DRY MATTER ACCUMULATION BY THE START OF SEED FILLING AS A CRITERION FOR YIELD OPTIMIZATION IN SOYBEAN

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This Work is dedicated to the memory of my late grand father
Sri Evani Sreerama Murthy,
Who was responsible for laying a great foundation in my life.

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ABSTRACT

Identification of criteria for predicting soybean [*Glycine max* (L.) Merril] yield would provide farmers with useful management tools. Such criteria not only help in predicting the yield potential but also aid the farmer in determination of environmental factors limiting crop yield. Since a certain total dry matter (TDM) level is expected to optimize yield and R5 marks the end of the period for vegetative TDM accumulation, TDM(R5) is a good putative criterion for optimal yield. Determination of yield components important in yield formation helps substantiate TDM(R5) as a criterion for optimum yield, since they are formed during discrete periods and therefore would indicate when TDM accumulation is important. Because TDM(R5) could be an efficient and accurate yield criterion and because little research has been done on this subject, our objectives were to use analyses of relationships between yield components, TDM, and yield to determine : 1. If TDM(R5) can be used as criterion for optimum yield; and 2. What level of TDM(R5) is required to optimize yield.

The data for this study were collected from previous studies, that contained a variety of cultural treatments, such as planting dates, row spacings, plant populations, partial defoliation, and waterlogging stress, conducted near Baton Rouge, LA (30^0 N Lat) between 1987 to 1996 and combined to make a single data set. The data thus pooled were subjected to correlation, regression and path coefficient analyses to achieve our objectives. The study clearly indicated that use of TDM(R5) as a yield criterion is valid and the critical level of TDM(R5) was found to be 600 g m^{-2} to achieve optimum yield. The TDM(R5) criterion can be used as a good management tool by the farmers. Yield

components like seed number per area, pod number per area, reproductive node number per area and node number per area, which responded strongly to TDM accumulation, are likely to be affected by the cultural practices of the farmer. The farmer should adjust cultural practices to ensure that length of emergence to R5 period is long enough to achieve the required TDM(R5).

CHAPTER 1: INTRODUCTION

1.1 Introduction

Identification of criteria for indicating soybean yield would provide farmers with useful management tools. Such criteria could be used not only to predict yield potential and pricing the crop but also aid the farmer in determination of environmental factors limiting crop yield. Possible yield criteria are yield components, morphological factors that affect soybean yield formation, and growth dynamic parameters, such as total dry mater (TDM), leaf area index (LAI), and light interception (LI). Use of yield components as yield criteria is not promising because of their variability and the difficulty for assessing them in production environments (Board et al., 1990). The timing for achievement of 95% LI or optimal LAI (LAI required for 95% LI) to obtain optimal yield is not consistent enough to be a valid criterion. In a study involving row spacing and planting dates, Egli et al. (1987) reported that a TDM (R5) of 500 g m^{-2} was required to optimize yield. Since a certain TDM level is expected to optimize yield, and R5 marks the end of the period for vegetative TDM accumulation, TDM (R5) is a good putative criterion for optimal yield. However, aside from the one study cited above (Egli et al., 1987), no research has verified TDM (R5) as a criterion for optimal yield.

Determination of yield components important in yield formation helps substantiate TDM (R5) as a criterion for optimum yield. The yield components are formed during discrete periods of soybean development and dry matter accumulation during the formation period of an important yield component would be associated with optimal yield. Thus, adoption of TDM (R5) as a yield criterion would have greater efficacy if it were shown that significant yield components responded to TDM (R5) in a manner similar to that shown for yield. Because TDM (R5) could be an efficient and accurate yield criterion and because little research has been done on this subject, our objectives were to use analyses of relationships between yield components, TDM, and yield to determine: 1. If TDM (R5) can be used as criterion for optimum yield; and 2. What level of TDM (R5) is required to optimize yield.

Soybean [Glycine *max* (*L.*) Merr.] is one of the most important crops grown in the USA. It is also widely grown in East Asia and South America. The crop is important in Louisiana's agricultural economy, although hectareage has fallen across the years (Gibson and Bensen, 2002). Soybean is an annual dicot plant commercially grown for seed that is primarily used for oil and livestock feed production. It belongs to the family Leguminosae. It is also used for human consumption in East Asia. The crop has a wide range of maturity groups (MG), which allows for a wide latitudinal growth area. The classification of soybean cultivars into MG is based on the number of days from emergence to harvest maturity. Soybean cultivars are placed into one of 12 MG with 00 to IV designated as early maturing, and V to X designated as late maturing (Roth et al., 2003). Groups 00, 0 and I are adapted to the longer days and cooler temperatures of Canada and the northern USA, where as groups II to VIII are adapted as one goes progressively further south (Loomis and Connor, 1992a). The latest maturity group is X which includes cultivars developed for production in tropical environments at low latitudes. Generally, cultivars adapted to the northern USA [MG 00 to IV] are indeterminate, where as cultivars used in the southern USA (MG V to VIII) are determinate (Hartwig, 1973), with only a few exceptions.

Yield of a soybean crop is a function of light interception, dry matter production, and partition of dry matter into the plant's seed. Optimal crop growth rate (CGR) is achieved when leaf area index is large enough (3.5 to 4.0) to intercept 95% of the sun light (Shibles and Weber, 1966). Yield responses of soybean to environmental changes, whether induced by cultural practices or abiotic stresses, mainly influence yield through effects on seed number per area (Egli, 1998). The seed number per area is determined near the beginning of rapid seed filling, about 10 to 12 days after the start of seed filling (Board and Tan, 1995). Along with optimal seed number per area, the soybean crop needs to have a certain total dry matter level by this time to optimize its yield. Currently, the total dry matter levels required to optimize seed number per area and also yield have not been studied, with the single exception of a row spacing/planting date study indicated that seed number per area was optimized at a dry matter level of 500 g m^{-2} by the beginning of the seed filling stage (Egli et al., 1987).

Yield components explaining how environmental changes affect seed number per area have also not been clarified. Identification of a total dry matter level required for optimum seed number per area and yield per area would provide a growth criterion useful to predict optimal yield. Clarification of yield components controlling seed number per area would add to our understanding of the yield formation process in soybean. Since yield components are formed during discrete periods of soybean's development, identification of important yield components would help identify developmental periods that are significant for optimizing yield. This information would be useful in advising farmers concerning when growing conditions should be optimal to achieve best yield.

Soybean growth is measured by the amount of total dry matter accumulating in the plant. Dry weight consists of everything in the plant except water, including carbohydrates, proteins, oils, and mineral nutrients. The soybean plant produces 95% of its total dry matter through photosynthesis (Taiz and Zeiger, 2002). The economically useful part of soybean is its seed. The harvested seed of soybean has a high protein content (380 g kg^{-1}) apart from carbohydrates (380 g kg^{-1}) and oil (200 g kg^{-1}) (Bewley and Black, 1994). Yield is a function of individual seed weight and seed number per area when the crop is mature (Egli, 1998).

The biomass accumulation of soybean with time follows a sigmoid growth (S-shaped) curve (Loomis and Connor, 1992b). The slope of this curve is called the CGR (Watson, 1958), which is defined as the rate of change of biomass with time, and measured in units of g m^{-2} day^{-1}. Sigmoid curves can be divided into an early “exponential phase” of production, a “grand period of growth” during mid season, and a final “senescent phase” (Loomis and Connor,1992b). During the exponential phase, growth rate of soybean plants is limited by leaf area and light interception. However, as leaf area increases, light interception and photosynthesis increase, and so does CGR. This increase in CGR continues up to the time when the foliage achieves canopy closure of the land area. This usually corresponds to 95% light interception or greater. The grand period of growth starts at canopy closure when light interception and photosynthesis are at maxima. Crop growth rate then varies mainly with changes in solar radiation. The final senescent stage of growth is characterized by leaf abscission, declining CGR, and maturity.

Greater understanding of the yield formation process can be gained by identifying the yield components affecting seed number per area. Identification of yield components was used as early as the 1920s to analyze wheat yield responses to changes in plant population (Engledow and Wadham, 1923). The number of seeds produced in soybean is determined by nodes per unit area, flowers per node, proportion of flowers that develop into mature pods, and seeds per pod (Egli and Crafts-Brandner, 1996). Seed size is determined between pod initiation and the end of seed filling (Peterson et al., 1992). The potential seed number per area is determined about 10-12 days after the start of seed filling (Board and Tan, 1995). It can potentially be affected by a variety of yield components: seeds per pod (no.), pod number per area (no. m^{-2}), pods per reproductive node (no.), reproductive node per area (no. m^{-2}), node number per area (no. m^{-2}), and fraction of nodes becoming reproductive (%) (see Appendix A). A reproductive node is a node having at least one developed seed. Node number per area is determined between emergence and the start of seed filling (Board and Settimi, 1986). Reproductive node number per area, fraction of nodes becoming reproductive, pods per reproductive node, and seed per pod are formed between first flowering until the start of rapid seed filling (Pigeaire et al., 1986; Board and Tan, 1995). Several workers have shown linear relationships between CGR during flowering and pod set and seeds per unit area for several cultivars in a variety of environments (Herbert and Litchfield, 1984; Ramseur et al., 1985; Egli and Yu, 1991; Egli, 1993).

1.2 Review of Literature

1.2.1 Background Information

Soybean is a member of the family Leguminosae, subfamily Papilionoideae, and tribe Phaseoleae. The crop originated in Manchuria, a province of China and domestication probably took place between 1700 and 1100 BC (Hymowitz and Singh, 1987). Soybean has been repeatedly mentioned in later records as an important cultivated legume crop throughout Asia and particularly in China.

According to several authors, soybean production was localized in China until after the Sino-Japanese war of 1894-95 when the Japanese began to import soybean oil cake for use as fertilizer (Gibson and Benson, 2002). Europeans had been aware of soybeans as early as 1712. Soybean was first shipped to Europe in about 1908 and attracted world-wide attention. Though the crop is grown in many countries, in 1992 four countries accounted for nearly 90% of world production: the USA (52% of total production), Brazil (17%), Argentina (10%), and China (8%) (FAO, 1993). By 2000, the USA share of the world's soybean production had shrunk from 52% to 45%, while that of Argentina and Brazil had increased to 15 and 21%, respectively (Gibson and Benson, 2002).

Soybean may have been grown in the USA as early as 1765 in Georgia (Hymowitz and Harlan, 1983); however, large scale production as a grain crop began just before World War II (Probst and Judd, 1973). Prior to this, soybean was used in the USA for forage rather than harvested for seed. For many years, soybean acreage increased very slowly. There were only 0.72 million hectares in the USA in 1924 when the first official estimate became available. At that time, most of the crop was used for hay. It was not until the 1930s that soybean hectareage expanded to any large area in the Midwestern U.S (Gibson and Benson, 2002).

Before World War II, the USA imported more than 40% of its edible fats and oils (Gibson and Benson, 2002). Disruption of trade routes during the war resulted in a rapid expansion of soybean acreage in the USA as the country looked for alternatives to these imports. Soybean was one of only two major new crops introduced into the USA in the 20th century. The other major crop, Canola (*Brassica napus*) was initially developed in Canada and grown in some parts of the USA. The main reasons for soybean's success in the USA are meeting the need for soybean oil and meal. Additionally, it was also adopted because its culture was similar to that of corn (*Zea mays* L.) and it benefited other crops in a rotation. Following World War II, soybean production expanded from the Midwest to the southeast USA (Gibson and Benson, 2002).

The yields in the USA have increased steadily from 1300 kg ha^{-1} in the early 1940s to nearly 2400 kg ha^{-1} 1992 and to 2560 kg ha^{-1} in 2001. The major soybean producing states of Iowa, Illinois, Minnesota, Indiana, Ohio, Missouri, and Nebraska accounted for 72 percent of total USA production in 2000 (Gibson and Benson, 2002). The southeastern states of Arkansas, Mississippi, North Carolina, Kentucky, Tennessee, Louisiana, Alabama, and Georgia produced 10 percent. Other states with significant soybean acreage are South Dakota, Kansas, Michigan, Wisconsin, and North Dakota. The USA produced 73.3 million metric tons of soybeans in 2002 according to the USDA production estimates (USDA, 2002). This is a decrease of 7 % from 2001, and the lowest level since 1999. The mean soybean yield was 2520 kg ha^{-1} in the year 2002. An estimated 29.1 million hectares of soybean were harvested, a 2 % decrease from the year 2001 to 2002.

