual ratings and seed yield. These two traits were highly correlated under flooding conditions, suggesting that visual selection for flood tolerance may be an effective method for improving soybean flood tolerance in eastern North Carolina. Surprisingly, the correlation of genotypic means for yield under control conditions *vs.* flooded conditions was close to zero. We hypothesize that yield genes linked to flooding tolerance may not express under control conditions. This study identified new genetic sources of flood tolerance among breeding lines and cultivars in the USDA soybean breeding program, and two breeding lines from the University of Arkansas (AR) and University of Missouri (MO) were validated as flood tolerant in a new environment. Identifying parental stock through these experiments is an essential first step in developing a breeding program to improve flood tolerance in NC and the southeastern US. Additional steps will include identifying the mechanism(s) and genes that underlie this crucial stress tolerance and incorporating them into successful, high-yielding cultivars.

Against the Tide: Evaluating Yield and Visual Response of Southern Soybean Germplasm to Flooding in North Carolina

by
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DEDICATION

Thank you to my parents for always providing support and encouragement in school and throughout life. Graduate school has been rewarding and challenging, and I owe my model of good work ethic to you both.

BIOGRAPHY

Casey James Reagan was born in February, 1993, and raised in Whitehall, MI. He credits his parents' encouragement of curiosity and exposure to nature along the shore and dunes of Lake Michigan for his interest in plants and science. After high school, Casey attended Michigan State University in East Lansing, MI, where he was active in the student Outdoors Club and discovered plant breeding as a career. He earned a B.S. in Crop and Soil Sciences and a minor in Geographic Information Systems. Following graduation, he began working on his M.S. thesis in Crop Science at North Carolina State University in Raleigh, NC with Dr. Tommy Carter, focusing on evaluation of soybean to flood tolerance. Following completion of his thesis, Casey plans to work as a plant breeder in private industry.

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Chapter 1: Literature Review

Origin of Soybean

Although soybean is a relatively new crop in the United States (US), this leguminous plant has supported civilization in Asia for millennia. Soybean is native to eastern Asia, likely domesticated in northern China during the 11th century B.C. or earlier and introduced to Korea and Japan circa 200 B.C - 200 A.D (Nagata, 1953; Probst and Judd, 1973). The plant has been long cultivated as a food and feed source. Soybean was commonly used as a feed source for livestock as well as a staple in numerous food products, including tofu, soybean sprouts, edamame and miso (Hymowitz et al., 1981). The legume was and still is an important resource for nutrients (namely, amino acids glycinin and β-conglycinin and healthy polyunsaturated fatty acids) for the people of East Asia (Birt et al., 2004). The many uses of this versatile plant were celebrated around the world during the Age of Exploration and Trade (15th-16th centuries) (Hymowitz, 2004). New sea routes and migration allowed for the adoption of soybean into Southeast Asia (Indonesia, Philippines, Vietnam, Malaysia, and India), now considered secondary gene centers for soybean (Hymowitz, 2004). In the 1700s, soybean and its popular food products spread to Europe and North America. Beginning in the 19th century, soybean was introduced in western countries as a forage crop for livestock. It was grown in rotation with hay, millet, cowpeas and sorghum for hay feed, or grown as a standalone crop (Probst and Judd, 1973).

NC Soybean history

Early in the adoption of soybean in the United States, North Carolina was an important region for soybean. NC produced over 13,000 bushels in 1909, roughly 80% of the national total that year (Shurtleff and Aoyagi, 2004). In 1915, the first commercial extraction of soybean oil in the US occurred in Elizabeth City, NC using a cottonseed expeller press. Following this advancement in seed processing for downstream applications, popularity and acreage of soybean increased (Probst and Judd, 1973).

Today, soybean is grown virtually entirely for seed in the US. Seed are primarily used as a high-protein feed source for livestock and as a source of cooking oil. Soybeans are approximately 80% meal and 20% oil, but these percentages vary among genotypes and growing environments. Soybean meal is typically 45-50% protein (Hymowitz et al., 1972; Brummer et al., 1997; Ustun et al., 2001) expressed on a 12.5% moisture basis (Gillen and Shelton, 2018). Approximately 97% of US soybean meal is used for livestock feed, while only 3% is used in human food products (Stowe, 2017). Soybean is a vital component in animal diets around the world because of its high protein content, high yield and wide adaptability as compared to other leguminous or high protein crops (Speedy, 2004; Stowe, 2017). Soybean fills an important role in providing protein in the diets of millions of people worldwide; therefore, it is critical to increase the plant's tolerance to abiotic stresses in the environment.

Diversity of quantitative traits in US Soybean collection

Diversity among *G. max* cultivars in the United States (US) is a small subset of the diversity found in Eastern Asia, the center of origin for soybean (Hymowitz et al., 1981). Many accessions collected in Asia and brought to the United States early in the 20th century were not used by breeders or farmers because they did not perform well agronomically. This lack of fitness for production reduced the immediate value of some accessions, because more breeding effort would be required to transfer beneficial alleles to a well-adapted cultivar (Carter Jr. et al., 2004). Instead of being saved for their potential genetic diversity, many soybean accessions were lost or otherwise remained unused, leading to the relatively narrow base of germplasm for soybean breeding that exists in the US today. Despite the narrow genetic base, traditional breeding methods have increased yield of soybean from 1350 to 2250 kg ha^{-1} over the past 80 years in the US (Ustun et al., 2001). Boerma reported a 0.7%/year increase in yield from 1942 to 1973; roughly 13.7 kg ha^{-1}/year (Boerma, 1979). Progress was faster in the following decades; yield improved by 31.4 kg ha^{-1}/year from 1972 to 1997 (Specht et al., 1999). In an effort to preserve the best yield genes for high-yield environments, breeders repeatedly used popular cultivars as parents to make crosses, limiting the array of alleles in the gene pool. As a result, by the mid-1990s, 84% of the genetic base of soybean in North America was derived from only 17 cultivars (Gizlice et al., 1994). Even currently popular South American soybean cultivars have been extensively derived from this narrow base of North American cultivars (Carter Jr., 2018, personal comm.). Because of this genetic bottleneck, and because of the tendency to re-use high performing, landmark cultivars as genetic stock in breeding programs over the decades, genetic diversity for many quantitative traits is restricted (Carter Jr. et al., 2004). In particular, flooding tolerance may have been lost during the domestication of many crop plants we rely on today (Crawford and Braendle, 1996).

Hypoxic soil as a threat to production

Most cultivated crops do not possess agronomically important tolerance to flooding conditions (Oosterhuis et al., 1990; VanToai et al., 1994a; Wu et al., 2017b; Ye et al., 2018). Economic catastrophes resulting from flooding are a major risk for farmers, with larger flooding events causing billions of dollars in losses nationwide (Karl et al., 2008; Bailey-Serres et al., 2012a; Wu et al., 2017b). For example, Hurricane Matthew struck the Caribbean and southeastern US in 2016. Among the hardest hit nations was Haiti, where 75% of the nation's farmers suffered from damaged farmland, infrastructure and livestock. Damages to staple crops such as yam, banana, and black pea resulted in a 15-20% increase in food prices for Haitians following the storm (ReliefWeb, 2017). Cultivated crops in developed countries are equally at risk from catastrophes such as Hurricane Matthew. The extensive flooding that occurred in the US Midwest in 1993 caused an estimated $6-8 billion in damage to farmers. Flooding in North Dakota in 1997 caused an approximate $1 billion in crop loss (Rosenzweig et al., 2002) Although most agronomically preferable crop variants may be described as sensitive to flooding, many crop species possess variants that exhibit some tolerance to flooding conditions, such as wheat, barley and maize (Collaku and Harrison, 2002; Valliyodan et al., 2017). Notably, some lowland rice varieties possess the ability to thrive under flooded conditions (Khush, 1997; Sarkar and Panda, 2009; Bailey-Serres et al., 2012b).

There are numerous scientific definitions for the term "flooding" in published plant studies. In contrast to agricultural landscapes, seasonal flooding in wetlands and rainforests forces trees in the Amazon rainforest to adapt physiologically to both dry and saturated soil conditions (Parolin et al., 2010). In flooding research focused on crops, Thomas *et al.* (2005) defined a "waterlogged" soil as submergence of the root system and soil in water up to the base of the stem of the plant (Thomas et al., 2005; Bailey-Serres et al., 2012a). Flooding can also be described as the complete submergence of the plant vegetative portion under water for an extended period of time (Kawano et al., 2009; Bailey-Serres et al., 2012a). Both of these water stresses have an adverse effect on plant health. In the present study, flooding treatment is defined as inundation of the root system and partial submergence of the lower canopy with 10 to 12 cm of standing water. This is an important distinction, because fully submerging a plant under water for an extended period impedes gas diffusion into and between shoots and roots more completely than submerging the root system alone (Jackson and Kowalewska, 1983). By saturating the atmosphere surrounding a leaf's surface, transpiration will be limited and reduce a plant's ability to "pull" water upward via capillary action. Submergence also limits availability of CO_2 and sunlight necessary for photosynthesis. In addition to affecting shoot function, submergence and partial submergence can dramatically change the chemistry in soil. Hypoxic conditions force microbiota and plants to rapidly consume available oxygen in the soil rhizosphere and cause an imbalance in available nutrients and reduction in pH, as well as exacerbate micronutrient toxicities (Setter et al., 2009; Bailey-Serres et al., 2012a). The ability to absorb nutrients through the root system is critical to photosynthesis and plant health (Grable, 1966; Linkemer et al., 1998).

The most important factor behind the harmful effects of partial submergence in plants is the lack of oxygen available to submerged roots (Yamauchi et al., 2013; Locke et al., 2018). O_2 is required for cellular respiration, and its diffusion is slowed immensely under water (resistance to diffusion is 10,000 times greater in water than in air) (Armstrong et al., 1994). Because of reduced gas diffusion under water, CO_2 builds up in the rhizosphere as carbonate, which can be toxic to soybean plants in anaerobic conditions (Boru et al., 2003). In a study by Yamauchi *et al.* (2013), this toxicity was measured in above-ground plant development and below ground root and shoot growth. Total plant submergence severely restricts the flow of O_2 and CO_2 gas between the leaves and the roots, resulting in a transition from aerobic to anaerobic conditions in the plant and a reduction in growth and plant development (Yamauchi et al., 2013).

Rice (*Oryza sativa* L.) is one of few cultivated plants that has multiple flood tolerance mechanisms. Lowland varieties are adapted to regions where seasonal flooding is expected, and are generally more flood tolerant than upland varieties (Khush, 1997). One flooding survival strategy may involve using stored carbohydrates to carry out energy production for cell metabolism during hypoxia or anoxia (Ram et al., 2002). Tolerant rice varieties can endure anoxic or hypoxic conditions via quiescence, a process that effectively halts cell metabolism in a low oxygen environment and conserves carbohydrate sources for post-submergence growth (Fukao et al., 2006; Locke et al., 2018). In flood tolerant legumes, nodules may produce an excess of oxygen in slightly hypoxic environments, which is detrimental to the O_2-sensitive nitrogenase enzyme found in N_2 fixing nodules. This can sometimes be ameliorated by the protein leghemoglobin, which binds oxygen and allows small amounts of oxygen diffuse in the nodule (Crawford, 1992). By maintaining appropriate O_2 concentration in the nodule, this protein allows for the production of ATP (adenine tri-phosphate), a critical short-term energy storage molecule required for many biochemical processes, including N_2 fixation. Plant nodules use a combination of leghemoglobin and variable resistance to diffusion of oxygen to maintain steady O_2 supply (Crawford, 1992). In addition to limited gas exchange, hormonal interactions as a result of anaerobic conditions can affect plant response to waterlogging stress. Ethylene is a driving factor in flooding response in plants. Water restricts ethylene diffusion away from the plant, enhancing the flood response, including desiccation and senescence of leaves during and after flooding (Bailey-Serres et al., 2012b). Certain species of plants have been shown to respond morphologically to these conditions in order to maintain cell growth. This can include the formation of adventitious roots and stem elongation, the latter caused by up-regulation of ethylene production (Bailey-Serres et al., 2012b). One mechanism of adaptation involves directly facilitating the flux of O_2 to and from the roots and leaves; this is the production of aerenchyma cells in the stem and roots. Aerenchyma are small air spaces that form in the vascular system of some plants, and have been observed in many crop species including wheat (Malik et al., 2003), soybean (Bacanamwo and Purcell, 1999a), maize (Watanabe et al., 2017) and rice (Bailey-Serres et al., 2012a). The quantity of aerenchyma in a plant depends primarily on the type of environment in which that plant has evolved; a wetland species such as rice will constitutively produce aerenchyma in well-drained soils and enhance production during flooding conditions. Conversely, some dryland species such as soybean do not produce aerenchyma unless hypoxic flooding conditions are present (Bacanamwo and Purcell, 1999a; Yamauchi et al., 2013). Schizogenous aerenchyma form through cell differentiation without cell death; lysigenous aerenchyma form from programmed cell death, leaving spaces for dissolved gases to move through (Jackson and Armstrong, 1999). There are two well-known types of lysigenous aerenchyma tissue formed in plants. Primary (cortical) aerenchyma forms in the roots of certain plants, including wheat, rice, and maize (Jackson and Armstrong, 1999; Yamauchi et al., 2013). Secondary aerenchyma, composed mainly from a type of tissue that is derived from phellogen but constitutionally different, is a white, spongy tissue filled with gas pockets and forms in the stem, roots and hypocotyls of legumes like soybean (Glycine max) and wild soybean (Glycine soja) (Yamauchi et al., 2013).

Current knowledge of flood tolerance in soybean

Soybean yield can be significantly reduced after 1 to 2 days of flooding conditions (Scott et al., 1989). The species is susceptible to flooding at all developmental stages, but most sensitive at the early vegetative (V1) (Sallam and Scott, 1987), (V2) and early reproductive (R1, R3, and R5) stages (Linkemer et al., 1998). In a study performed by Scott *et al.* (1989), eight cultivars of *G. max* had a negative yield response in relation to increasing flood treatment length, regardless of the growth stage during treatment (Scott et al., 1989). Yield losses as a result of flooding conditions (in terms of seed weight and seed number) of up to 50% have been reported in the greenhouse (Githiri et al., 2006) and 25 to 39% (Rhine et al., 2009) to 95% (Sullivan et al., 2001) in the field. Among crops that are grown in mostly aerated soil (soil that goes through periods of wetting and drying), such as soybean, lack of cellular oxygen to the roots is the most likely cause of loss in production in waterlogging conditions (Vantoai et al., 2001; Ye et al., 2018). Anoxia is likely the cause of a decrease in N_2 fixation soon after flooding conditions are present (Justino and Sodek, 2013). Soybean forms a symbiotic relationship with bacteria in the soil (rhizobacteria) that help form N_2 fixing nodules on roots (Bacanamwo and Purcell, 1999b; Staton, 2011; Crozier and Hardy, 2017). Soybean nodules produce approximately 50-75% of the nitrogen needs for the plant when sufficient inoculum is present in the soil (Staton, 2011). Decreased growth under flooding conditions may partially result from reduced nodule health and N_2 fixation (Bacanamwo and Purcell, 1999b). Indeed, N_2 fixation is greatly slowed within minutes of flooding (Justino and Sodek, 2013). Aerenchyma cells have been shown to play an important role in sustaining N_2 fixation in hypoxic conditions (Thomas et al., 2005; Bailey-Serres et al., 2012b; Justino and Sodek, 2013; Yamauchi et al., 2013). It has been reported that secondary aerenchyma cover the surface of N_2 fixing nodules on a soybean plant in flooded soil conditions, something not typically observed on soybean roots in an aerobic growing environment (Yamauchi et al., 2013). It is thought that soybeans utilize this tissue to maintain essential functions during hypoxic stress (Bacanamwo and Purcell, 1999a; Yamauchi et al., 2013). Adventitious (shoot-born) roots have also been noted on soybean plants in response to hypoxic stress (Boru et al., 2003; Kim et al., 2015).

Additionally, soybean is susceptible to phytophthora root and stem rot caused by multiple *Phytophthora* species (Schmitthenner, 1985; VanToai et al., 1994a) which thrive in flooded soil conditions. It can be difficult to separate the effects of this pathogen on the plant from the effects of hypoxic or anoxic soil; symptoms of phytophthora include chlorosis, wilting and collapse (Schmitthenner, 1985). These symptoms are also indicative of flood stress. Decreased transpiration may be one effect of a reduction in turgor and water potential throughout the plant that is caused by a saturated soil environment around roots (Jackson and Kowalewska, 1983). The decrease in turgor causes wilting symptoms similar to that of drought (personal observation). Phytophthora flourishes in consistently wet and warm soil, which makes it particularly well suited to the low-lying areas in eastern NC soybean fields. Varieties that are susceptible to the pathogen typically wilt and collapse within several days of the onset of conditions that facilitate phytophthora. Symptoms from flooding, by contrast, typically take longer to manifest in the plant than phytophthora symptoms. This allows for possible differentiation of the two. However, an important question remains: Are healthy-looking plants in the flooded field tolerant to an anaerobic soil environment, or simply more resistant to the pathogen? VanToai *et al.* (2001) identified a marker (Sat_064) that was associated with flood tolerance in a tolerant × susceptible recombinant inbred line (RIL) population. However, this marker was located close to a known marker for phytophthora resistance (*Rps4*), putting into question whether the Sat_064 marker is a bona fide flood tolerance allele (Vantoai et al., 2001). Further analyses of a ‘flood tolerance’ gene was performed by Nguyen *et al.* (2012), in which minimal overlapping was found between known markers for P. *sojae* resistance and the suspected flood tolerance QTL region, suggesting that there may be independent genes responsible for each trait and that there is likely a pleiotropic effect of the genes (Nguyen et al., 2012)

Genotypic differences in flooding response can be captured with visual ratings, but other traits of agronomic importance are more economically relevant indicators of flood response. When determining whether a variety of soybean is tolerant to flooding, it is important to consider yield relative to that of a non-stressed plant. Tolerance to any stress factor may be defined as minimal or no loss of yield in a high or low yielding environment (Rosielle and Hamblin, 1981). This is especially true of flood tolerance in flooding conditions compared to controls (VanToai et al., 1994a; Setter and Waters, 2003). In areas of the US which see flooding regularly, such as the Mississippi Delta region and the Midwest, soybean yields were observed to drop ~25-50% under flooded conditions at various growth stages when compared to controls (Wu et al., 2017c). Scott *et al.* (1989) tested eight genotypes in the field at two flooding stages (V4 and R2) (Scott et al., 1989). They found shorter canopy height in a two week flood treatment when compared to a 2 day treatment, as well as lower yield. No visual rating system was implemented in this study. Previous testing of soybean germplasm for flood tolerance has been conducted using populations from a series of wide crosses. In a study performed on two related RIL populations, Cornelious *et al.* (2005) found that genetic variation does exist for flood tolerance in soybean when tested in an Arkansas environment (Cornelious et al., 2005). Two populations of plants were developed in the late 1990's from the crosses of two southern adapted varieties to one northern, flood tolerant variety, Archer. One population showed significantly different visual ratings in flooded conditions between years and through genotype × year (G×Y) interaction, while the other population showed no significant interactions. Moderate heritabilities were reported for visual ratings, but no flood tolerant segregates were identified from testing the two populations. More recently, researchers at MO have investigated a select group of genotypes in field and greenhouse screening using a visual rating system (Wu et al., 2017c; Ye et al., 2018). Plants were evaluated phenotypically based on percentage of foliar damage or plant death per plot and assigned a damage score on a 0 to 9 scale. Wu *et al*. (2017a) showed that significant variation can be captured by visual ratings, and ratings can be used to select flood tolerant types for crossing with adapted, high-yielding cultivars in Arkansas (Wu et al., 2017a).

Tolerance to flooding conditions has been measured or observed in several different ways. Tolerance or resistance to extreme soil nutrient toxicities has been proposed as a method of survival in saturated soil conditions. One study showed that interactions between micronutrient toxicity and pH reduction due to flooding may account for flood tolerance variation in plants between unique locations (Setter et al., 2009). Additionally, the effects of flooding on seed germination in the field are easily noticeable. Seed germination rate in soybean has been shown to decrease by 65% in the first 24 hours of flooding conditions, and up to 90% germination failure after 48 hours in a flooded field environment (Wu et al., 2017a). Chlorosis, necrosis, stunted growth, and plant death often result when significant flooding occurs at either vegetative or reproductive stages of soybean growth (Ahmed et al., 2013), and detrimental effects of flooding are also still apparent at maturity (Scott et al., 1989). An anoxic soil environment (complete lack of O_2 availability) was shown to decrease root growth and alter architecture of the root system in soybean (Huck, 1970). Leaf senescence is also a common result of flooding in pea (*Pisum sativum*. *(L.)*) (Jackson and Kowalewska, 1983) and soybean (Boru et al., 2003; Wu et al., 2017a; b; Ye et al., 2018). Flooding can occur at any time during the growing season worldwide. There is a pressing need for discovery of genetic tolerance to hypoxic soil conditions to mitigate current yield losses and provide security for farmers.

While soybean is one of the most important crop plants grown in the US today, relatively little is known about its adaptive mechanisms for hypoxic soil conditions. It is important to study flood-stressed plants in the field because various factors such as geographic region, climate, plant population and soil variability can interact with stress treatments and genotypes. A large soil flooding study containing diverse genotypes, controlled treatments and geographic relevance is much needed in the soybean research community and will provide insight to breeders as well as other research scientists. By noting differences in genotypes in a field setting for flood tolerance, this study can provide the genetic materials necessary for population development and determining a mechanism of flood tolerance.

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Chapter 2: Agronomic and Visual Response of Diverse Soybean Genotypes to Flooding in North Carolina

Abstract

Soybean [*Glycine max* (L.) Merrill] producers are often faced with flooding stress as a result of excessive rainfall. The effects of prolonged flooding include stunted roots, leaf chlorosis, and a decrease in seed yield. Genotypic variation in response to flooding has not been reported in North Carolina (NC). To remedy this, flooding responses of a diverse array of soybean genotypes were quantified at the Tidewater Research Station in Plymouth, NC in 2016 and 2017. Flood treatments were imposed by building berms around replicated blocks of genotypes and filling the berms with about 10 to 12 cm of water for 7 to 12 days. In Experiments I and II, 32 genotypes of maturity group (MG) IV and V and 24 genotypes of MG VI through VIII were evaluated for visual appearance and seed yield response to flooding at the early reproductive stage. Flooding reduced seed yield more than 50% as compared to control plots. Significant ($p < 0.05$) genotypic differences in flooding response were observed for visual ratings and seed yield. The two traits were highly correlated ($r = -0.84$, $p < 0.05$) under flooding conditions, suggesting that visual selection may be useful for selecting for flood tolerance in eastern North Carolina. Remarkably, genotypic means for yield exhibited no correlation between control and flooded conditions, and genotypes shifted markedly in ranking. Additionally, correlations that existed between yield and maturity under control conditions did not exist for flooded conditions. New sources of flood tolerance were identified among genetic materials in the USDA soybean breeding program in Raleigh and other public soybean breeding programs in the Southeastern US. Two breeding lines from the Universities of Arkansas and Missouri were validated as flood tolerant based on yield and visual ratings. The identification of potential parental stock through this study provides the building blocks for a flood tolerance breeding program in North Carolina and the Atlantic states.

Introduction

Flooding damage is a threat that farmers face around the world. In 2011 in the United States, crop losses due to flooding cost more than $3 billion, with over half of the damage borne by corn and soybean growers in the Midwest (Bailey-Serres et al., 2012b). Extensive flooding in the Midwestern US in 1993 caused upwards of $6 billion in damage to farmers (Rosenzweig et al., 2002). Flooding of crop lands is expected to become more frequent over time, with climatic factors becoming more unpredictable in scope and timing (Olesen et al., 2011). In that regard, a rising global mean temperature signals a change in the distribution of precipitation and temperature norms. Heavy precipitation is likely to increase in frequency and strength and light precipitation is expected to decrease (Karl et al., 2008). Past weather and future climate model predictions suggest that flooding is a serious threat to agricultural production, and steps should be taken to improve crop tolerance to this environmental stress.

Soybean [*Glycine max* (L.) Merrill] is particularly sensitive to flooding, suffering yield losses ranging from 25% (Rhine et al., 2009) to 95% (Sullivan et al., 2001) depending on flood duration and growing conditions. Phytophthora root and stem rot (*Phytophthora sojae* Kaufmann and Gerdemann) is active in flooded soil conditions and can add to soybean yield loss (Schmitthenner, 1985; VanToai et al., 1994b). Symptoms of phytophthora root and stem rot include chlorosis (yellowing of foliage), leaf wilting and shoot collapse (Schmitthenner, 1985). These symptoms are similar to those caused by flooding.

Excess water can be defined in many ways. Waterlogging is commonly referred to as a nearly saturated root system and soil, where the aerial organs of the plant are not submerged (Thomas et al., 2005; Bailey-Serres et al., 2012; Ye et al., 2018). Flooding is often defined as the complete submergence of the plant shoot in water, or complete saturation of the plant roots and a majority of the aerial organs of a plant (Bailey-Serres et al., 2012). In this study, the term flooding is defined as the partial submergence of soybean plants to a depth of 10 to 12 cm above the soil surface for 7 to 12 days.

Barring damage from biotic factors such as phytophthora, the most acute cause of stress in flooded soil is a deficiency of oxygen available for diffusion into the plant (Vantoai et al., 2001; Ye et al., 2018). The diffusion rate of gases is approximately 10,000 times slower in water than in air (Armstrong et al., 1994). This problem can be especially acute for plants that are adapted to aerated soil (soil that regularly goes through periods of wetting and drying). Buildup of dissolved carbonate is also a consequence of saturated soil conditions in which CO_2 cannot diffuse normally (Ponnamperuma, 1972; Boru et al., 2003). Such diffusion restrictions and buildups in the plant rhizosphere inhibit many functions of the plant. Under normal conditions, soybean forms a symbiotic relationship with rhizobia (*Bradyrhizobium spp.*) in the soil, forming nodules on soybean roots and fixing atmospheric nitrogen into a form usable by the plant (Bacanamwo and Purcell, 1999a; Staton, 2011; Crozier and Hardy, 2017). The critical process of N_2 fixation provides soybean with roughly 50-75% of its nitrogen needs (Staton, 2011). However, flooding conditions may slow or inhibit N_2 fixation (Justino and Sodek, 2013), reducing nodule health and bacteria activity.

Although symptoms of flooding stress may be evident in the field, there is no clear consensus as to the mechanism for flooding tolerance in soybean. Despite a fundamental lack of knowledge in this area, decades of soybean breeding in the Mid-South and Midwest have produced new cultivars and breeding lines with improved flooding tolerance. Breeders at the Universities of Arkansas and Missouri screened a diverse panel of genotypes in an artificial flooding environment, identified five flood tolerant genotypes, and developed high-yielding cultivars exhibiting flooding tolerance (Wu et al., 2017c). Two RIL populations were developed by crossing southern cultivars A5403 and P9641 with cultivar Archer from the University of Minnesota. The resulting populations were evaluated for flood tolerance in Arkansas using a visual scoring system. No tolerant segregates were found in the populations, but the authors reported moderate broad-sense heritabilities ($H^2 = 0.59$ and 0.43) in each population for visual ratings, based on genotypic means over years (Cornelious et al., 2005). In Ohio, soybean genotypes were evaluated for flooding tolerance in terms of seed yield and plant height, and also scored for resistance to phytophthora root and stem rot (VanToai et al., 1994b). A quantitative trait locus (QTL) was detected for flood tolerance, but it is not clear that it was independent from a known phytophthora resistance gene (*Rps4*) (Vantoai et al., 2001). Visual ratings have been shown to offer a quick and reproducible method of assessing a genotype's response to stress (Wu et al., 2017a), and they are being used currently in breeding programs aimed at improving flooding tolerance (Cornelious et al., 2005; Wu et al., 2017b; c; Ye et al., 2018).

Genotype × environment interaction may be an important factor in flooding tolerance, such that cultivars or breeding lines that appear flooding tolerant in one environment may not perform as well in another. This topic is an active area of study in the Mid-South (Chen, 2018, personal comm.). In northeastern NC, soybean production is extensive, and flooding and waterlogging are common problems in the high organic matter soils of the area. However, tolerance of soybean to excess water is not well characterized in this region in terms of yield or visual response. The impact of genetic advances in the Mid-South on flooding tolerance in NC has not been assessed.

The main objective of this study was to evaluate a diverse collection of 56 soybean genotypes for yield and visual response to flooding in North Carolina. Germplasm included cultivars and breeding lines previously rated as flood tolerant or sensitive from AR and MO, plus an array of materials developed by soybean breeders from Atlantic coast states. The second objective was to determine the impact of flooding and flooding tolerance on other agronomic characteristics such as seed weight, height, lodging, and seed oil and protein content.

Materials and Methods

Genotypes

Experiment I (MG IV-V). Thirty-two genotypes were selected for the early maturity group experiment to represent extreme flooding responses in the Mid-South. Some were selected based on previous observations by Drs. P. Chen and H. Nguyen (personal comm.) in Arkansas and Missouri (Table 2.1). In addition, diverse genotypes were selected from the USDA soybean breeding program at Raleigh, NC as well as control cultivars from regional soybean trials.

Experiment II (MG VI –VIII). Twenty-four genotypes were selected for the late maturity experiment to represent an array of diverse breeding lines and cultivars developed in the Atlantic coast states (Table 2.1). Few of these genotypes had been previously tested for flooding response.

Field study

The field studies were conducted at the Tidewater Research Station (TRS) near Plymouth, NC in 2016 and 2017 on a Portsmouth fine-sandy loam with approximately 3.2% organic matter (NCDA, 2017). The TRS is operated by the NC Department of Agriculture and North Carolina State Agricultural Research Service. The TRS was selected for study because of its flat landscape, high water table, and high organic matter, all common to flooding-prone eastern NC. Plots were planted on May 20 in 2016 and May 18 in 2017, using a John Deere 1700 MaxEmerge Plus Integral 3-row modified unit with Almaco cone planters. Plots were harvested in mid-November of each year with an Almaco SPC20 plot combine. Each plot consisted of three rows 6.1 m in length (2016) and 5.8 m in length (2017) at a row spacing of 76.2 cm. Seeding rate was approximately 36 per m of row. All measurements were taken on the bordered center row. To facilitate implementation of flooding treatments, each experiment was arranged as a split-split design, with flooding treatments as whole plots, two repeated blocks of genotypes as subplots within whole plots, and genotype as the sub-sub plot. The experiments had three replications in each year. Approximately one week before treatment initiation, earthen berms were constructed around appropriate blocks using a tractor-mounted inverted disc plow to produce walls of 0.75 m height and 1 m width (Fig. 2.1). The four corners of the berm were connected manually and packed to prevent water spillage. Each berm was approximately 107 × 21 m, and 55 × 21 m in 2016 and 2017, respectively. Smaller berms were used in 2017 to improve precision of treatment imposition. In 2016, the treatment was imposed at the R1 growth stage (August 13, 2016) (Fehr and Caviness, 1977) (Fig. 2.2). After 12 days of flooding to a depth of 10-12 cm, berms were opened and water was directed toward a drainage system. In 2017, the treatment was imposed at the same depth for seven days beginning at approximately the R2 growth stage (July 24, 2017).

Visual ratings were taken for each plot on a weekly basis commencing two weeks after stress was relieved. Ratings were assigned on a 0 to 9 scale, where 0 indicates no damage and 9 indicates >95% dead plants. Ratings of 1, 3, 5, 7 and 9 indicate roughly no damage, slight yellowing, moderate yellowing and canopy defoliation, extensive yellowing and defoliation, and finally > 95% severe chlorosis and plant death, respectively (Fig. 2.3). Individual rating dates were defined as the number of weeks after flood termination (WAFT). In 2016, flooding was terminated on August 27 and ratings were taken 1, 2, 3 and 4 WAFT. In 2017, flooding was terminated on August 1 and ratings were taken 2, 3, 4, 5 and 6 WAFT. For the first ratings of visual response in 2016, data were collected by two raters, and averaged for analysis.

Traits Measured

Yield

All plots were mechanically end trimmed to ensure uniform yield estimates on a 4.6 m plot. Only the center row of three rows was harvested. Seed were air dried to approximately eight percent moisture prior to weighing for yield. Plots were harvested in early or mid-November in each year.

Maturity date

The date of harvest maturity was defined as the first day on which 95% of the pods in the plot reached their mature pod color (Fehr and Caviness, 1977). Plots were visited every five days after plots were first rated until all plots were mature. Maturity was recorded as October 1 = 1.

Lodging

Lodging was recorded after maturity and prior to harvest in 2016 and 2017. A 1 to 5 scale was used, with one indicating no lodging and five indicating a prostrate plant (Gillen and Shelton, 2018).

Height

Plant height was recorded after maturity and prior to harvest in 2016 and 2017 as the mean of three random plants per plot. Plant height was defined as distance from ground level to the apical meristem.

100-Seed weight

Seed weight was measured after drying to approximately eight percent moisture by counting 100 random seed from a harvest bag and weighing the seed.

Seed Protein and Oil composition

Seed protein and oil content were measured on a Perten DA 7250 near infrared (NIR) spectroscopy analysis instrument (Perten Instruments, Springfield, IL) and reported on a 0% moisture basis.

Statistical analysis

Genotypes and flooding treatment were considered fixed effects. All other effects were treated as random. Statistical analyses were performed with SAS 9.4 (SAS Institute Inc., Cary, NC). Analysis of variance (ANOVA) were performed using the GLM procedure (Tables 2.4, 2.5, 2.6). Least Square Means (LS means) were calculated using the LSMEANS statement in PROC GLM. Fischer's protected least significant difference (LSD) was used to compare genotypic means. The ANOVAs were performed in a combined analysis over years, for each year separately, and for each treatment separately to assess Genotypic, Genotype × Year (G × Y) and Genotype × flooding Treatment (G × T) effects.

Data curation and transformation

For each experiment, preliminary analyses were performed to assess flooding treatment effects on seed yield on an individual block basis. Blocks were removed from subsequent analyses if the flooding treatment was deemed to have been imposed inadequately as a result of inconsistent water levels throughout the block. Some plots were clearly not covered by water throughout the treatment, and adequate imposition was defined as a minimum of 35% reduction in yield, averaged across all genotypes, as compared to control blocks. In Experiment I, one and a half blocks (three reps total) and two blocks (four reps total) were dropped out of both 2016 and 2017 flooding treatment. In Experiment II, two blocks were dropped out of each year's flooding treatment. Data which were retained after this preliminary analysis were subjected to residual analysis for each combination of treatment and year for all traits. Individual data points were removed from analysis if its residual was three times the standard deviation of the error term (approximately a 1% probability of being a larger residual by chance alone, Snecedor and Cochran, 1967) and if a reasonable cause for dropping (i.e. plot damage, inadequate flood pressure, poor stand) was noted for that plot. Employing this approach, data from four and nine additional plots were deleted in 2016 and 2017, respectively. The finalized data set became the basis for assessing flooding effects on genotypes (Table 2.2). Heterogeneity of error variance was detected for yield between flooding and control treatments in each year for both experiments. In an attempt to reduce the effect of this heterogeneity, yield and rating data were subjected to square root and natural log transformations. For the log transformation, data were subtracted from a constant (equal to the maximum value of the data) to ensure all values were greater than zero. Analyses using these transformations led to the same conclusions as the untransformed data regarding significance testing for treatment and genotypic effects (Appendix A). In addition, genotypic means for non-transformed and transformed data were highly correlated for each trait, producing correlation coefficients above 0.95 (Appendix B). Thus, results presented here are based on the untransformed data. Pearson correlations were estimated for genotypic means in Excel 2017 (Microsoft, Redman, WA). When analysis over years indicated no Genotype × Year interaction, Genotype × Year interactions were pooled over years for significance testing as suggested by (Carmer et al., 1969). Fisher's protected LSD was calculated from error terms in those pooled analyses if applicable. For visual ratings, we conducted a separate analysis for each date as well as a combined analysis over dates for each experiment and year. Genotypic correlations of phenotypic means among dates were high in both years (above 0.90 and 0.64 in 2016 and 2017, respectively). Thus, only the combined analysis and LS means over dates are presented here.

Variance components for yield and visual ratings were estimated using the VARCOMP procedure in SAS. Broad-sense heritability (Nyquist and Baker, 1991) was calculated on a plot mean and entry mean basis for each experiment using the formulae below:

$$H^2_{\text{(plot basis)}} = \frac{\sigma^2_G}{\sigma^2_G + \sigma^2_{GxE} + \sigma^2}$$

$$H^2_{\text{(entry mean basis)}} = \frac{\sigma^2_G}{\sigma^2_G + \frac{\sigma^2_{GxE}}{l} + \frac{\sigma^2}{l \times r}}$$

Where,

H^2 = heritability	σ^2_G = genetic variance	$\sigma^2_{G\times E}$ = genotype × environment variance
σ^2 = error variance	l = number of locations used	r = number of replications used

Results

Experiment I. The flooding treatment was imposed successfully in most blocks (as mentioned previously) during flowering in each year. Flooded plots produced much lower yield over years (776 kg ha^{-1}) than did control plots (2748 kg ha^{-1}, $p < 0.001$, Table 2.2) and exhibited obvious, widespread yellowing of leaves, beginning about two weeks after treatments were terminated. Most other agronomic traits showed only minor overall effects from flooding. One exception was seed protein content, which exhibited a mean decrease over genotypes of 21 and 9 g kg^{-1} as a result of flooding in 2016 and 2017, respectively. Seed oil content increased proportionately (12 and 4 g kg^{-1}) in those same years. Year × flooding Treatment (Y × T) interaction was detected for yield but no other traits ($p < 0.05$), and likely reflected higher yields for the controls in 2017 than in 2016 (Table 2.2). Yields of flooded plots were similar in the two years (Appendices C and D).

Genotypes differed significantly ($p < 0.05$) for all traits in the combined analysis over year and treatments excluding visual ratings, which were recorded only for the flooded plots (Table 2.4). Genotype × treatment interactions were detected for yield only ($p < 0.05$) (Tables 2.3, 2.4). In a separate analysis of the flooding treatment over years, genotypes differed significantly ($p < 0.001$) for all traits, including visual ratings of flooding damage (Table 2.5). Genotype × year (G × Y) interactions were small and non-significant ($p > 0.05$) in the separate analysis of flooding. Where applicable, G × Y and error sums of squares were pooled for significance testing, following guidelines established by Carmer et al. (1969). Only visual ratings and plant height had sufficiently large G × Y sums of squares (F tests of means squares were $p = 0.233$ and 0.192, respectively) to preclude pooling with error. In the control treatment, the genotype effect was significant ($p < 0.01$) for all traits (Table 2.6), and G × Y interactions were present for all traits ($p < 0.05$).

Genotypes Ellis, RM-22590, and S11-25615 had the highest yields under flooding conditions (1664, 1624, and 1134 kg ha^{-1}, respectively, Table 2.3). RM-22590 and S11-25615 were identified previously as flood tolerant (Chen and Nguyen, 2018, personal comm.). Ellis and RM-22590 also yielded well in the control plots (3144 kg ha^{-1} and 2697 kg ha^{-1}, respectively). Several genotypes could not be harvested in some or all flooded plots because of extensive premature death from flooding. For example, known flooding-susceptible line S99-2281 (Chen and Nguyen, 2018, personal comm.) yielded 2553 kg ha^{-1} under control conditions, but only 67 kg ha^{-1} under flooded conditions based on those reps that were harvested. Although significant G × T interactions were not detected for other traits in the analysis of variance, we noted a trend in which R10-2379 matured 10 days later under flooded conditions as compared to control conditions, while the remaining genotypes matured similarly in both treatments. Additionally, AG4632 and AG5334 exhibited a reduced 100-seed weight as a result of flooding (14.4 to 11.7 g and 14.6 and 11.9 g, respectively), while 100-seed weight of Osage was unaffected (12.2 g in both treatments). Two MO breeding lines, S99-2281 and S12-1362, exhibited reduced seed protein content by over 30 g kg^{-1} in flooded vs. control plots. A similar trend was present in the remaining genotypes. Genotypes differed for visual ratings of flood damage ($p < 0.05$) and no G × Y was detected ($p > 0.05$, Tables 2.4 and 2.6). RM-22590, S11-25615, and Ellis received the best visual scores, with mean visual ratings of 2.7, 4.1, and 4.1 respectively, over years, showing little to no yellowing or defoliation of the canopy and indicating tolerance to flooding stress. Breeding line S99-2281, previously identified as a susceptible type, scored the worst numerically (8.7). Maturity scores of genotypes were highly correlated between the flooding and control treatments ($r = 0.72$, $p < 0.01$); however, maturity was not associated with other agronomic traits except seed protein content ($r= 0.51$, $p < 0.05$) for the flooding treatment (Table 2.7). There was no significant ($p < 0.05$) correlation of genotypic means for yield between flooding and control treatments over years ($r = 0.04$). Genotype means were positively correlated ($r \geq 0.69$, $p < 0.05$) between flooded and control conditions for all other traits (Table 2.7). The phenotypic correlation of genotypic yield means between 2016 and 2017 in the control treatment was moderate ($r = 0.54$, $p < 0.05$, Appendix E). For the flooding treatment, yield and visual ratings were highly negatively correlated ($r = -0.85$, $p < 0.01$) and followed a linear relationship (Fig. 2.4). A strong negative correlation ($r = -0.67$, $p < 0.01$) was present between protein and oil content in the flooding treatment (Table 2.7).

Experiment II. The treatment was successfully imposed on the late maturity group genotypes. The severity of visual damage from flooding was greater in 2016 than in 2017 (Table 2.2). The mean visual ratings were 6.4 and 3.8 in 2016 and 2017, respectively, indicating a greater degree of leaf yellowing and defoliation as a result of flooding in 2016. The control treatment yielded significantly ($p < 0.06$) more than the flooded treatment over years (2508 kg ha^{-1} vs. 1010 kg ha^{-1}), respectively (Table 2.3). The remaining traits showed only minor effects from flooding. Genotype × treatment interactions were detected for yield and seed protein content ($p < 0.05$), but not for other traits (Table 2.4). The correlation of genotypic means for control and flooded plots was not significant at $p < 0.05$ ($r=0.26$).

Analysis of control plots over years showed that genotypes differed for all traits ($p < 0.01$, Table 2.6), and all traits exhibited significant ($p < 0.05$) G × Y interactions. In a separate analysis of flooded plots over years, genotypes differed significantly ($p \leq 0.06$) for all traits except visual ratings (Table 2.5). The Year × Genotype interaction was significant ($p < 0.05$) for visual ratings and appeared to mask the overall genotypic effect. This was attributed to greater overall leaf yellowing and death in 2016 compared to the following year. However, genotypes differed significantly ($p < 0.05$) for visual ratings within each individual year (data not shown). Regarding yield, a trait for which G × Y was less pronounced than for visual ratings, cultivar NC-Dunphy yielded well in the control treatment and was the highest yielding genotype in the flooding treatment (3100 and 1935 kg ha^{-1}, respectively, Table 2.3). N7002 (1415 kg ha^{-1}), N8002 (1223 kg ha^{-1}), Dillon (1356 kg ha^{-1}), and N93-110-6 (1297 kg ha^{-1}) also maintained yields well above the mean (1010 kg ha^{-1}) for the flooding treatment. TCHM06-Morph 204 yielded well in the control treatment, but was ranked among the lowest in the flooding treatment (2849.3 kg ha^{-1} and 362.9 kg ha^{-1}, respectively). NMS4-1-77 increased in seed protein content in the flooding treatment from 427 to 443 g kg^{-1}, while N6002 decreased in protein content (435 to 420 g kg^{-1}). Although G × T was not significant for most traits, a trend was noted in N6001 and Boggs that 100-seed weight increased (from 1 to 2 g) as a result of flooding.

The correlation of genotypic means in the flooded treatment revealed moderate association between years for seed yield ($r = 0.44$, $p < 0.05$, Appendices F and P). However, a poor association was noted between years for visual ratings ($r = 0.19$, $p > 0.10$, Appendices F and Q). Despite significant G × Y for visual ratings, linear regression of yield and ratings over years revealed that certain genotypes appeared consistently tolerant or sensitive in both years (Appendices P and Q). For example, cultivars N7002 and NC-Dunphy performed well over years in terms of both yield and visual ratings. TCHM06-Morph 204 was consistently poor.

The phenotypic correlation of genotypic means for yield and maturity date in the control treatment was strongly negative ($r = -0.68$, $p < 0.01$, Appendix E), but nearly absent under flooded conditions ($r = -0.10$). Orthogonal partitioning of maturity group effects in Experiment II (MG 6 vs MG7-8) showed that within each maturity grouping, genotypes differed significantly ($p < 0.06$) for yield and also exhibited G × T interactions (Appendix G). Correlations of yield and maturity under control conditions remained strong when estimated within each MG separately ($r \leq -0.54$, $p < 0.01$, Appendix H).

Despite the G × Y for visual ratings in the flooded treatment, the correlation of genotypic means were strongly negative between visual ratings and seed yield ($r = -0.85$, $p < 0.05$, Table 2.7) and followed a linear relationship ($R^2 = 0.71$, Fig. 2.5). This high association of visual ratings and yield for genotypic means was also evident within each year ($r \geq 0.80$, $p < 0.05$, Appendix E, Figs. 2.6, 2.7). Protein and oil were strongly negatively correlated, as expected ($r = -0.69$).

Discussion

More than two decades of flooding tolerance research in Missouri and Arkansas (Wu et al., 2017b; c; Ye et al., 2018), has produced an array of breeding lines which contrast for flooding tolerance. Although flooding is often a problem in the low-lying, high organic matter fields of northeastern North Carolina, little information is available regarding performance of soybean genotypes under these conditions in NC. To assess the potential to improve flooding tolerance in soybean for NC, we evaluated a diverse array of 56 genotypes, including contrasting soybean types from MO and AR, and breeding lines and cultivars from soybean breeding programs on the Atlantic coast.

In this study, imposing flooding stress at flowering time for 7-12 days reduced yield by more than 50% and produced visual symptoms of plant damage, including death. Although many genotypes were sensitive to flooding, some appeared to have substantial tolerance in NC, as evidenced by visual ratings and seed yield (Figs 2.4 and 2.5). In the early maturity group set, previously identified flooding tolerant lines from AR and MO, RM-22590 and S11-25615, respectively, appeared tolerant in NC. A breeding line that was reported sensitive from MO (S99-2281) also appeared flood sensitive in NC. However, most of the other eleven breeding lines from AR and MO did not perform in a manner consistent with previous observations in the Delta. Surprisingly, in both the early and late maturity group sets, additional cultivars and breeding lines were identified as flooding tolerant which were not previously known. Cultivar Ellis (Pantalone et al., 2017) appeared tolerant in the early maturity set of genotypes. Late maturity genotypes were less consistent in their response and G × Y interaction for visual ratings partially masked genotypic effects. However, cultivars N7002 (Carter et al., 2007), NC-Dunphy (Gillen and Shelton, 2018), Dillon (Shipe et al., 1997), N8002 (Carter et al., 2016), and breeding line N93-110-6 all yielded substantially better after flooding than most other genotypes and exhibited less foliar damage (Fig. 2.1). All of these newly identified flood tolerant genotypes, except Ellis and Dillon, trace a portion of their pedigree to PI 416937, a slow-wilting introduction from Japan, which is believed to harbor alleles for improving both drought tolerance and yield potential. The combination of reduced foliar damage and superior yields under flooding conditions for these genotypes suggests that they could make good parental stock for flooding tolerance breeding and hints that PI 416937 may carry alleles for flood tolerance. However, other genotypes involving PI 416937 pedigree in this study performed poorly in flood conditions, and the genetic relationship of these individual genotypes was not included in this study. It is therefore unclear whether PI 416937 was a source of flood tolerance in the genotypes that performed well in flood conditions. Interestingly, NC genotypes Holladay (MG V) and

TCHM06-Morph-204 (MG VII) both appeared sensitive to flooding in this study. The line TCHM06-Morph-204 is a near isogenic mutant of Holladay, selected for late maturity (Carter, 2018, personal comm.). The wide maturity range of these two genotypes and close genetic similarity make the pair good candidates to serve as sensitive checks in future flooding studies which compare southern maturity genotypes.

Within the late maturity group set, many NC breeding lines performed inconsistently over years for visual ratings. Cultivar N8002 was somewhat inconsistent across years for visual ratings, yet emerged with favorable yield and better than average visual ratings overall. Boggs, N7103 and G00-3213 also exhibited inconsistency in visual ratings over years, performing better than the mean in 2016, but worse in 2017 (Appendix Q). This effect of G × E for flooding tolerance has been observed previously in soybean in the mid-South. Wu *et al.* (2017c) reported that only a small percentage of genotypes tested (11 of 722) were rated as tolerant in all five years of their study. The low frequency of tolerant types that we observed in the present study (5 of 56) is roughly on par with that of Wu at al. (2017c). This study, along with research in the Delta, highlights the importance of screening for flooding tolerance over environments to cope with substantial GxE that is likely to be present.

Visual rating was a good predictor of yield under flooded conditions in both maturity sets ($R^2 > 0.70$ in each experiment, Figs 2.4 and 2.5). Although G × Y was present for visual ratings in the late maturity set, the association between yield and visual ratings (based on genotypic means) was good in each year as well as over years. An improvement of one unit in visual rating score was predicted to increase yield by approximately 270 kg ha^{-1} under flooded conditions. By contrast, neither yield nor maturity under control conditions was an effective predictor of yield under flooded conditions. These results are supported by Reyna *et al.* (2003) who reported a high correlation of yield and visual ratings under flooding stress in Arkansas. Weekly ratings in our study were highly correlated, suggesting that only a few ratings are necessary to obtain useful and repeatable information for an individual environment. However, ratings taken within the week following treatment termination were less descriptive of genotypic differences than those ratings taken 2 or 3 weeks after termination (data not shown). These findings contrast with those of others who based conclusions on ratings taken after one week of flooding (Wu et al., 2017a) or on the first week of ratings out of three weeks in which plots were observed (Reyna et al., 2003).

One objective of this study was to determine the repeatability or heritability of visual ratings in NC. Cornelious *et al.* (2005) reported moderate narrow sense heritabilities ($H^2 = 0.59$ and 0.43) in two RIL populations of soybeans for visual ratings that were evaluated for flooding tolerance from 2001 to 2003. Wu *et al.* (2017b; a; c) found that foliar damage scores collected after flooding were an effective measure of tolerance, but did not report heritability. In the present study, broad sense heritabilities of visual ratings were 0.62 and 0.29 for Exp. I and II, respectively, based on genotypic means over two years, two replications and three rating dates (Appendix I). Heritabilities of yield under flooded conditions were intermediate to that of visual ratings, based on this same resource allocation basis ($H^2 = 0.58$ in Exp. I and 0.58 in Exp. II). However, the high cost of yield testing over multiple environments, comparable heritabilities for the two traits, and high correlation between the traits appears to justify the use of relatively inexpensive single-row plots and visual selection. The marked increase in heritability for visual ratings when testing over years vs. an individual year signifies the necessity of multi-environment testing when selecting for flood tolerance using visual ratings. Developmental stage of genotypes during flooding and duration of flooding may have been affected overall flooding intensity and contributed to differences in heritability between Experiments I and II; more testing and replication may be needed to clarify this numerical trend in the data.

The strong negative correlation of yield with maturity in control conditions among the late maturity set was still present when individual maturity groups were analyzed separately, indicating that variation in yield is due to genotypic differences within maturity group rather than between maturity groups. Although yield and maturity were negatively correlated in the control treatment, yield and maturity were not correlated in flooding conditions.

Agronomic traits were not greatly affected by the flooding treatment. Mean seed protein content decreased in flooding conditions in Experiment I, but changed little overall in Experiment II. Mean seed oil content increased slightly from flooding in Experiment II. However, several genotypes in Experiment I exhibited numeric reduction in seed protein content (~30 kg ha^{-1}) as a result of flooding. One genotype (NMS4-1-77) in Experiment II increased protein content by 16 g kg^{-1} in the flooded treatment. For seed oil content, there were no such changes for genotypes in either experiment as a result of flooding. The well-known highly negative genotypic correlation of seed protein and oil (Brim, 1973; Burton, 1987; Brummer et al., 1997; Pathan et al., 2013) was present in both control and flooded treatments in this study.

Implications for plant breeding

Plant breeders are always searching for ways to maximize genetic gain. By reducing or increasing components of the genetic gain formula (namely time per breeding cycle, heritability of the trait, and selection intensity), one can alter the rate at which beneficial alleles are stabilized in a population of plants, or certain lines, through traditional breeding. The strong correlation of yield and visual damage ratings coupled with generally higher heritabilities for visual ratings suggest that visual selection can be a very effective selection tool, especially in initial breeding stages when large populations are likely to be evaluated. No genotypes in this study exhibited poor visual ratings while also yielding well, indicating that visual ratings are reliable indicators of flood tolerance (Table 2.3, Fig. 2.4 and 2.5). Visual selection for flooding tolerance is currently practiced in breeding programs in MO and AR. The high correlation of genotypic means for rating dates suggests that a breeder would only need 2 to 3 days of ratings on three replications of single row plots to glean useful visual ratings and make selection progress (Table 2.8). However, G × E for flooding response is likely to be present for both seed yield and visual ratings, such that multiple testing environments will be the norm in applied breeding programs. In our study, increasing the number of replications and locations would have likely helped reduce the impact of the G × E observed in the later maturity genotypes for visual ratings. Adoption of high-throughput phenotyping via un-manned aerial vehicle (UAV) would be a promising technique to capture genotype response with visual and/or infrared imagery, enabling a breeding program to process many more plots than the methods described.

This survey of genetic materials identified several which may be very useful for initiating a breeding program for flooding tolerance in NC. These materials may also be good candidates for scientists seeking to identify mechanisms for flooding tolerance and the QTL which control them. Root architecture morphology and unique characteristics of vascular tissue are thought to impart flooding tolerance in some species (Bacanamwo and Purcell, 1999a; Thomas et al., 2005; Shimamura et al., 2010). In addition to flooding tolerance, a major QTL *qWT_Gm03* has been found to increase waterlogging tolerance in the Delta (Ye et al., 2018), and may have utility in NC, where waterlogging is perhaps even more common than flooding. Soybean producers should be encouraged that there are flood tolerant resources that can be used to develop varieties for eastern NC.

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Table 2.1. Genotypes screened in Experiments I and II and their pedigrees.

Experiment	Entry †	Maturity Group	Code	Pedigree	Traits	Prior flood tolerance designation
				Maturity Group IV lines and cultivars		
I (MG IV-V).	**AG4632**	IV	19			
	R13-12552	IV	3			tolerant ‡
	S11-25108	IV	15			tolerant ‡
	S11-25615	IV	17			tolerant ‡
	S99-2281[†]	IV	18	N90-516 x S92-1069		sensitive ‡
	UA 5014C	IV	8	Ozark x Anand ‡	check	sensitive ‡
				Maturity Group V lines and cultivars		
	AG5334	V	20			
	Camp	V	27	Selection from Vance	small seed, narrow leaf	
	Ellis	V	24	5601T X 5002T (OR REVERSE)	high yield	
	Holladay	V	28	N77-179 x Johnston	Landmark cultivar	Yielded well in wet years
	Hutcheson	V	21	V68-1034 x Essex	Landmark cultivar	
	N02-7002	V	23	Cook x Anand	high yield, SCN resist.	
	N02-7779	V	31	Carver x Lambert	Diverse pedigree (MG V11 x MG 0)	Midwest pedigree, tolerant?
	N07-15307	V	30	N98-7265 x N98-7018	slow wilting 50% pedigree derivde from PI 471938	
	NC-Miller	V	26	Santee x Holladay §	high oil, high yield	
	NMS4-6-10	V	32	N7103 x Soja PI 366122	50% pedigree derived from wild soybean PI 366122	
	Osage	V	25	HARTZ 5545 X KS4895	high protein, high yield	
	R06-4433	V	9	Lonoke x P9594 ‡		sensitive ‡
	R07-6669	V	4	Lonoke x R00-33 ‡		tolerant ‡
	R09-4095	V	14	S01-9265 x R00-1940 ‡		sensitive ‡
	R10-230	V	1	5002T X R04-357 ¶		
	R10-2379	V	12			sensitive ‡
	R10-4892	V	2	5002T x R01-3474F ‡		tolerant ‡
	R11-2915	V	13			sensitive ‡
	R99-1613F	V	10	NKRA 452 X PI 290126B ‡		sensitive ‡
	S12-1362	V	16			tolerant ‡
	UA 5612	V	5	R97-1650 x 98601 ¶		check ‡
	Walters	V	6	Forrest x Narow ‡		1st flood tolerant cultivar ‡
				Maturity Group VI lines and cultivars		
	N07-15137	VI	29	N98-7265 x N98-7018	slow wilting 50% pedigree derivde from PI 471938	
	NCC09-135	VI	22	NCC04-619 x NCC04-1555	high yield, lodging resist.	
	R04-342	VI	7	R97-1650 X 98601 ¶		tolerant ‡
	RM-22590	VI	11		natto derived line	sensitive ‡

† All entries with names beginning in N, NCC, R, S, and SC were developed by USDA-ARS at Raleigh, NC; North Carolina State University; University of Arkansas; University of Missouri; and Clemson University, respectively.

‡ Pedigree and tolerance designation information obtained from Wu et al, 2017a.

§ https://soybase.org/uniformtrial/index.php?page=lines

¶ https://soybase.org/uniformtrial/index.php?page=lines&filter=Camp

file:///C:/Users/cjreagan/Downloads/Registration_of_NC-Raleigh_Soybean.pdf

Source: Wu, C., P. Chen, W. Hummer, A. Zeng, and M. Klepadlo. 2017a. Effect of Flood Stress on Soybean Seed Germination in the Field. Am. J. Plant Sci. 08(01): 53–68. doi: 10.4236/ajps.2017.81005.

Table 2.1. Continued.

Experiment	Entry †	Maturity Group	Code	Pedigree	Traits	Prior flood tolerance designation
Maturity Group VI lines and cultivars						
II (MG VI-VIII).	**Boggs**	VI	1	G81-152 x Coker 6738	Nematode resistance	
	Dillon	VI	2	Centennial x Young	loding resistance	Yielded well in wet years
	N06-6	VI	6	N99-510 x G98-1053	high yield, lodging resistance, exotic ped.	
	N6001	VI	12	Young x N94-7350	25% pedigree derived from Japanese cultivar Suzuyataka	
	N6002	VI	13	Young x N6202	25% pedigree derived from Japanese cultivars (Fukuyataka and Nakasennari)	
	N93-110-6	VI	22	Young x PI 416937	slow wilting, 50% pedigree derived from PI 416937	
	NC-Dilday	VI	20	N99-8137 x TN99-117	high yield, lodging resistance, 12.5% pedigree from PI 416937	
	NC-Dunphy	VI	19	MD99-6226 x N97-9677	high yield, lodging resistance, 12.5% pedigree from PI 416937	
	Young	VI	14	Davis x Essex	landmark cultivar	
Maturity Group VII lines and cultivars						
	G00-3213	VII	18	Cook x N7001	high yield, 25% pedigree from PI 416937 (what is nema resistance profile?)	
	N7001	VII	16	50% PI 416937	high yield, 50% pedigree from derived from PI 416937	soja pedigree
	N7002	VII	17	N7001 × Cook	high yield, 25% of pedigree derived from PI 416937	soja pedigree
	N7003CN	VII	3	Cook × Anand	high yield, resistant to all field races of soybean cyst nematode	tolerant?
	N7103	VII	8	NTCPR90-143 x PEARL	small seed, resistant to Kudzu bug (Sci name?),narrow leaf	
	NC-Wilder	VII	21	R97-1634 x N97-9693	high yield, lodging resistance, 12.5% pedigree from PI 416937	soja pedigree
	NC-Raleigh	VII	4	N85-492 x N88-480 #	high oil	flood susc.?
	NLM09-77	VII	15	N6202 x G98SF114	high protein, 25% pedigree derived from Japanese cultivars (Fukuyataka and Nakasennari)	
	NMS4-1-77	VII	10	N7103 x PI 366122 (G. soja)	50% pedigree derived from wild soybean PI 366122	
	NMS4-44-329	VII	9	N7103 x SOJA PI 366122	50% pedigree derived from wild soybean PI 366122	
	TCHM06-Morph 204	VII	5	Late maturity mutant from Holliday	Maturiy Group VII mutant of Holladay	
	TCWN05/06-5068	VII	24	Cook x SC97-1821	resistant to Mn deficiency	tolerant?
Maturity Group VIII lines and cultivars						
	N8002	VIII	23	N7002 x N98-7264	high yield, slow wilting cultivar, 37.5% of pedigree derivde from PI 471938 and PI 416937	resistant to wilting?
	N8101	VIII	7	N94-7440 x N7101	small seed,narrow leaf	

† All entries with names beginning in N, NCC, R, S, and SC were developed by USDA-ARS at Raleigh, NC; North Carolina State University; University of Arkansas; University of Missouri; and Clemson University, respectively.

‡ Pedigree and tolerance designation information obtained from Wu et al, 2017a.

§ https://soybase.org/uniformtrial/index.php?page=lines

¶ https://soybase.org/uniformtrial/index.php?page=lines&filter=Camp

file:///C:/Users/cjreagan/Downloads/Registration_of_NC-Raleigh_Soybean.pdf

Source: Wu, C., P. Chen, W. Hummer, A. Zeng, and M. Klepadlo. 2017a. Effect of Flood Stress on Soybean Seed Germination in the Field. Am. J. Plant Sci. 08(01): 53–68. doi: 10.4236/ajps.2017.81005.

Table 2.2. Flooding Treatment and Year means for soybean genotypes of maturity groups (MG) IV-VIII grown at Plymouth, NC in 2016 and 2017. Experiments I (MG IV-V) and II (MG VI-VIII) encompassed 31 and 23 genotypes, respectively. Flooding treatment was imposed at flowering or early podding stages for approximately 7 days.

Experiment		**Yield**		**Rating** §		**Maturity**¶		**Lodging**#	
	Treatment†	**2016**	**2017**	**2016**	**2017**	**2016**	**2017**	**2016**	**2017**
		kgha^{-1}		0-9 scale		1 = Oct.1		1-5 scale	
I (MG IV-V)	**Flood**	676.1 **	809.5 **	6.9	5.4	11 ns	9 ns	1.7 ns	1.8 ns
	Control	2385.5	3110.5	‡	‡	12	9	1.8	1.6
II (MG VI-VIII)	**Flood**	860.3 **	1159.5 **	6.4	3.8	27 **	21 ns	2.8 *	2.0 ns
	Control	2230.1	2786.4	‡	‡	24	21	2.6	2.0

*, ** used to designate significance between treatments at the five and one percent Type I error levels, respectively.

ns indicates not significant, p > 0.10

† Flooding was successfully imposed in three and two replications in 2016 and 2017, respectively. Six and five replications of control plots were employed in 2016 and 2017, respectively.

‡ visual ratings not taken on control plots.