In the USA, changes in production practices and cultivar improvement have contributed to this increase in yield. Specht and Williams (1984) estimated that, after 1940, about 50% of the yield increase in the USA was due to improved cultivars. Characteristics that have been reported to be associated with higher yields of modern cultivars include disease and nematode resistance (Hartwig,1973), lodging resistance (Cooper and Waranyuwat, 1985), larger seeds (Specht and Williams, 1984), longer seed-filling periods (Gay et al.,1980; Mc Blain and Hume, 1981)and higher canopy photosynthesis during seed filling (Boerma and Ashley, 1988).

Louisiana adopted the soybean crop very rapidly. The acreage went from 0.081 million in 1960 to 0.65 in 1970, and to more than 1.215 million ha in 1980, respectively (Morrison and Mc Cormick, 1994). In 1967, the Soybean Association was incorporated as the state growers association, which represented growers in legislative matters. In Louisiana, soybean production averaged 1680 kg ha^{-1} from 1965 to 2001(LSU, Ag center, 2001). Soybean acreage has declined from a high of 1.42 million ha in 1980 to an average of about 0.42 million ha in 2003. The main reason for this was that prices did not rise with ever-increasing costs and growers could not raise their yield levels to offset these costs (Morrison and Mc Cormick, 1994). Positive changes are occurring in Louisiana soybean production though. A major change has been adoption of the early season production system (ESPS), in which maturity group IV and V cultivars are planted in the early spring (vs. the normal mid to late spring planting period). This system avoids the typical mid-summer droughts common to the southeastern USA. Although not as important as it once was, soybean continues to play a major part in the Louisiana's agricultural economy.

1.2.2 Uses of Soybeans

Soybeans were grown for centuries in Asia mainly for their seeds. The seed of soybean is approximately 18% oil and 38% protein (Norman, 1978). The major fatty acids include linoleic acid (about 54%), linolenic acid (7%), stearic acid (5%), palmitic acid (10%) and oleic acid (24%).

Early uses of soybeans in the USA were for forage and to some extent, green manure. The majority of the soybean crop is presently processed into oil and meal. Oil extracted from soybean is made into shortening, margarine, cooking oil, and salad dressings. Soybean accounts for 80 % or more of the edible fats and oils consumed in the USA. Soy oil is also used in industrial paint, varnishes, caulking compounds, linoleum, printing inks, and other compounds. Development efforts in recent years have resulted in several soy oil-based lubricants and fuel products that replace non-renewable petroleum products.

Lecithin, a product extracted from soybean oil, is a natural emulsifier and lubricant used in many foods, commercial, and industrial applications (Gibson and Benson, 2002). The high protein meal remaining after extraction can be used and made into soybean flour for human food or added to animal feed. Soybean protein helps balance the nutrient deficiencies of such grains as corn and wheat (*Triticum aestivum* L.), which are low in the essential amino acids. Soybean has a low content of the two sulfur containing amino acids: methionine and cysteine. To avoid deficiencies, sometimes there is a need to add these two amino acids as food supplements to soybean products.

Use of vegetable proteins for human consumption continues to increase in the USA. They can be used as meat and dairy substitutes in various items. The soy proteins are also being used in baby foods, weight-loss drinks and also as a low fat diet substitute.

1.2.3 Development of Soybean

An understanding of the developmental stages of a soybean plant is important in evaluating its yield potential. The use of indeterminate versus determinate as well as plants of various maturity groups allows growers to maximize the yield potential within their growing season.

The developmental stages in soybeans are characterized by the standards established by Fehr and Caviness (1977) (See Appendix B). The life cycle of soybean is split into vegetative (V stage) and reproductive (R stage) stages. The stages begin with VE, defined as seedling emergence, the appearance of the seedling above the soil surface. The next stage is the VC stage, which is when the cotyledonary leaf is open and the node above it has a leaf that has just unrolled. In an unrolled leaf, the edges of the leaf blade must not be touching one another. Following the VC stage, all other vegetative (V stages) stages are numbered according to the number of nodes on the main axis (Vn) with a fully developed leaf (Bean and Miller, 1998). A fully developed leaf is defined as one that has a leaf above it (at the next node) that has just unrolled. The V1 stage is defined as when the primary unifoliate leaves (at the next node above the cotyledons) are fully developed and the leaf at the node above them has just unrolled. Subsequent vegetative stages are defined in a similar manner. For example, the V5 stage is when the sixth node above the cotyledon has a fully developed leaf and the leaf above it has just unrolled.

The reproductive (R stage) stages are split into two flower stages (R1 and R2), two pod stages (R3 and R4), two seed stages (R5 and R6), and two maturity stages (R7 and R8). The R1 stage is defined as the stage at which one open flower appears at any node on the main stem. The R2 stage refers to an open flower at one of the two upper most nodes on the main axis with a fully developed leaf. The R3 stage is when at least one pod 5 mm (3/16 inch) long is apparent on one of the four uppermost nodes of the main stem axis with a fully developed leaf. The R4 stage occurs when at least one pod reaches 2 cm (3/4 inch) at one of the four uppermost nodes of the main stem axis with a fully developed leaf. The R5 stage occurs when at least one seed within a pod is 3 mm (1/8 inch) long at one of the four uppermost nodes of the main stem axis with a fully developed leaf. At the R6 stage at least one seed extends to the length and width of the pod cavity at one of the four uppermost nodes of the main stem axis with a fully developed leaf. The R7 stage is considered to be the point at which one normal pod on the main stem reaches its mature pod color. The R7 stage is when seed filling ends and is called physiological maturity. At this stage, the seed has about 60% moisture and contains all necessary plant parts to germinate. The normal color of a mature pod can range from tan to brown depending on the genotype. The R8 stage is when 95% of the pods have reached their mature pod color and is called harvest maturity. By this time, the soybean seed would have a moisture level of 15%, which is considered the harvestable level.

Soybean cultivars are classified by their morphological (form and structure) growth habit. They exhibit either a determinate, an indeterminate or semi-determinate growth pattern (Bernard, 1972). Indeterminate cultivars continue main stem growth after initial flowering, while main stem growth in determinate types terminates shortly after initial flowering. Indeterminate types flower sequentially up the main stem and can have well-developed pods on lower nodes with newly developed flowers on top nodes. Determinate types flower more uniformly at all nodes on the main stem. In spite of the differences on the main stem, both the types continue to accumulate vegetative dry weight during flowering and pod set and reach maximum vegetative dry weight at R5 (Egli and Leggett, 1973; Beaver et al., 1985). Most of the vegetative growth during flowering and pod set occurs on branches with determinate types and on the main stem with indeterminate types (Egli et al., 1985). The semi-determinate types have indeterminate stems that terminate vegetative growth abruptly after the flowering period. Their growth habits and flowering lie between the growth habits of determinate and indeterminate cultivars of soybean.

As is true for other grain crops, soybean growth and development are influenced by temperature. Soybean, however, is very sensitive to photoperiod (daylength) and does not change from vegetative to reproductive growth until a critical daylength is met. Soybean has been recognized as a quantitative short-day plant (Garner and Allard, 1920). A quantitative short-day plant is one in which flowering is promoted within a certain time range but is retarded and/or diminished outside this time frame (Loomis and Connor, 1992a). The soybean plant flowers earlier and more profusely in response to day lengths that are shorter than a certain value (usually 14 hours) within a 24-hour cycle (maturity group V and up). This requirement restricts a cultivar's adaptability to a band of about 150 miles north and south of its adapted area. Photoperiod and temperature are the two main environmental factors controlling classification of soybean cultivars into maturity groups (discussed before in the introduction). Cultivars grown outside their zone of adaptation flower too soon if planted to the south and too late if planted to the north of their adapted areas. The North American cultivars in early maturity groups flower in about 30 days after planting in their zone of adaptation (Loomis and Connor, 1992a).

In the southern Unites States, the early soybean production system (ESPS) (McPherson et al., 1999) has been promoted as a cropping practice that reduces the possibility of drought stress to the crop that often occurs in this region during the July through late August period, and thus improves profitability (Heatherly and Bowers, 1998). In the ESPS, early-maturing soybean (MG III and IV) are planted in early to mid-April, about three weeks before the conventional early May through mid-June planting period. The objective behind the early planting of the soybean crop is to put the flowering and pod set periods before the drought-prone period (mid-July through August) (Boyd et al., 1997). Boyd et al. (1997) also indicated that early planting helps avoid harvesting the crop during the fall. Mc Pherson et al. (1996) showed that the ESPS might reduce the severity of insect attacks and may also avoid harvesting of soybean in wet conditions.

1.2.4 Growth Analysis Concepts

Growth of plant communities has been studied by a technique called "Growth Analysis" whereby certain calculations are made relative to the total dry matter (TDM) present and the LAI during the growing season. The term partitioning describes the distribution of the new assimilate to growth of various plant parts. The total assimilate accumulated by the crop is called TDM, and that portion partitioned to formation of seed is called economic yield. The fraction, economic yield/ TDM, is termed as the harvest index (HI). The concept of HI was described as the migration coefficient (the ratio of grain yield to the TDM at maturity) (Donald and Hamblin, 1976).

Knowledge of the leafiness of the crop is needed to assess the performance of the crop, as it determines the photosynthetic capacity of the crop. Watson (1947) introduced the concept of leafiness in relation to land area. This was named leaf area index (LAI), and is defined as leaf area per unit area of land. It is a dimensionless ratio. For some crops, an "optimum" LAI exists such that the rate of dry matter production is at a maximum at a particular LAI and is less at LAI values below or above this value (Donald, 1963). In soybean, the rate of dry matter production increases as LAI increases up to about 3.5 to 4.0 but does not decrease at greater LAI values (Hicks et al., 1969). However, this value can vary with environmental and cultural conditions (Jeffers and Shibles, 1969; Board and Harville, 1992). Light interception (LI) is the amount of light utilized by the crop canopy for photosynthesis. It is the fraction of the sun's light intercepted by the crop canopy. Light interception efficiency (LIE) is the LI per unit leaf area (Board and Harville, 1992).

Crop growth rate (CGR) is defined as the increase in plant dry matter per unit of time per unit land area [g m^{-2} (land area) day^{-1}] (Radford, 1967). Watson (1958) first defined the term CGR. The crop growth rate is a function of net assimilation rate (NAR) and LAI. Net assimilation rate is the increase in plant dry weight per unit leaf area per unit time. It is denoted by

NAR = ª g (dry matter) /m^{2}(leaf area).day or g m^{-2} (leaf area) day^{-1}.

Where ª g = change in total dry matter; m^{-2} = square meter of leaf area; g = grams.

Relative growth rate (West, Briggs and Kidd, 1920) is the increase in total dry matter per unit of total dry matter per day.

$$\text{RGR (R)} = {}^{a}\, g/\, g \text{ day or } g\, g^{-1}\, \text{day}^{-1}.$$

Where ª g = change in total dry matter; g = grams of total dry matter.

Relative growth rate is also called the ‘efficiency index’ and it gives the efficiency of current dry matter to produce future dry matter. Relative leaf area expansion rate (RLAER) is the increase in total leaf area per unit of leaf area per day. It is measured as increase in m^{2} (total leaf area) per m^{-2}(unit leaf area) d^{-1}. In RLAER, the concept of RGR is applied to leaf area instead of dry matter accumulation.

1.2.5 Effect of Various Environmental and Cultural Factors on Yield Components and Yield of Soybean

Seed number per unit area of crop land is the yield component that accounts for most of the environmental variation in the yield of soybean (Egli, 1998). Such environmental factors may be drought stress, wind-induced lodging, waterlogging, mineral deficiencies or toxicities, and other factors. The effect of these stresses on yield can be ameliorated through cultural practices, such as planting date, row spacing, irrigation, drainage, etc. These cultural practices increase yield by affecting the relationship between LI, CGR, TDM, and LAI. These factors demonstrate a circular cause-and -effect relationship (Loomis and Connor, 1992b). Greater LI stimulates CGR, which in turn increases TDM and LAI. Greater LAI causes higher LI which then further enhances CGR and thus results in higher yields.