§ visual ratings on given on a 0 to 9 scale (0 = healthy plot, 9 = > 95% dead plants) and based on yellowing of the canopy and canopy fullness.

¶ maturity date was assigned when 95% of the pods in the plot had reached a mature color (tan). Number is the date in October.

lodging ratings given on a plot basis on a 1 to 5 scale (1 = erect plants, 5 = prone), measured before harvest

†† height measured from the ground level to the apical meristem of 3 random plant per plot, measured before harvest

‡‡ protein and oil contents represented at zero percent moisture

Table 2.2. Continued.

Height[††]		100 SDWT		Protein[‡‡]		Oil[‡‡]	
2016	2017	2016	2017	2016	2017	2016	2017
cm		g		g/kg			
73 ns	84 ns	11.7 **	14.4 **	390.6 **	405.5 **	242.6 **	230.6 **
72	92	12.7	14.2	411.1	414.5	230.4	226.2
85 **	92	13.6 **	12.3 **	433.8 *	424.6 ns	210.4 ns	214.8 **
79	93	12.2	13.3	429.8	423.0	209.5	220.1

*, ** used to designate significance between treatments at the five and one percent Type I error levels, respectively.
ns indicates not significant, p > 0.10

† Flooding was successfully imposed in three and two replications in 2016 and 2017, respectively. Six and five replications of control plots were employed in 2016 and 2017, respectively.

‡ visual ratings not taken on control plots.

§ visual ratings on given on a 0 to 9 scale (0 = healthy plot, 9 = > 95% dead plants) and based on yellowing of the canopy and canopy fullness.

¶ maturity date was assigned when 95% of the pods in the plot had reached a mature color (tan). Number is the date in October.

lodging ratings given on a plot basis on a 1 to 5 scale (1 = erect plants, 5 = prone), measured before harvest

†† height measured from the ground level to the apical meristem of 3 random plant per plot, measured before harvest

‡‡ protein and oil contents represented at zero percent moisture

Table 2.3. LS means of 31 and 23 genotypes from Experiment I (MG IV-V) and II (MG VI-VIII) in flooded and control treatments at Plymouth, NC in 2016 and 2017. The flooding treatment consisted of 3-5 inches of water on soil surface for ~7 days. The control treatment consisted of conventional management. R99-1613F was dropped from Experiment I because of segregation. N6202 was dropped from Experiment II because of missing data.

				Control (NON)							Flooding (FLO) [†]							
Experiment	**Entry**	**Maturity Group**	**Code**	**Yield**	**Maturity** [‡]	**Lodging** [§]	**Height** [¶]	**100-seed weight**	**Protein**[#]	**Oil**[#]	**Yield**	**Visual Rating**[††]	**Maturity**	**Lodging**[‡‡]	**Height**[‡‡]	**100-seed weight**	**Protein**	**Oil**
				kg ha^{-1}	Oct. 1 = 1	1 to 5	cm	g	-----g kg^{-1}-----		kg ha^{-1}	1 to 9	Oct. 1 = 1	1 to 5	cm	g	-----g kg^{-1}-----	
I (MG IV-V).	**AG4632**	IV	19	2386	3	2.2	95	14.4	415	234	1226	6.0	5	1.8	91	11.7	385	247
	R13-12552	IV	3	2531	9	1.9	117	12.9	406	231	937	5.6	10	2.0	106	12.7	395	233
	S11-25108	IV	15	2504	7	2.8	107	13.9	406	245	1058	6.0	8	2.7	102	13.6	383	257
	S11-25615	IV	17	2344	7	2.2	107	14.3	423	229	1134	4.1	13	2.2	107	15.6	427	226
	S99-2281	IV	18	2554	4	1.5	72	12.4	405	232	70	8.7	4	1.7	§§	10.1	362	246
	UA 5014C	IV	8	2806	3	1.2	69	14.4	416	225	439	7.4	8	1.3	62	12.9	391	236
	AG5334	V	20	2924	9	1.5	98	14.6	424	227	746	6.0	6	1.5	84	11.9	393	244
	Camp	V	27	2110	13	1.1	54	7.7	426	212	926	5.3	10	1.5	58	9.1	424	217
	Ellis	V	24	3144	8	1.2	69	12.1	407	225	1664	4.1	10	1.3	71	11.8	383	236
	Holladay	V	28	2764	9	1.3	67	14.7	396	235	660	7.2	7	1.3	64	12.6	378	251
	Hutcheson	V	21	2536	9	1.6	85	13.8	417	232	312	7.4	8	2.0	87	14.0	388	250
	N02-7002	V	23	2978	9	1.4	80	13.6	411	216	1339	4.7	12	1.7	69	13.7	393	226
	N02-7779	V	31	2738	9	1.3	65	14.4	396	236	716	7.3	9	1.5	62	13.2	386	251
	N07-15307	V	30	2512	12	1.2	71	14.1	396	232	132	6.9		1.2	§§		§§	§§
	NC-Miller	V	26	3012	14	1.4	71	16.4	383	242	640	5.4	15	2.0	69	16.4	373	250
	NMS4-6-10	V	32	2679	4	1.5	72	11.7	414	222	216	7.5	4	1.3	§§	10.8	383	238
	Mean	-	-	**2748**	**11**	**1.7**	**82**	**13.5**	**413**	**228**	**729**	**6.3**	**11**	**1.7**	**77**	**12.8**	**397**	**238**
	LSD$_{0.05}$	-	-	**366**	**5.9**	**0.5**	**5.5**	**1.0**	**14**	**6**	**749**	**2.0**	**6**	**0.7**	**13**	**2.0**	**22**	**12**

[†] Flooding was successfully imposed in three and two replications in 2016 and 2017, respectively. Six and five replications of control plots were employed in 2016 and 2017, respectively.

[‡] maturity date was assigned when 95% of the pods in the plot had reached a mature color (tan). Number is the date in October.

[§] lodging values given on a plot basis on a 1 to 5 scale (1 = erect plants, 5 = prostrate), measured before harvest. Data from 2016 only.

[¶] height measured from the ground level to the apical meristem of 3 random plant per plot, measured before harvest

[#] protein and oil contents represented at zero percent moisture

[††] visual ratings on given on a 0 to 9 scale (0 = no damage, 9 = > 95% dead plants) and based on yellowing of the canopy and canopy fullness.

[‡‡] 2016 height and lodging scores dropped from flood treatment if based on only one rep

§§ non-estimable as a result of missing data

Table 2.3. Continued.

				Control (NON)							Flooding (FLO) †							
Experiment	Entry	Maturity Group	Code	Yield	Maturity ‡	Lodging §	Height ¶	100-seed weight	Protein #	Oil #	Yield	Visual Rating ††	Maturity	Lodging ‡‡	Height ‡‡	100-seed weight	Protein	Oil
				kg ha^{-1}	Oct. 1 = 1	1 to 5	cm	g	-----g kg^{-1}-----		kg ha^{-1}	1 to 9	Oct. 1 = 1	1 to 5	cm	g	-----g kg^{-1}-----	
	Osage	V	25	2794	7	1.1	66	12.2	444	214	1078	4.9	9	1.0	68	12.2	426	228
	R09-4095	V	14	2927	8	1.4	70	14.8	413	242	754	6.6	8	1.3	68	13.7	378	251
	S12-1362	V	16	2912	12	2.5	124	13.7	415	226	563	6.5	9	2.7	110	13.0	378	249
	R10-4892	V	2	2857	13	1.7	81	12.2	411	237	626	6.5	7	1.3	76	10.1	378	247
	Walters	V	6	2582	7	2.3	82	13.1	417	226	946	5.3	9	2.3	83	13.8	412	231
	R10-230	V	1	2931	15	2.0	81	14.1	421	232	195	7.3	7	1.8	§§	12.7	409	238
	R11-2915	V	13	3008	11	1.6	83	15.2	420	230	731	5.9	11	1.7	81	14.3	401	234
	UA 5612	V	5	2780	14	1.8	86	12.9	419	230	614	6.4	12	2.0	82	11.9	406	239
	R07-6669	V	4	3006	13	2.1	89	13.3	415	221	681	6.8	10	2.3	§§	12.6	395	235
	R06-4433	V	9	2973	16	2.0	80	14.2	418	224	523	7.1	10	2.0	§§	15.3	423	229
	R10-2379	V	12	2727	17	1.7	97	15.8	427	230	222	7.1	27	1.3	§§	16.1	426	245
	N07-15137	VI	29	2687	16	1.5	78	13.2	397	235	0	7.2	19	1.3	§§			
	NCC09-135	VI	22	2910	20	1.7	71	13.2	409	223	668	5.3	23	1.2	§§	11.3	408	228
	R04-342	VI	7	2876	16	1.8	80	15.6	426	226	1175	5.6	17	1.8	§§	14.9	417	228
	RM-22590	VI	11	2697	12	1.4	74	8.1	403	208	1624	2.7	14	1.3	72	8.4	404	210
	Mean	-	-	**2748**	**11**	**1.7**	**82**	**13.5**	**413**	**228**	**729**	**6.3**	**11**	**1.7**	**77**	**12.8**	**397**	**238**
	$LSD_{0.05}$	-	-	**366**	**5.9**	**0.5**	**5.5**	**1.0**	**14**	**6**	**749**	**2.0**	**6**	**0.7**	**13**	**2.0**	**22**	**12**

† Flooding was successfully imposed in three and two replications in 2016 and 2017, respectively. Six and five replications of control plots were employed in 2016 and 2017, respectively.

‡ maturity date was assigned when 95% of the pods in the plot had reached a mature color (tan). Number is the date in October.

§ lodging values given on a plot basis on a 1 to 5 scale (1 = erect plants, 5 = prostrate), measured before harvest. Data from 2016 only.

¶ height measured from the ground level to the apical meristem of 3 random plant per plot, measured before harvest

protein and oil contents represented at zero percent moisture

†† visual ratings on given on a 0 to 9 scale (0 = no damage, 9 = > 95% dead plants) and based on yellowing of the canopy and canopy fullness.

‡‡ 2016 height and lodging scores dropped from flood treatment if based on only one rep

§§ non-estimable as a result of missing data

Table 2.3. Continued.

				Control (NON)							Flooding (FLO) †							
Experiment	**Entry**	**Maturity Group**	**Code**	**Yield**	**Maturity ‡**	**Lodging §**	**Height ¶**	**100-seed weight**	**Protein#**	**Oil#**	**Yield**	**Visual Rating††**	**Maturity**	**Lodging‡‡**	**Height‡‡**	**100-seed weight**	**Protein**	**Oil**
				kg ha^{-1}	Oct. 1 = 1	1 to 5	cm	g	-----g kg^{-1}-----		kg ha^{-1}	1 to 9	Oct. 1 = 1	1 to 5	cm	g	-----g kg^{-1}-----	
II (MG VI-VIII).	**Boggs**	VI	2	2324	21	2.7	89	11.9	447	216	1141	5.0	21	3.5	94	13.3	435	220
	Dillon	VI	1	2732	18	1.8	91	13.7	419	225	1356	4.0	18	2.1	93	14.2	426	220
	N06-6	VI	6	2851	21	1.3	74	12.1	418	223	1132	4.4	26	1.3	74	13.4	428	214
	N6001	VI	12	2655	21	2.3	84	13.9	432	220	813	4.7	24	2.8	83	15.8	433	217
	N6002	VI	13	2582	16	2.1	86	14.3	435	213	674	6.2	17	2.3	86	14.5	420	222
	N93-110-6	VI	22	2542	21	2.5	96	14.6	442	214	1297	4.0	24	2.3	87	14.5	445	210
	NCC07-1090	VI	20	2960	18	1.9	77	16.4	391	237	393	7.3	§§	§§	§§	§§	§§	§§
	NCC08-8138	VI	19	3100	15	1.5	69	15.3	405	224	1935	3.5	21	1.3	66	15.7	401	222
	Young	VI	14	2279	20	2.8	103	13.5	434	219	1040	4.7	17	2.8	98	14.0	433	216
	G00-3213	VII	18	2582	25	1.8	93	13.7	451	209	1112	5.6	28	2.8	91	13.6	437	213
	N7001	VII	16	2227	28	2.2	80	12.6	429	210	176	6.2	26	2.2	78	§§	§§	§§
	N7002	VII	17	2483	25	2.5	87	11.3	423	213	1415	3.2	25	2.6	92	11.7	431	210
	N7003CN	VII	3	2563	25	1.8	86	14.6	399	223	1116	4.7	25	2.1	96	14.8	402	221
	N7103	VII	8	2433	25	1.8	81	7.0	441	193	749	5.1	23	1.3	80	7.2	446	195
	NCC07-899	VII	21	2714	23	2.4	88	13.1	418	222	1357	4.7	25	2.6	93	13.4	409	222
	NC-Raleigh	VII	4	2330	26	2.4	80	11.3	397	237	1342	5.2	26	3.0	99	10.9	406	232
	NLM09-77	VII	15	2438	18	1.9	82	18.1	486	201	1035	5.5	20	2.4	79	18.2	485	198
	NMS4-1-77	VII	10	2368	21	3.2	87	9.3	427	216	1181	4.5	21	2.6	87	10.3	443	205
	NMS4-44-329	VII	9	1977	26	3.8	92	8.9	426	186	449	6.9	24	3.4	103	8.9	§§	§§
	TCHM06-Morph 204	VII	5	2834	18	2.0	76	13.3	389	229	365	7.9	§§	§§	§§	§§	§§	§§
	TCWN05/06-5068	VII	24	2296	31	2.4	102	15.7	432	216	904	5.7	34	2.4	102	15.9	430	215
	N8002	VIII	23	2479	30	2.6	87	12.4	430	206	1223	4.0	30	2.1	86	12.7	433	204
	N8101	VIII	7	1940	31	2.8	91	5.2	436	190	1023	4.5	31	2.8	94	5.4	434	188
	Mean	-	-	**2508**	**23**	**2.3**	**86**	**12.7**	**426**	**215**	**1010**	**5.1**	**24**	**2.4**	**89**	**12.9**	**430**	**213**
	LSD$_{0.05}$‡	-	-	**348**	**4**	**0.6**	**10**	**1.2**	**12**	**9**	**776**	**2.9**	**6**	**0.9**	**11**	**1.5**	**14**	**10**

† Flooding was successfully imposed in three and two replications in 2016 and 2017, respectively. Six and five replications of control plots were employed in 2016 and 2017, respectively.

‡ maturity date was assigned when 95% of the pods in the plot had reached a mature color (tan). Number is the date in October.

§ lodging values given on a plot basis on a 1 to 5 scale (1 = erect plants, 5 = prostrate), measured before harvest. Data from 2016 only.

¶ height measured from the ground level to the apical meristem of 3 random plant per plot, measured before harvest

\# protein and oil contents represented at zero percent moisture

†† visual ratings on given on a 0 to 9 scale (0 = no damage, 9 = > 95% dead plants) and based on yellowing of the canopy and canopy fullness.

‡‡ 2016 height and lodging scores dropped from flood treatment if based on only one rep

§§ non-estimable as a result of missing data

Table 2.4. Analysis of variance of 31 and 23 genotypes in Experiments I (MG IV-V) and II (MG VI-VIII) for all traits over both flood and control treatments in 2016 and 2017 at Plymouth, NC. The flooding treatment consisted of 3-5 inches of water on soil surface for ~7 days. The control treatment consisted of conventional management. R99-1613F was dropped from Experiment I because of segregation. N6202 was dropped from Experiment II because of missing data.

Experiment	Source	Yield		Maturity‡		Lodging§		Height¶	
		DF	Mean Squares	DF	Mean Squares	DF	Mean Squares	DF	Mean Squares
			kg ha^{-1}		Oct. 1 = 1		1 to 5		cm
I (MG IV-V).	Year	1	22340157.35	1	423.69	1	0.05	1	15551.11
	Treatment †	1	408886969.25 0	1	0.00 ns	1	0.33 ns	1	787.14 ns
	Year x Treatment	1	8902090.07 **	1	0.00 ns	1	1.03 ns	1	1014.10 ns
	Rep(year trt)	12	557713.38	12	25.16	12	1.15	12	639.58
	Entry	30	892496.53 **	30	147.81 **	30	2.61 **	30	1821.80 **
	Year x Entry	30	245415.54 0	30	20.13 **	30	0.76 **	30	172.78 **
	Trt x Entry	30	822612.59 *	29	18.96 ns	30	0.61 ns	30	49.85 ns
	Year x Trt x Entry	30	364909.68	20	19.37	23	0.69	20	48.34
	Error	352	168335.16	318	7.12	333	0.14	314	46.84
II (MG VI-VIII).	Year	1	12555997.96	1	1215.33	1	25.67	1	6660.08
	Treatment	1	127997357.32 0	1	29.31 ns	1	0.49 ns	1	189.20 ns
	Year x Treatment	1	944320.99	1	110.19	1	0.64	1	747.00
	Rep(year trt)	11	176729.02	11	38.98	11	3.90	11	347.34
	Entry	22	765232.43 **	22	202.09 **	22	2.73 **	22	637.69 **
	Year x Entry	22	264504.26 **	22	19.53 **	22	0.45 *	22	96.14 **
	Trt x Entry	22	485255.32 *	22	12.56 ns	22	0.41 ns	22	79.33
	Year x Trt x Entry	22	226734.09	20	15.72	20	0.33	20	44.26
	Error	229	90826.59	224	4.48	225	0.24	218	46.34

*,** indicates significance at $p < 0.05$ and $p < 0.01$, respectively

ns indicates not significant, $p > 0.10$

† Flooding was successfully imposed in three and two replications in 2016 and 2017, respectively. Six and five replications of control plots were employed in 2016 and 2017, respectively.

‡ maturity date was assigned when 95% of the pods in the plot had reached a mature color (tan). Number is the date in October.

§ lodging ratings given on a plot basis on a 1 to 5 scale (1 = erect plants, 5 = prone), measured before harvest

¶ height measured from the ground level to the apical meristem of 3 random plant per plot, measured before harvest

protein and oil contents represented at zero percent moisture

†† visual ratings on given on a 0 to 9 scale (0 = healthy plot, 9 = > 95% dead plants) and based on yellowing of the canopy and canopy fullness

‡‡ visual ratings not taken on control plots

Table 2.4. Continued.

Experiment	Source	100-seed weight		Protein#		Oil#		Visual Ratings††	
		DF	Mean Squares	DF	Mean Squares	DF	Mean Squares	DF	Mean Squares
			g	--------------------- g kg^{-1} ----------------------					0 to 9
I (MG IV-V).	Year	1	184.98	1	4938.22	1	4478.73	1	84.30
	Treatment †	1	3.27 ns	1	18074.24 ns	1	5503.13 ns	0 ‡‡	-
	Year x Treatment	1	9.27 ns	1	2359.34 ns	1	1086.80 0	0	-
	Rep(year trt)	12	4.53	12	2336.19	12	239.79	3	6.47
	Entry	30	32.50 **	30	1850.69 **	30	913.98 **	30	7.58 **
	Year x Entry	30	2.16 **	30	238.42 **	30	67.97 **	30	2.39 ns
	Trt x Entry	28	2.21 ns	29	367.53 ns	29	75.74 ns	0	-
	Year x Trt x Entry	15	1.44	23	335.59	23	55.47	0	-
	Error	312	0.75	319	122.59	315	31.14	90	1.91
II (MG VI-VIII).	Year	1	0.38	1	3490.09	1	3726.84	1	157.57
	Treatment	1	7.53 ns	1	85.19 ns	1	164.50 ns	0	-
	Year x Treatment	1	57.53	1	176.29	1	100.66	0	-
	Rep(year trt)	11	8.09	7	331.12	7	15.06	2	4.84
	Entry	22	86.91 **	22	3196.02 **	22	1238.54 **	22	5.58 ns
	Year x Entry	22	1.91 **	22	199.70 **	22	104.47	22	3.96 **
	Trt x Entry	22	0.69 ns	22	135.05 *	22	35.78 ns	0	-
	Year x Trt x Entry	19	0.89	18	56.41	18	35.54	0	-
	Error	224	0.52	136	67.09	136	22.18	44	1.55

*,** indicates significance at $p < 0.05$ and $p < 0.01$, respectively

ns indicates not significant, $p > 0.10$

† Flooding was successfully imposed in three and two replications in 2016 and 2017, respectively. Six and five replications of

‡ maturity date was assigned when 95% of the pods in the plot had reached a mature color (tan). Number is the date in October.

§ lodging ratings given on a plot basis on a 1 to 5 scale (1 = erect plants, 5 = prone), measured before harvest

¶ height measured from the ground level to the apical meristem of 3 random plant per plot, measured before harvest

protein and oil contents represented at zero percent moisture

†† visual ratings on given on a 0 to 9 scale (0 = healthy plot, 9 = > 95% dead plants) and based on yellowing of the canopy and

‡‡ visual ratings not taken on control plots

Table 2.5. Analysis of variance of 31 genotypes from Experiment I (MGIV-V) for flood treatment. The flooding treatment consisted of 3-5 inches of water on soil surface for ~7 days. Visual ratings and height analyzed with a full model over years. Yield, maturity, lodging and 100 seed weight and composition traits analyzed with a pooled analysis, where Year x Entry and error sum of squares were pooled for significance testing following guidelines by Carmer et al (1969).

Experiment	**Source**	**Visual Ratings†**			**Height‡§**			**Yield**			**Maturity¶**		
		DF	**Mean Squares**		**DF**	**Mean Squares**		**DF**	**Mean Squares**		**DF**	**Mean Squares**	
			0 to 9			cm			kg ha^{-1}			Oct. 1 = 1	
I (MG IV-V).	Year	1	84.30	*	1	1679.16	**	0			0		
	Rep(year)	3	6.47		3	16.55		0			0		
	Rep	0	-		0	-		4	868519.42		4	25.93	
	Entry	30	7.58	**	30	499.58	**	30	918969.05	**	30	7.15	**
	Entry*Year	30	2.39	ns	20	98.86	ns	0			0		
	Error	90	1.90		50	76.29		120	357725.38		120	2.03	
II (MG VI-VIII).	Year	1	157.57	*	1	620.04	**	1	1667743.90	0	1	689.29	*
	Rep(year trt)	2	4.84		2	5.52		2	135834.02		2	12.49	
	Entry	22	5.58	ns	22	248.94	**	22	543935.26	0	22	70.67	**
	Year x Entry	22	3.96	**	20	57.13	ns	22	281282.83	*	20	15.16	**
	Error	44	1.55		23	35.25		35	221986.58		29	5.22	

*,** indicates significance at $p < 0.05$ and $p < 0.01$, respectively

ns indicates not significant, $p > 0.10$

† visual ratings on given on a 0 to 9 scale (0 = healthy plot, 9 = > 95% dead plants) and based on yellowing of the canopy and canopy fullness

‡ Exp. I 2016 height and lodging scores dropped if based on only one rep

§ height measured from the ground level to the apical meristem of 3 random plant per plot, measured before harvest

¶ maturity date was assigned when 95% of the pods in the plot had reached a mature color (tan). Number is the date in October.

lodging ratings given on a plot basis on a 1 to 5 scale (1 = erect plants, 5 = prone), measured before harvest

†† protein and oil contents represented at zero percent moisture

‡‡ Flooding was successfully imposed in three and two replications in 2016 and 2017, respectively. Six and five replications of control plots were employed in 2016 and 2017, respectively.

Source: Carmer, S.G., W.M. Walker, and R.D. Seif. 1969. Practical Suggestions on pooling variances for F tests of treatment effects. Agron. J. 61: 334–336.

Table 2.5. Continued.

Experiment	Source	Lodging[‡#]			100-seed weight			Protein[††]			Oil[††]		
		DF	Mean Squares		DF	Mean Squares		DF	Mean Squares		DF	Mean Squares	
			1 to 5			g			--------------------------g kg^{-1}------------------------				
I (MG IV-V).	Year	0			0			0			0		
	Rep(year)	0			0			0			0		
	Rep	2	0.52		4	23.81		4	2058.42		4	1080.78	
	Entry	30	0.58	**	28	11.91	**	29	1154.77	**	29	518.18	**
	Entry*Year	0			0			0			0		
	Error	60	0.19		63	2.40		81	306.56		81	91.74	
II (MG VI-VIII).	Year	1	9.87	*	1	25.30	ns	1	2382.63	0	1	1225.17	**
	Rep(year trt)	2	0.22		2	3.15		2	141.68		2	7.80	
	Entry	22	1.10	**	22	28.30	**	22	1200.36	**	22	531.94	**
	Year x Entry	20	0.35	**	19	1.00	ns	18	95.35	ns	18	49.83	ns
	Error	28	0.12		28	1.05		28	79.14		28	34.37	

*,** indicates significance at $p < 0.05$ and $p < 0.01$, respectively

ns indicates not significant, $p > 0.10$

† visual ratings on given on a 0 to 9 scale (0 = healthy plot, 9 = > 95% dead plants) and based on yellowing of the canopy and canopy fullness

‡ Exp. I 2016 height and lodging scores dropped if based on only one rep

§ height measured from the ground level to the apical meristem of 3 random plant per plot, measured before harvest

¶ maturity date was assigned when 95% of the pods in the plot had reached a mature color (tan). Number is the date in October.

lodging ratings given on a plot basis on a 1 to 5 scale (1 = erect plants, 5 = prone), measured before harvest

†† protein and oil contents represented at zero percent moisture

‡‡ Flooding was successfully imposed in three and two replications in 2016 and 2017, respectively. Six and five replications of control plots were

Source: Carmer, S.G., W.M. Walker, and R.D. Seif. 1969. Practical Suggestions on pooling variances for F tests of treatment effects. Agron. J. 61: 334–336.

Table 2.6. Analysis of variance of 31 and 23 genotypes in Experiments I (MG IV-V) and II (MG VI-VIII) for all traits in the control treatment in 2016 and 2017 at Plymouth, NC. The control treatment consisted of conventional management. R99-1613F was dropped from Experiment I because of segregation. N6202 was dropped from Experiment II because of missing data.

Experiment	**Source**	**Yield**			**Maturity**[†]			**Lodging**[‡]			**Height**[§]		
		DF	**Mean Squares**		**DF**	**Mean Squares**		**DF**	**Mean Squares**		**DF**	**Mean Squares**	
			kg ha^{-1}			Oct. 1 = 1			1-5 scale			cm	
I (MG IV-V).	Year[#]	1	42266876.67		1	543.29		1	2.17		1	35014.17	
	Rep(year trt)	9	431191.24		9	15.38		9	1.41		9	847.25	
	Entry	30	581543.21	**	30	190.23	**	30	1.94	**	30	2554.00	**
	Year x Entry	30	177435.73	*	30	30.24	**	30	0.33	**	30	180.35	**
	Error	262	106026.59		265	4.40		268	0.14		264	41.27	
II (MG VI-VIII).	Year	1	18972284.34		1	626.47		1	20.20		1	13383.68	
	Rep(year trt)	9	185816.43		9	44.87		9	4.72		9	423.30	
	Entry	22	861756.84	**	22	229.19	**	22	3.52	**	22	767.45	**
	Year x Entry	22	155474.50	**	22	23.43	**	22	0.48	*	22	117.52	**
	Error	194	67164.09		195	4.37		197	0.26		195	47.65	

*,** indicates significance at $p < 0.05$ and $p < 0.01$, respectively

ns indicates not significant, $p > 0.10$

† maturity date was assigned when 95% of the pods in the plot had reached a mature color (tan). Number is the date in October.

‡ lodging ratings given on a plot basis on a 1 to 5 scale (1 = erect plants, 5 = prone), measured before harvest

§ height measured from the ground level to the apical meristem of 3 random plant per plot, measured before harvest

¶ protein and oil contents represented at zero percent moisture

Six and five replications of control plots were employed in 2016 and 2017, respectively.

Table 2.6. Continued.

Experiment	**Source**	**100-seed weight**			**Protein**¶			**Oil**¶		
		DF	**Mean Squares**		**DF**	**Mean Squares**		**DF**	**Mean Squares**	
			g		------------------------g kg^{-1}----------------------					
I (MG IV-V).	Year#	1	202.86		1	928.21		1	1412.43	
	Rep(year trt)	9	3.31		9	2566.49		9	206.12	
	Entry	30	37.32	**	30	1524.23	**	30	749.53	**
	Year x Entry	30	1.38	**	30	250.63	**	30	45.48	**
	Error	264	0.48		261	79.24		257	15.98	
II (MG VI-VIII).	Year	1	73.31		1	1474.48		1	3577.03	
	Rep(year trt)	9	9.19		5	406.90		5	17.96	
	Entry	22	94.37	**	22	2584.81	**	22	904.35	**
	Year x Entry	22	1.92	**	22	184.01	**	22	100.06	**
	Error	196	0.44		108	63.96		108	19.02	

*,** indicates significance at $p < 0.05$ and $p < 0.01$, respectively

ns indicates not significant, $p > 0.10$

† maturity date was assigned when 95% of the pods in the plot had reached a mature color (tan). Number is the date in October.

‡ lodging ratings given on a plot basis on a 1 to 5 scale (1 = erect plants, 5 = prone), measured before harvest

§ height measured from the ground level to the apical meristem of 3 random plant per plot, measured before harves

¶ protein and oil contents represented at zero percent moisture

Six and five replications of control plots were employed in 2016 and 2017, respectively.

Table 2.7. Genotypic correlations of phenotypic means for 31 and 23 genotypes in Experiment I (MG IV-V) and II (MG VI-VIII) in flooded and control treatments at Plymouth, NC in 2016 and 2017. The flooding treatment consisted of 3-5 inches of water on soil surface for ~7 days. The control treatment consisted of conventional management. R99-1613F was dropped from Experiment I because of segregating traits. N6202 was dropped from Experiment II because of missing data.

			Control†							Flood†							
Experiment	**Treatment**	**Trait**	Yield ‡	Mat §	Lod ¶	Ht #	100-seed weight	Pro††	Oil††	Yield	Visual Ratings‡‡	Mat	Lod	Ht	100-seed weight	Pro	Oil
I. MG (IV-V)	Control																
		Yield	1.00														
		Maturity	0.30	1.00													
		Lodging	-0.11	0.01	1.00												
		Height	-0.08	-0.04	0.77	1.00											
		100-seed weight	0.38	0.06	0.23	0.28	1.00										
		Protein	-0.07	-0.04	0.14	0.15	-0.11	1.00									
		Oil	0.01	-0.07	0.28	0.23	0.64	-0.45	1.00								
	Flood																
		Yield)	0.04	-0.19	0.04	0.05	-0.28	0.14	-0.36	1.00							
		Visual Rating	-0.01	-0.05	-0.05	-0.08	0.36	-0.12	0.47	-0.84	1.00						
		Maturity	0.13	0.72	-0.05	0.01	0.14	0.00	-0.11	-0.03	-0.24	1.00					
		Lodging	-0.10	-0.06	0.83	0.68	0.21	0.00	0.23	0.09	-0.02	-0.20	1.00				
		Height	-0.26	-0.10	0.87	0.96	0.21	0.13	0.26	-0.04	-0.10	-0.06	0.78	1.00			
		100-seed weight	0.25	0.17	0.29	0.31	0.83	0.02	0.43	-0.14	0.10	0.34	0.38	0.28	1.00		
		Protein	-0.19	0.43	0.06	0.00	-0.14	0.69	-0.51	0.17	-0.36	0.51	-0.06	0.02	0.20	1.00	
		Oil	0.11	-0.22	0.20	0.23	0.58	-0.37	0.86	-0.45	0.62	-0.29	0.21	0.17	0.28	-0.67	1.00

† Flooding was successfully imposed in three and two replications in 2016 and 2017, respectively. Six and five replications of control plots were employed in 2016 and

‡ Yield: $kgha^{-1}$

§ Maturity date was assigned when 95% of the pods in the plot had reached a mature color (tan). Number is the date in October (Oct. 1 = 1).