1.2.5.1 Effect of Row Spacing on Soybean Yield Components and Yield

A wide-row culture is typically defined as an interrow spacing of 75-100 cm, whereas a narrow-row culture is considered to be 75 cm or less (Tanner and Hume, 1978). Yield responses to narrow-row culture are influenced by place of cultivation, stress on the crop, and planting date (Carter and Boerma, 1979; Taylor, 1980; Boerma and Ashley, 1982; Boquet et al., 1982; Johnson, 1987; Heatherly, 1988). The above studies have reported that narrow-row yield increases tended to be greater at late compared with optimum planting dates, with early compared with late-flowering cultivars, and under irrigated compared with nonirrigated conditions.

Previous research (Wiggans, 1939; Johnson, 1987; Parvez et al., 1989) had indicated that equidistant plant spacings optimize yield of the soybean crop. These studies indicate that higher yields can be obtained as row spacing is reduced where interrow and intrarow spacings are similar and yield increases were attributed to minimization of inter-plant competition for resources, such as water, minerals, and light. However, other research indicated little yield enhancement in narrow (50-cm or less) vs. wider-row spacings (Beaver and Johnson, 1981; Helsel et al., 1981) or reduced yield (Board et al., 1992).

The studies on yield increases in narrow vs. wide rows have been consistent in the Midwest compared with southeastern USA. Previous studies on advantages of narrow-row soybean culture in the southeastern USA have given variable results. Higher yield for soybean grown in 50-cm compared with 100-cm rows was reported by several authors (Boerma and Ashley, 1982; Boquet et al., 1982; Parks et al., 1982). Cooper (1977) also obtained his largest yield at a narrow-row spacing (20 cm). Narrow vs. wide- rows do not benefit mineral and water uptake (Bennie et al., 1982; Mason et al., 1982). Beaver and Johnson (1981) conducted research in the Illinois region and concluded that seed yields of both determinate and indeterminate cultivars increased by 5 - 9% as row width was reduced from 80-cm to 50-cm, whereas, seed yields in 50 and 20-cm row spacings did not differ. Soybean yield enhancement when the row spacing was reduced from 100- to 50- was reported by Board et al. (1994b). But they also concluded that the yield obtained in the 25-cm rows was less than the yield obtained in 50-cm rows. Therefore, the yield increases in soybean occur only when the wider row spacing was reduced to 50-cm rows, with little increase in yield beyond this reduction.

The response of soybean to narrow-row culture also depends on the stress on the crop. Devlin et al. (1995) indicated that narrow-row yield enhancement, achieved in soybean under favorable conditions of moisture availability, cannot be obtained under moisture stress. They also indicated that under favorable conditions of moisture availability, narrow rows (20-cm) require twice as much population than wider-row (75-cm) to achieve maximum yields. Rainfed soybean under moisture stress does not provide the narrow-row seed yield enhancement as it would in irrigated conditions (Elmore et al., 1998). Taylor (1980) has indicated that during the years of plentiful water supply, the narrow-row soybean yields were higher than those obtained with wide-row culture. He also concluded that under conditions of low water supply, there were no significant differences in yield between the wider-row and narrow-row soybeans. Similar results stating that moisture stress needs to be alleviated to gain the advantages of narrow-row yield enhancement were reported by Heatherly (1988). However, Linkemer et al. (1998) indicated that waterlogging stress in soybean resulted in increased yields in the narrow vs. wide rows. Board and Harville (1994) concluded that soybean achieving TDM (R8) levels of at least 800 g m^{-2} with wide-row culture probably will not benefit form reduced row width.

The narrow-row yield responses of soybean differ due to planting date. Boquet et al. (1982) reported that the yield increases for the optimal dates of planting were more in the 100-cm rows when compared with 50-cm or 25-cm rows. They also reported that soybean yield at optimal planting dates was not affected by row spacing. Earlier research has also shown that the yield advantage in narrow compared with wide rows was greater with delayed planting (Carter and Boerma, 1979; Boerma and Ashley, 1982). Board et al. (1990) stated that greater TDM by seed initiation was related to narrow-row yield increases at late but not optimal planting dates.

The reasons for the narrow-row yield enhancement in soybean has been extensively studied and well documented. Several authors have indicated that to attain optimum yield, soybean needs to have maximum LI (95%) by the start of seed filling (R5) (Shibles and Weber, 1966) or during the late pod-filling period (Taylor et al., 1982). The positive effects of narrow vs. wide-row culture might be due to increased LI during the vegetative (E to R1) or reproductive stages (R1-R7). Earlier research studies have indicated that maximum LI has to be achieved by R1 to obtain the yield advantage due to narrow-row culture (Johnson et al., 1982; Johnson, 1987; Tanner and Hume, 1978). Shibles and Webber (1965; 1966) indicated that attainment of sufficient LAI to produce maximum LI during seed formation was the main reason for narrow-row seed yield enhancement in soybean. Taylor et al. (1982) have shown that greater LI during pod filling rather than greater LAI and dry matter accumulation before seed filling, was responsible for narrow-row yield enhancement. Greater LI in narrow rows can also be caused by greater light interception efficiency (LIE = LI/ LAI) due to more equidistant plant spacing (Board and Harville, 1992). Alternatively the radiation-use efficiency during the first half of seed filling was significantly lower in the 25-cm rows than in the 50- or 100-cm rows.

This resulted in reduced pod number per area associated with lower CGR from pod initiation to 10 days after seed initiation (Board et al., 1994b).

The mechanism behind the influence of narrow-row LI advantage over the wider rows on yield components and yield was investigated by Board et al. (1992). Increased LI stimulated assimilatory capacity (as measured by CGR) and created greater pod number per area through a combination of increased nodes, reproductive nodes, and pods per reproductive node. They concluded that greater LI (R5-R7) had little effect on yield, since the pod number per area adjustment was made before most of the seed filling occurred. However, other researchers (Vitoonvitialak, 1987; Board et al., 1990) have shown that yield increases in narrow-row spacing are due to increased pod number per area which is determined between R3 and R6 in soybean (Board and Tan, 1995). Although LIE can influence LI during the vegetative period when LAI levels are low, it had little effect on LI during the R1 to R5 period (Board and Harville, 1992).

To study the row-spacing effects on LI, CGR, and other growth dynamic parameters during the vegetative period and how these parameters affect yield, Board and Harville (1996) conducted research on late-planted soybean at Baton Rouge. They concluded that source strength (CGR) during the vegetative period was shown to affect yield at late planting dates. Crop growth rate reflects canopy apparent photosynthesis (Imsande, 1989). Previous studies reported that changes in CGR during the vegetative period had little effect on yield (Johnson et al., 1969; Jiang and Egli, 1995). However, these studies were done at optimal plantings rather than at late planting studies as done by Board and Harville (1996), in which, shorter photoperiods curtail the emergence to R5 period (Board and Settimi, 1986). The advantages of narrow-row culture are most likely to be achieved when the dry matter accumulation between E to R5 period is restricted. Such situations are likely to occur with nonoptimal planting dates, where reduced day length curtails this period.

1.2.5.2 Effect of Planting Date on Soybean Yield Components and Yield

Soybeans in the southeastern USA are sometimes planted after the optimal planting period because of doublecropping after a winter cereal and/ or adverse weather (Boerma and Ashley, 1982). Optimal planting time for soybeans in the southeastern USA is early May through mid-June (Board, 1985). According to Wallace et al. (1992), about one-half of the soybean acreage in the southeastern USA is doublecropped after winter wheat. The yield of the soybean crop planted before or after the optimal planting period usually results in reduced yield (Board and Hall, 1984; Graves et al., 1978; Griffin et al., 1983; Hodges et al., 1983). Expansion of the planting period allows more time for planting, minimizes seed yield losses when soybeans are planted late after a winter cereal crop, allows early planting under better moisture conditions, and opens the possibility of obtaining two soybean crops in one year. Earlier research in the southeastern USA has indicated that soybean planted at an optimal planting date (May-June) requires at least 45 days from emergence to R1 to attain sufficient growth for adequate yield (Hartwig, 1954). Premature flowering induced by short days has also been reported to be a major seed yield-reduction factor at early planting dates (Hartwig, 1954; Board and Hall, 1984).

Seed yield reduction at nonoptimal planting dates resulted from reduced pod set (Carter, 1974). Reduced node number per area and fertile node number per area (Carter, 1974; Constable, 1977; Carter and Boerma, 1979; Beatty et al., 1982) have also been reported at nonoptimal planting dates. Earlier research on the effect of planting date on seed per pod gave variable results (Carter, 1974; Constable, 1977). Seed size (g per 100 seed) as affected by planting date has varied with location and growth habit (determinate vs. indeterminate) (Weiss, 1950; Caviness and Smith, 1959; Leffel, 1961; Carter, 1974; Carter and Boerma, 1979).

1.2.5.3 Effect of Plant Population on Soybean Yield Components and Yield

Optimal plant population is also an important factor that determines the yield of the soybean crop. Optimum population is the minimum population required by the crop to produce maximum yield. Boquet and Walker (1980) indicated that the various production costs (seeding, disease and pest control) and losses from lodging can be minimized by planting the soybean at an optimal plant population. Earlier research had concluded that the optimum plant population of soybean varies from 30, 000 to 500, 000 plants ha^{-1} (Lehman and Lambert, 1960; Leffel and Barber, 1961; Lueschen and Hicks, 1977; Costa et al., 1980; Parks et al., 1982; Egli, 1988; Wells, 1991). Several authors (Moore and Longer, 1987; Wells, 1991) have also reported a 100% variation in optimum plant population across years. Much of this variability can be explained by environmental conditions, with increased levels of population required under adverse conditions (Wells, 1991). Shibles and Weber (1966) demonstrated positive relationship between increased plant population, LAI, percentage LI, CGR, and TDM. They concluded that optimal yield resulted from combinations of optimum plant population and row spacing that achieved optimum 95% LI by the R5 stage. However, a large effect of interrow spacing on optimum plant population was not reported in several studies (Boquet and Walker, 1980; Moore and Longer, 1987). However, Boquet (1990) indicated that narrow rows (0.5 m) required more population (38 plants m^{-2}) when compared with wide rows (1.0 m) and low population (13 plants m^{-2}).

Duncan (1986) postulated two theories for explaining improved yield with different soybean planting patterns. He stated that, within a certain range of increasing plant population, yield could increase even with no increase in LI during pod filling. Duncan's second theory was that, within limits, greater TDM by seed initiation would result in higher yields. Understanding how growth dynamic factors in low vs. medium or high plant populations will result in similar yield will aid in identifying genetic and environmental strategies for reducing optimal plant population. Carpenter and Board (1997a, b) indicated that similar yield across plant populations (sparse vs. dense) resulted from equilibration of CGR by the early reproductive period, which caused an equivalent number of pods per square meter. Carpenter and Board (1997a), reported that with determinate soybean, branch pods were mainly responsible for greater pod per plant when grown at sparse populations and that regulation occurred through increased branch dry matter per plant. Greater NAR and RGR in low compared with normal plant populations during the late vegetative and early reproductive periods is sometimes a contributing factor to CGR equilibration (Wells, 1993, Carpenter and Board, 1997b). Greater LIE was associated with this NAR advantage for low plant populations (Carpenter and Board, 1997b). Studies with earlier sampling compared with these studies confirmed that greater LIE and NAR, as well as increased partition of TDM into branches were responsible for CGR equilibration in low vs. normal plant populations (Board, 2000).

Several researchers have reported that when soybean is planted at low vs. normal plant populations, there is greater partition of TDM into branches (Kasperbauer, 1987; Sanchez et al., 1993; Board, 2000). Differences in red/far red light ratios within the canopy help in explaining why soybean in low plant population partitions a greater percentage of TDM into branches compared with normal populations. Kasperbauer (1987) demonstrated under field conditions that an increased ratio of red/far red light resulted in greater branch development in soybean.

According to Sanchez et al. (1993), plants in sparse stands receive a higher red/far red light ratios vs. those in dense stands because of less shading.

Optimal plant population for soybean can be better determined by investigating the growth dynamic factors that maintain similar pod number per square meter across different plant populations. Pod number per square meter is largely determined by CGR (Board et al., 1992; Board and Tan, 1995). Therefore, studying the CGR and its effects on pod number per square meter and other dry matter parameters will aid in determining the optimum plant population for soybean. Crop growth rate affects TDM at specific growth stages and determines the dry matter accumulated by that stage. Egli et al. (1987) indicated that soybean required a TDM of 500 g m^{-2} by R5 stage to optimize yield at a late planting date. However, Board et al. (1990) indicated a higher HI at late vs. normal planting dates. Thus, greater TDMR5 might be necessary to optimize the yield at normal plantings. Loomis and Connor (1992) indicated that planting the soybean at nonoptimal planting dates would result in reduced CGR and TDM levels that result in yield loss. Plant population effects on yield formation could also be determined by how TDM is partitioned into certain plant parts.