¶ Lodging (1-5) scores given on a plot basis on a 1 to 5 scale (1 = erect plants, 5 = prone), measured before harvest. Data from 2016 only.

Height (cm) measured from the ground level to the apical meristem of 3 random plants per plot, measured before harvest

†† Protein and oil contents (g/kg) represented at zero percent moisture

‡‡ Visual ratings given on a 0 to 9 scale (0 = healthy plot, 9 = > 95% dead plants) and based on yellowing of the canopy and canopy fullness.

Table 2.7. Continued.

			Control†							Flood†							
Experiment	**Treatment**	**Trait**	Yield ‡	Mat §	Lod ¶	Ht #	100-seed weight	Pro††	Oil††	Yield	Visual Ratings‡‡	Mat	Lod	Ht	100-seed weight	Pro	Oil
II. MG (VI-VIII)	Control																
		Yield	1.00														
		Maturity	-0.68	1.00													
		Lodging	-0.74	0.39	1.00												
		Height	-0.58	0.38	0.55	1.00											
		100-seed weight	0.56	-0.48	-0.47	-0.06	1.00										
		Protein	-0.43	0.10	0.15	0.41	0.01	1.00									
		Oil	0.67	-0.46	-0.42	-0.30	0.53	-0.65	1.00								
	Flood																
		Yield)	0.26	-0.13	-0.14	0.04	0.07	0.04	0.19	1.00							
		Visual Rating	-0.06	-0.06	0.05	-0.13	0.14	-0.17	0.03	-0.85	1.00						
		Maturity	-0.27	0.87	0.07	0.12	-0.22	-0.12	-0.19	-0.10	0.03	1.00					
		Lodging	-0.63	0.24	0.74	0.55	-0.15	0.20	-0.12	-0.22	0.35	0.00	1.00				
		Height	-0.60	0.46	0.61	0.77	-0.18	-0.12	-0.02	-0.14	0.26	0.20	0.73	1.00			
		100-seed weight	0.58	-0.52	-0.46	-0.02	0.98	0.16	0.52	0.25	-0.05	-0.26	-0.15	-0.24	1.00		
		Protein	-0.36	-0.03	0.16	0.21	0.04	0.91	-0.63	-0.40	0.19	-0.10	0.13	-0.15	0.05	1.00	
		Oil	0.47	-0.36	-0.20	-0.08	0.48	-0.58	0.92	0.30	0.08	-0.26	0.15	0.20	0.49	-0.69	1.00

† Flooding was successfully imposed in three and two replications in 2016 and 2017, respectively. Six and five replications of control plots were employed in 2016 and 2017, respectively.

‡ Yield: kgha^{-1}

§ Maturity date was assigned when 95% of the pods in the plot had reached a mature color (tan). Number is the date in October (Oct. 1 = 1).

¶ Lodging (1-5) scores given on a plot basis on a 1 to 5 scale (1 = erect plants, 5 = prone), measured before harvest. Data from 2016 only.

Height (cm) measured from the ground level to the apical meristem of 3 random plants per plot, measured before harvest

†† Protein and oil contents (g/kg) represented at zero percent moisture

‡‡ Visual ratings given on a 0 to 9 scale (0 = healthy plot, 9 = > 95% dead plants) and based on yellowing of the canopy and canopy fullness.

Table 2.8. Genotypic correlation of phenotypic means for individual dates of visual rating after flood treatment termination for 31 and 23 genotypes in Experiments I and II in flooded conditions at Plymouth, NC in 2016 and 2017. The flooding treatment consisted of 3-5 inches of water on soil surface for ~7 days.

			2016				2017				
Experiment	*Year*	*Rating Date* †	*1 WAFT* ‡	*2 WAFT*	*3 WAFT*	*Mean*	*3 WAFT*	*4 WAFT*	*5 WAFT*	*Mean*	
I (MG IV-V).	*2016*										
		1 WAFT	1.00								
		2 WAFT	0.90	1.00							
		3 WAFT	0.91	0.94	1.00						
		Mean	0.99	0.95	0.96	1.00					
	2017										
		3 WAFT	0.54	0.55	0.51	0.55	1.00				
		4 WAFT	0.55	0.53	0.48	0.55	0.91	1.00			
		5 WAFT	0.50	0.47	0.47	0.50	0.88	0.93	1.00		
		Mean	0.59	0.57	0.52	0.59	0.95	0.95	0.94	1.00	
			1 WAFT	*2 WAFT*	*3 WAFT*	*Mean*	*3 WAFT*	*4 WAFT*	*5 WAFT*	*6 WAFT*	*Mean*
II (MG VI-VIII).	2016										
		1 WAFT	1.00								
		2 WAFT	0.92	1.00							
		3 WAFT	0.92	0.90	1.00						
		Mean	0.98	0.96	0.97	1.00					
	2017										
		3 WAFT	0.21	0.12	0.07	0.14	1.00				
		4 WAFT	0.21	0.18	0.17	0.19	0.81	1.00			
		5 WAFT	0.17	0.16	0.17	0.17	0.65	0.88	1.00		
		6 WAFT	0.22	0.20	0.22	0.22	0.68	0.87	0.91	1.00	
		Mean	0.22	0.18	0.17	0.20	0.83	0.96	0.94	0.94	1.00

† Visual ratings given on a 0 to 9 scale (0 = healthy plot, 9 = > 95% dead plants) and based on yellowing of the canopy and canopy fullness.

‡ WAFT = weeks after flooding termination (1 WAFT = visual ratings were taken one week after flooding treatment termination)

Figure 2.1. Building the berms using an inverted disc implement. Soil is turned and then packed to prevent water leaking.

Figure 2.2. Flooding treatment underway in 2016. Treatment is maintained for 7 days then released into canal drainage system. Ratings are taken for the next five weeks.

Figure 2.3. Visual rating scale based on greenness, defoliation and general appearance. Ratings were given on a 0 to 9 scale (0=unaffected, 9= >95% plant death. Photos taken in third week after treatment (3 WAFT).

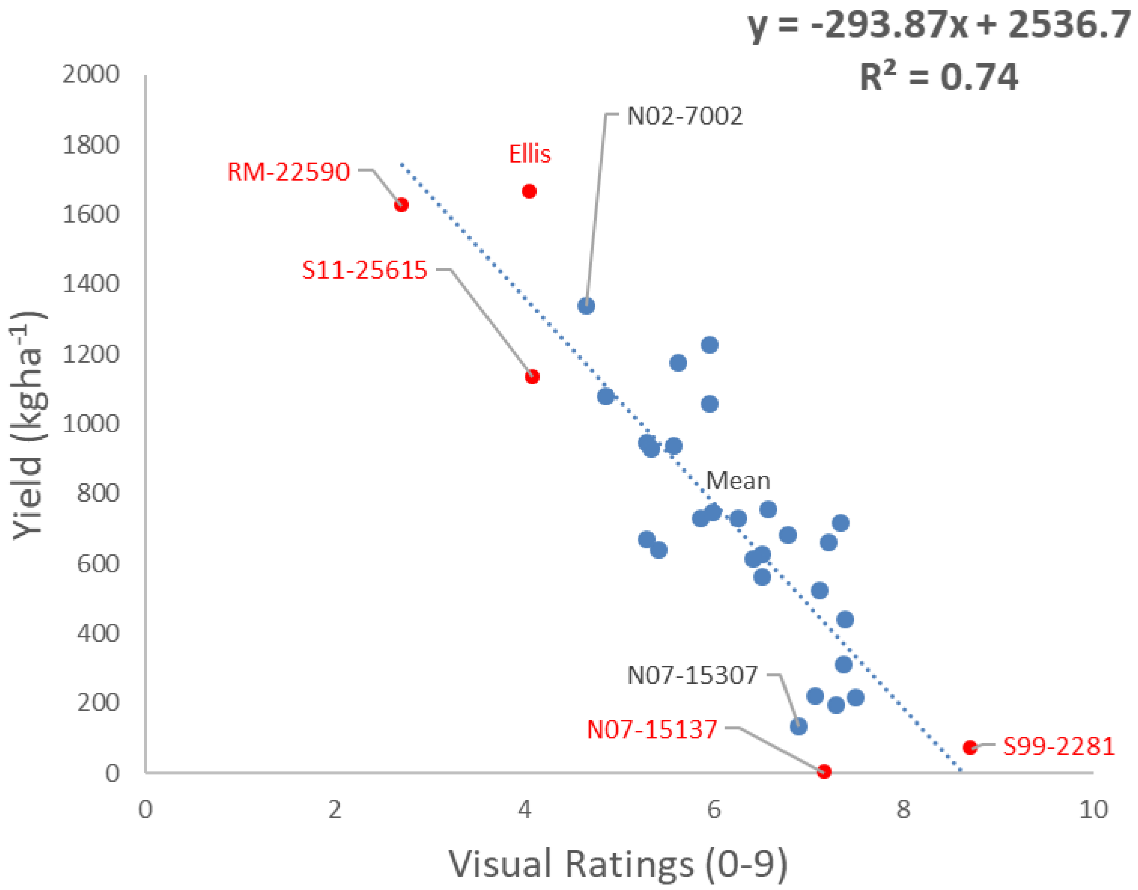

Figure 2.4. Linear regression of yield and visual ratings for 31 genotypes in Experiment I (MG IV-V) over 2016 and 2017 in Plymouth, NC.

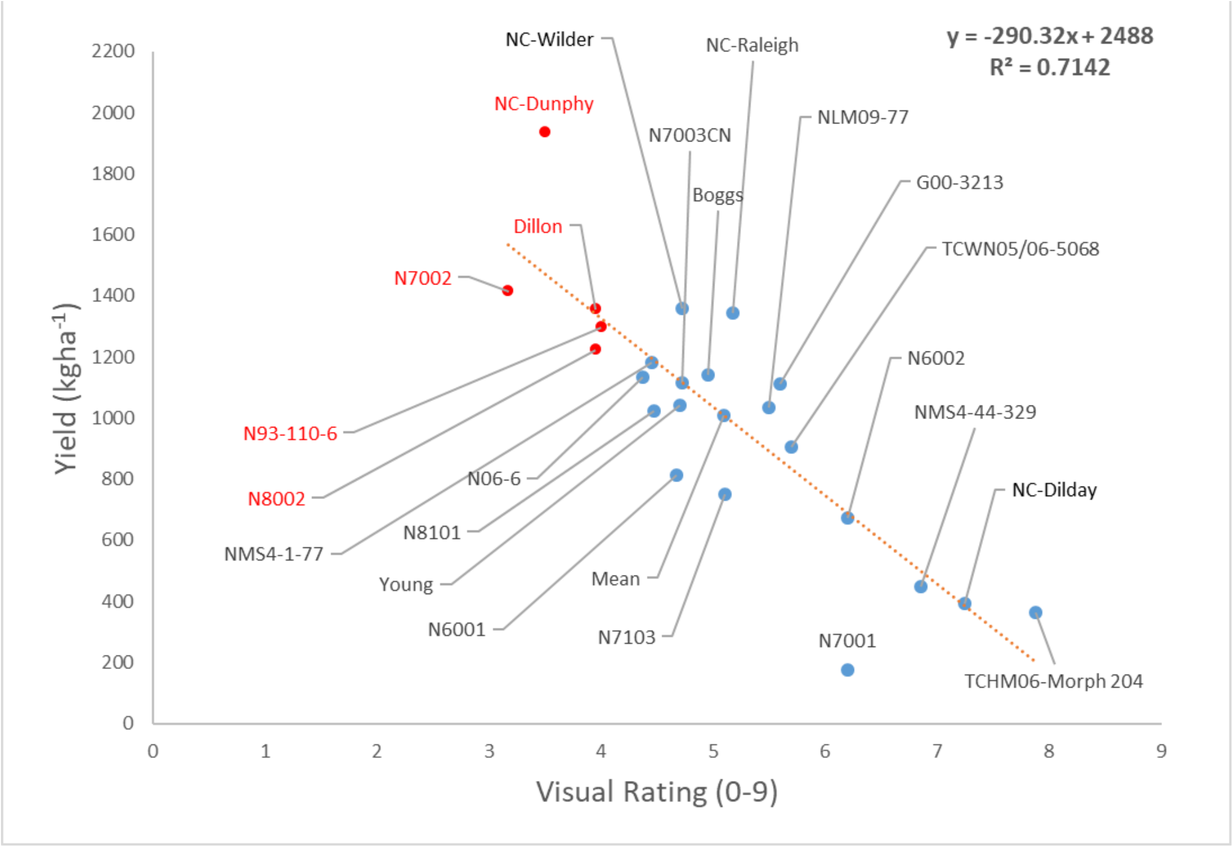

Figure 2.5. Linear regression of yield and visual ratings for 23 genotypes in Experiment II (MG VI-VIII) over 2016 and 2017 in Plymouth, NC.

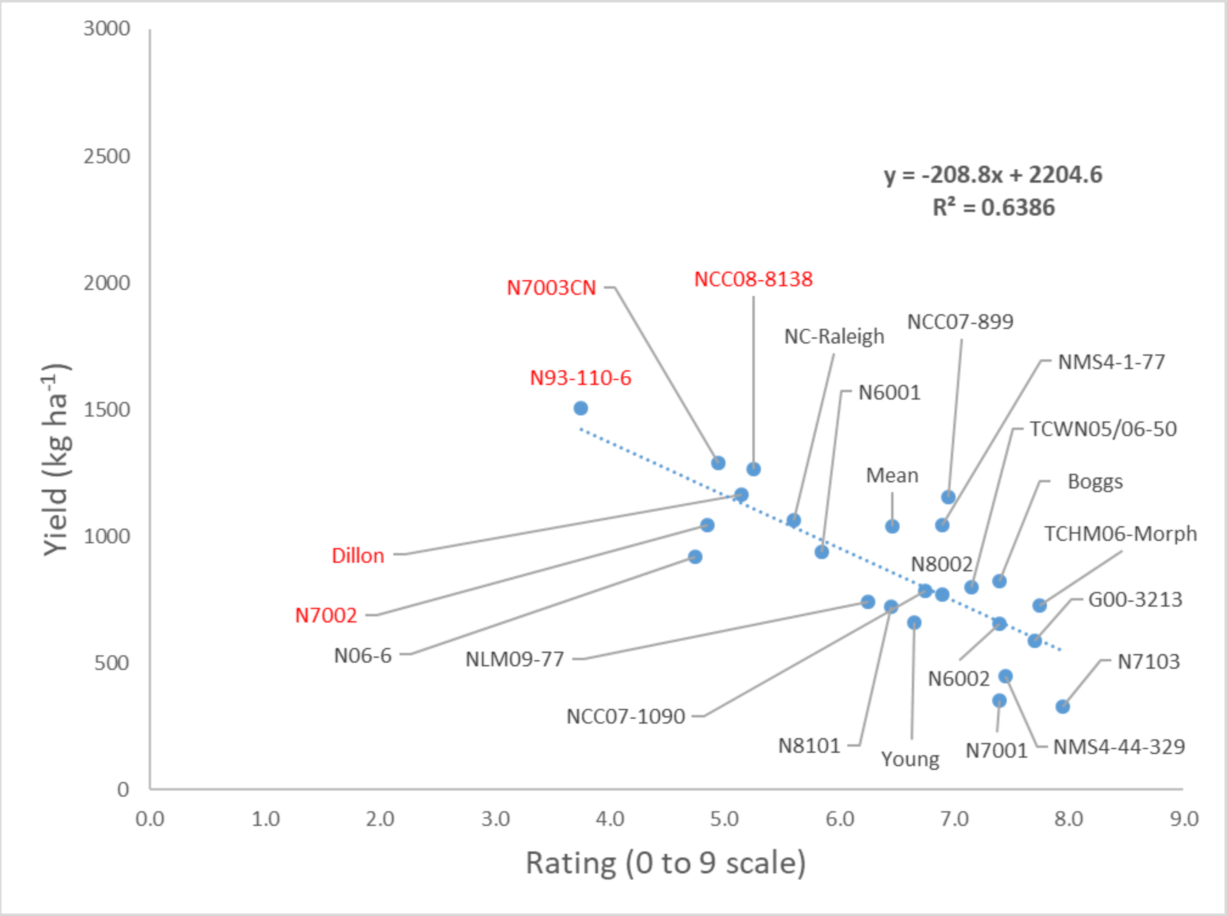

Figure 2.6. Linear regression of yield and ratings for 23 genotypes in Experiment II (MG VI-VIII) in 2016 in Plymouth, NC.

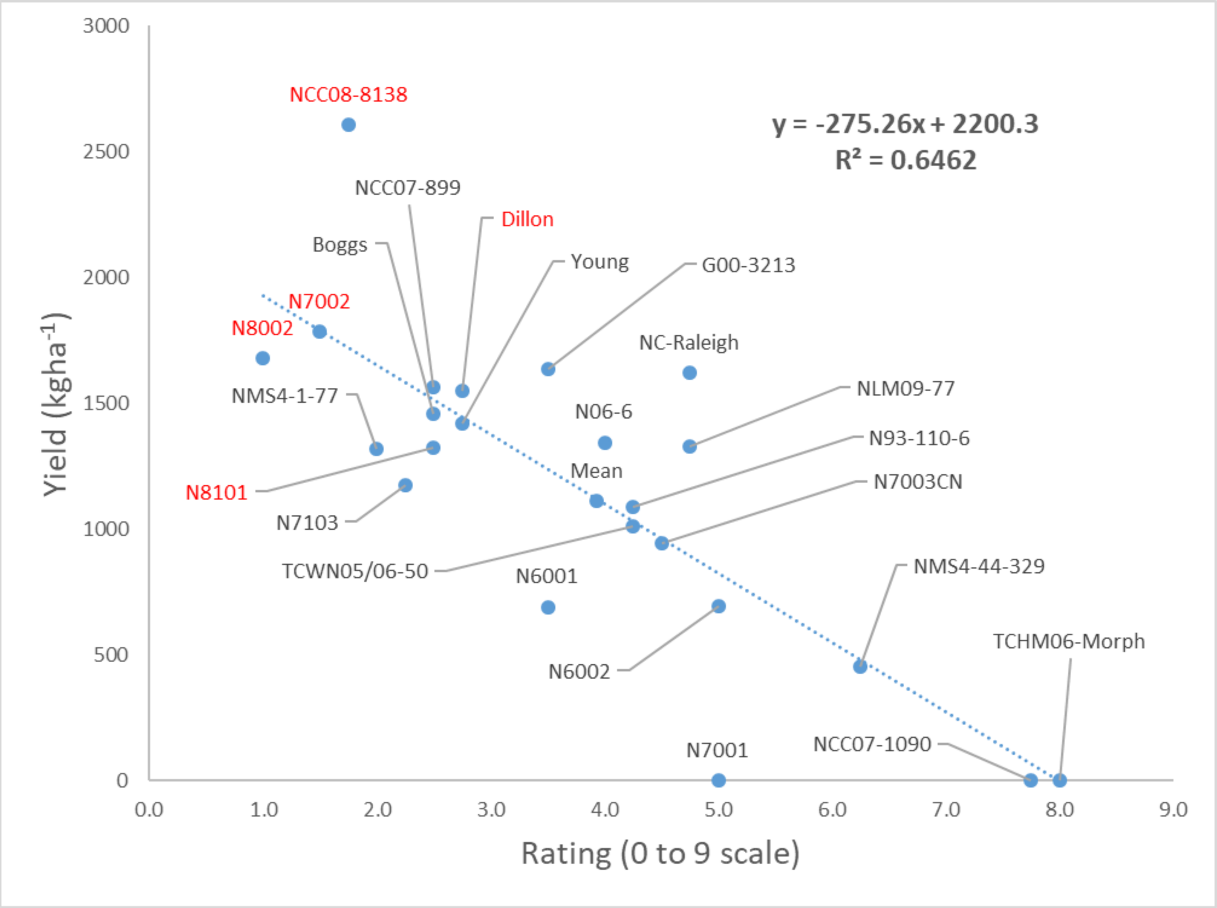

Figure 2.7. Linear regression of yield and ratings for 23 genotypes in Experiment II (MG VI-VIII) in 2017 in Plymouth, NC.

Chapter 3: Visual Response of Soybean to Flooding at Vegetative and Reproductive Growth Stages

Abstract

Soybean [Glycine max (L.) Merrill] production in Northeastern North Carolina (NC) is often threatened by unpredictable excess precipitation events throughout the growing season, suggesting that development of improved flood-tolerant cultivars would aid farmers in the region. Genotypic tolerance to flooding has been observed in NC. However, the impact of the timing of flood stress on genotypic response has not. To address this concern, a diverse panel of 81 genotypes from maturity groups (MG) IV through VIII was selected from public breeding programs in the Mid-South and Southeastern US and evaluated in two sets (early and late maturity) for flood response at vegetative and flowering growth stages. The contrasting flooding treatments were imposed for 7 days in a split-split plot experimental design at Plymouth, NC in 2016 and 2017. Visual ratings of flood response (i.e. leaf color, defoliation and plant death) were recorded on a weekly basis, commencing two weeks after flooding treatments were terminated. Genotypes differed in visual response to flooding when averaged over treatments, but interaction with flooding timing was not observed ($p>0.05$). Genotypic means for the two flooding treatments (averaged over years and maturity sets) were positively correlated ($r = 0.56$, $p < 0.05$), and broad sense heritability averaged over maturity sets was moderate for flooding imposed at either vegetative or flowering growth stages (0.48 and 0.52), respectively, based on genotypic means over two years and three replications. Genotype x year (G × Y) interactions were present, and G × Y variance components were numerically larger than were genotype × flooding treatment variances. Despite the presence of G × Y interactions, the correlation of genotypic means between years (averaged over treatments and maturity groups) was 0.46 ($p < 0.05$). Genotypes S99-2281, N07-15307, Holladay and TCHM06-Morph-204, a late maturity mutant derived from Holladay, were rated consistently as sensitive to flooding. Based on genotypic

means over both treatments, the most consistent flood-tolerant genotypes appeared to be N11-352, RM-22590, S11-25615, N7002, N8002, and NC-Dunphy. For soybean breeders interested in development of flood-tolerant cultivars, these results suggest that flooding imposition, whether imposed at vegetative or flowering growth stage, should be effective at identifying germplasm with the least foliar damage in response to flooding. New sources of flood tolerance were identified for future use as parents in an applied breeding program in NC.

Introduction

Calamitous precipitation can occur at any point in the growing season. In North Carolina, the most devastating flooding events for the general public usually occur during the peak months of the Atlantic hurricane season (mid-August through early October, Smith, 1999). However, spring and early summer flooding is typically more threatening for farmers in NC. Strong storms are predicted to increase in frequency and unpredictability during the 21st century (Karl et al., 2008; Olesen et al., 2011), leading to increased risk of damage to agriculture from flooding. Thus, stress from excess water is a major threat to crop production now and for the foreseeable future in NC, the US and around the world.

Phenological timing of flooding stress during plant development can differentially affect plant response. For example, summer flooding severely increased mortality of Common Nettle (*Urtica dioica* L.) seedlings, while autumnal flooding resulted in no mortality but lower dry biomass (Klimesová, 1994). Soybean [*Glycine max* (L.) Merrill] is sensitive to flooding at all growth stages (Wu et al., 2017b).

In soybean, visual ratings of flooding damage (leaf yellowing, defoliation, and plant death) have been employed to assess genotypic variation in flood tolerance in soybean in the Mid-South (Reyna et al., 2003; Cornelious et al., 2005; Nguyen et al., 2012; Wu et al., 2017b, a; c; Ye et al., 2018). In Arkansas, flooding of soybean during the reproductive stage caused more damage than in the early vegetative flooding stage (Wu et al., 2017b). Reagan (Chapter 1, 2018), reported that visual ratings for flood tolerance correlated highly with seed yield under flooding conditions, suggesting that visual ratings can be effective for selecting flood tolerant germplasm. However, the efficacy of visual ratings to quantify flood tolerance for soybean genotypes at contrasting growth stages has yet to be established.

The objective of this study was to assess the interaction of soybean genotypes with timing of flooding stress (i.e. flooding during vegetative growth vs. reproductive growth stages) in NC using visual ratings of flood tolerance and compare the two contrasting stress regimes for efficacy of selection for stress tolerance.

Materials and Methods

Genotypes

Experiment III. (MG IV-V). Forty early-maturity genotypes were selected to represent a broad array of breeding lines and cultivars developed in the Mid-South and Southeast (Table 3.1). All of the 32 genotypes in Experiment I (Chapter 1) were included in Experiment III.

Experiment IV. (MG VI –VIII). Forty-five late-maturity genotypes were selected to represent an array of diverse breeding lines and cultivars developed in the Southeast. All of the 24 genotypes in Experiment II (Chapter 1) were included in Experiment IV.

Field Study

The research site was described previously in Chapter 2. Briefly, the study was performed at TRS, located near Plymouth, NC in 2016 and 2017 on Portsmouth fine-sandy loam soil (~3.2% organic matter). One-row plots were planted at TRS on May 20 in 2016 and May 18 in 2017, with a John Deere 1700 MaxEmerge Plus Integral 3-row modified unit with Almaco cone planters. Each plot consisted of one row that was 3 m in length. Row spacing was 76.2 cm and plots were seeded at approximately 36 per m of row.

Earthen berms were created in the same manner as the yield trial experiments described previously (Chapter 2, materials and methods). Briefly, berms were constructed using an inverted disc plow to dimensions of roughly 80 × 95 m in both 2016 and 2017. Berms were packed to prevent water leaking through the soil. Flooding was imposed at vegetative and flowering growth stages (roughly V4 and R1 stages, respectively (Fehr and Caviness, 1977). In 2016, flooding treatments were imposed on July 5 and August 13. In 2017, flooding treatments were imposed on June 28 and July 10. Flooding duration was approximately seven days at a depth of 10-12 cm.

Visual ratings were taken on each plot on a weekly basis commencing two weeks after flooding termination (WAFT). Briefly, visual ratings are assigned on a 0 to 9 scale, and taken in weekly increments after termination of flooding (Appendix J). In 2016, the vegetative flooding treatment was terminated on July 10 and ratings were taken 2, 3, and 5 WAFT. Ratings at 5 WAFT in 2016 were assigned by two raters, and averaged for analysis. Flooding initiated at flowering was terminated on August 27 and ratings were taken 2, 3 and 4 WAFT. Ratings at 2 WAFT were assigned by two raters and averaged prior to analysis. In 2017, flooding initiated during the vegetative stage was terminated on July 3 and ratings were taken on 1 and 2 WAFT. Ratings at 2 WAFT were recorded as the mean of two raters. Flooding initiated during flowering was terminated on July 15 and ratings were collected on 1, 2 and 3 WAFT. Ratings at 3 WAFT were recorded as the mean of two scores. Visual ratings were collected until canopies were partially recovered.

Statistical Analysis

A split-split-plot experimental design was employed in which whole plot was assigned to flooding treatments (vegetative vs. reproductive timing), subplots were assigned to blocks within a flood treatment, and genotypes were ascribed to sub-sub-plots. One replicate of whole plots was employed in each year, and three blocks were employed within a berm. Flooding treatment was considered a fixed effect. All other effects were treated as random. Statistical analyses were performed employing SAS 9.4 (SAS Institute Inc., Cary, NC). Data was analyzed using analysis of variance (ANOVA) in PROC GLM (Tables 3.2, 3.3, Appendices K and L) and Least Square Means (LS means) calculated with the LSMEANS statement. Genotypic means separation was based on Fischer's protected least significant difference (LSD). The ANOVA was performed in a combined analysis over years, for each year separately, and for each flooding treatment separately to assess genotypic and genotype × year (G × Y) effects.

Data curation

Preliminary analyses were performed to assess the impact of flooding treatments on visual ratings on an individual block basis. Blocks were considered adequately stressed by flooding if the majority of plots appeared to develop chlorosis or canopy defoliation. All blocks appeared to exhibit visual symptoms of flood damage. Data were then subjected to residual analysis for each combination of treatment and year and removed if the residual was greater than three times the standard deviation of the error term (Snedecor and Cochran, 1967) and a field note (i.e. deer damage, uneven flood pressure, poor stand) was recorded for that plot. Three data observations were removed from Experiment III in each year, and four and one observations were removed from Experiment IV in 2016 and 2017, respectively. The resulting data set became the basis for analysis of flooding effects on genotypic performance (Table 3.4). In Experiment I, genotypes Clifford and Graham were dropped from analysis because they segregated for flood response within plots. R09-4095 and Tokyo were omitted from analysis of Experiments III and IV, respectively because of poor stands in 2017.

Pearson correlations of genotypic means were performed in Excel (Microsoft Office Excel, 2017, Redman, WA). Correlations among rating dates were high in both years (above 0.69 in both 2016 and 2017, Appendix M). Thus, visual scores were averaged over dates within rep for each year prior to analysis. When analysis over years indicated no Genotype × Year (G × Y) interaction, G × Y interactions were pooled with error for significance testing following guidelines established by Carmer *et al*. (1969). Fischer's protected LSD were calculated from error terms in those restricted models if applicable. Visual ratings were analyzed initially for each year and flooding treatment separately, and then over years.

Variance components for visual ratings were estimated using similar methods as Chapter 2. Heritability (Nyquist and Baker, 1991) was calculated for both experiments using the formula:

$$H^2_{\text{(entry mean basis)}} = \frac{\sigma^2_G}{\sigma^2_G + \frac{\sigma^2_{GxE}}{l} + \frac{\sigma^2}{l \times r}}$$

Where,

H^2 = heritability	σ^2_G = genetic variance	$\sigma^2_{G\times E}$ = genotype × environment variance
σ^2 = error variance	l = number of locations used	r = number of replications used

Results

Experiment III. The flooding treatments were successfully imposed for seven days in both years at vegetative and reproductive growth stages, with yellowing of leaves and defoliation observed in varying degrees among all genotypes. Mean visual ratings over years for vegetative and reproductive treatments were 5.5 and 4.9, respectively (Table 3.4), but did not differ significantly from each other ($p > 0.10$, Table 3.2).

Genotypes differed significantly ($p < 0.01$) for visual ratings over flooding treatments and years (Tables 3.1, 3.2, 3.3). Overall mean genotypic ratings ranged from 4.2 to 7.1. Genotypes also differed significantly ($p < 0.01$, Table 3.3) within years, averaged over flooding treatments. Breeding lines S11-25615, S11-25108, and R11-2915 were significantly and/or numerically better than the mean of the overall experiment, in each year, and in each flooding treatment (Table 3.1). Cultivars AG4632 AG5334, UA5612, Osage, UA 5014C, and Manokin exhibited similar trends. In contrast, breeding lines S99-2281 and N07-15307 appeared sensitive in each year and each flooding treatment. The G × T interaction was non-significant ($p > 0.10$, Table 3.2), indicating good agreement between the flooding treatments regarding genotypic performance ($r = 0.53$, $p < 0.01$, Table 3.5, $R^2 = 0.34$, Fig 3.1). The G × Y interaction was significant ($p < 0.05$), but not sufficiently large to mask overall genotypic effects. Overall genotypic means were correlated between years for visual ratings ($r = 0.53$, $p < 0.01$, Table 3.5, $R^2 = 0.28$, Fig 3.2). Genotypic means were also correlated between years within a flooding treatment ($r = 0.32$, $p < 0.06$ and $r = 0.44$, $p < 0.01$ for vegetative and reproductive growth stages, respectively). However, breeding line R99-1613F exhibited a substantial discrepancy in performance between years, performing near the test mean in 2016, but ranking first in the test, numerically, in 2017 (Table 3.1). PI 416937 also appeared more tolerant in the second year. Genotypes differed significantly ($p < 0.05$) at each rating date, except for the first week of the vegetative flooding treatment in 2017 ($p < 0.10$, Appendix L). The correlations of genotypic means between rating dates within a year were highly correlated ($r > 0.69$, $p < 0.01$, Appendix M). Broad sense heritability of visual ratings based on entry means over two years and three replications was comparable in the two flooding treatments ($H^2 = 0.54$ and 0.59 for vegetative and reproductive flooding, respectively, Table 3.6, Appendix N).