1.2.5.4 Effect of Defoliation on Soybean Yield Components and Yield

Experimental removal of leaves from the plant (partially or completely) aims at manipulation of photosynthetic capacity of the plant and analyzes the effect of this on growth and yield of the crop. Turnipseed and Kogan (1987) indicated that various defoliation experiments such as insect-induced defoliation or hole punching matched up with manual defoliation by giving similar yield responses.

Identification of growth periods where potential yield is limited by assimilatory capacity (source restricted) would help in designing genetic and cultural strategies for increasing soybean yield. Such knowledge can be obtained by studying the effect of varying levels of defoliation at different growth periods of the crop on the yield components of the crop and also from understanding the stages at which these yield components are determined. The yield of soybean is also greatly affected by defoliating insects. Migratory defoliating insect pests, such as the soybean looper [*pseudoplusia includens* (Walker)] and the velvetbean caterpillar (*Anticarcia gemmatalis),* are frequent pests of the soybean crop (especially in the southeastern USA) during the mid to late seed-filling period (Tynes and Boethel, 1993).

Earlier defoliation studies have indicated that soybean yield is affected by the extent of defoliation and the time at which defoliation occurred during growth of the crop. Defoliation during the vegetative growth period of soybean showed little effect on yield because of the potential of the soybean canopy to accelerate leaf growth rate during its vegetative growth period. Pickle and Caviness (1984) reported no yield loss when 100% defoliation was imposed at mid vegetative development (V5). Weber (1955) indicated a 20% yield loss when complete defoliation was done between V2 and full bloom (R2). They reported only a little effect on yield when 50% defoliation was applied during the same period. Several authors reported different mechanisms of recovery by soybean after defoliation had occurred, e.g., delayed lower leaf senescence after defoliation (Klubertanz et al., 1996) and reduced transpiration by the canopy after defoliation (Ostlie and Pedigo, 1984). Yield compensation after 75% defoliation at full-bloom period was reported (Haile et al., 1998) under favorable conditions of good rainfall.

Research on recovery of soybean from defoliation between emergence to R3 has given consistent results across different environments and cultivars (Turnipseed and Kogan, 1987). Pickle and Caviness (1984) indicated a 33% yield loss when soybean crop was subjected to complete defoliation (100%) at R3 stage. This was supported by McAlister and Krober (1958), who demonstrated that 40% defoliation at seed initiation resulted in 9% yield loss and a 32% yield loss when 80% defoliation was done at R3 stage.

The yield of soybean is most sensitive to defoliation when it occurred at the start of the seed-filling period (Turnipseed and Kogan, 1987). Turnipseed and Kogan (1987) also provided second-degree equations that indicated that 55% defoliation at R5 would result in a 20% yield loss. This research was also supported by Fehr et al. (1981), who demonstrated that in both determinate and indeterminate cultivars of soybean, 100% defoliation at R5 stage resulted in 80% yield loss. Other studies have reported greater yield reduction when 100% defoliation was induced at R4 or R5 stage compared with R6 stage of soybean (Goli and Weaver, 1986). Goli and Weaver (1986) also concluded that even at the R4-R5 stage, the defoliation had to be substantial to cause any yield loss. However, Caviness and Thomas (1980) reported only 13-17 % yield reductions when 50 % defoliation was applied during the R4 to R5 period.

Yield sensitivity to defoliation declines as soybean passes the R6 stage. By R6, 70 % defoliation resulted in only a 20% yield loss (Turnipseed and Kogan, 1987). Other studies have also reported yield reductions caused by defoliation at R6 stage (Thomas et al., 1974; Fehr et al, 1977). Board et al. (1994a) concluded that drastic reductions in source strength (100% defoliation) applied shortly after R6 (yield loss of 37%) in this study. However, they reported that this had little effect on pod number per area. Thomas et al. (1974) indicated that 33% defoliation at R6 caused yield losses. However, the same amount of defoliation applied before or after this time did not affect yield

Different mechanisms of yield loss induced by defoliation have been reported. The yield loss may occur from reduced LI capacity after defoliation (Haile et al., 1998) or reduced root nodule activity and nodule weight after defoliation (Layton and Boethel, 1989). The yield components affected by defoliation depends on when the defoliation occurs in soybean. Several authors have reported that defoliation-induced yield reduction was caused by reduced seed or pod number per area (McAlister and Krober, 1958; Caviness and Thomas, 1980; Board and Harville, 1993). However, other studies indicated seed size as the yield component affected by defoliation (Egli and Leggett, 1973; Ingram et al., 1981; Nolting and Edwards, 1989). Egli (1989) indicated that environmental effects on seed size occur mainly through modification of the effective seed-filling period. Board and Harville (1993) have shown that defoliations during the early reproductive period (R1-R5) primarily affect pod number per area. They also concluded that pod number per area is reduced in response to lower LAI and LI, thus keeping the seed per pod and seed size unaffected during seed filling. However, other studies have shown that when defoliation occurs during the seed-filling period, significant reduction in seed size can occur (Goli and Weaver, 1986; Ingram et al., 1981).

Board and Harville (1998) indicated that soybean yield formation was relatively more sensitive to source strength during the early compared with late reproductive period. This is the most sensitive period during which the various stresses that cause reduction in source strength (CGR) must be avoided. Their conclusion was supported by previous studies, demonstrating that the most sensitive period for various stresses [drought (Elmore et al., 1988), lodging (Woods and Swearingin, 1977), and defoliation (Fehr et al., 1981)] was during pod formation or the early reproductive period.

1.2.5.5 Effect of Waterlogging on the Growth and Yield of Soybean

Several authors have indicated different causes, such as drought (Muchow et al., 1986), adverse soil pH (Mengel and Kamprath, 1978), compacted soil (Smucker and Allmaras, 1993), and toxic levels of minerals (Hanson and Kamprath, 1979), for reduced soybean yields in southeastern USA. Board and Harville (1996) indicated that soybean yield can be increased by minimizing environmental stresses that slow CGR between emergence and start of seed filling (R5). Waterlogging is also a common problem in this region, which may adversely affect soybean yield depending on the time and severity of occurrence (Scott et al., 1989). The ponding of water over a poorly drained field after a heavy rainfall or excessive irrigation results in waterlogging and affects about 12% of agricultural soils in the USA (Boyer, 1982).

Previous research on causes of yield reduction as a result of waterlogging indicated inadequate oxygen supply for root respiration as one of the main causes for reduced yield (Grable, 1966; Russell, 1977). Sallam and Scott (1987) concluded that root nodulation and growth of soybean were affected by waterlogging. Waterlogging in soybean usually results in reduced leaf photosynthetic rate as a result of reduced stomatal conductance (Oosterhius et al., 1990). Waterlogging also results in inadequate transport of minerals and many essential elements, such as nitrogen to the above ground portions of the plant, which, in turn, results in chlorotic, stunted plants (Nathanson et al., 1984). All the above factors collectively reduce CGR to suboptimal levels and thus reduce the soybean crop yield (Griffin and Saxton, 1988; Scott et al., 1989). Griffin and Saxton (1988) also concluded that waterlogging affects yield of the crop by reducing seed per pod and seed per plant. However, Sumarno (1986) in Indonesia reported that soybean grown in saturated culture yielded higher than the normally irrigated soybean. Similar results of higher seed yield of soybean under saturated culture were also reported by Troedson et al. (1989). Wright et al. (1988) reported that saturated culture in soybean results in severe lodging and reduces seed yields in southeastern Australia. They concluded that saturated culture results in reduced LI efficiency due to lodging and thus limits supply of photosynthate.

Waterlogging effects on soybean depend upon the time, duration and severity of its occurrence. Previous studies indicated that CGR is affected only when waterlogging occurred for more than 2 days (Griffin and Saxton, 1988; Scott et al., 1989). Linkemer et al.(1998) conducted research to identify the growth stages that were sensitive to waterlogging . They concluded that waterlogging for 7 days caused the greatest yield loss for late-planted soybean when stress was applied at R3. Significant yield loss also occurred when stress was applied at R1, R5, and V2. All other growth stages were unaffected by waterlogging. The adverse effect of waterlogging on CGR occurred through effects on NAR. Reduced CGR, in turn, affected yield mainly through pod number per area by regulation of pods per reproductive node and branch number. Waterlogging occurring at R3 or R5 can also have adverse effects on seed size.

1.2.5.5 Effect of Lodging on the Growth and Yield of Soybean

Lodging is also a common problem in the southeastern USA that causes reduced yields in soybean. Several workers indicated high velocity winds and frequent rainfall as the reasons for lodging in soybean (Noor and Caviness, 1980; Mancuso and Caviness, 1991). The various kinds of losses due to lodging occur because of mechanical harvesting problems (Weber and Fehr, 1966) and reduced pod production (Woods and Swearingin, 1977; Noor and Caviness, 1980). Yield losses due to lodging were during the R4 to R6 period. Noor and Caviness (1980) also concluded that, apart from losses due to harvesting, yield losses due to lodging in soybean can be as much as 22%. Earlier studies recognized that lodging increased with an increase in plant population (Cooper, 1971).

Lodging can be ameliorated by reducing plant height (Cooper, 1981; Mancuso and Caviness, 1991). Reducing the plant population results in sparse stands with reduced plant heights and wider stem diameter (Nagata, 1968). Earlier research by Wilcox and Sediyama

(1981) indicated that across a range of genotypes there was a 0.3 increase in lodging score (1 = erect; 5 = completely lodged) with each 10 cm increase in plant height. The possible environmental factors explaining reduced plant heights and thicker stems in sparse vs. dense stands are light quantity and quality. Photomorphogenesis (Kendrick and Kronenberg, 1986) is the phenomenon by which light quantity and quality influence the development and morphology of plants. Light has profound effects on the development of plants. The stem sections of plants that receive more light usually tend to have slower elongation rates (Garrison and Briggs, 1972).

The effect of light quality on stem elongation can be better understood by studying the ratio of red/far red light and blue light irradiance. As the sun rays penetrate deep into crop canopies, the level of light as well as the ratio of red/far red light is reduced because of greater absorption of red vs. far red light by the canopy (Holmes and Smith, 1977). Smith and Morgan (1981) have reported greater importance of red/far red changes when compared with light quantity in influencing stem elongation. Ballare et al. (1990) stated that stem elongation effects of red/far red light occur between neighboring plants before any mutual shading occurs. Apart from the ratio of red/far red light, low levels of blue light (< 6.3 W m^{-2}) can also stimulate stem elongation (Wheeler et al., 1991). Board (2001) conducted a study to determine if altered red/far red and/or differential blue light irradiance in sparse vs. dense plant populations was/were responsible for shorter plant height (and hence less lodging) in sparse populations. They concluded that greater lodging resistance for soybean in low compared with denser populations was related to internode extension and greater thickness of the top internodes (7-13) of the main stem. They also concluded that lodging can be avoided by planting at a seeding rate that achieves optimum yield, while at the same time increasing red/far red during the vegetative period to create a short, thick main stem.

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CHAPTER 2: DRY MATTER ACCUMULATION BY THE START OF SEED FILLING AS A CRITERION FOR YIELD OPTIMIZATION IN SOYBEAN

2.1 Introduction

Identification of criteria for indicating soybean [*Glycine max* (L.) Merril] yield would provide farmers with useful management tools. Such criteria could be used to predict yield potential and thus aid the producer in pricing his crop. More importantly, yield criteria could also aid the farmer in determination of environmental factors limiting crop yield. For example, failure to achieve a certain criterion by some stage during the growing season, combined with knowledge of important environmental factors (light, temperature, water, soil properties, pests, etc.), would indicate to the farmer what cultural practices (row spacing, plant population, tillage, irrigation, pesticide application, etc.) could be used to remedy the situation.

Possible yield criteria are yield components, morphological factors (example: seed size, seed number per area, node number per area, etc.) that affect soybean yield formation; and growth dynamic parameters such as total dry mater (TDM), leaf area index (LAI), and light interception (LI). Among yield components, seed number per area of crop land is the yield component that accounts for most of the environmental variation in the yield of soybean (Egli, 1998). This yield component is determined near the R6 stage, about 10 to 12 days after R5, and before rapid seed filling begins (Board and Tan, 1995). Yield components explaining how environmental changes affect seed number per area have not been clarified. Use of yield components as yield criteria is not promising because of their high variation and the difficulty for assessing them in production environments (Board et al., 1990a).

Among growth dynamic factors, achievement of 95% LI by R5 has been proposed as a yield criterion (Shibles and Weber, 1966). However, subsequent research demonstrated that in some cases, achievement of 95% LI before R5 was required to optimize yield (Egli, 1988; Board et al., 1992). Thus, timing for achievement of 95% LI to obtain optimal yield is not consistent enough to be a valid criterion. Achievement of optimal LAI (LAI required for 95% LI) has also been suggested as a yield criterion, but it suffers from the same problems as LI. In a study involving row spacing and planting dates, Egli et al. (1987) suggested that a TDM(R5) of 500 g m^{-2} was required to optimize seed per area and yield. Since a certain TDM level is expected to optimize yield, and R5 marks the end of the period for vegetative TDM accumulation, TDM(R5) is a good putative criterion for optimal yield. However, aside from the study by Egli et al. 1987, no research has verified TDM(R5) as a criterion for optimal yield.

Use of TDM(R5) as a yield criterion has appeal because of the ease of determination and predictability of the R5 growth stage (Fehr et al., 1977; Board and Boethel, 2001). Another advantage is that TDM(R5) can be easily identified through spectral analysis. The spectral reflectance of crops can be measured by airplanes, satellites, or hand-held radiometers (Printer et al., 1981). The plant canopy absorbs red light and reflects infrared light. As the density of leaf canopy increases, reflectance of radiation decreases in the red region of the visible spectrum and increases in the infrared region of the spectrum. Thus, the relative amounts of red and infrared light reflected by the canopy (i.e., vegetation index) indicate the level of LAI and TDM of the crop. Examples of vegetation indices are the simple ratio (SR) and normalized difference vegetation index (NDVI) (Aparicio et al., 2000). The NDVI is calculated as $(R_{IR} - R_R)/ (R_{IR} + R_R)$ and SR as R_{IR} /R_R, according to Penuelas et al. (1997), where R_{IR} is the reflected infrared radiation and R_R is the reflected red radiation. The reflectance values used in the calculation of

SR and NDVI include reflection by the canopy as well as reflection by the soil background (if any).

Determination of yield components important in yield formation helps substantiate TDM(R5) as a criterion for optimum yield. Since yield components are formed during discrete periods of soybean development, dry matter accumulation during the formation period of a significant yield component would be linked to yield. Thus, adoption of TDM(R5) as a yield criterion would have greater efficacy if it were shown that significant yield components responded to TDM(R5) in a manner similar to that shown for yield. Because TDM(R5) could be an efficient and accurate yield criterion and because little research has been done on this subject, our objectives were to use analyses of relationships between yield components, TDM, and yield to determine: 1. If TDM(R5) can be used as criterion for optimum yield; and 2. What level of TDM(R5) is required to optimize yield.

2.2 Materials and Methods

2.2.1 Data Collection

The data for this study were collected from previous studies conducted near Baton Rouge, LA (30^0 N Lat) between 1987 and 1996 and combined to make a single data set (methods similar to those followed by Loomis and Connor, 1992; Robert and Andrew, 1989). Details describing soil types, planting dates, seedling rates, cultural practices, and other information are contained in the following publications: Board et al., 1990a,b; Board et al., 1992; Board and Harville, 1993; Board and Harville, 1996; Board and Harville, 1998; Board, 2000; Carpenter and Board, 1997a,b; and Linkemer et al., 1998. Data collected were yield, TDM(R5), and the following yield components : seed size (g/ 100 seed), seed per pod (no.) seed number per area (no. m^{-2}), pod number per area (no. m^{-2}), pod per reproductive node (no.), reproductive node number per area (no. m^{-2}), node number per area (no. m^{-2}), and fraction of nodes becoming reproductive (%). These studies contained a variety of cultural treatments that altered environmental growing conditions (planting dates, row spacings, plant populations, partial defoliation, and waterlogging stress). Across all studies, only four cultivars (Centennial, Forrest, DP3606 and DP415), were used resulting in limited genetic variation. Thus, our analyses involved mainly a study of environmental rather that genetic influences on yield. The means for all treatment combinations within data sets were combined into one set (See Appendix F). The data thus pooled were subjected to correlation, regression and path coefficient analyses to achieve our objectives.

2.2.2 Correlation and Regression Analyses

Correlation and regression analyses were done with the PROC CORR and PROC GLM procedures of the SAS system. Regression analyses of yield and yield components on TDM(R5) were done using SAS regression (PROC GLM) in which linear, quadratic, and cubic components were successively tested for significance and included if the residual sum of squares was significantly reduced ($p<0.05$).

2.2.3 Path Coefficient Analysis

Yield components subjected to path analysis were classified into primary traits affecting yield (seed number per area, and seed size), secondary traits affecting the seed number per area (seed per pod, and pod number per area), tertiary traits affecting the pod number per area (pods per reproductive node and reproductive node number per area), and quaternary traits affecting reproductive node number per area (percent nodes becoming reproductive and node number per area). The path diagram showing the interrelationships among the yield components and between yield components and yield is shown in Fig. 1.

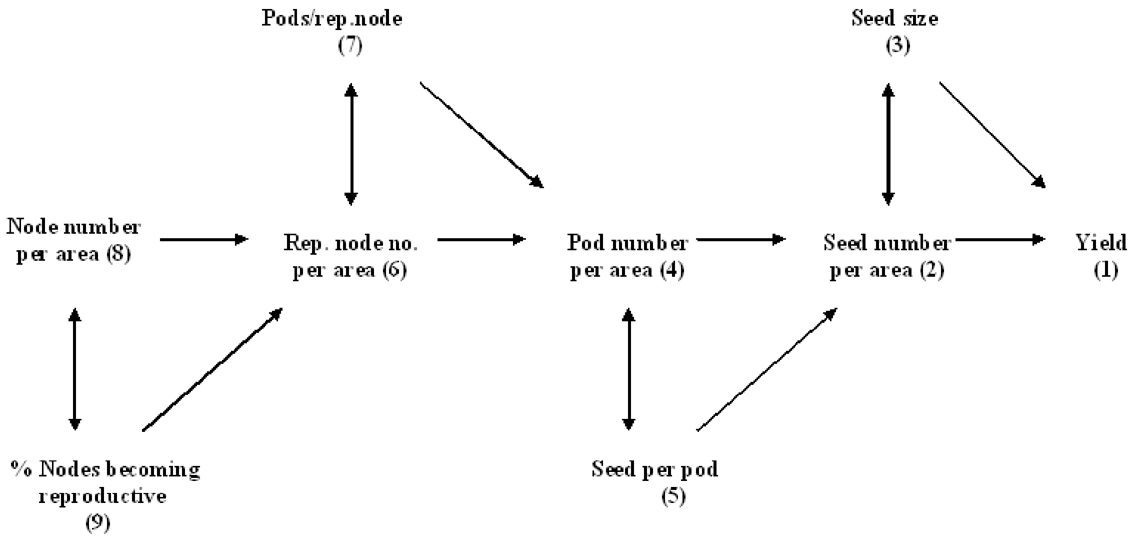

Fig.1 Path diagram showing interrelationships among primary level traits (traits 2, 3 6 1), secondary level traits (traits 4, 5 6 2), tertiary level traits (traits 6, 7 6 4) and quaternary traits (traits 8, 9 6 6) of the yield components and yield of soybean.

This diagram shows direct and indirect pathways for influence of predictor variables on a response variable. Simultaneous equations within each level of a trait were solved for direct path coefficients by a PROC IML (SAS Inst., Cary, NC) version of a software program given by Kang (1994). The indirect path coefficients were calculated by multiplying appropriate simple correlation coefficient (r) and path coefficient values (p). The residual effect and R^2 were calculated according to a procedure described by Kang (1994).

Better understanding of how yield components influence the yield formation process in soybean can be obtained by applying path analysis to determine the direct and indirect effects of primary, secondary, tertiary, and quaternary traits on the yield formation process. The main advantage is that path analysis not only identifies the most important factor directly affecting a trait, but also indicates how factors affect the trait indirectly through other factors (Kang et al., 1983; Kang et al., 1989). Previous research has indicated that the path coefficient analysis provides more information on the interrelationships between the yield components and yield than do the correlation coefficients (Dewey and Lu, 1959; Kang et al., 1983; Gravois and McNew, 1993; Board et al., 1997). Path analysis helps determine whether yield component compensation is occurring. Yield component compensation is when two or more yield components affecting yield or any other yield component act inversely in their effects. For example, among the two primary traits affecting yield, seed number per area and seed size, path analysis helps determine the direct positive effects of these yield components on yield as well as the effect of seed number per area on yield through seed size and the effect of seed size on yield through seed number per area. A negative indirect effect of seed size on yield via seed number per area indicates that compensation is going on between these two yield components. This explains if an increase in seed number per area increases yield with or without bringing about a reduction in seed size and vice versa.

2.3 Results

2.3.1 Yield and Yield Components vs. TDM(R5) (See Appendix D and E)

The relationship between yield and TDM(R5) was described by a strong cubic regression model (Fig. 2; $r^2 = 0.82$). Yield increased steeply with TDM(R5) at low dry matter levels (< 200 gm^{-2}). Yield responses to increased TDM(R5) progressively declined as dry matter rose above this level. Yield did not respond to TDM(R5) at levels above 600 gm^{-2} (Fig. 2). Yield was inversely related to harvest index (Fig. 3). Yield and harvest index showed a weak cubic relationship ($r^2 = 0.47$). Yield tended to decline as harvest index rose from slightly above forty to sixty percent.

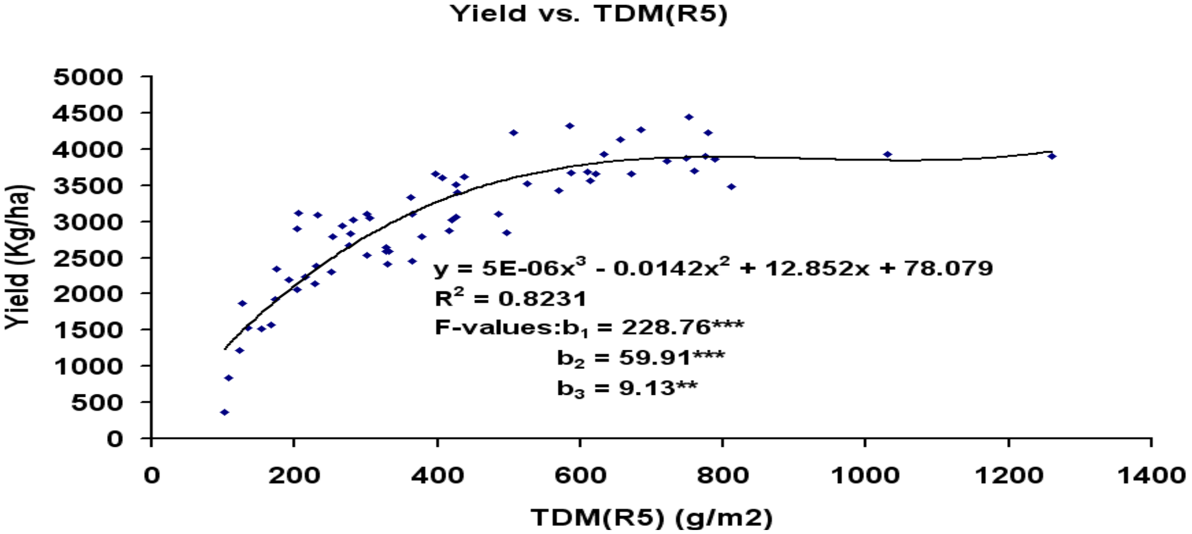

Fig. 2. Regression of yield on total dry matter at R5 [TDM (R5)] for soybean planted across a range of cultural and environmental conditions near Baton Rouge, LA, 1987-1996. *,,*** Significant at the 0.05, 0.01, and 0.0001 probability levels, respectively.**