Experiment IV. Flooding resulted in visually obvious stress symptoms in both flooding treatments in each year. However, damage from flooding was more substantial in 2016 (mean score of 6.2 and 4.8 in 2016 vs. 2017, respectively, Tables 3.1, 3.4). Averaged over years, visual damage was more severe for flooding imposed at flowering vs. vegetative growth stages (6.0 and 5.0, respectively, $p < 0.01$, Tables 3.1, 3.2 and 3.4). Genotypes differed significantly overall ($p < 0.01$, Table 3.2). No significant ($p > 0.10$) G × T interactions were present, and the correlation between genotypic means for the two treatments over years was 0.54 ($p < 0.01$, Table 3.5, $R^2 = 0.29$, Fig. 3.3) Breeding line N11-352 was numerically the best in the experiment and performed well in each year as well as in each flooding treatment (Table 3.1). Breeding lines NTCPR94-5157, N10-792, N08-174, N11-8098, and NMS4-1-77, and cultivars N7103, N8002, N8101, Boggs, and NC-Dunphy were also rated significantly and/or numerically better than the experiment mean in each treatment and in each year. N6202 was the least flood tolerant genotype.

A significant ($p < 0.01$) G × Y interaction was also present (Table 3.2). Several genotypes (N6002, N6202, N10-7189, N6001, N94-7440, N10-711, NLM09-77, and Cook) appeared more sensitive to flooding in 2016 than in 2017. Only N7001 appeared more tolerant in 2016. In an analysis of variance over flooding treatments within each year, genotypes differed significantly ($p < 0.01$, Table 3.3).

Genotypic means were correlated moderately well between years, averaged over flooding treatments ($r = 0.38$, $p < 0.06$, Table 3.5, Fig. 3.4). Genotypic means were also correlated between years for each of the two flooding treatments (r = 0.34, $p < 0.05$ and r = 0.31, $p < 0.05$ for vegetative and reproductive, respectively, Table 3.5). Broad sense heritability for visual ratings of genotypes were similar in the two treatments, based on two years and three replications ($H^2 = 0.42$ and 0.45 for vegetative and reproductive flooding treatments, respectively, Table 3.6).

Discussion

Flooding tolerance has been quantified successfully in soybean in the Mid-South (Scott et al., 1989; Reyna et al., 2003; Wu et al., 2017c; Ye et al., 2018). However, only Wu et al. (2017b) examined the impact of the timing of flooding on genotypic response. In their study, they mentioned an interaction between genotype and timing of flooding (vegetative vs. flowering) for foliar damage among 40 genotypes of MG V, but no specific comparisons were reported. No other studies appear to have assessed stability of genotypic response to flooding in soybean at these contrasting growth stages. Our findings indicated that relative genotypic performance was not greatly affected by timing of flooding stress. The genotype × flooding treatment interactions in the present study were non-significant ($p > 0.05$) in both the early and late maturity groups, and the correlations of genotypic means between treatments, averaged over years, were moderately high (0.54 and 0.58, $p < 0.05$, for the early and late groups, respectively). Broad-sense heritability over years and replications was moderately high for both flooding treatments in both maturity sets (an average of 0.47), indicating that selection at vegetative or flowering growth stages should be effective with roughly equal precision. Also, variance component analysis indicated that genotype × treatment variance was much smaller than genotype or genotype × year variances (Table 3.6). Taken together, these results suggest that selection under one flooding regime should lead to progress in the other in NC.

In this study, genotypes were identified which performed well over both flooding regimes. In the early maturity set, three breeding lines and five cultivars that appeared tolerant in the Mid-south appeared more tolerant than the mean of the present study over years and treatments (Figs. 3.1, 3.2). S99-2281 was uniformly sensitive to flooding. In the late maturity set, six breeding lines and five cultivars had consistently superior ratings in both treatments over years (Figs. 3.3, 3.4). None of the late maturity materials had been evaluated previously for flood tolerance, revealing new material that may be useful as parental stock in a breeding program in NC.

Soybean growth demands are drastically different for vegetative versus reproductive growth stages (Imsande, 1989; Scott et al., 1989) and one might expect greater sensitivity to flooding in older plants where the capacity to produce new leaves and nodules may be diminished. Such differential sensitivity, if present, could lead to genotype × growth stage interactions for flooding. Although this study did not detect a statistical interaction it is nevertheless possible that some genotypes may have been differentially affected by timing of flooding stress. Three breeding lines (N02-7002, N02-7779, and R07-6669) in the early maturity set appeared more tolerant than the mean for the flooding treatment imposed at flowering and less tolerant than the mean when flooding was imposed during vegetative growth (Table 3.1). In the late maturity set, which generally appeared more sensitive to flooding at the reproductive stage, breeding line N94-7440 and cultivar Dillon seemed more tolerant than the mean in the vegetative stage, but more sensitive than the mean in reproductive stage. Further studies are needed to confirm these numerical trends.

Genotype × Year interactions were noted in both sets of genotypes (early and late maturity), but were not sufficiently large to mask overall genotype effects. A genotype × year × flooding treatment (G × Y × T) interaction was also noted for the set of late maturity genotypes, but again was insufficient to mask overall genotypic effects. The three way interaction was best exemplified by the performance of the cultivar Benning and breeding line N94-7440, which appeared to be more sensitive than the mean in only one of the year and treatment combinations. The year × genotype interaction was exemplified best by varieties N6002 and N6202, which appeared more tolerant in 2017 (Table 3.1).

Implications for plant breeding

The vulnerability of soybean to flooding at any point during the growing season necessitates that soybean breeders interested in development of flood tolerant cultivars examine the potential impact of genotype x flooding stage interactions on selection progress. The positive correlation of visual ratings we observed between vegetative and reproductive growth stages is encouraging, and suggests that breeders may likely achieve selection progress regardless of timing of stress. Moderate heritabilities over years at both vegetative and flowering growth stages suggests that reasonable selection progress for flood tolerance is possible using visual ratings.

All of the genotypes that were evaluated in Chapter 2 (Reagan, 2018) were also screened in the present study. Genotypic means for yield under flooding conditions from Chapter 2 were moderately correlated with mean visual ratings averaged over treatments in the present chapter (r = -0.50 and -0.37 for early and late maturity groups, respectively, Appendix O). Ratings in each treatment of the present chapter also correlated agreeably to yield in both maturity sets.

Genotypic means for visual ratings of flood damage for the two experiments were positively correlated (r = 0.42 and 0.46 for early and late maturity groups respectively). Although correlation of yield and visual ratings was higher when data were taken on the same plot, the lower correlations of two traits taken from independent tests (described in Chapters 2 and 3) provide an unbiased and likely more reliable estimate of the relationship between yield and ratings than an estimate obtained from one individual test. Based on genotypic means over both treatments, the most consistent flood tolerant genotypes appeared to be RM-22590 and S11-25615 in the early maturity set and N7002, N8002, and NC-Dunphy in the late maturity set.

In summary, the results of this study shed light on the effects of flooding on soybean at contrasting growth stages on genotypes in NC. Visual ratings were shown to correlate between multiple years, between growth stages. Further sources of flood tolerance were identified for potential use of parental stock in an applied breeding program for the trait.

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Table 3.1. LS means of flood tolerance ratings for 37 and 44 entries in Experiment III (MG IV-V) and IV (MG VI-VIII) in 2016 and 2017 at Plymouth, NC. Shown are the overall means, annual means, and means for each flooding stage. Genotypes Clifford and Graham were omitted from Exp. III due to within-plot segregation. R09-4095 and Tokyo were omitted from Exp. III and IV due to poor stand establishment in 2017.

							--------------2016-------------		-------------2017--------------		----Over 2016 and 2017-----		
Experiment	Entry[†]	Maturity Group	Code	Overall[‡]	2016	2017	Vegetative[§] flooding	Reproductive[¶] flooding	Vegetative flooding	Reproductive flooding	Vegetative Mean	Reproductive Mean	Developer
III (MG IV-V).	AG4632[#]	IV	19	4.6	4.9	4.3	4.8	5.0	5.6	3.0	5.2	4.0	Monsanto
	PI 471931	IV	34	4.9	4.9	5.0	5.3	4.4	5.7	4.2	5.5	4.3	Plant introduction from Nepal
	R13-12552	IV	3	5.1	5.6	4.6	4.6	6.6	5.0	4.1	4.8	5.3	Univ. of Arkansas
	S11-25108[#]	IV	15	4.3	3.7	4.8	2.3	5.2	6.0	3.6	4.1	4.4	Univ. of Missouri
	S11-25615[#]	IV	17	3.9	3.9	4.0	2.9	4.8	4.0	4.1	3.4	4.5	Univ. of Missouri
	S99-2281	IV	18	6.6	7.0	6.2	5.8	8.1	6.3	6.0	6.1	7.0	Univ. of Missouri
	UA 5014C[#]	IV	8	4.5	5.3	3.7	5.7	4.9	4.2	3.2	5.0	4.1	Univ. of Arkansas
	AG5334[#]	V	20	4.2	5.0	3.4	5.6	4.4	3.4	3.4	4.5	3.9	Monsanto
	Camp	V	27	5.8	6.1	5.6	6.4	5.8	5.8	5.4	6.1	5.6	Virgina Tech
	Ellis	V	24	5.4	5.4	5.5	5.7	5.0	6.5	4.5	6.1	4.8	Univ. of Tennessee
	Holladay	V	28	5.8	6.1	5.6	7.1	5.2	6.1	5.0	6.6	5.1	USDA-ARS, Raleigh, NC
	Hutcheson	V	21	5.9	6.0	5.9	5.6	6.4	6.4	5.3	6.0	5.9	Virginia Tech.
	Jake	V	37	5.2	5.3	5.2	5.5	5.2	6.5	3.8	6.0	4.5	Univ. of Missouri
	Manokin[#]	V	40	4.7	4.6	4.8	4.1	5.1	5.9	3.8	5.0	4.4	Univ. of Maryland
	N02-7002	V	23	5.2	5.3	5.2	6.4	4.2	6.1	4.3	6.3	4.2	USDA-ARS, Raleigh, NC
	N02-7779	V	31	5.7	5.8	5.7	6.5	5.0	6.7	4.7	6.6	4.8	USDA-ARS, Raleigh, NC
	N07-14221	V	39	5.0	5.4	4.6	5.1	5.8	5.7	3.4	5.4	4.6	USDA-ARS, Raleigh, NC
	N07-15307	V	30	7.1	8.3	5.9	8.1	8.5	6.9	4.9	7.5	6.7	USDA-ARS, Raleigh, NC
	Mean	-	-	**5.2**	**5.5**	**4.9**	**5.4**	**5.6**	**5.7**	**4.2**	**5.5**	**4.9**	
	LSD0.05	-	-	**0.3**	**0.7**	**0.5**	**1.9**	**1.9**	**1.7**	**1.4**	**0.6**	**0.6**	

† All materials with names beginning in N, NCC, R, S, and SC were developed by USDA-ARS at Raleigh, NC; North Carolina State University, University of Arkansas, University of Missouri, and Clemson University, respectively.

‡ Visual ratings on given on a 0 to 9 scale (0 = healthy plot, 9 = > 95% dead plants) and based on yellowing of the canopy and canopy fullness.

§ Vegetative flooding began July 5, 2016 and June 28, 2017

¶ Reproductive flooding began August 13, 2016 and July 24-5, 2017

Appeared tolerant to flooding in this study.

Table 3.1. Continued.

							--------------2016-------------		-------------2017--------------		----Over 2016 and 2017-----		
Experiment	Entry[†]	Maturity Group	Code	Overall[‡]	2016	2017	Vegetative[§] flooding	Reproductive[¶] flooding	Vegetative flooding	Reproductive flooding	Vegetative Mean	Reproductive Mean	Developer
III (MG IV-V).	NC-Miller	V	26	6.0	5.9	6.1	5.9	5.8	6.4	5.7	6.2	5.8	USDA-ARS, Raleigh, NC
	NMS4-6-10	V	32	5.1	6.0	4.3	5.9	6.0	4.5	4.2	5.2	5.1	USDA-ARS, Raleigh, NC
	Osage[#]	V	25	4.4	4.0	4.7	4.0	4.1	5.8	3.6	4.9	3.8	Univ. of Arkansas
	PI 416937	V	35	6.1	7.1	5.2	6.5	7.7	6.0	4.3	6.2	6.0	Plant introduction from Japan
	PI 471938	V	33	6.7	7.2	6.2	6.5	7.9	7.6	4.9	7.0	6.4	Plant introduction from Nepal
	R99-1613F	V	10	4.7	5.6	3.8	5.9	5.2	4.2	3.4	5.1	4.3	Univ. of Arkansas
	S12-1362	V	16	5.0	5.1	4.9	4.2	5.9	6.2	3.5	5.2	4.7	Univ. of Missouri
	R10-4892	V	2	4.9	4.8	5.0	4.7	4.8	5.6	4.4	5.1	4.6	Univ. of Arkansas
	Walters	V	6	4.8	4.6	5.0	4.6	4.7	5.6	4.3	5.1	4.5	Univ. of Arkansas
	R10-230	V	1	5.3	5.7	4.9	5.4	6.0	4.8	5.0	5.1	5.5	Univ. of Arkansas
	R11-2915[#]	V	13	4.8	5.2	4.4	5.6	4.8	4.7	4.2	5.1	4.5	Univ. of Arkansas
	UA 5612[#]	V	5	4.5	4.8	4.1	4.6	4.9	4.3	4.0	4.5	4.5	Univ. of Arkansas
	R07-6669	V	4	5.1	5.5	4.7	5.9	5.1	6.3	3.1	6.1	4.1	Univ. of Arkansas
	R06-4433	V	9	5.1	5.8	4.3	5.5	6.0	5.1	3.5	5.3	4.8	Univ. of Arkansas
	R10-2379	V	12	5.7	6.0	5.5	5.7	6.3	5.5	5.5	5.6	5.9	Univ. of Arkansas
	N07-15137	VI	29	5.9	6.8	5.0	6.9	6.7	5.9	4.1	6.4	5.4	USDA-ARS, Raleigh, NC
	NCC09-135	VI	22	5.6	6.1	5.1	6.4	5.8	6.2	3.9	6.3	4.9	North Carolina State Univ.
	R04-342	VI	7	5.0	5.5	4.5	5.4	5.7	5.7	3.2	5.6	4.4	Univ. of Arkansas
	RM-22590	VI	11	4.8	4.4	5.2	4.3	4.5	5.7	4.6	5.0	4.5	Univ. of Arkansas
	Mean	**-**	-	**5.2**	**5.5**	**4.9**	**5.4**	**5.6**	**5.7**	**4.2**	**5.5**	**4.9**	
	$LSD_{0.05}$	**-**	-	**0.3**	**0.7**	**0.5**	**1.9**	**1.9**	**1.7**	**1.4**	**0.6**	**0.6**	

[†] All materials with names beginning in N, NCC, R, S, and SC were developed by USDA-ARS at Raleigh, NC; North Carolina State University, University of Arkansas, University of Missouri, and Clemson University, respectively.

[‡] Visual ratings on given on a 0 to 9 scale (0 = healthy plot, 9 = > 95% dead plants) and based on yellowing of the canopy and canopy fullness.

[§] Vegetative flooding began July 5, 2016 and June 28, 2017

[¶] Reproductive flooding began August 13, 2016 and July 24-5, 2017

[#] Appeared tolerant to flooding in this study.

Table 3.1. Continued.

							--------------2016-------------		-------------2017--------------		----Over 2016 and 2017-----		
Experiment	Entry[†]	Maturity Group	Code	Overall[‡]	2016	2017	Vegetative[§] flooding	Reproductive[¶] flooding	Vegetative flooding	Reproductive flooding	Vegetative Mean	Reproductive Mean	Developer
IV (MG VI-VIII).	PI 416937	V	32	6.5	7.3	5.7	6.5	8.0	5.2	6.1	5.9	7.1	Plant introduction from Japan
	Boggs[#]	VI	2	5.0	5.9	4.1	5.4	6.4	3.5	4.6	4.5	5.5	Univ. of Georgia
	Dillon	VI	1	5.6	6.6	4.6	5.3	7.9	3.8	5.4	4.6	6.7	Clemson Univ.
	N06-6	VI	6	5.6	5.8	5.3	5.5	6.2	4.9	5.8	5.2	6.0	USDA-ARS, Raleigh, NC
	N08-174[#]	VI	36	5.1	5.4	4.8	5.4	5.3	4.0	5.6	4.7	5.5	USDA-ARS, Raleigh, NC
	N10-7189	VI	40	5.7	6.8	4.6	6.3	7.3	3.7	5.4	5.0	6.4	USDA-ARS, Raleigh, NC
	N11-352[#]	VI	38	4.0	4.0	3.9	3.6	4.4	3.2	4.6	3.4	4.5	USDA-ARS, Raleigh, NC
	N11-8098[#]	VI	34	4.6	4.6	4.6	4.7	4.4	3.8	5.4	4.2	4.9	USDA-ARS, Raleigh, NC
	N11-8508	VI	41	5.3	5.8	4.7	5.5	6.2	4.4	5.0	4.9	5.6	USDA-ARS, Raleigh, NC
	N11-8526	VI	42	5.9	6.8	5.0	5.5	8.0	4.2	5.9	4.9	6.9	USDA-ARS, Raleigh, NC
	N6001	VI	12	6.0	7.1	4.8	6.6	7.6	4.3	5.3	5.5	6.4	USDA-ARS, Raleigh, NC
	N6002	VI	13	6.2	7.8	4.5	6.8	8.8	4.0	5.0	5.4	6.9	USDA-ARS, Raleigh, NC
	N6202	VI	11	7.2	8.9	5.6	8.9	8.9	4.9	6.2	6.9	7.5	USDA-ARS, Raleigh, NC
	N93-110-6	VI	22	5.5	6.4	4.5	6.0	6.8	3.9	5.1	5.0	5.9	USDA-ARS, Raleigh, NC
	N94-7440	VI	45	5.2	6.3	4.0	4.7	7.9	3.3	4.7	4.0	6.3	USDA-ARS, Raleigh, NC
	Young	VI	14	6.1	7.0	5.2	6.2	7.8	4.8	5.5	5.5	6.7	USDA-ARS, Raleigh, NC
	NC-Dunphy[#]	VI	19	5.1	5.6	4.6	4.8	6.3	4.0	5.2	4.4	5.8	North Carolina State Univ.
	NC-Dilday	VI	20	6.5	7.4	5.6	6.2	8.6	5.1	6.2	5.6	7.4	North Carolina State Univ.
	Benning	VII	25	5.2	5.6	4.8	6.2	4.9	4.3	5.3	5.2	5.1	Univ. of Georgia
	Bragg	VII	26	6.0	6.7	5.3	5.9	7.4	4.4	6.1	5.2	6.8	Univ. of Georgia
	G00-3213	VII	18	6.0	6.6	5.5	5.5	7.6	4.4	6.5	5.0	7.0	Univ. of Georgia
	Haskell	VII	27	6.1	7.0	5.2	6.9	7.0	5.0	5.4	6.0	6.2	Univ. of Georgia
	Mean		-	**5.5**	**6.2**	**4.8**	**5.7**	**6.7**	**4.3**	**5.4**	**5.0**	**6.0**	
	LSD$_{0.05}$		-	**0.4**	**0.7**	**0.3**	**1.9**	**1.7**	**1.1**	**1.0**	**0.6**	**0.7**	

† All materials with names beginning in N, NCC, R, S, and SC were developed by USDA-ARS at Raleigh, NC; North Carolina State University, University of Arkansas, University of Missouri, and Clemson University, respectively.

‡ Visual ratings on given on a 0 to 9 scale (0 = healthy plot, 9 = > 95% dead plants) and based on yellowing of the canopy and canopy fullness.

§ Vegetative flooding began July 5, 2016 and June 28, 2017

¶ Reproductive flooding began August 13, 2016 and July 24-5, 2017

Appeared tolerant to flooding in this study.

Table 3.1. Continued.

							--------------2016-------------		-------------2017--------------		----Over 2016 and 2017-----		
Experiment	Entry[†]	Maturity Group	Code	Overall[‡]	2016	2017	Vegetative[§] flooding	Reproductive[¶] flooding	Vegetative flooding	Reproductive flooding	Vegetative Mean	Reproductive Mean	Developer
IV (MG VI-VIII).	N09-13890	VII	39	6.2	6.9	5.6	7.0	6.7	5.2	6.0	6.1	6.4	USDA-ARS, Raleigh, NC
	N09-13914	VII	35	6.6	7.4	5.8	6.2	8.7	5.2	6.4	5.7	7.6	USDA-ARS, Raleigh, NC
	N10-711	VII	37	5.3	6.5	4.1	5.3	7.8	3.5	4.8	4.4	6.3	USDA-ARS, Raleigh, NC
	N10-7404	VII	44	5.2	5.8	4.5	7.0	4.5	3.6	5.4	5.3	5.0	USDA-ARS, Raleigh, NC
	N10-792[#]	VII	43	4.7	5.0	4.4	5.1	4.8	4.1	4.7	4.6	4.8	USDA-ARS, Raleigh, NC
	N11-7046	VII	33	5.8	6.0	5.5	5.9	6.2	5.0	6.0	5.5	6.1	USDA-ARS, Raleigh, NC
	N7001	VII	16	5.4	4.7	6.0	3.5	5.8	5.7	6.3	4.6	6.1	USDA-ARS, Raleigh, NC
	N7002	VII	17	5.2	5.6	4.9	5.0	6.2	4.3	5.4	4.6	5.8	USDA-ARS, Raleigh, NC
	N7003CN	VII	3	5.8	6.7	5.0	6.1	7.2	4.7	5.3	5.4	6.3	USDA-ARS, Raleigh, NC
	N7103[#]	VII	8	4.7	5.4	4.0	5.3	5.5	3.8	4.1	4.6	4.8	USDA-ARS, Raleigh, NC
	NC-Raleigh	VII	4	5.3	5.6	5.0	5.1	6.0	4.5	5.5	4.8	5.8	USDA-ARS, Raleigh, NC
	NLM09-77	VII	15	5.6	6.9	4.4	6.2	7.6	4.1	4.7	5.1	6.1	USDA-ARS, Raleigh, NC
	NMS4-1-77[#]	VII	10	4.9	5.4	4.5	4.2	6.6	3.9	5.1	4.1	5.8	USDA-ARS, Raleigh, NC
	NMS4-44-329	VII	9	5.7	6.5	4.8	6.0	7.1	4.9	4.7	5.4	5.9	USDA-ARS, Raleigh, NC
	NTCPR94-5157[#]	VII	31	4.5	5.2	3.7	5.1	5.3	3.6	3.8	4.4	4.6	USDA-ARS, Raleigh, NC
	TCHM06-Morph-204	VII	5	5.5	5.6	5.4	4.8	6.4	4.4	6.3	4.6	6.4	USDA-ARS, Raleigh, NC
	TCWN05/06-5068	VII	24	5.8	6.6	5.1	6.9	6.2	4.2	6.0	5.6	6.1	USDA-ARS, Raleigh, NC
	NC-Wilder	VII	21	5.3	6.2	4.4	5.8	6.6	4.3	4.5	5.1	5.5	North Carolina State Univ.
	Cook	VIII	28	5.9	7.0	4.9	7.6	6.4	4.9	4.8	6.3	5.6	Univ. of Georgia
	N8002[#]	VIII	23	4.8	5.2	4.4	4.7	5.8	3.7	5.1	4.2	5.4	USDA-ARS, Raleigh, NC
	N8101[#]	VIII	7	5.1	5.0	5.2	4.2	5.7	4.6	5.7	4.4	5.7	USDA-ARS, Raleigh, NC
	SC97-1821	VIII	29	6.0	6.8	5.3	5.4	8.2	4.4	6.1	4.9	7.1	Clemson Univ.
	Mean		-	**5.5**	**6.2**	**4.8**	**5.7**	**6.7**	**4.3**	**5.4**	**5.0**	**6.0**	
	$LSD_{0.05}$		-	**0.4**	**0.7**	**0.3**	**1.9**	**1.7**	**1.1**	**1.0**	**0.6**	**0.7**	

† All materials with names beginning in N, NCC, R, S, and SC were developed by USDA-ARS at Raleigh, NC; North Carolina State University, University of Arkansas, University of Missouri, and Clemson University, respectively.

‡ Visual ratings on given on a 0 to 9 scale (0 = healthy plot, 9 = > 95% dead plants) and based on yellowing of the canopy and canopy fullness.

§ Vegetative flooding began July 5, 2016 and June 28, 2017

¶ Reproductive flooding began August 13, 2016 and July 24-5, 2017

Appeared tolerant to flooding in this study.

Table 3.2. ANOVA of 37 and 44 genotypes in Experiments III (MG IV-V) and IV (MG VI-VIII) for visual ratings over vegetative and reproductive flooding treatments in 2016 and 2017 at Plymouth, NC. Flooding treatment was imposed at early vegetative and early flowering stages for approximately 7 days. Genotypes Clifford and Graham were omitted from Exp. III due to within-plot segregation. R09-4095 and Tokyo were omitted from Exp. III and IV due to poor stand establishment in 2017.

Experiment	Source	Visual Ratings†		
		DF	**Mean Squares**	**Expected Mean Squares**
			0 to 9	
III (MG IV-V).	Year	1	35.11	$\sigma^2_E + 6\sigma^2_{EY} + 37\sigma^2_{R(YT)} + 222\sigma^2_Y$
	Treatment‡	1	42.26 ns	$\sigma^2_E + 3\sigma^2_{EYT} + 6\sigma^2_{ET} + 37\sigma^2_{R(YT)} + 37\sigma^2_{YT} + 222\sigma^2_Y$
	Year x Treatment	1	66.31	$\sigma^2_E + 3\sigma^2_{EYT} + 37\sigma^2_{R(YT)} + 37\sigma^2_{YT}$
	Rep(year trt)	8	4.44	$\sigma^2_E + 37\sigma^2_{R(YT)}$
	Entry	36	5.91 **	$\sigma^2_E + 6\sigma^2_{EY} + 12\sigma^2_E$
	Year x Entry	36	1.94 *	$\sigma^2_E + 6\sigma^2_{EY}$
	Trt x Entry	36	1.59 ns	$\sigma^2_E + 3\sigma^2_{EYT} + 6\sigma^2_{ET}$
	Year x Trt x Entry	36	1.54	$\sigma^2_E + 3\sigma^2_{EYT}$
	Error	274	1.15	σ^2_E
IV (MG VI-VIII).	Year	1	241.82	$\sigma^2_E + 6\sigma^2_{EY} + 44\sigma^2_{R(YT)} + 264\sigma^2_Y$
	Treatment	1	141.94 **	$\sigma^2_E + 3\sigma^2_{EYT} + 6\sigma^2_{ET} + 44\sigma^2_{R(YT)} + 44\sigma^2_{YT} + 264\sigma^2_Y$
	Year x Treatment	1	0.17	$\sigma^2_E + 3\sigma^2_{EYT} + 44\sigma^2_{R(YT)} + 44\sigma^2_{YT}$
	Rep(year trt)	8	6.33	$\sigma^2_E + 44\sigma^2_{R(YT)}$
	Entry	43	4.83 **	$\sigma^2_E + 6\sigma^2_{EY} + 12\sigma^2_E$
	Year x Entry	43	2.43 **	$\sigma^2_E + 6\sigma^2_{EY}$
	Trt x Entry	43	1.48	$\sigma^2_E + 3\sigma^2_{EYT} + 6\sigma^2_{ET}$
	Year x Trt x Entry	43	1.13 *	$\sigma^2_E + 3\sigma^2_{YET}$
	Error	343	0.79	σ^2_E

*,** significantly different from zero at $p < 0.05$ and $p < 0.01$, respectively

ns indicates not significant, $p > 0.10$

† Visual ratings were recorded on a 0 to 9 scale (0 = healthy plot, 9 = > 95% dead plants) and based on yellowing of the canopy and canopy fullness.

‡ Vegetative flooding began July 5, 2016 and June 28, 2017. Reproductive flooding began August 13, 2016 and July 24-5, 2017.

Table 3.3. ANOVA of 37 and 44 genotypes in Experiments III (MGIV-V) and IV (MG VI-VIII) for visual ratings in each year and flooding treatment at Plymouth, NC in 2016 and 2017. Flooding treatment was imposed at early vegetative and early flowering stages for approximately 7 days. Genotypes Clifford and Graham were omitted from Exp. III due to within-plot segregation. R09-4095 and Tokyo were omitted from Exp. III and IV due to poor stand establishment in 2017.

		Visual Ratings †									
Experiment	Source	2016		2017			Early Vegetative‡		Early Reproductive§		
		DF	Mean Squares	DF	Mean Squares	Expected Mean Squares	DF	Mean Squares	DF	Mean Squares	Expected Mean Squares
			0 to 9								
III (MG IV-V).	Treatment	1	1.45 ns	1	100.13 **	$\sigma^2_E + 3\sigma^2_{ET} + 37\sigma^2_{R(T)} + 111\sigma^2_T$	0		0		-
	Year	0		0		-	1	2.30	1	106.48	$\sigma^2_E + 3\sigma^2_{EY} + 37\sigma^2_{R(Y)} + 111\sigma^2_Y$
	Rep(Trt)	4	5.22	4	3.67	$\sigma^2_E + 37\sigma^2_{R(T)}$	0		0		-
	Rep(Year)	0		0		-	4	6.38	4	2.50	$\sigma^2_E + 37\sigma^2_{R(Y)}$
	Entry	36	5.38 **	36	2.62 **	$\sigma^2_E + 3\sigma^2_{ET} + 6\sigma^2_G$	36	3.68 **	36	3.77 **	$\sigma^2_E + 3\sigma^2_{EY} + 6\sigma^2_G$
	Trt x Entry	36	1.95	36	1.21	$\sigma^2_E + 3\sigma^2_{ET}$	0		0		-
	Year x Entry	0		0		-	36	1.85	36	1.54	$\sigma^2_E + 3\sigma^2_{EY}$
	Error	144	1.38	130	0.89	σ^2_E	130	1.27	144	1.04	σ^2_E
IV (MG VI-VIII).	Treatment	1	66.40 **	1	75.68 **	$\sigma^2_E + 3\sigma^2_{ET} + 44\sigma^2_{R(T)} + 132\sigma^2_T$	0		0		-
	Year	0		0		-	1	127.69	1	114.34	$\sigma^2_E + 3\sigma^2_{EY} + 44\sigma^2_{R(Y)} + 132\sigma^2_Y$
	Rep(Trt)	4	8.21	4	4.46	$\sigma^2_E + 44\sigma^2_{R(T)}$	0		0		-
	Rep(Year)	0		0		-	4	3.30	4	9.37	$\sigma^2_E + 44\sigma^2_{R(Y)}$
	Entry	43	5.44 **	43	1.83 **	$\sigma^2_E + 3\sigma^2_{ET} + 6\sigma^2_G$	43	2.68 **	43	3.64 **	$\sigma^2_E + 3\sigma^2_{EY} + 6\sigma^2_G$
	Trt x Entry	43	2.17 **	43	0.44	$\sigma^2_E + 3\sigma^2_{ET}$	0		0		-
	Year x Entry	0		0		-	43	1.56 **	43	2.00 **	$\sigma^2_E + 3\sigma^2_{EY}$
	Error	172	1.17	171	0.41	σ^2_E	172	0.71	171	0.88	σ^2_E

*,** significantly different from zero at $p < 0.05$ and $p < 0.01$, respectively

ns indicates not significant, $p > 0.10$

† visual ratings on given on a 0 to 9 scale (0 = healthy plot, 9 = > 95% dead plants) and based on yellowing of the canopy and canopy fullness

‡ Vegetative flooding began July 5, 2016 and June 28, 2017

§ Reproductive flooding began August 13, 2016 and July 24-5, 2017

Table 3.4. Flooding Treatment and Year means for soybean genotypes of maturity groups (MG) IV-VIII grown at Plymouth, NC in 2016 and 2017. Experiments III (MG IV-V) and IV (MG VI-VIII) encompassed 37 and 44 genotypes, respectively. Flooding treatment was imposed at early vegetative and early flowering stages for approximately 7 days.