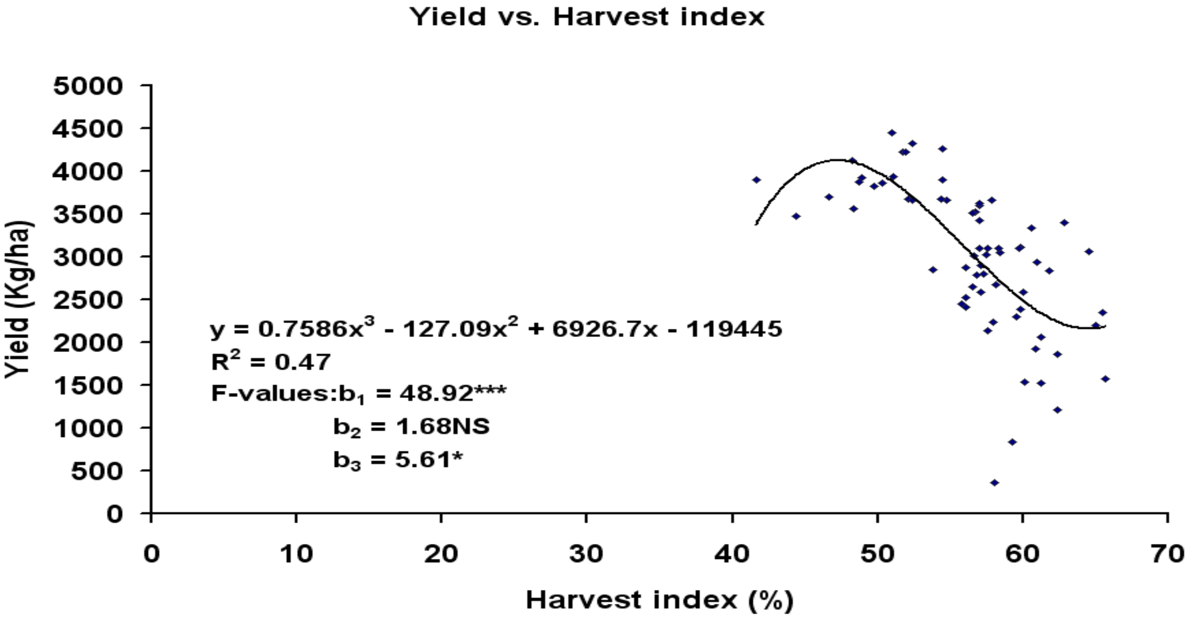

Fig. 3. Regression of yield on harvest index (HI) for soybean planted across a range of cultural and environmental conditions near Baton Rouge, LA, 1987 – 1996. *,,*** Significant at the 0.05, 0.01, and 0.0001 probability levels, respectively.**

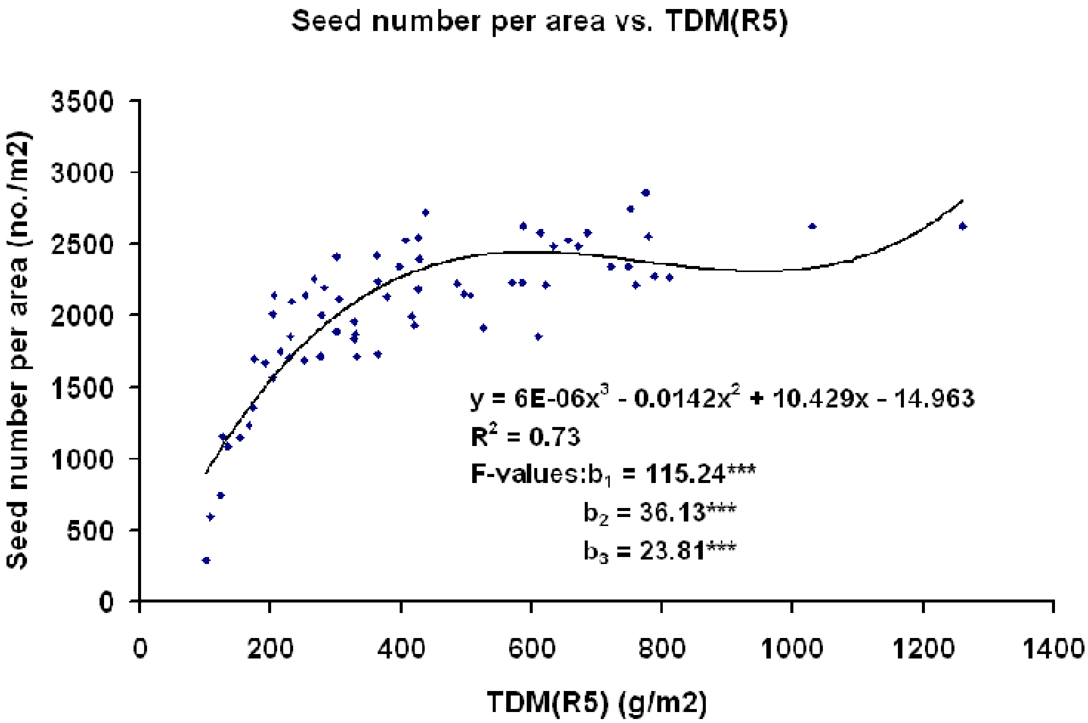

Fig. 4. Regression of seed number per area on total dry matter at R5 [TDM (R5)] for soybean planted across a range of cultural and environmental conditions near Baton Rouge, LA, 1987 – 1996. *,,*** Significant at the 0.05, 0.01, and 0.0001 probability levels, respectively.**

Seed number per area responded to TDM(R5) in a manner similar to that shown for yield (Fig. 4; $r^2 = 0.73$). Large increases in seed number per area with increased TDM(R5) occurred at low dry matter levels (< 200 gm^{-2}) and then progressively declined as TDM(R5) increased to about 500 gm^{-2}. Seed number per area did not increase after TDM(R5) reached this level. In contrast to seed number per area, seed size was weakly related with TDM(R5) (Fig. 5; $r^2 = 0.31$). The two parameters appeared to be independent of one another. Seed per pod was not related to TDM(R5) (linear $r^2 = 0.16$; Fig. 6).

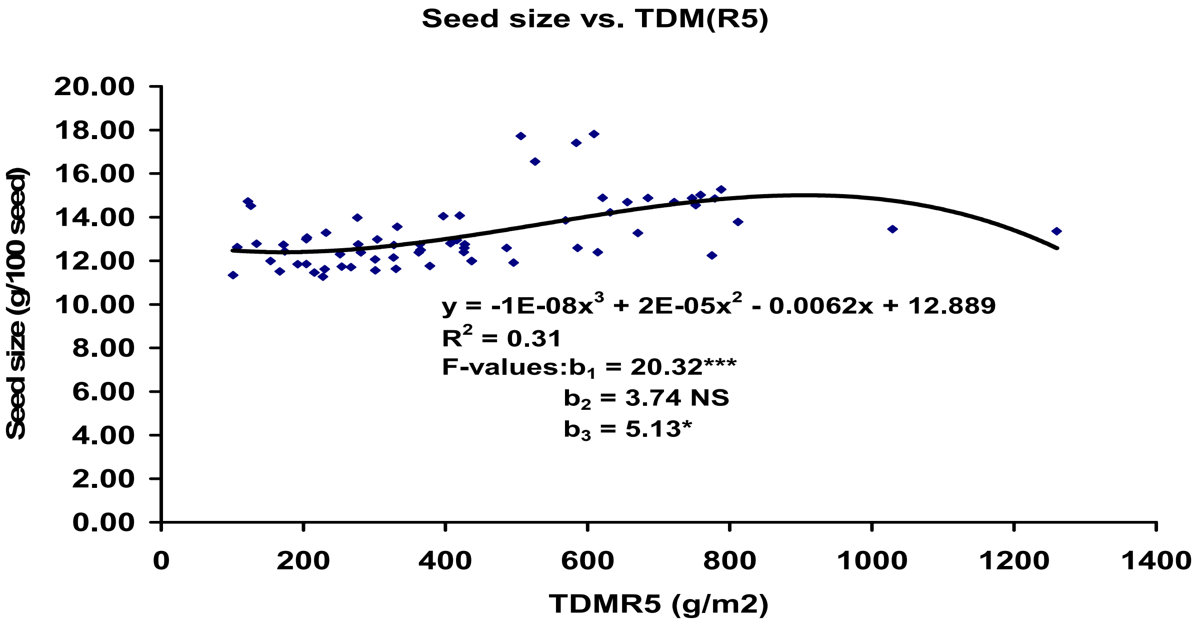

Fig. 5. Regression of seed size on total dry matter at R5 [TDM (R5)] for soybean planted across a range of cultural and environmental conditions near Baton Rouge, LA, 1987 – 1996. *,**,*** Significant at the 0.05, 0.01, and 0.0001 probability levels, respectively.

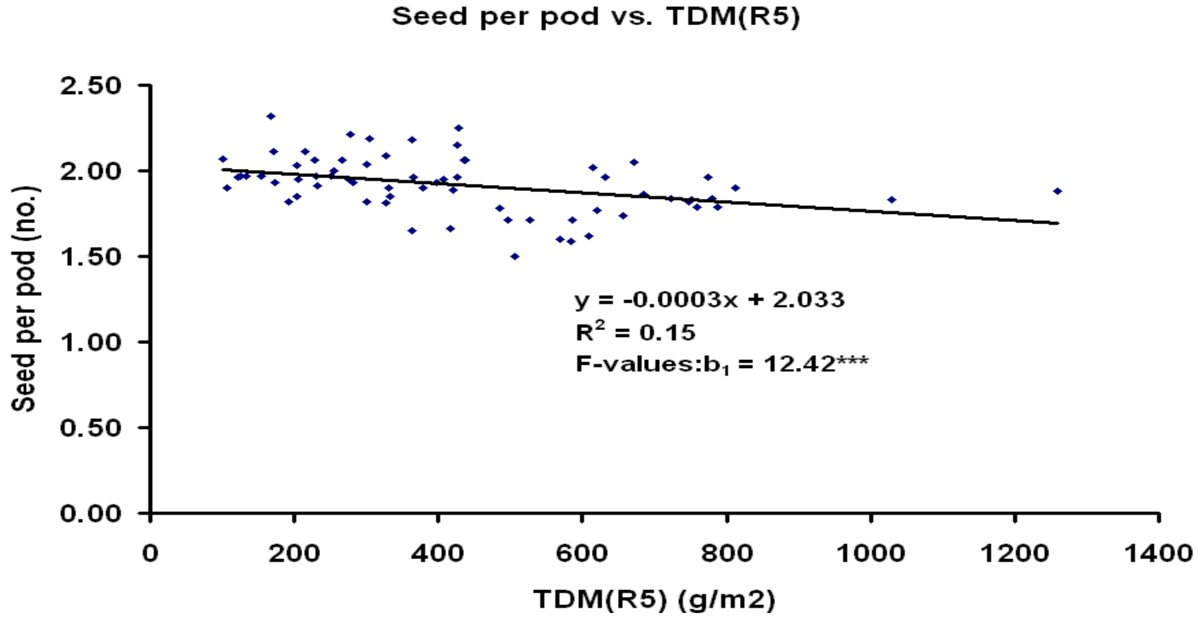

Fig. 6. Regression of seed per pod on total dry matter at R5 [TDM (R5)] for soybean planted across a range of cultural and environmental conditions near Baton Rouge, LA, 1987 – 1996. *,**,*** Significant at the 0.05, 0.01, and 0.0001 probability levels, respectively.