Experiment	Treatment	Rating[†]			
		2016		2017	
		-----0-9 scale-----			
III (MG IV-V).	Vegetative[‡]	5.4	ns	5.7	**
	Reproductive[§]	5.6		4.2	
IV (MG VI-VIII).	Vegetative	5.7	**	4.3	**
	Reproductive	6.7		5.4	

*, ** used to designate significance between treatments at the five and one percent Type I error levels, respectively.

ns indicates not significant, p > 0.10

† visual ratings on given on a 0 to 9 scale (0 = healthy plot, 9 = > 95% dead plants) and based on yellowing of the canopy and canopy fullness.

‡ Vegetative flooding began July 5, 2016 and June 28, 2017

§ Reproductive flooding began August 13, 2016 and July 24-5, 2017

Table 3.5. Genotypic correlation coefficients of phenotypic means of visual ratings for 37 and 44 genotypes in Experiments III (MG IV-V) and IV (MG VI-VIII) in both flooding treatments taken in 2016 and 2017 at Plymouth, NC. Flooding treatment was imposed at early vegetative and early flowering stages for approximately seven days.

						-------------2016-----------		-----------2017-------------		--Over 2016 and 2017--	
Experiment		*Code*	*Overall* †	*2016*	*2017*	*Vegetative flooding* ‡	*Reproductive flooding* §	*Vegetative flooding*	*Reproductive flooding*	*Vegetative Mean*	*Reproductive Mean*
		---					*0 to 9*	---			
III (MG IV-VIII).	Code	1.00									
	Overall	0.37	1.00								
	2016	0.30	0.91	1.00							
	2017	0.37	0.83	0.53	1.00						
	2016										
	Vegetative	0.31	0.76	0.86	0.40	1.00					
	Reproductive	0.20	0.81	0.85	0.51	0.47	1.00				
	2017										
	Vegetative	0.43	0.69	0.42	0.85	0.32	0.40	1.00			
	Reproductive	0.15	0.68	0.46	0.79	0.35	0.44	0.36	1.00		
	Trt means										
	Vegetative	0.45	0.89	0.82	0.74	0.86	0.54	0.76	0.43	1.00	
	Reproductive	0.21	0.88	0.81	0.74	0.49	0.90	0.45	0.79	0.58	1.00
IV (MG VI-VIII).	Code	1.00									
	Overall	-0.11	1.00								
	2016	-0.08	0.91	1.00							
	2017	-0.11	0.72	0.38	1.00						
	2016										
	Vegetative	-0.17	0.81	0.87	0.36	1.00					
	Reproductive	0.05	0.73	0.82	0.27	0.44	1.00				
	2017										
	Vegetative	-0.02	0.63	0.32	0.91	0.34	0.18	1.00			
	Reproductive	-0.19	0.66	0.36	0.89	0.31	0.31	0.61	1.00		
	Trt means										
	Vegetative	-0.05	0.86	0.79	0.60	0.47	0.91	0.41	0.68	1.00	
	Reproductive	-0.14	0.90	0.81	0.66	0.92	0.41	0.68	0.49	0.54	1.00

*,** significantly different from zero at $p < 0.05$ and $p < 0.01$, respectively

† visual ratings on given on a 0 to 9 scale (0 = healthy plot, 9 = > 95% dead plants) and based on yellowing of the canopy and canopy fullness

‡ Vegetative flooding began July 5, 2016 and June 28, 2017

§ Reproductive flooding began August 13, 2016 and July 24-5, 2017

Table 3.6. Variance component estimates and broad-sense heritability from analysis of variance of visual ratings of flood damage in response to flooding treatments imposed at vegetative and flowering growth stages at Plymouth, NC in 2016 and 2017.

Source	Experiment III (MG IV-V).			Experiment IV (MG VI-VIII).		
	Veg.	Repr.	Overall	Veg.	Repr.	Overall
G	0.37	0.37	0.33	0.19	0.27	0.20
GxY	0.21	0.17	0.13	0.28	0.38	0.27
GxT	-	-	0.01	-	-	0.06
GxTxY	-	-	0.13	-	-	0.11
E	1.27	1.04	1.15	0.71	0.88	0.79
H2 †	0.54	0.59	0.5 ‡	0.42	0.45	0.43

† Broad Sense heritability based on experiment wide means over 2 years and 3 repliciations for each flooding treatment

‡ Overall heritability is based on mean over treatments as well as years and replications

Table 3.7. Visual flood tolerance ratings and yield data for genotypes common to both Chapters 2 and 3 (32 entries Experiments 1 and III (MG IV-V) and 24 entries in Experiments II and IV (MG VI-VIII). Data collected in 2016 and 2017 at Plymouth, NC.

				Chapter 3 (Exps. III and IV)			Chapter 2 (Exps. I and II)			
Experiment	Entry †	Maturity Group	Code	Overall	Vegetative‡ Mean	Reproductive§ Mean	Flood Yield	Control Yield	Rating Mean	Developer
				--------------------0 to 9--------------------			----kg ha^{-1}----		0 to 9	
III (MG IV-V).	AG4632¶	IV	19	4.6	5.2	4.0	1226	2386	6.0	Monsanto
	R13-12552	IV	3	5.1	4.8	5.3	937	2530	5.6	Univ. of Arkansas
	S11-25108¶	IV	15	4.3	4.1	4.4	1058	2504	6.0	Univ. of Missouri
	S11-25615¶#	IV	17	3.9	3.4	4.5	1134	2344	4.1	Univ. of Missouri
	S99-2281	IV	18	6.6	6.1	7.0	70	2554	8.7	Univ. of Missouri
	UA 5014C¶	IV	8	4.5	5.0	4.1	439	2806	7.4	Univ. of Arkansas
	AG5334¶	V	20	4.2	4.5	3.9	746	2924	6.0	Monsanto
	Camp	V	27	5.8	6.1	5.6	926	2110	5.3	Virginia Tech.
	Ellis	V	24	5.4	6.1	4.8	1664	3143	4.1	Univ. of Tennessee
	Holladay	V	28	5.8	6.6	5.1	660	2763	7.2	USDA-ARS, Raleigh, NC
	Hutcheson	V	21	5.9	6.0	5.9	312	2536	7.4	Virginia Tech.
	N02-7002	V	23	5.2	6.3	4.2	1338	2977	4.7	USDA-ARS, Raleigh, NC
	N02-7779	V	31	5.7	6.6	4.8	716	2738	7.3	USDA-ARS, Raleigh, NC
	N07-15307	V	30	7.1	7.5	6.7	132	2512	6.9	USDA-ARS, Raleigh, NC
	NC-Miller	V	26	6.0	6.2	5.8	640	3011	5.4	USDA-ARS, Raleigh, NC
	NMS4-6-10	V	32	5.1	5.2	5.1	216	2679	7.5	USDA-ARS, Raleigh, NC
	Mean	**-**	**-**	**5.4**	**5.3**	**5.4**	**818**	**2551**	**5.7**	**-**

† All materials with names beginning in G, N, NCC, R, S, and SC were developed by University of Georgia, USDA-ARS at Raleigh, NC; North Carolina State University, University of Arkansas, University of Missouri, and Clemson University, respectively.

‡ Vegetative flooding began July 5, 2016 and June 28, 2017

§ Reproductive flooding began August 13, 2016 and July 24-5, 2017

¶ Appeared tolerant to flooding based on Experiments III and IV

Appeared tolerant in both chapters

Table 3.7. Continued.

				Chapter 3 (Exps. III and IV)			Chapter 2 (Exps. I and II)			
Experiment	Entry †	Maturity Group	Code	Overall	Vegetative[‡] Mean	Reproductive[§] Mean	Flood Yield	Control Yield	Rating Mean	Developer
				--------------------0 to 9--------------------			----kg ha^{-1}----		0 to 9	
III (MG IV-V).	Osage[¶]	V	25	4.4	4.9	3.8	1078	2794	4.9	Univ. of Arkansas
	R99-1613F	V	10	4.7	5.1	4.3	0	0	4.9	Univ. of Arkansas
	S12-1362	V	16	5.0	5.2	4.7	563	2912	6.5	Univ. of Missouri
	R10-4892	V	2	4.9	5.1	4.6	626	2857	6.5	Univ. of Arkansas
	Walters	V	6	4.8	5.1	4.5	946	2581	5.3	Univ. of Arkansas
	R10-230	V	1	5.3	5.1	5.5	195	2930	7.3	Univ. of Arkansas
	R11-2915[¶]	V	13	4.8	5.1	4.5	731	3007	5.9	Univ. of Arkansas
	UA 5612[¶]	V	5	4.5	4.5	4.5	614	2780	6.4	Univ. of Arkansas
	R07-6669	V	4	5.1	6.1	4.1	681	3005	6.8	Univ. of Arkansas
	R06-4433	V	9	5.1	5.3	4.8	523	2973	7.1	Univ. of Arkansas
	R10-2379	V	12	5.7	5.6	5.9	222	2727	7.1	Univ. of Arkansas
	N07-15137	VI	29	5.9	6.4	5.4	0	2687	7.2	USDA-ARS, Raleigh, NC
	NCC09-135	VI	22	5.6	6.3	4.9	668	2910	5.3	North Carolina State Univ.
	R04-342	VI	7	5.0	5.6	4.4	1174	2876	5.6	Univ. of Arkansas
	RM-22590[#]	VI	11	4.8	5.0	4.5	1623	2696	2.7	Univ. of Arkansas
	R09-4095	VI	14				754	2927	6.6	Univ. of Arkansas
	Mean	**-**	**-**	**5.4**	**5.3**	**5.4**	**818**	**2551**	**5.7**	**-**

† All materials with names beginning in G, N, NCC, R, S, and SC were developed by University of Georgia, USDA-ARS at Raleigh, NC; North Carolina State University, University of Arkansas, University of Missouri, and Clemson University, respectively.

‡ Vegetative flooding began July 5, 2016 and June 28, 2017

§ Reproductive flooding began August 13, 2016 and July 24-5, 2017

¶ Appeared tolerant to flooding based on Experiments III and IV

Appeared tolerant in both chapters

Table 3.7. Continued.

				Chapter 3 (Exps. III and IV)			Chapter 2 (Exps. I and II)			
Experiment	Entry †	Maturity Group	Code	Overall	Vegetative[‡] Mean	Reproductive[§] Mean	Flood Yield	Control Yield	Rating Mean	Developer
				--------------------0 to 9--------------------			----kg ha^{-1}----		0 to 9	
IV (MG VI-VIII).	Boggs[¶]	VI	2	5.0	4.5	5.5	1141	2323	5.0	Univ. of Georgia
	Dillon	VI	1	5.6	4.6	6.7	1356	2732	4.0	Clemson Univ.
	N06-6	VI	6	5.6	5.2	6.0	1132	2850	4.4	USDA-ARS, Raleigh, NC
	N6001	VI	12	6.0	5.5	6.4	813	2654	4.7	USDA-ARS, Raleigh, NC
	N6002	VI	13	6.2	5.4	6.9	674	2581	6.2	USDA-ARS, Raleigh, NC
	N6202	VI	11	7.2	6.9	7.5	0	0		USDA-ARS, Raleigh, NC
	N93-110-6	VI	22	5.5	5.0	5.9	1297	2541	4.0	USDA-ARS, Raleigh, NC
	Young	VI	14	6.1	5.5	6.7	1040	2279	4.7	USDA-ARS, Raleigh, NC
	NC-Dunphy[¶#]	VI	19	5.1	4.4	5.8	1935	3099	3.5	North Carolina State Univ.
	NC-Dilday	VI	20	6.5	5.6	7.4	393	2959	7.3	North Carolina State Univ.
	G00-3213	VII	18	6.0	5.0	7.0	1112	2582	5.6	Univ. of Georgia
	N7001	VII	16	5.4	4.6	6.1	176	2227	6.2	USDA-ARS, Raleigh, NC
	Mean	**-**	**-**	**5.4**	**5.3**	**5.4**	**818**	**2551**	**5.7**	**-**

† All materials with names beginning in G, N, NCC, R, S, and SC were developed by University of Georgia, USDA-ARS at Raleigh, NC; North Carolina State University, University of Arkansas, University of Missouri, and Clemson University, respectively.

‡ Vegetative flooding began July 5, 2016 and June 28, 2017

§ Reproductive flooding began August 13, 2016 and July 24-5, 2017

¶ Appeared tolerant to flooding based on Experiments III and IV

Appeared tolerant in both chapters

Table 3.7. Continued.

				Chapter 3 (Exps. III and IV)			Chapter 2 (Exps. I and II)			
Experiment	Entry †	Maturity Group	Code	Overall	Vegetative[‡] Mean	Reproductive[§] Mean	Flood Yield	Control Yield	Rating Mean	Developer
				--------------------0 to 9--------------------			----kg ha^{-1}----		0 to 9	
	N7002[#]	VII	17	5.2	4.6	5.8	1414	2482	3.2	USDA-ARS, Raleigh, NC
	N7003CN	VII	3	5.8	5.4	6.3	1115	2563	4.7	USDA-ARS, Raleigh, NC
	N7103[¶]	VII	8	4.7	4.6	4.8	749	2433	5.1	USDA-ARS, Raleigh, NC
	NC-Raleigh	VII	4	5.3	4.8	5.8	1342	2330	5.2	USDA-ARS, Raleigh, NC
	NLM09-77	VII	15	5.6	5.1	6.1	1035	2437	5.5	USDA-ARS, Raleigh, NC
	NMS4-1-77[¶]	VII	10	4.9	4.1	5.8	1181	2368	4.5	USDA-ARS, Raleigh, NC
	NMS4-44-329	VII	9	5.7	5.4	5.9	448	1976	6.9	USDA-ARS, Raleigh, NC
	TCHM06-Morph 204	VII	5	5.5	4.6	6.4	365	2834	7.9	USDA-ARS, Raleigh, NC
	TCWN05/06-5068	VII	24	5.8	5.6	6.1	904	2295	5.7	USDA-ARS, Raleigh, NC
	NC-Wilder	VII	21	5.3	5.1	5.5	1357	2713	4.7	North Carolina State Univ.
	N8002[¶#]	VIII	23	4.8	4.2	5.4	1223	2479	4.0	USDA-ARS, Raleigh, NC
	N8101[¶]	VIII	7	5.1	4.4	5.7	1023	1940	4.5	USDA-ARS, Raleigh, NC
	Mean	-	-	**5.4**	**5.3**	**5.4**	**818**	**2551**	**5.7**	-
	LSD	-	-							-

† All materials with names beginning in G, N, NCC, R, S, and SC were developed by University of Georgia, USDA-ARS at Raleigh, NC; North Carolina State University, University of Arkansas, University of Missouri, and Clemson University, respectively.

‡ Vegetative flooding began July 5, 2016 and June 28, 2017

§ Reproductive flooding began August 13, 2016 and July 24-5, 2017

¶ Appeared tolerant to flooding based on Experiments III and IV

Appeared tolerant in both chapters

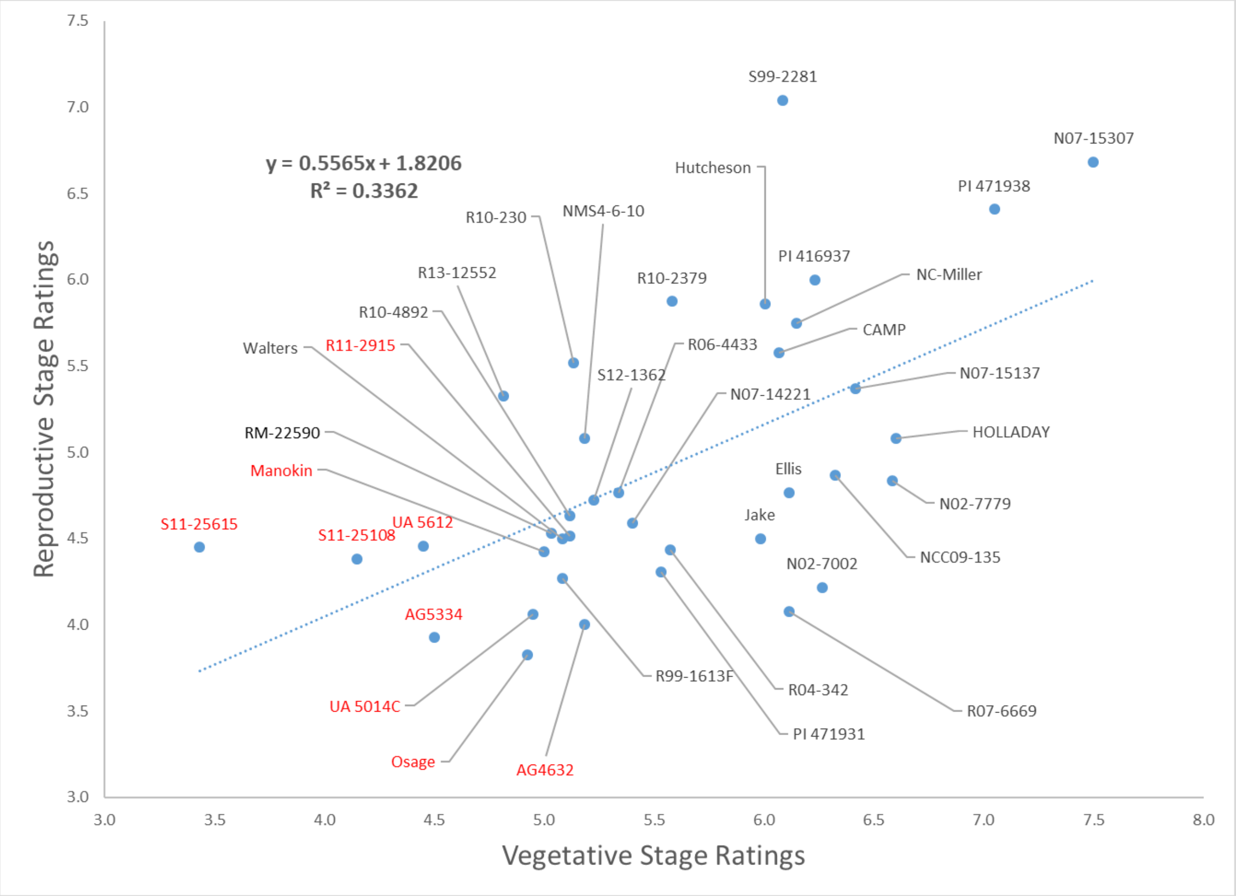


Figure 3.1. Linear regression of 37 genotypes in Experiment III (MG IV-V) for visual ratings in both vegetative and reproductive stage flooding treatments over 2016 and 2017 in Plymouth, NC. Visual ratings are assigned on a 0-9 scale (0=healthy plants, 9=95% dead plants).

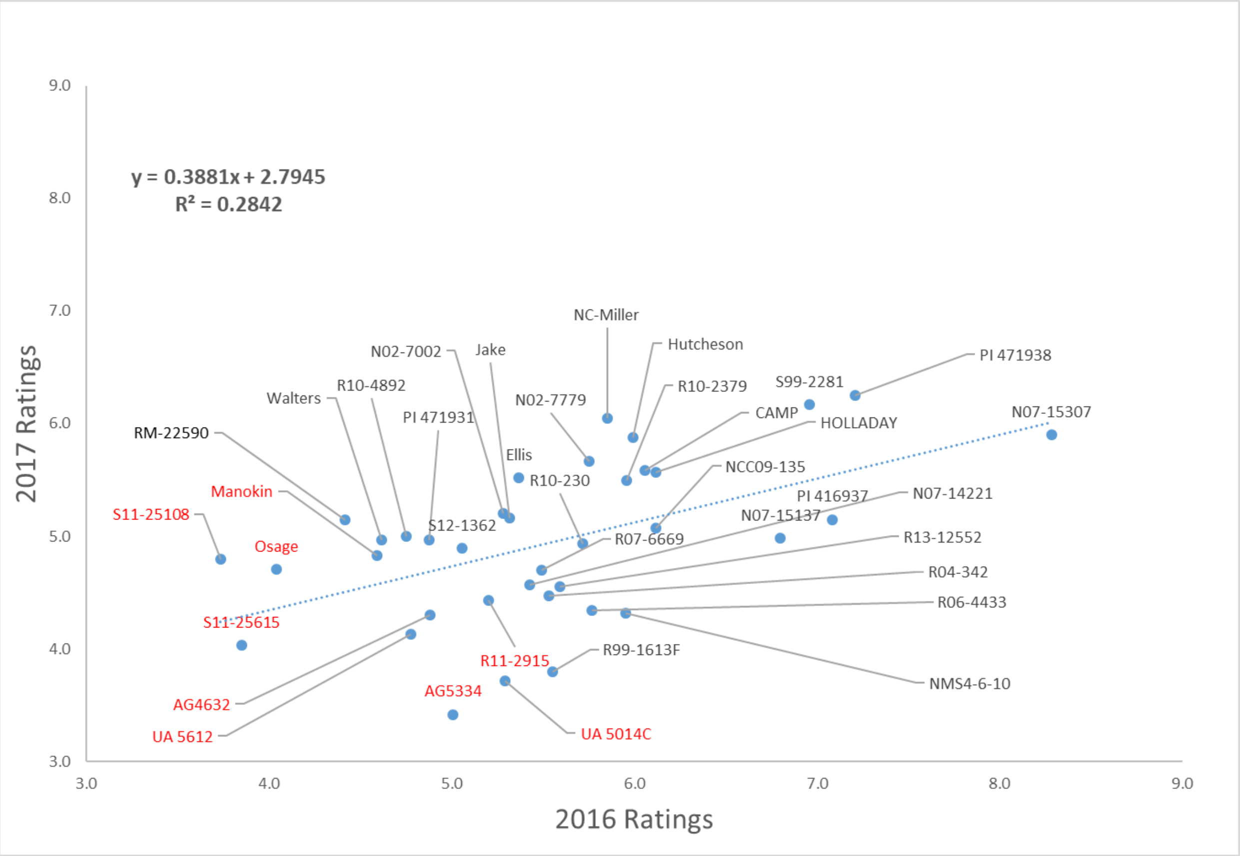


Figure 3.2. Linear regression of 37 genotypes in Experiment III (MG IV-V) for visual ratings over both flooding treatments in 2016 and 2017 at Plymouth, NC. Visual ratings are assigned on a 0-9 scale (0=healthy plants, 9=95% dead plants).

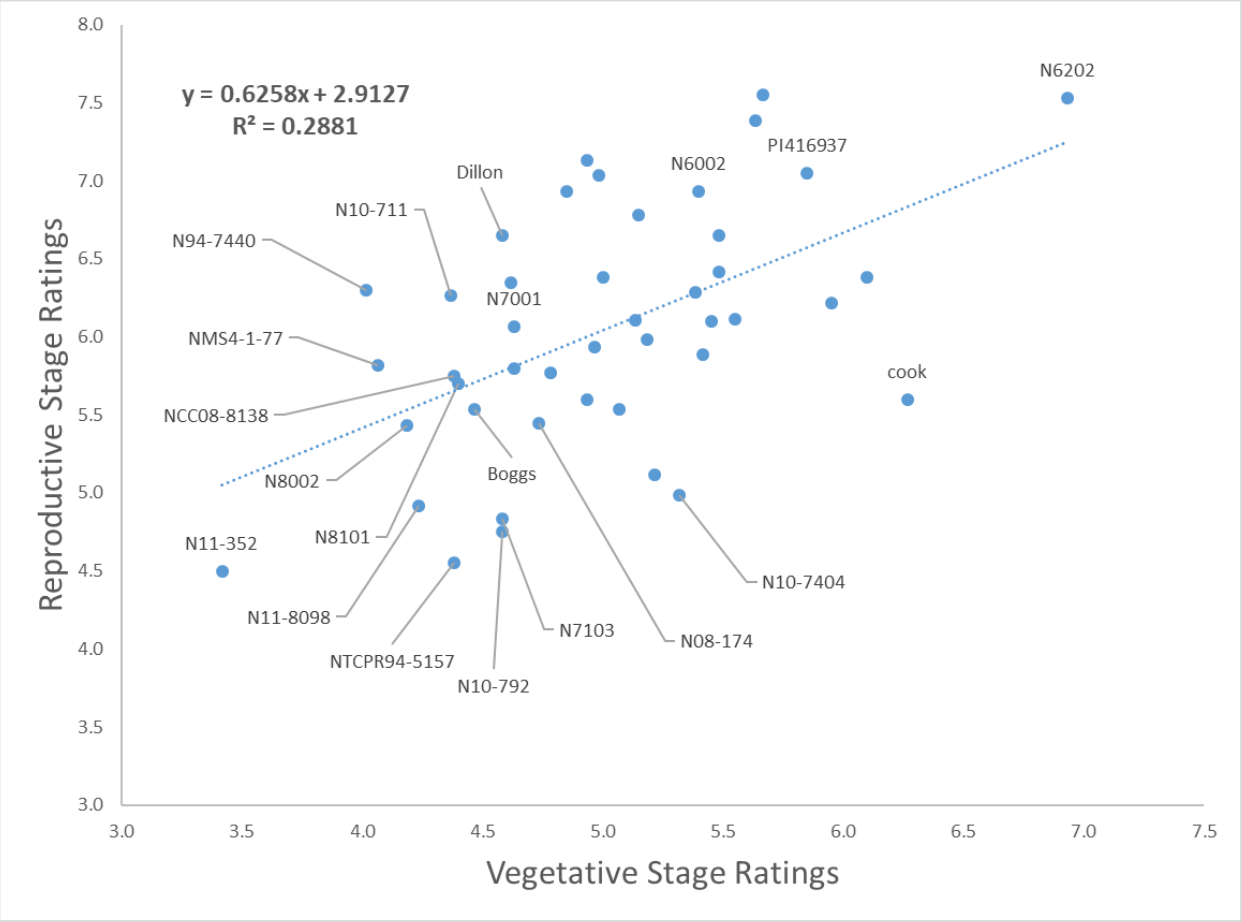


Figure 3.3. Linear regression of 44 genotypes in Experiment IV (MG VI-VIII) for visual ratings in both vegetative and reproductive stage flooding treatments over 2016 and 2017 in Plymouth, NC. Visual ratings are assigned on a 0-9 scale (0=healthy plants, 9=95% dead plants).

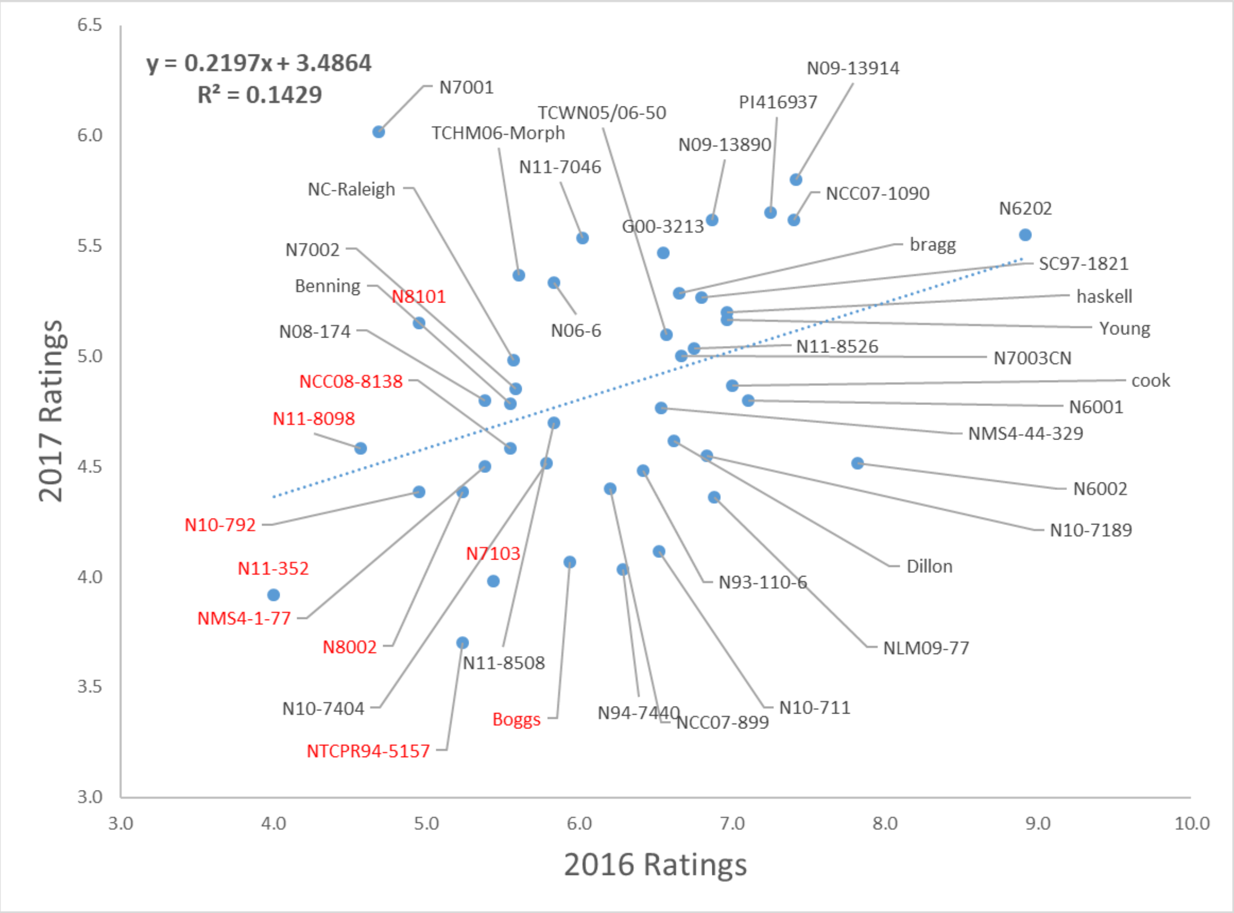


Figure 3.4. Linear regression of 44 genotypes in Experiment IV (MG VI-VIII) for visual ratings over both flooding treatments in 2016 and 2017 in Plymouth, NC. Visual ratings are assigned on a 0-9 scale (0=healthy plants, 9=95% dead plants).

APPENDICES

Appendix A. Analysis of variance of log transformed and untransformed yield data from 31 genotypes in Experiment I in 2016 and 2017. Log(max-x) function used.

Source	Yield: LOG(max-x) transformed						Yield: Untransformed					
	2016			2017			2016			2017		
	DF	**Mean Squares**		**DF**	**Mean Squares**		**DF**	**Mean Squares**		**DF**	**Mean Squares**	
	----------kg ha^{-1}----------											
Treatment[†]	1	27.38	**	1	59.04	**	1	177165232.82	**	1	231820760.37	**
Rep(Trt)	7	0.12		5	0.61		7	462986.77		5	689932.29	
Genotype	30	0.06	ns	30	0.20	ns	30	427567.93	ns	30	677343.75	ns
Trt*Genotype	30	0.08		30	0.14		30	540493.53		30	630253.04	
Error	206	0.02		145	0.16		206	92736.46		146	274880.53	

**,* indicate significance at $p < 0.01$ and $p < 0.05$, respectively.

ns indicates not significant, $p > 0.10$

[†] Flooding was successfully imposed in three and two replications in 2016 and 2017, respectively. Six and five replications of control plots were employed in 2016 and 2017, respectively.