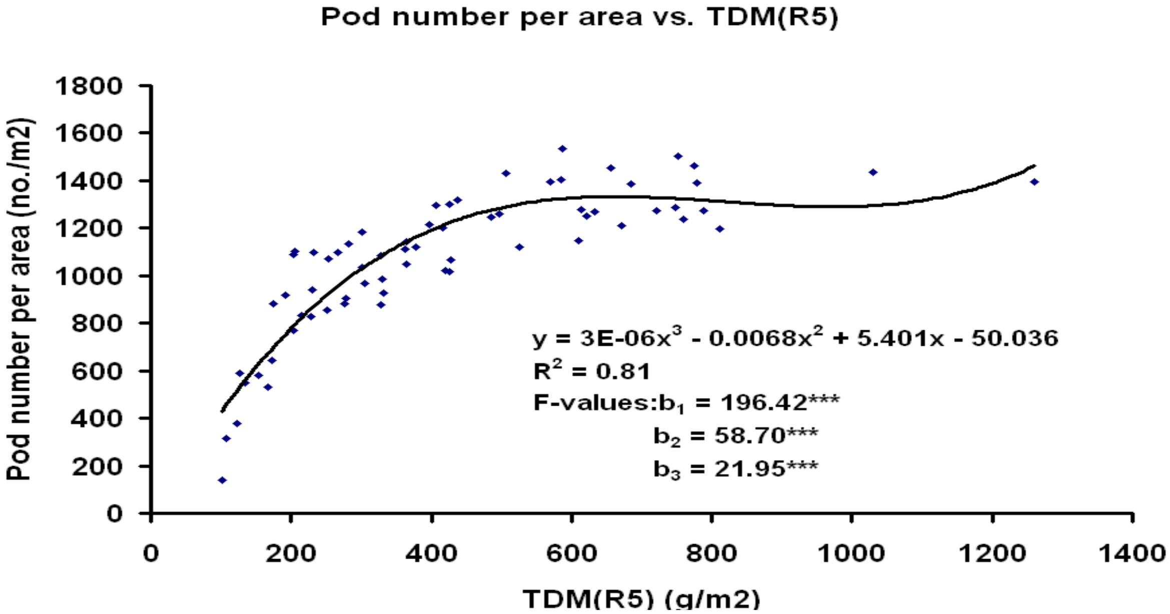

Fig. 7. Regression of pod number per area on total dry matter at R5 [TDM (R5)] for soybean planted across a range of cultural and environmental conditions near Baton Rouge, LA, 1987 – 1996. *,**,*** Significant at the 0.05, 0.01, and 0.0001 probability levels, respectively.

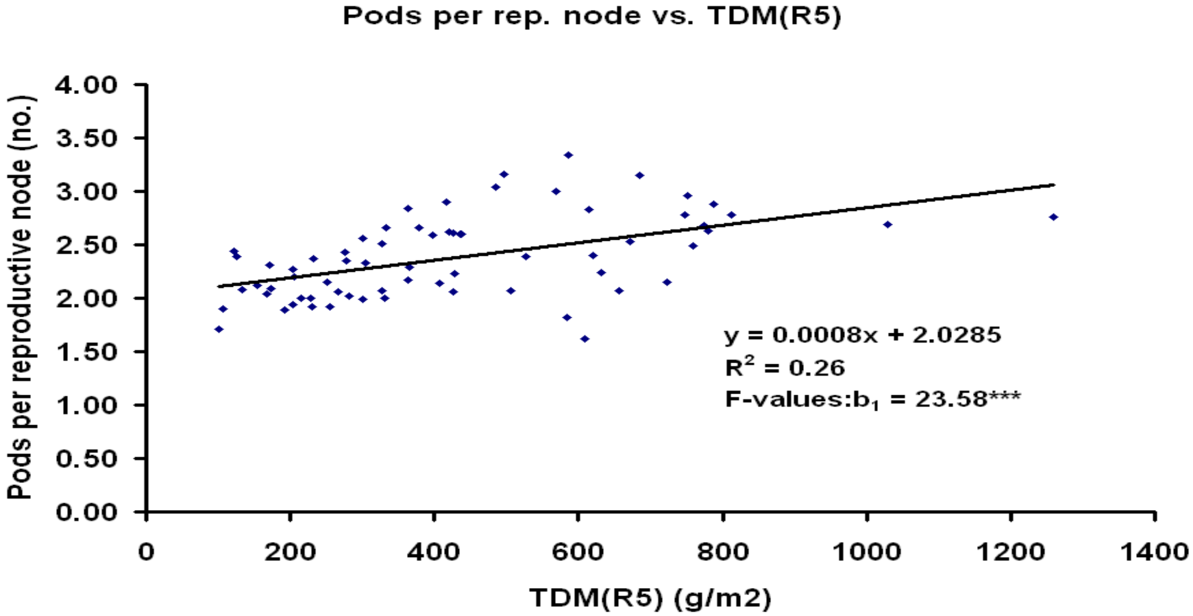

Fig. 8. Regression of pods per reproductive node on total dry matter at R5 [TDM (R5)] for soybean planted across a range of cultural and environmental conditions near Baton Rouge, LA, 1987 – 1996. *,**,*** Significant at the 0.05, 0.01, and 0.0001 probability levels, respectively.

Pod number per area responded to TDM(R5) in a manner similar to that shown for seed number per area and yield (Fig. 7). Pod number per area and TDM(R5) demonstrated a strong cubic relationship ($r^2 = 0.81$). Pod number per area responses to increased TDM(R5) were greatest at TDM(R5) less than 300 gm^{-2}. Pod number per area increases declined as TDM(R5) approached 600 gm^{-2} and then plateaud at that level. In contrast, pods per reproductive node was only slightly linked with TDM(R5), showing a linear r^2 value of only 0.26 (Fig. 8).

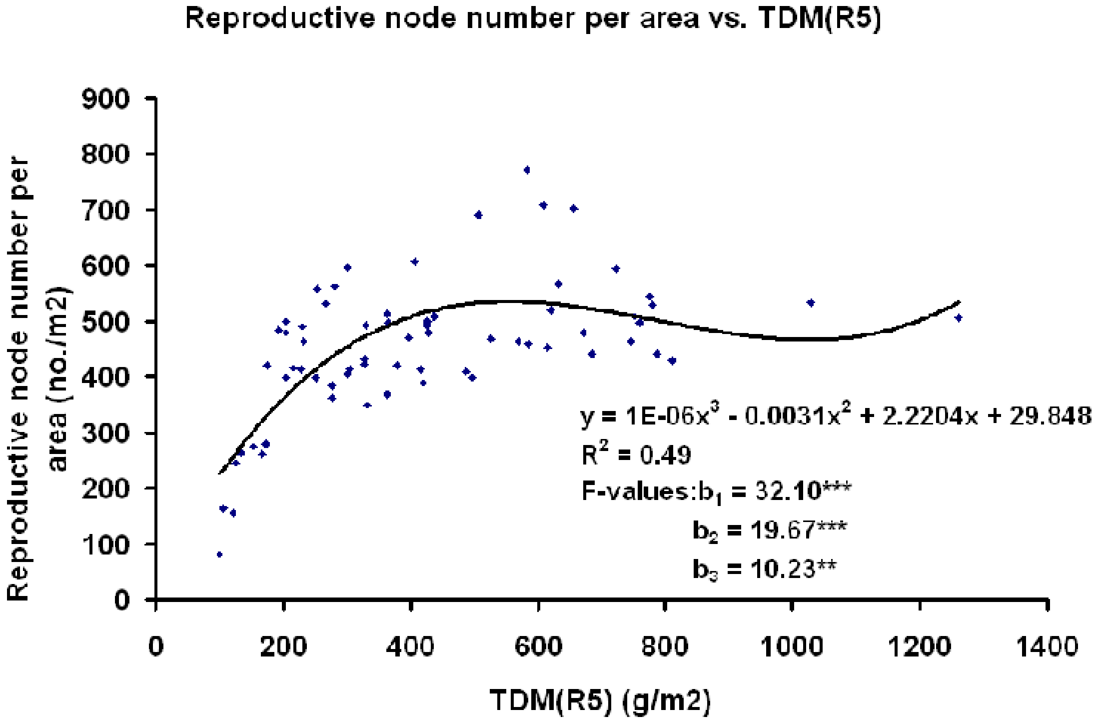

Fig. 9. Regression of reproductive node number per area on total dry matter at R5 [TDM (R5)] for soybean planted across a range of cultural and environmental conditions near Baton Rouge, LA, 1987 – 1996. *,,*** Significant at the 0.05, 0.01, and 0.0001 probability levels, respectively.**

Reproductive node number per area was related to TDM(R5) in the same pattern shown by yield, seed number per area, and pod number per area. The relationship between reproductive node number per area and TDM(R5) was best explained by a cubic regression (Fig. 9; $r^2 = 0.49$).

Reproductive nodes had the greatest responses to TDM(R5) at levels below 300 gm^{-2}. Responses declined as TDM(R5) increased to 450 gm^{-2} and leveled off above that point. As shown by lower r value, reproductive node number per area was not as strongly linked with TDM(R5) as were yield, seed number per area, and pod number per area.

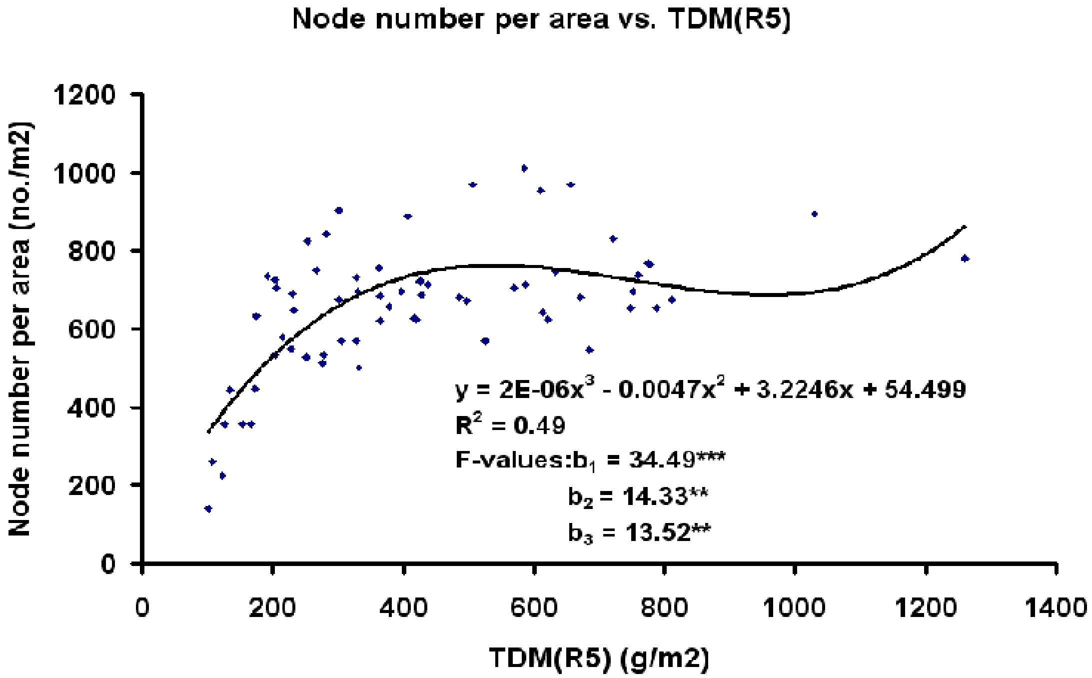

Fig. 10. Regression of node number per area on total dry matter at R5 [TDM (R5)] for soybean planted across a range of cultural and environmental conditions near Baton Rouge, LA, 1987 – 1996. *,,*** Significant at the 0.05, 0.01, and 0.0001 probability levels, respectively.**

The relationship between node number per area and TDM(R5) paralleled the pattern shown by reproductive node number per area and TDM(R5) described above. The regression showed a cubic pattern with r^2 = 0.49 (Fig. 10). In contrast, the fraction of nodes becoming reproductive was unrelated with TDM(R5).

2.3.2 Relationship between Yield and Yield Components

Yield was strongly related to seed number per area in a linear relationship ($r^2 = 0.84$; Fig. 11). In contrast, yield was only slightly related to seed size in a linear fashion ($r^2 = 0.28$; Fig. 12). Seed number per area and seed size were not significantly correlated (Fig. 13). These regression/ correlation results were supported by path analysis. The direct path effect for seed number per area on yield was 0.86 vs. 0.40 for seed size (Table 1). Indirect effects of either yield component on yield via the other yield component (0.06 and 0.13) were small.