Appendix B. Phenotypic correlation coefficients of 31 genotypes in Experiment I (MG IV-V) for log transformed and untransformed yield data. For the log transformation, data were subtracted from a constant (equal to the maximum value of the data) to ensure all values were greater than zero.

Experiment		Yield			Visual Ratings		
		Untrans.	*SQRT*	*LOG*	*Untrans.*	SQRT	LOG
I (MG IV-V).	*Yield*	1.00					
	SQRT Yield	0.97	1.00				
	LOG Yield	0.83	0.72	1.00			
	Ratings	-0.83	-0.73	-0.84	1.00		
	SQRT Rating	-0.83	-0.72	-0.83	0.99	1.00	
	LOG Ratings	-0.74	-0.61	-0.82	0.87	0.89	1.00

*,** indicates significance at $p < 0.05$ and $p < 0.01$, respectively

† Yield: kg ha^{-1}

Appendix C. Phenotypic correlation coefficients of 31 genotypic means in Experiment I (MG IV-V) for all traits in control conditions. Data collected in Plymouth, NC in 2016 and 2017. Six and five replications of control plots were employed in 2016 and 2017, respectively.

	Yield[†]			Maturity[‡]			Lodging[§]		
Trait	*2016*	*2017*	*Mean*	*2016*	*2017*	*Mean*	*2016*	*2017*	*Mean*
Yield									
2016	1.00								
2017	0.54	1.00							
Mean	0.90	0.85	1.00						
Maturity									
2016	0.45	0.22	0.39	1.00					
2017	0.12	0.22	0.19	0.73	1.00				
Mean	0.29	0.24	0.30	0.91	0.94	1.00			
Lodging									
2016	0.16	-0.14	0.02	0.10	0.09	0.10	1.00		
2017	-0.02	-0.41	-0.23	-0.04	-0.04	-0.04	0.71	1.00	
Mean	0.07	-0.30	-0.11	0.04	0.03	0.03	0.92	0.93	1.00
Height									
2016	0.09	-0.29	-0.09	-0.01	-0.14	-0.09	0.72	0.65	0.74
2017	0.11	-0.27	-0.07	0.08	-0.03	0.02	0.69	0.73	0.77
Mean	0.11	-0.28	-0.08	0.04	-0.08	-0.03	0.73	0.71	0.78
100-seed weight									
2016	0.55	0.04	0.36	0.23	0.01	0.12	0.26	0.12	0.20
2017	0.53	0.11	0.38	0.11	-0.07	0.01	0.32	0.14	0.25
Mean	0.55	0.07	0.38	0.17	-0.03	0.06	0.30	0.14	0.23
Protein Content									
2016	-0.13	0.02	-0.07	-0.12	-0.15	-0.15	0.03	0.13	0.09
2017	-0.01	-0.08	-0.05	0.20	0.01	0.10	0.09	0.22	0.17
Mean	-0.08	-0.03	-0.07	0.03	-0.08	-0.04	0.06	0.19	0.14
Oil Content									
2016	0.12	-0.25	-0.06	-0.08	-0.06	-0.08	0.34	0.23	0.30
2017	0.31	-0.20	0.09	-0.01	-0.11	-0.07	0.19	0.22	0.22
Mean	0.21	-0.24	0.01	-0.05	-0.08	-0.07	0.28	0.23	0.28

† Yield: kg ha^{-1}

‡ Maturity date was assigned when 95% of the pods in the plot had reached a mature color (tan). Number is the date in October (Oct. 1 = 1).

§ Lodging (1-5) scores given on a plot basis on a 1 to 5 scale (1 = erect plants, 5 = prone), measured before harvest. Data from 2016 only.

¶ Height (cm) measured from the ground level to the apical meristem of 3 random plants per plot, measured before harv

Protein and oil contents (g/kg) represented at zero percent moisture

Appendix C. Continued.

		Height[¶]			100-seed weight			Protein Content[#]			Oil Content[#]		
Trait		*2016*	*2017*	*Mean*	*2016*	*2017*	*Mean*	*2016*	*2017*	*Mean*	*2016*	*2017*	*Mean*
Yield													
	2016												
	2017												
	Mean												
Maturity													
	2016												
	2017												
	Mean												
Lodging													
	2016												
	2017												
	Mean												
Height													
	2016	1.00											
	2017	0.89	1.00										
	Mean	0.97	0.98	1.00									
100-seed weight													
	2016	0.26	0.25	0.26	1.00								
	2017	0.28	0.29	0.29	0.93	1.00							
	Mean	0.28	0.27	0.28	0.98	0.99	1.00						
Protein Content													
	2016	0.21	0.11	0.16	-0.09	-0.11	-0.10	1.00					
	2017	0.10	0.12	0.11	-0.08	-0.09	-0.09	0.69	1.00				
	Mean	0.17	0.13	0.15	-0.10	-0.11	-0.11	0.93	0.91	1.00			
Oil Content													
	2016	0.22	0.26	0.25	0.57	0.59	0.59	-0.45	-0.45	-0.49	1.00		
	2017	0.17	0.19	0.19	0.68	0.64	0.67	-0.32	-0.37	-0.37	0.90	1.00	
	Mean	0.20	0.23	0.23	0.63	0.63	0.64	-0.40	-0.42	-0.45	0.98	0.97	1.00

† Yield: kg ha^{-1}

‡ Maturity date was assigned when 95% of the pods in the plot had reached a mature color (tan). Number is the date in October (Oct. 1 = 1).

§ Lodging (1-5) scores given on a plot basis on a 1 to 5 scale (1 = erect plants, 5 = prone), measured before harvest. Data from 2016 only.

¶ Height (cm) measured from the ground level to the apical meristem of 3 random plants per plot, measured before harvest

Protein and oil contents (g/kg) represented at zero percent moisture

Appendix D. Phenotypic correlation coefficients of 31 genotypic means in Experiment Ii (MG VI-VIII) for all traits in flooding and control conditions. Data collected in Plymouth, NC in 2016 and 2017. Flooding was successfully imposed in three and two replications in 2016 and 2-17, respectively. Six and five replications of control plots were employed in 2016 and 2017, respectively.

			Yield†								Maturity Date‡				
			TRT Means		2016			2017			TRT Means		Yearly Means		
Trait			*Flood*	*Control*	*Flood*	*Control*	*Mean*	*Flood*	*Control*	*Mean*	*Flood*	*Control*	*2016*	*2017*	*Overall*
Yield	Treatment Means	Flood	1.00												
		Control	0.26	1.00											
	2016	Flood	0.71	0.44	1.00										
		Control	0.18	0.90	0.38	1.00									
		Mean	0.56	0.78	0.86	0.80	1.00								
	2017	Flood	0.94	0.12	0.44	0.05	0.31	1.00							
		Control	0.28	0.95	0.42	0.73	0.67	0.16	1.00						
		Mean	0.90	0.54	0.55	0.37	0.56	0.89	0.59	1.00					
Maturity Date	Treatment Means	Flood	-0.10	-0.27	-0.08	-0.32	-0.22	-0.09	-0.20	-0.15	1.00				
		Control	-0.13	-0.68	-0.28	-0.66	-0.55	-0.03	-0.61	-0.31	0.87	1.00			
	Yearly Means	2016	0.10	-0.47	-0.08	-0.49	-0.32	0.16	-0.39	-0.05	0.95	0.92	1.00		
		2017	-0.29	-0.57	-0.28	-0.57	-0.47	-0.24	-0.50	-0.38	0.91	0.95	0.85	1.00	
		Overall	-0.03	-0.54	-0.17	-0.55	-0.41	0.04	-0.47	-0.18	0.96	0.97	0.96	0.96	1.00
	Visual Ratings	2016	-0.59	-0.30	-0.81	-0.20	-0.64	-0.37	-0.33	-0.45	0.06	0.19	-0.03	0.27	0.09
		2017	-0.71	0.12	-0.23	0.14	-0.07	-0.80	0.08	-0.62	-0.01	-0.20	-0.30	-0.01	-0.22
		Mean	-0.85	-0.06	-0.57	0.01	-0.37	-0.81	-0.10	-0.71	0.03	-0.06	-0.24	0.17	-0.13
	Lodging	Flood	-0.22	-0.63	-0.14	-0.40	-0.30	-0.21	-0.71	-0.46	0.00	0.24	-0.01	0.26	0.13
		Control	-0.14	-0.74	-0.16	-0.48	-0.36	-0.10	-0.84	-0.47	0.07	0.39	0.16	0.34	0.27
	Height	Flood	-0.14	-0.60	-0.01	-0.49	-0.26	-0.19	-0.60	-0.39	0.20	0.46	0.28	0.39	0.35
		Control	0.04	-0.58	-0.03	-0.49	-0.29	0.06	-0.57	-0.21	0.12	0.38	0.27	0.29	0.31
	100-Seed Weight	Flood	0.25	0.58	0.39	0.56	0.55	0.09	0.52	0.31	-0.26	-0.52	-0.39	-0.38	-0.40
		Control	0.07	0.56	0.32	0.54	0.50	-0.06	0.51	0.19	-0.22	-0.48	-0.39	-0.35	-0.40
	PRO	Flood	-0.40	-0.36	-0.41	-0.35	-0.46	-0.25	-0.32	-0.33	-0.10	-0.03	-0.20	0.07	-0.07
		Control	0.04	-0.43	-0.30	-0.43	-0.44	0.19	-0.37	-0.01	-0.12	0.10	0.06	0.03	0.09
	OIL	Flood	0.30	0.47	0.44	0.52	0.57	0.11	0.38	0.26	-0.26	-0.36	-0.24	-0.37	-0.32
		Control	0.19	0.67	0.54	0.62	0.69	-0.01	0.62	0.28	-0.19	-0.46	-0.37	-0.35	-0.39

† Yield: kgha-1

‡ Maturity date was assigned when 95% of the pods in the plot had reached a mature color (tan). Number is the date in October (Oct. 1 = 1).

§ Visual ratings given on a 0 to 9 scale (0 = healthy plot, 9 = > 95% dead plants) and based on yellowing of the canopy and canopy fullness.

¶ Lodging (1-5) scores given on a plot basis on a 1 to 5 scale (1 = erect plants, 5 = prone), measured before harvest. Data from 2016 only.

Height (cm) measured from the ground level to the apical meristem of 3 random plants per plot, measured before harvest

†† Protein and oil contents (g/kg) represented at zero percent moisture

Appendix D. Continued.

			Visual Ratings[§]			Lodging[¶]		Height[#]		100-Seed Weight		Protein Content[††]		Oil Content[††]	
Trait			*2016*	*2017*	*Mean*	*Flood*	*Control*	*Flood*	*Control*	*Flood*	*Control*	*Flood*	*Control*	*Flood*	
Yield	Treatment Means	Flood													
		Control													
	2016	Flood													
		Control													
		Mean													
	2017	Flood													
		Control													
		Mean													
Maturity Date	Treatment Means	Flood													
		Control													
	Yearly Means	2016													
		2017													
		Overall													
	Visual Ratings	2016	1.00												
		2017	0.19	1.00											
		Mean	0.64	0.88	1.00										
	Lodging	Flood	0.30	0.21	0.35	1.00									
		Control	0.25	-0.09	0.05	0.74	1.00								
	Height	Flood	0.16	0.21	0.26	0.73	0.61	1.00							
		Control	0.08	-0.22	-0.13	0.55	0.55	0.77	1.00						
	100-Seed Weight	Flood	-0.30	0.19	-0.05	-0.15	-0.46	-0.24	-0.02	1.00					
		Control	-0.23	0.32	0.14	-0.15	-0.47	-0.18	-0.06	0.98	1.00				
	PRO	Flood	0.20	0.05	0.19	0.13	0.16	-0.15	0.21	0.05	0.04	1.00			
		Control	0.17	-0.32	-0.17	0.20	0.15	-0.12	0.41	0.16	0.01	0.91	1.00		
	OIL	Flood	-0.21	0.30	0.08	0.15	-0.20	0.20	-0.08	0.49	0.48	-0.69	-0.58	1.00	
		Control	-0.33	0.25	0.03	-0.12	-0.42	-0.02	-0.30	0.52	0.53	-0.63	-0.65	0.92	1.00

† Yield: kg ha^{-1}

‡ Maturity date was assigned when 95% of the pods in the plot had reached a mature color (tan). Number is the date in October (Oct. 1 = 1).

§ Visual ratings given on a 0 to 9 scale (0 = healthy plot, 9 = > 95% dead plants) and based on yellowing of the canopy and canopy fullness.

¶ Lodging (1-5) scores given on a plot basis on a 1 to 5 scale (1 = erect plants, 5 = prone), measured before harvest. Data from 2016 only.

Height (cm) measured from the ground level to the apical meristem of 3 random plants per plot, measured before harvest

†† Protein and oil contents (g/kg) represented at zero percent moisture

Appendix E. Expanded ANOVA for yield for 23 genotypes in Experiment II. Linear contrasts are defined for each maturity group. MG 6 includes those genotypes in MG VI, MG 7-8 includes those genotypes in MGs VII and VIII.

Source	Yield (bu/ac)					
	DF	Type III Sum of Squares	Mean Squares	F	p	
Year	1	2780.30	2780.43			
Treatment	1	28344.09	28344.09	135.54	0.055	
Year x Treatment	1	209.11	209.11			
Rep(year trt)	11	430.49	39.14			
Entry	22	3728.01	169.46	2.89	0.008	**
MG[†]	1	455.01	455.01	7.77	0.011	*
MG 6	8	1616.12	202.01	3.45	0.010	**
MG 7-8	13	1634.13	125.70	2.15	0.056	
Year x Entry	22	1288.60	58.57	2.91	<.0001	**
MG*year	1	2.05	2.05	0.10	0.750	ns
MG 6	8	642.11	80.26	3.99	0.0002	**
MG 7-8	13	615.23	47.33	2.35	0.006	**
Trt x Entry	22	2364.04	107.46	2.14	0.041	**
MG*trt	1	64.70	64.70	1.29	0.257	ns
MG 6	8	1093.57	136.70	2.72	0.007	**
MG 7-8	13	1118.25	86.02	1.71	0.060	0.1
Year x Trt x Entry	22	1104.59	50.21	2.50	<.0001	**
MG*year*trt	1	10.79	10.79	0.54	0.460	ns
MG 6	8	496.45	62.06	3.09	0.002	**
MG 7-8	13	563.42	43.34	2.15	0.012	*
Error	229	4605.85	20.11			

*,** significantly different from zero at $p < 0.05$ and $p < 0.01$, respectively

ns indicates not significant, $p > 0.10$

† MG = maturity group

Appendix F. Phenotypic correlation coefficients of maturity date, yield and visual ratings for 9 and 14 genotypes in MG 6 and MG 7-8, respectively in Experiment II (MG VI-VIII). N6202 was dropped from Experiment II because of missing data. MG 6 includes those genotypes in MG VI, MG 7-8 includes those genotypes in MGs VII and VIII.

			Control	Overall Yield	Overall Yield	2016 Yield			2017 Yield			Ratings		
Maturity Group			*MD*	*Flood*	*Control*	*Flood*	*Control*	*Mean*	*Flood*	*Control*	*Mean*	*2016*	*2017*	*Mean*
MG 6	Control	MD	1.00											
	Overall Yld	Flood	-0.30	1.00										
	Overall Yld	Control	-0.54	0.21	1.00									
	2016 Yield	Flood	-0.03	0.67	0.33	1.00								
		Control	-0.49	0.05	0.96	0.17	1.00							
		Mean	-0.31	0.50	0.81	0.81	0.72	1.00						
	2017 Yield	Flood	-0.35	0.96	0.12	0.42	-0.01	0.29	1.00					
		Control	-0.55	0.32	0.98	0.43	0.89	0.84	0.22	1.00				
		Mean	-0.50	0.93	0.47	0.52	0.33	0.56	0.93	0.56	1.00			
	Ratings	2016	-0.15	-0.54	-0.35	-0.86	-0.18	-0.72	-0.32	-0.46	-0.44	1.00		
		2017	0.04	-0.81	0.24	-0.28	0.31	-0.01	-0.87	0.17	-0.68	0.19	1.00	
		Mean	-0.05	-0.89	0.00	-0.67	0.14	-0.39	-0.82	-0.11	-0.74	0.67	0.85	1.00
MG 7-8	Control	MD	1.00											
	Overall Yld	Flood	0.06	1.00										
	Overall Yld	Control	-0.60	0.21	1.00									
	2016 Yield	Flood	-0.16	0.73	0.37	1.00								
		Control	-0.57	0.18	0.81	0.37	1.00							
		Mean	-0.40	0.60	0.67	0.88	0.76	1.00						
	2017 Yield	Flood	0.16	0.94	0.09	0.46	0.05	0.34	1.00					
		Control	-0.50	0.20	0.93	0.30	0.53	0.48	0.11	1.00				
		Mean	-0.10	0.87	0.52	0.52	0.29	0.51	0.88	0.57	1.00			
	Ratings	2016	-0.05	-0.61	0.01	-0.74	0.08	-0.47	-0.43	-0.05	-0.37	1.00		
		2017	-0.36	-0.67	0.05	-0.22	0.07	-0.12	-0.77	0.04	-0.62	0.22	1.00	
		Mean	-0.32	-0.81	0.05	-0.49	0.09	-0.29	-0.81	0.01	-0.67	0.60	0.91	1.00

† Maturity date was assigned when 95% of the pods in the plot had reached a mature color (tan). Number is the date in October (Oct. 1 = 1).

Appendix G. Allocation of resources for broad-sense heritability of yield and visual ratings for 31 and 23 genotypes in Experiments I (MG IV-V) and II (MG I-VIII) in the flooded treatment.

			Experiment I (MG IV-V)		Experiment II (MG VI-VIII)	
Variance	Env	Reps	Yield	Ratings	Yield	Ratings
	1	1	0.23	0.31	0.29	0.13
	1	2	0.36	0.45	0.41	0.17
	1	3	0.45	0.53	0.49	0.19
	1	4	0.51	0.58	0.53	0.20
	1	5	0.56	0.62	0.57	0.21
	2	1	0.37	0.47	0.44	0.23
	2	2	0.53	0.62	0.58	0.29
	2	3	0.62	0.69	0.65	0.32
	2	4	0.68	0.74	0.70	0.34
	2	5	0.72	0.76	0.72	0.35
	3	1	0.47	0.57	0.55	0.31
	3	2	0.63	0.71	0.68	0.38
	3	3	0.71	0.77	0.74	0.41
	3	4	0.76	0.81	0.77	0.43
	3	5	0.79	0.83	0.80	0.44
	4	1	0.54	0.64	0.62	0.37
	4	2	0.69	0.77	0.74	0.45
	4	3	0.77	0.82	0.79	0.48
	4	4	0.81	0.85	0.82	0.50
	4	5	0.84	0.87	0.84	0.52
	5	1	0.60	0.69	0.67	0.42
	5	2	0.74	0.80	0.78	0.50
	5	3	0.80	0.85	0.83	0.54
	5	4	0.84	0.87	0.85	0.56
	5	5	0.87	0.89	0.87	0.57
				Variance Source		
Genotype	-	-	23.67	0.94	22.67	0.40
Genotype x Year	-	-	2.95	0.20	7.61	1.21
Error	-	-	77.44	1.91	49.16	1.55
H^{2} †	-	-	0.58	0.66	0.58	0.29

† Broad Sense heritability based on experiment wide means over 2 years and 5 or 4 replications (Exp. 1 or 2, respectively) for each yield and ratings

Appendix H. LS means of 31 and 23 genotypes from Experiment I (MG IV-V) and II (MG VI-VIII) in flooded and control treatments at Plymouth, NC in 2016. The flooding treatment consisted of 3-5 inches of water on soil surface for ~7 days. The control treatment consisted of conventional management. R99-1613F was dropped from Experiment I because of segregation. N6202 was dropped from Experiment II because of missing data.

				Control							Flooding †							
Experiment	Entry	Maturity Group	Code	Yield	Maturity‡	Lodging§	Height¶	100-seed weight	Protein#	Oil#	Yield	Visual Rating††	Maturity	Lodging‡‡	Height‡‡	100-seed weight	Protein	Oil
				kg ha^{-1}	Oct. 1 = 1	1 to 5	cm	g	-------g kg^{-1}-------		kg ha^{-1}	0 to 9	Oct. 1 = 1	1 to 5	cm	g	-------g kg^{-1}-------	
I (MG IV-V).	AG4632	IV	19	2282	6	1.8	80	14.0	415	232	681	8	5	1.8	83	10.8	377	256
	R13-12552	IV	3	2292	11	2.1	112	12.4	406	235	896	6	11	2.0	100	12.0	390	238
	S11-25108	IV	15	2158	8	3.0	92	12.8	406	252	1032	7	8	2.7	86	12.6	369	269
	S11-25615	IV	17	2037	10	2.1	102	13.7	421	231	1223	5	15	2.2	98	14.7	422	231
	S99-2281	IV	18	1992	5	1.3	59	11.3	398	237	116	9	6	1.7	65	9.2	357	251
	UA 5014C	IV	8	2432	6	1.3	63	13.3	418	225	311	8	9	1.3	66	10.8	378	240
	AG5334	V	20	2398	13	1.7	83	13.8	434	227	690	8	7	1.5	80	10.4	380	250
	CAMP	V	27	1408	11	1.2	50	7.5	429	213	1035	6	11	1.5	57	8.7	420	221
	Ellis	V	24	2713	9	1.3	60	11.6	409	227	1355	6	10	1.3	69	10.7	380	239
	HOLLADAY	V	28	2214	7	1.5	58	13.4	396	240	882	8	10	1.3	66	11.6	374	256
	Hutcheson	V	21	2202	12	1.6	69	13.0	411	237	414	8	9	2.0	69	13.0	392	252
	N02-7002	V	23	2539	11	1.6	71	12.3	403	216	1062	6	11	1.7	68	12.7	389	227
	N02-7779	V	31	2288	8	1.3	57	13.5	402	239	782	8	10	1.5	64	12.1	385	257
	N07-15307	V	30	2199	15	1.3	58	13.2	390	237	0	8		1.2	0		0	0
	NC-Miller	V	26	2792	16	1.7	67	16.0	387	243	761	5	19	2.0	70	15.4	377	251
	NMS4-6-10	V	32	2232	6	1.8	65	11.0	413	225	361	8	6	1.3	65	9.9	378	242
	Mean	**-**	**-**	**2385**	**12**	**1.8**	**72**	**12.7**	**411**	**230**	**676**	**7**	**11**	**1.7**	**66**	**11.7**	**391**	**243**

† Flooding was successfully imposed in three and two replications in 2016 and 2017, respectively. Six and five replications of control plots were employed in 2016 and 2017, respectively.

‡ maturity date was assigned when 95% of the pods in the plot had reached a mature color (tan). Number is the date in October.

§ lodging values given on a plot basis on a 1 to 5 scale (1 = erect plants, 5 = prostrate), measured before harvest. Data from 2016 only.

¶ height measured from the ground level to the apical meristem of 3 random plant per plot, measured before harvest

protein and oil contents represented at zero percent moisture

†† visual ratings on given on a 0 to 9 scale (0 = no damage, 9 = > 95% dead plants) and based on yellowing of the canopy and canopy fullness.

‡‡ 2016 height and lodging scores dropped from flood treatment if based on only one rep

§§ non-estimable as a result of missing data

Appendix H. Continued.

				Control							Flooding †							
Experiment	Entry	Maturity Group	Code	Yield	Maturity‡	Lodging§	Height¶	100-seed weight	Protein#	Oil#	Yield	Visual Rating††	Maturity	Lodging‡‡	Height‡‡	100-seed weight	Protein	Oil
				kg ha^{-1}	Oct. 1 = 1	1 to 5	cm	g	-------g kg^{-1}-------		kg ha^{-1}	0 to 9	Oct. 1 = 1	1 to 5	cm	g	-------g kg^{-1}-------	
I (MG IV-V).	Osage	V	25	2428	11	1.2	60	11.9	448	213	1142	6	10	1.0	67	10.9	417	234
	R09-4095	V	14	2791	13	1.7	67	13.7	407	243	620	7	11	1.3	68	12.4	389	252
	S12-1362	V	16	2581	12	2.7	109	12.3	417	231	347	8	9	2.7	101	11.6	375	258
	R10-4892	V	2	2530	14	1.6	71	11.9	412	238	755	8	8	1.3	66	9.2	365	254
	Walters	V	6	2170	8	2.5	73	12.0	416	232	1053	6	10	2.3	76	12.8	410	234
	R10-230	V	1	2521	15	2.0	69	13.4	418	232	325	8	9	1.8	71	11.8	405	243
	R11-2915	V	13	2765	15	1.7	69	13.9	415	230	408	7	12	1.7	69	13.1	401	235
	UA 5612	V	5	2474	14	1.6	70	11.7	415	230	797	7	11	2.0	75	11.0	398	245
	R07-6669	V	4	2675	14	2.3	77	12.7	412	222	974	7	11	2.3	75	11.6	389	238
	R06-4433	V	9	2754	16	2.2	71	13.1	417	226	623	8	11	2.0	71	14.3	419	230
	R10-2379	V	12	2482	16	1.8	82	15.3	425	232	0	8		1.3	0		0	0
	N07-15137	VI	29	2399	17	1.8	63	12.6	384	239	0	6	20	1.3	70		0	0
	NCC09-135	VI	22	2598	22	1.8	58	13.1	393	224	0	8	23	1.2	0		0	0
	R04-342	VI	7	2405	17	2.0	75	14.7	425	229	1041	6	19	1.8	69	14.2	413	232
	RM-22590	VI	11	2189	14	1.3	62	7.7	402	208	1270	4	18	1.3	67	9.0	397	217
	Mean	-	-	**2385**	**12**	**1.8**	**72**	**12.7**	**411**	**230**	**676**	**7**	**11**	**1.7**	**66**	**11.7**	**391**	**243**

Appendix H. Continued.

				Control							Flooding [†]							
Experiment	Entry	Maturity Group	Code	Yield	Maturity[‡]	Lodging[§]	Height[¶]	100-seed weight	Protein[#]	Oil[#]	Yield	Visual Rating[††]	Maturity	Lodging[‡‡]	Height[‡‡]	100-seed weight	Protein	Oil
				kg ha^{-1}	Oct. 1 = 1	1 to 5	cm	g	-------g kg^{-1}-------		kg ha^{-1}	0 to 9	Oct. 1 = 1	1 to 5	cm	g	-------g kg^{-1}-------	
II (MG VI-VIII).	Boggs	VI	2	2084	23	3.3	81	11.8	460	208	823	7.4	21	4.1	94	14.8	440	217
	Dillon	VI	1	2356	18	2.2	81	13.3	423	221	1162	5.2	21	2.5	94	15.6	435	217
	N06-6	VI	6	2477	22	1.3	67	11.9	424	215	921	4.8	34	1.5	72	13.8	445	201
	N6001	VI	12	2483	21	2.8	77	13.5	433	217	937	5.9	28	3.0	77	16.2	440	213
	N6002	VI	13	2305	18	2.5	78	14.3	439	211	655	7.4	20	3.0	89	14.4	420	224
	N93-110-6	VI	22	2187	21	2.6	81	13.7	443	208	1505	3.8	30	3.0	81	15.5	453	205
	NC-Dilday	VI	20	2699	17	2.5	71	14.8	385	238	786	6.8	20	2.3	79	16.0	402	239
	NC-Dunphy	VI	19	2738	17	1.8	64	14.4	400	224	1263	5.3	27	1.5	64	16.5	398	224
	Young	VI	14	2066	21	3.3	99	13.4	438	213	662	6.7	19	2.9	91	14.4	437	0
	G00-3213	VII	18	2384	30	2.2	86	13.4	464	199	588	7.7	31	3.6	84	14.0	443	210
	N7001	VII	16	2005	32	2.4	71	11.5	441	197	353	7.4	26	1.4	71	12.9	438	204
	N7002	VII	17	2147	28	2.8	80	10.8	425	207	1045	4.9	31	3.0	86	13.2	431	211
	Mean	-	-	**2230**	**24**	**2.8**	**79**	**12.2**	**430**	**209**	**860.2**	**6.4**	**27**	**2.6**	**85**	**13.6**	**434**	**210**

Appendix H. Continued.

				Control								Flooding[†]							
Experiment	Entry	Maturity Group	Code	Yield	Maturity[‡]	Lodging[§]	Height[¶]	100-seed weight	Protein[#]	Oil[#]		Yield	Visual Rating[††]	Maturity	Lodging[‡‡]	Height[‡‡]	100-seed weight	Protein	Oil
				kg ha^{-1}	Oct. 1 = 1	1 to 5	cm	g	-------g kg^{-1}-------			kg ha^{-1}	0 to 9	Oct. 1 = 1	1 to 5	cm	g	-------g kg^{-1}-------	
II (MG VI-VIII).	N7003CN	VII	3	2278	30	2.0	78	14.4	397	214		1287	5.0	30	3.0	84	15.3	407	215
	N7103	VII	8	1982	27	1.8	74	6.7	452	180		326	8.0	28	1.4	76	7.9	459	190
	NC-Wilder	VII	21	2385	25	2.3	78	12.5	421	218		1152	7.0	29	2.9	86	14.3	419	217
	NC-Raleigh	VII	4	2021	28	2.6	72	10.9	395	232		1065	5.6	29	3.0	97	11.0	406	226
	NLM09-77	VII	15	2071	19	2.6	80	17.7	493	195		742	6.3	20	3.1	74	18.5	494	187
	NMS4-1-77	VII	10	2349	22	3.2	80	8.9	430	214		1045	6.9	23	2.9	84	11.0	457	198
	NMS4-44-329	VII	9	2054	28	4.1	96	8.9	425	192		447	7.5	26	3.9	114	10.6	0	228
	TCHM06-Morph 204	VII	5	2383	18	2.0	65	12.7	384	229		729	7.8	19	2.9	84	13.9	409	209
	TCWN05/06-5068	VII	24	1987	33	2.7	94	14.8	443	207		800	7.2	37	3.3	104	15.8	437	213
	N8002	VIII	23	2241	31	3.0	78	11.1	432	197		769	6.9	30	2.8	79	13.0	437	202
	N8101	VIII	7	1606	33	3.3	80	4.7	438	182		722	6.5	33	3.0	89	5.4	437	180
	Mean	-	-	**2230**	**24**	**2.8**	**79**	**12.2**	**430**	**209**		**860.2**	**6.4**	**27**	**2.6**	**85**	**13.6**	**434**	**210**
	$LSD_{0.05}$[‡]	-	-																

† Flooding was successfully imposed in three and two replications in 2016 and 2017, respectively. Six and five replications of control plots were employed in 2016 and 2017, respectively.

‡ maturity date was assigned when 95% of the pods in the plot had reached a mature color (tan). Number is the date in October.

§ lodging values given on a plot basis on a 1 to 5 scale (1 = erect plants, 5 = prostrate), measured before harvest. Data from 2016 only.

¶ height measured from the ground level to the apical meristem of 3 random plant per plot, measured before harvest

protein and oil contents represented at zero percent moisture

†† visual ratings on given on a 0 to 9 scale (0 = no damage, 9 = > 95% dead plants) and based on yellowing of the canopy and canopy fullness.

‡‡ 2016 height and lodging scores dropped from flood treatment if based on only one rep

§§ non-estimable as a result of missing data

Appendix I. LS means of 31 and 23 genotypes from Experiment I (MG IV-V) and II (MG VI-VIII) in flooded and control treatments at Plymouth, NC in 2017. The flooding treatment consisted of 3-5 inches of water on soil surface for ~7 days. The control treatment consisted of conventional management. R99-1613F was dropped from Experiment I because of segregation. N6202 was dropped from Experiment II because of missing data.

					Control (NON)							**Flooding (FLO) †**							
Experiment	**Entry**	**Maturity Group**	**MG**	**Code**	**Yield**	**Maturity ‡**	**Lodging §**	**Height ¶**	**100-seed weight**	**Protein #**	**Oil #**	**Yield**	**Visual Rating ††**	**Maturity**	**Lodging ‡‡**	**Height ‡‡**	**100-seed weight**	**Protein**	**Oil**
					kgha^{-1}	Oct. 1 = 1	1 to 5	cm	g	---------- g/kg------		kgha^{-1}	0 to 9	Oct. 1 = 1	1 to 5	cm	g	---------- g/kg------	
I (MG IV-V).	**R10-230**	V	6	1	2490	1	2.7	110	14.8	414	235	2043	4	4	1.8	100	12.8	398	234
	R10-4892	V	5	2	3450	5	1.3	112	15.4	414	226	830	4	8	1.0	89	14.8	429	232
	R13-12552	IV	4	3	2813	16	1.1	59	8.0	422	211	763	5	10	1.0	60	9.2	426	214
	R07-6669	V	6	4	3573	8	1.1	78	12.5	405	223	2127	2	9	1.0	73	13.5	388	233
	UA 5612	V	6	5	3312	12	1.1	76	16.0	396	230	326	7	-1	1.0	61	§§	382	241
	Walters	V	6	6	2870	7	1.7	102	14.7	423	227	158	7	§§	§§	104	§§	388	245
	R04-342	VI	6	7	3416	7	1.3	88	14.8	419	215	1754	3	13	1.3	70	15.5	398	225
	UA 5014C	IV	5	8	3187	10	1.2	73	15.3	391	234	618	7	8	1.0	60	15.5	379	243
	R06-4433	V	6	9	2975	15	1.2	93	13.7	410	231	0	8	§§	§§	0	§§	0	0
	RM-22590	VI	6	11	2825	9	1.1	84	15.1	402	227	329	6	§§	1.0	74	§§	391	245
	R10-2379	V	6	12	3230	12	1.1	75	16.9	379	240	457	6	6	1.5	68	§§	372	247
	R11-2915	V	6	13	3221	18	1.7	84	13.2	425	222	1670	3	22	1.3	75	12.8	415	222
	R09-4095	V	5	14	3126	3	1.2	80	12.5	416	219	0	8	§§	§§	0	§§	0	0
	S11-25108	IV	5	15	3159	4	1.0	72	12.5	440	215	981	4	8	1.0	69	14.1	449	218
	S12-1362	V	5	16	3346	15	1.6	86	16.6	426	224	1374	6	§§	§§	0	15.9	420	224
	S11-25615	IV	5	17	3192	16	1.9	90	15.4	420	222	373	7	§§	§§	0	§§	429	226
	S99-2281	IV	5	18	3335	11	1.9	100	13.9	417	219	242	7	§§	§§	0	§§	403	235
	AG4632	IV	4	19	3061	3	1.2	74	16.0	420	241	954	6	3	1.0	69	16.4	360	251
	AG5334	V	5	20	3338	15	2.0	93	14.8	424	231	0	7	§§	§§	0	§§	0	0
	Hutcheson	V	5	21	2972	17	1.5	112	16.2	428	228	554	6	25	3.0	94	17.8	433	238
	NCC09-135	VI	6	22	3183	12	1.8	90	12.5	410	236	433	5	7	2.5	85	§§	398	237
	N02-7002	V	5	23	3249	8	1.6	97	16.5	425	230	1216	5	8	2.5	92	16.7	400	232
	Ellis	V	5	24	2768	8	1.8	122	13.4	407	227	998	5	8	1.5	113	13.0	406	225
	Osage	V	5	25	3204	10	1.4	85	8.6	404	208	2153	1	8	1.0	77	7.6	415	201
	NC-Miller	V	5	26	2850	6	2.5	121	14.9	406	238	1095	5	7	2.0	118	§§	413	228
	CAMP	V	5	27	2651	4	2.3	111	14.8	425	228	1001	3	9	4.0	115	16.4	437	217
	HOLLADAY	V	5	28	3243	12	2.3	139	15.2	414	222	887	6	9	1.5	119	15.7	382	234
	N07-15137	VI	6	29	3115	3	1.7	85	13.5	411	228	0	9	§§	1.0	0	§§	0	0
	N07-15307	V	5	30	3179	1	1.1	74	15.6	415	225	632	7	6	1.0	59	17.0	407	229
	N02-7779	V	5	31	3085	14	2.1	102	14.1	423	229	339	6	17	5.0	89	§§	425	229
	NMS4-6-10	V	5	32	2993	6	2.0	90	14.2	419	221	786	5	8	5.0	91	15.4	407	232
	Mean	-	-	-	**3110**	**9**	**1.6**	**92**	**14.2**	**414**	**226**	**809**	**5**	**9**	**1.8**	**84**	**14.4**	**405**	**231**
	LSD$_{0.05}$	-	-	-															
II (MG VI-VIII).	**Dillon**	VI	6	1	3107	18.2	1.5	101	14.2	415	230	1549	2.8	15.0	1.8	92	12.8	417	224
	Boggs	VI	6	2	2563	19.0	2.1	97	11.9	434	224	1458	2.5	20.5	3.0	94	11.8	431	222
	N7003CN	VII	7	3	2848	20.6	1.6	93	14.9	401	232	944	4.5	19.7	1.1	108	14.3	396	226
	NC-Raleigh	VII	7	4	2638	24.0	2.3	89	11.8	400	241	1619	4.8	22.0	3.0	102	10.9	406	238
	TCHM06-Morph 204	VII	7	5	3284	18.0	1.9	86	13.9	394	229	0	8.0	§§	§§	0	§§	0	0
	N06-6	VI	6	6	3224	19.6	1.3	81	12.4	411	230	1344	4.0	18.5	1.0	76	13.1	410	226
	N8101	VIII	8	7	2274	29.6	2.4	103	5.6	434	198	1324	2.5	29.5	2.5	99	5.4	432	196
	N7103	VII	7	8	2884	23.0	1.8	87	7.3	431	206	1172	2.3	17.0	1.3	83	6.6	433	201
	NMS4-44-329	VII	7	9	1899	24.6	3.6	89	9.0	428	181	450	6.3	21.3	2.9	91	7.3	435	169
	NMS4-1-77	VII	7	10	2387	19.8	3.3	93	9.7	423	217	1317	2.0	18.0	2.3	91	9.6	429	213
	N6001	VI	6	12	2826	22.2	1.8	91	14.3	431	224	689	3.5	21.0	2.5	89	15.5	427	221
	N6002	VI	6	13	2858	14.2	1.7	94	14.3	432	215	692	5.0	13.7	1.6	83	14.5	419	221
	Young	VI	6	14	2491	18.6	2.3	108	13.6	430	225	1418	2.8	14.0	2.8	105	13.6	429	219
	NLM09-77	VII	7	15	2804	17.2	1.2	84	18.6	479	206	1327	4.8	19.0	1.8	85	17.9	476	209
	N7001	VII	7	16	2450	23.2	1.9	88	13.8	417	222	0	5.0	26.3	2.9	84	§§	0	0
	N7002	VII	7	17	2818	22.4	2.1	95	11.7	422	219	1784	1.5	19.5	2.3	97	10.1	431	210
	G00-3213	VII	7	18	2779	21.0	1.5	100	14.1	438	219	1636	3.5	25.0	2.0	97	13.2	432	216
	NCC08-8138	VI	6	19	3460	12.8	1.3	75	16.2	410	223	2607	1.8	14.0	1.0	69	14.8	404	221
	NCC07-1090	VI	6	20	3220	19.2	1.3	82	18.1	397	237	0	7.8	§§	§§	0	§§	0	0
	NCC07-899	VII	7	21	3041	21.8	2.4	97	13.8	415	226	1562	2.5	21.5	2.3	99	12.5	399	227
	N93-110-6	VI	6	22	2896	20.2	2.4	110	15.5	440	221	1088	4.3	19.0	1.5	93	13.5	437	215
	N8002	VIII	8	23	2717	28.6	2.2	95	13.6	428	214	1676	1.0	29.5	1.5	93	12.5	429	206
	TCWN05/06-5068	VII	7	24	2604	28.6	2.1	111	16.7	421	224	1008	4.3	30.0	1.5	100	16.0	423	222
	Mean	-	-	-	**2786**	**21.1**	**2.0**	**93**	**13.3**	**423**	**220**	**1159**	**3.8**	**20.7**	**2.0**	**92**	**12.3**	**425**	**215**
	LSD$_{0.05}$‡	-	-	-															

† Flooding was successfully imposed in three and two replications in 2016 and 2017, respectively. Six and five replications of control plots were employed in 2016 and 2017, respectively.

‡ maturity date was assigned when 95% of the pods in the plot had reached a mature color (tan). Number is the date in October.

§ lodging values given on a plot basis on a 1 to 5 scale (1 = erect plants, 5 = prostrate), measured before harvest. Data from 2016 only.

¶ height measured from the ground level to the apical meristem of 3 random plant per plot, measured before harvest

protein and oil contents represented at zero percent moisture

†† visual ratings on given on a 0 to 9 scale (0 = no damage, 9 = > 95% dead plants) and based on yellowing of the canopy and canopy fullness.

‡‡ 2016 height and lodging scores dropped from flood treatment if based on only one rep

§§ non-estimable as a result of missing data

Appendix J. Summary of visual rating dates in 2016 and 2017 in both flooding treatments.

				WAFT†		
Experiment	Treatment	1	2	3	4	5
III (MG IV-V).	2016					
IV (MG VI-VIII).	Veg.		X	X		X ‡
	Repro.		X ‡	X	X	
	2017					
	Veg.	X	X ‡			
	Repro.	X	X	X ‡		

† WAFT = weeks after flooding termination

‡ Ratings were averaged between two people where indicated

Appendix K. ANOVA of 37 and 44 genotypes in Experiment III (MG IV-V) and IV (MG VI-VIII) for visual ratings taken on individual dates in both treatments in 2016 at Plymouth, NC. Flooding treatment was imposed at early vegetative and early flowering stages for approximately 7 days. Genotypes Clifford and Graham were omitted from Exp. III due to within-plot segregation. R09-4095 and Tokyo were omitted from Exp. III and IV due to poor stand establishment in 2017.

Experiment	Source	Vegetative † ‡								Reproductive † §					
		2 WAFT ¶		3 WAFT		5 WAFT		Mean		2 WAFT		3 WAFT		Mean	
		DF	Mean Squares	DF	Mean Squares	DF	Mean Squares	DF	Mean Squares	DF	Mean Squares	DF	Mean Squares	DF	Mean Squares
III (MG IV-V).	Rep	2	9.27	2	11.45	2	6.30	2	8.77	2	5.96	2	2.25	2	3.11
	Entry	37	2.68 **	37	4.25 **	37	6.23 **	37	3.94 **	37	5.93 **	37	2.52 **	37	3.44 **
	Error	74	1.09	73	1.28	73	1.98	74	1.41	74	1.88	74	1.33	74	1.35
IV (MG VI-VIII).	Rep	2	11.08	2	8.51	2	10.80	2	10.07	2	16.60	2	5.68	2	6.35
	Entry	43	2.78 **	43	5.24 **	43	5.99 **	43	4.40 **	43	4.58 **	43	3.16 **	43	3.21 **
	Error	86	1.00	86	1.48	86	1.88	86	1.30	86	1.63	85	0.89	86	1.05

*,** significantly different from zero at $p < 0.05$ and $p < 0.01$ respectively

ns indicates not significant, $p > 0.10$

† visual ratings on given on a 0 to 9 scale (0 = healthy plot, 9 = > 95% dead plants) and based on yellowing of the canopy and canopy fullness

‡ Vegetative flooding began July 5, 2016 and June 28, 2017

§ Reproductive flooding began August 13, 2016 and July 24-5, 2017

¶ WAFT = weeks after flooding termination

Appendix L. ANOVA of 37 and 44 genotypes in Experiment III (MG IV-V) and IV (MG VI-VIII) for visual ratings taken on individual dates in both treatments in 2017 at Plymouth, NC. Flooding treatment was imposed at early vegetative and early flowering stages for approximately 7 days. Genotypes Clifford and Graham were omitted from Exp. III due to within-plot segregation. R09-4095 and Tokyo were omitted from Exp. III and IV due to poor stand establishment in 2017.

Experiment	Source	Vegetative†‡												Reproductive†§											
		1 WAFT¶			2 WAFT			2.5 WAFT			Mean			1 WAFT			2 WAFT			3 WAFT			Mean		
		DF	Mean Squares		DF	Mean Squares		DF	Mean Squares		DF	Mean Squares		DF	Mean Squares		DF	Mean Squares		DF	Mean Squares				
III (MG IV-V).	Rep	2	11.01		2	0.67		2	2.35		2	4.60		2	0.67		2	7.38		2	2.46		2	2.35	
	Entry	36	4.68		36	1.06	*	36	1.80	*	36	2.01	*	37	0.81	**	37	2.68	**	37	2.68	*	37	1.73	**
	Error	58	3.08		52	0.63		53	0.95		58	1.04		71	0.34		73	1.28		74	1.41		74	0.76	
IV (MG VI-VIII).	Rep	2	30.94		2	3.15		2	1.41		2	8.67		2	0.09		2	0.20		2	1.43		2	0.25	
	Entry	43	2.65	**	43	1.15	**	43	1.06	**	43	1.25	**	43	0.37	**	43	1.72	**	43	2.10	**	43	1.02	**
	Error	84	1.43		84	0.45		81	0.45		85	0.46		86	0.20		86	0.87		86	0.66		86	0.37	

*,** significantly different from zero at $p < 0.05$ and $p < 0.01$ respectively

ns indicates not significant, $p > 0.10$

† visual ratings on given on a 0 to 9 scale (0 = healthy plot, 9 = > 95% dead plants) and based on yellowing of the canopy and canopy fullness

‡ Vegetative flooding began July 5, 2016 and June 28, 2017

§ Reproductive flooding began August 13, 2016 and July 24-5, 2017

¶ WAFT = weeks after flooding termination

Appendix M. Genotypic correlation coefficients of phenotypic means of visual ratings for 37 and 44 genotypes in Experiments III (MG IV-V) and IV (MG VI-VIII) for all rating dates in both flooding treatments taken in 2016 and 2017 at Plymouth, NC. Flooding treatment was imposed at early vegetative and early flowering stages for approximately seven days.

		vg216 LSMEAN	*vg316 LSMEAN*	*vg516 LSMEAN*	*vmean16 LSMEAN*	*rp216 LSMEAN*	*rp316 LSMEAN*	*rmean16 LSMEAN*	*vg117 LSMEAN*	*vg217 LSMEAN*	*vg2517 LSMEAN*	*vmean17 LSMEAN*	*rp117 LSMEAN*	*rp217 LSMEAN*	*rp317 LSMEAN*	*rmean17 LSMEAN*
III.	vg216 LSMEAN	1.00														
	vg316 LSMEAN	0.88	1.00													
	vg516 LSMEAN	0.82	0.92	1.00												
	vmean16 LSMEAN	0.95	0.95	0.93	1.00											
	rp216 LSMEAN	0.29	0.42	0.38	0.41	1.00										
	rp316 LSMEAN	0.35	0.50	0.43	0.47	0.69	1.00									
	rmean16 LSMEAN	0.34	0.49	0.44	0.47	0.95	0.88	1.00								
	vg117 LSMEAN	0.20	0.27	0.24	0.25	0.31	0.31	0.33	1.00							
	vg217 LSMEAN	0.30	0.40	0.29	0.35	0.36	0.36	0.39	0.69	1.00						
	vg2517 LSMEAN	0.30	0.42	0.30	0.34	0.34	0.37	0.38	0.75	0.84	1.00					
	vmean17 LSMEAN	0.27	0.37	0.29	0.32	0.36	0.39	0.40	0.93	0.87	0.93	1.00				
	rp117 LSMEAN	0.12	0.16	0.02	0.15	0.27	0.31	0.31	0.31	0.36	0.29	0.34	1.00			
	rp217 LSMEAN	0.38	0.37	0.27	0.42	0.29	0.42	0.37	0.27	0.24	0.24	0.29	0.74	1.00		
	rp317 LSMEAN	0.25	0.30	0.21	0.30	0.48	0.47	0.51	0.33	0.28	0.29	0.34	0.69	0.76	1.00	
	rmean17 LSMEAN	0.31	0.33	0.22	0.35	0.39	0.44	0.44	0.37	0.28	0.29	0.36	0.82	0.90	0.94	1.00

		Overall LSMEAN	*vg216 LSMEAN*	*vg316 LSMEAN*	*vg516 LSMEAN*	*vmean16 LSMEAN*	*rp216 LSMEAN*	*rp316 LSMEAN*	*rmean16 LSMEAN*	*vg117 LSMEAN*	*vg217 LSMEAN*	*vg2517 LSMEAN*	*vmean17 LSMEAN*	*rp117 LSMEAN*	*rp217 LSMEAN*	*rp317 LSMEAN*	*rmean17 LSMEAN*
IV.	Overall LSMEAN	1.00															
	vg216 LSMEAN	0.81	1.00														
	vg316 LSMEAN	0.76	0.94	1.00													
	vg516 LSMEAN	0.82	0.95	0.96	1.00												
	vmean16 LSMEAN	0.81	0.97	0.98	0.99	1.00											
	rp216 LSMEAN	0.59	0.31	0.26	0.29	0.29	1.00										
	rp316 LSMEAN	0.79	0.61	0.52	0.56	0.57	0.67	1.00									
	rmean16 LSMEAN	0.73	0.46	0.40	0.43	0.44	0.95	0.87	1.00								
	vg117 LSMEAN	0.61	0.36	0.30	0.39	0.36	0.01	0.31	0.16	1.00							
	vg217 LSMEAN	0.50	0.32	0.26	0.28	0.29	0.01	0.28	0.11	0.61	1.00						
	vg2517 LSMEAN	0.54	0.23	0.18	0.24	0.22	0.08	0.37	0.21	0.71	0.70	1.00					
	vmean17 LSMEAN	0.63	0.36	0.29	0.36	0.34	0.03	0.36	0.18	0.91	0.84	0.88	1.00				
	rp117 LSMEAN	0.65	0.36	0.34	0.45	0.40	0.31	0.39	0.37	0.50	0.36	0.46	0.51	1.00			
	rp217 LSMEAN	0.57	0.27	0.21	0.30	0.27	0.13	0.27	0.20	0.58	0.47	0.56	0.61	0.59	1.00		
	rp317 LSMEAN	0.60	0.23	0.19	0.28	0.24	0.28	0.30	0.33	0.59	0.30	0.45	0.53	0.66	0.76	1.00	
	rmean17 LSMEAN	0.66	0.29	0.25	0.35	0.31	0.24	0.33	0.31	0.62	0.41	0.54	0.61	0.77	0.92	0.94	1.00

Appendix N. Allocation of resources for broad-sense heritability of visual ratings in both flooding treatments for 37 and 44 genotypes in Experiments III (MG IV-V) and IV (MG I-VIII) in the flooded treatment.

		Experiment III (MG IV-V)		Experiment IV (MG VI-VIII)	
Env.	Reps	Veg[‡]	Repr[§]	Veg	Repr
1	1	0.20	0.23	0.16	0.18
1	2	0.31	0.35	0.23	0.25
1	3	0.37	0.42	0.27	0.29
1	4	0.41	0.46	0.29	0.32
1	5	0.44	0.50	0.31	0.33
2	1	0.33	0.38	0.27	0.30
2	2	0.47	0.52	0.37	0.40
2	3	0.54	0.59	0.42	0.45
2	4	0.58	0.63	0.45	0.48
2	5	0.62	0.66	0.47	0.50
3	1	0.43	0.48	0.36	0.40
3	2	0.57	0.62	0.47	0.50
3	3	0.64	0.68	0.52	0.55
3	4	0.68	0.72	0.55	0.58
3	5	0.71	0.75	0.57	0.60
4	1	0.50	0.55	0.43	0.47
4	2	0.64	0.68	0.54	0.57
4	3	0.70	0.74	0.59	0.62
4	4	0.74	0.78	0.62	0.65
4	5	0.76	0.80	0.64	0.67
5	1	0.56	0.61	0.49	0.52
5	2	0.69	0.73	0.60	0.63
5	3	0.75	0.78	0.64	0.67
5	4	0.78	0.81	0.67	0.70
5	5	0.80	0.83	0.69	0.71

† Broad Sense heritability based on experiment wide means over 2 years and 3 repliciations for each flooding treatment

‡ Vegetative flooding began July 5, 2016 and June 28, 2017

§ Reproductive flooding began August 13, 2016 and July 24-5, 2017

Appendix O. Phenotypic correlation coefficients of 32 and 24 genotypes in Experiments I and III (MG IV-V) and II and IV (MG VI-VIII) for visual ratings and yield in 2016 and 2017 in Plymouth, NC. CH2 and CH3 refer to Experiments discussed in Chapters 2 and 3, respectively.

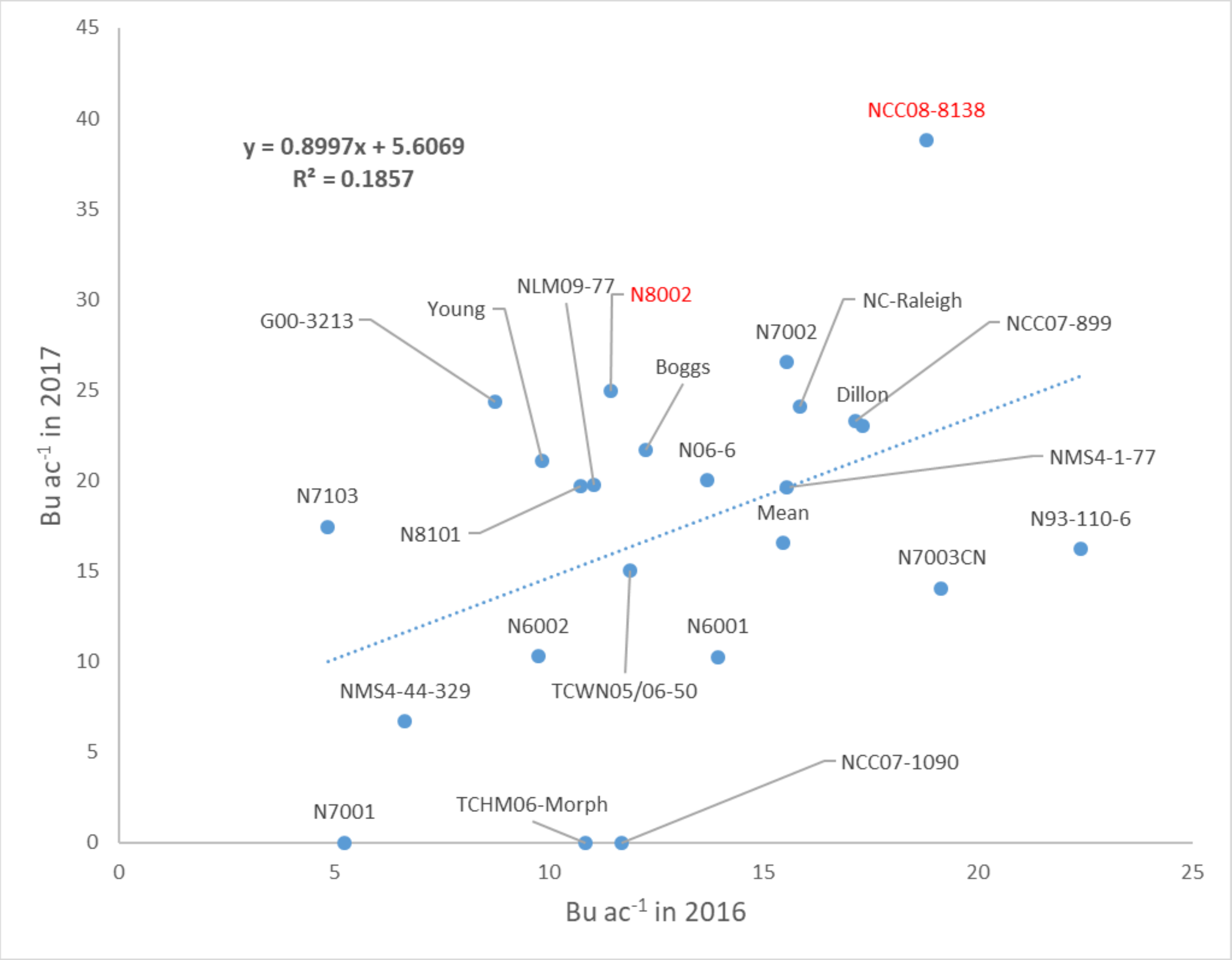
		CH3 Ratings†					CH2 Yield				CH2 Ratings		
Experiment		*Overall*	*2016*	*2017*	*Vegetative ‡*	*Reproductive §*	*2016*	*2017*	*FLO*	*NON*	*2016*	*2017*	*Mean*
I and III.	**CH3 Ratings**												
	Overall	1.00											
	2016	0.90	1.00										
	2017	0.83	0.50	1.00									
	Vegetative	0.88	0.81	0.71	1.00								
	Reproductive	0.87	0.77	0.73	0.53	1.00							
	CH2 Yield												
	2016	-0.53	-0.63	-0.24	-0.28	-0.65	1.00						
	2017	-0.33	-0.40	-0.13	-0.07	-0.52	0.60	1.00					
	FLO	-0.50	-0.64	-0.17	-0.29	-0.60	0.74	0.83	1.00				
	NON	-0.08	-0.04	-0.11	0.13	-0.28	0.53	0.38	0.04	1.00			
	CH2 Ratings												
	2016	0.30	0.42	0.06	0.20	0.34	-0.60	-0.43	-0.69	0.02	1.00		
	2017	0.44	0.52	0.21	0.31	0.47	-0.48	-0.81	-0.82	-0.02	0.58	1.00	
	Mean	0.43	0.54	0.17	0.30	0.47	-0.59	-0.74	-0.86	-0.01	0.84	0.93	1.00
II and IV.	**CH3 Ratings**												
	Overall	1.00											
	2016	0.90	1.00										
	2017	0.55	0.12	1.00									
	Vegetative	0.92	0.87	0.40	1.00								
	Reproductive	0.92	0.77	0.60	0.68	1.00							
	CH2 Yield												
	2016	0.15	0.25	-0.12	0.03	0.22	1.00						
	2017	-0.31	-0.11	-0.39	-0.34	-0.22	0.56	1.00					
	FLO	-0.37	-0.14	-0.46	-0.36	-0.31	0.56	0.90	1.00				
	NON	0.23	0.25	0.03	0.07	0.32	0.78	0.54	0.26	1.00			
	CH2 Ratings												
	2016	-0.02	-0.05	0.04	-0.04	0.00	-0.64	-0.45	-0.59	-0.30	1.00		
	2017	0.60	0.37	0.51	0.53	0.53	-0.07	-0.62	-0.71	0.12	0.19	1.00	
	Mean	0.46	0.27	0.42	0.40	0.42	-0.37	-0.71	-0.85	-0.06	0.64	0.88	1.00

*,** significantly different from zero at $p < 0.05$ and $p < 0.01$, respectively

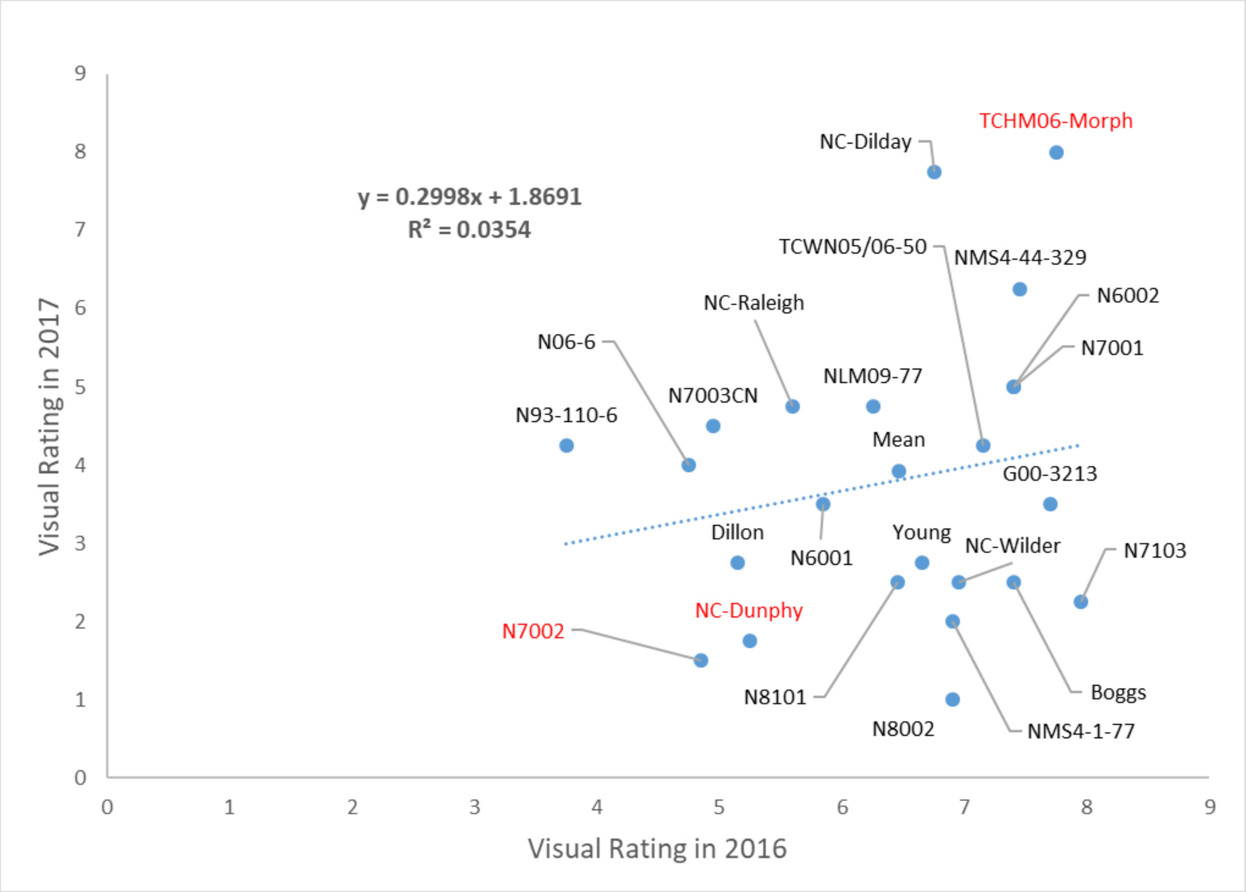
† visual ratings on given on a 0 to 9 scale (0 = healthy plot, 9 = > 95% dead plants) and based on yellowing of the canopy and canopy fullness

‡ Vegetative flooding began July 5, 2016 and June 28, 2017

§ Reproductive flooding began August 13, 2016 and July 24-5, 2017



Appendix P. Linear regression of 23 genotypes in Experiment II for yield in flooded conditions over 2016 and 2017 in Plymouth, NC.



Appendix Q. Linear regression of 23 genotypes in Experiment II for visual ratings over 2016 and 2017 in Plymouth, NC.