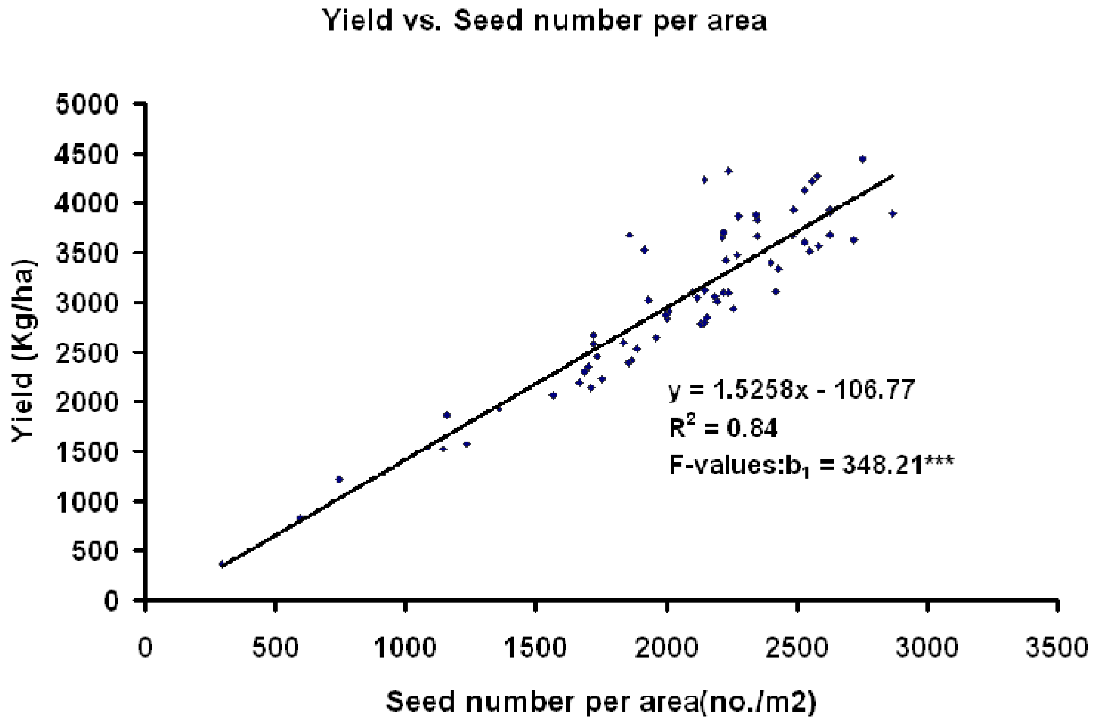

Fig. 11. Regression of yield on seed number per area for soybean planted across a range of cultural and environmental conditions near Baton Rouge, LA, 1987 – 1996. *,,*** Significant at the 0.05, 0.01, and 0.0001 probability levels, respectively.**

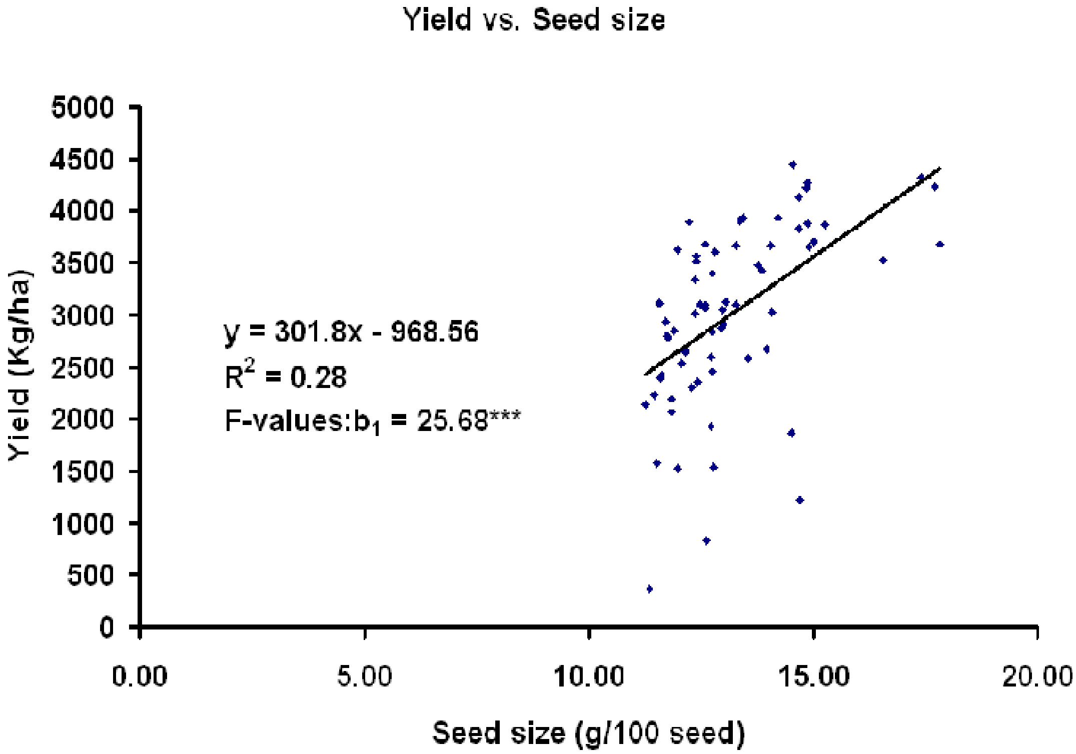

Fig. 12. Regression of yield on seed size for soybean planted across a range of cultural and environmental conditions near Baton Rouge, LA, 1987 – 1996. *,,*** Significant at the 0.05, 0.01, and 0.0001 probability levels, respectively.**

Seed number per area was strongly correlated with pod number per area (r^2 = 0.91; Fig. 14), but it was unrelated with seed per pod. Seed per pod and pod number per area showed a weak inverse relationship (r^2 = 0.21; Fig. 15). The direct path coefficient for pod number per area on seed number per area (P = 1.12) was more than twice as large as that for seed per pod (0.36) (Table. 1).

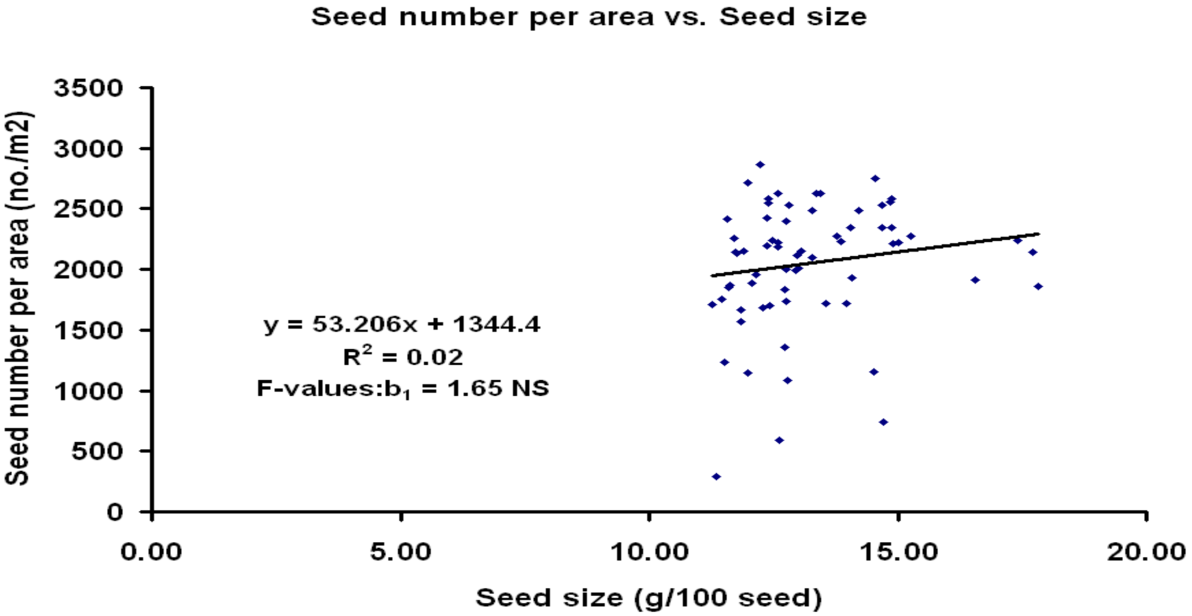

Fig. 13. Regression of seed number per area on seed size for soybean planted across a range of cultural and environmental conditions near Baton Rouge, LA, 1987 – 1996.

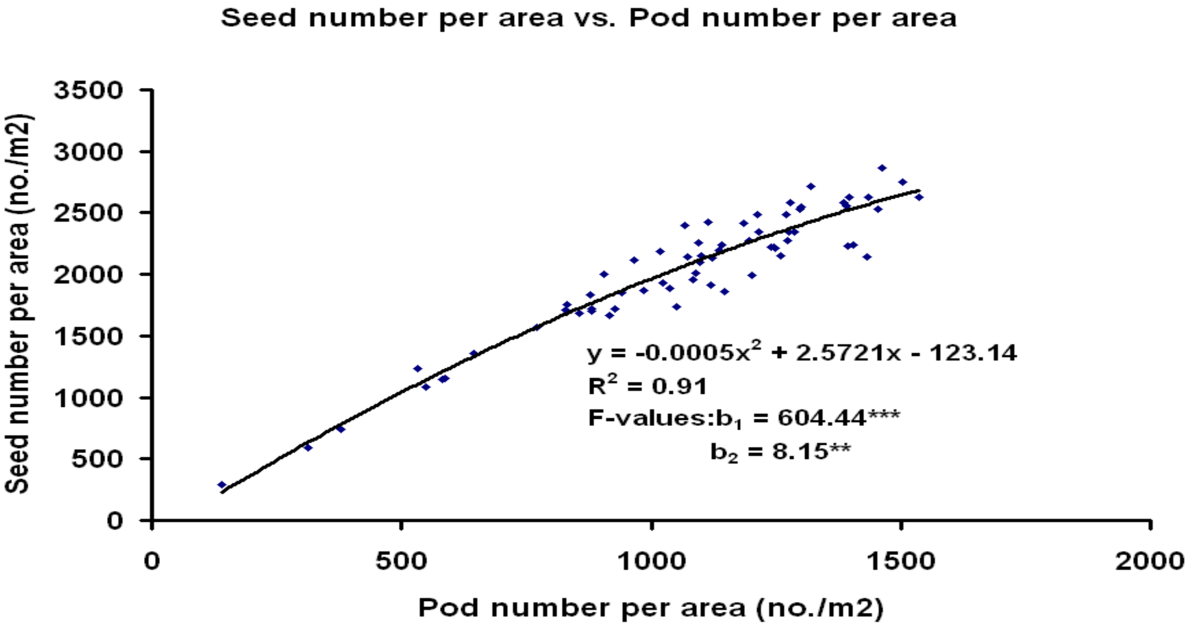

Fig. 14. Regression of seed number per area on pod number per area for soybean planted across a range of cultural and environmental conditions near Baton Rouge, LA, 1987 – 1996. *,**,*** Significant at the 0.05, 0.01, and 0.0001 probability levels, respectively.

Table 1. Correlations, direct path coefficients and indirect path coefficients between (a) Primary traits and yield, (b) secondary traits and seed number per area, (c) Tertiary traits and pod number per area, and (d) quaternary traits and reproductive node number per area for soybean grown across a range of environmental and cultural factors near Baton Rouge, LA, 1987 to 1996.

(A) Primary Traits	Correlation (r) of primary trait with yield:	Direct effect of primary traits on yield:	Indirect effect of primary trait on yield via: Seed no. per area	Indirect effect of primary trait on yield via: Seed size
Seed number per area	0.92 * * *	0.86	___	0.06
Seed size	0.53 * * *	0.40	0.13	___

Coefficient of determination $R^2 = 0.98$. Residual effect = 0.14

(B) Secondary Traits	Correlation (r) of seed no. per area with:	Direct effect of secondary traits on seed no. per area:	Indirect effect of primary trait on seed number per area via: Seed per pod	Indirect effect of primary trait on seed number per area via: Pod no. per area
Seed per pod	-0.15 NS	0.36	___	-0.51
Pod no. per area	0.95 * * *	1.12	-0.17	___

Coefficient of determination $R^2 = 0.99$. Residual effect = 0.10

(C) Tertiary Traits	Correlation (r) of pod no per area with	Direct effect of tertiary traits on pod no. per area	Indirect effect of primary trait on pod number per area via: Pods per rep. node	Indirect effect of primary trait on pod number per area via: Rep. node no. per area
Pods per rep. node	0.51 * * *	0.59	___	-0.08
Rep. node no. per area	0.80 * * *	0.85	-0.05	___

Coefficient of determination $R^2 = 0.99$. Residual effect = 0.10

(D) Quaternary Traits	Correlation (r) of rep. node no. per area with:	Direct effect of quaternary traits on rep. node no. per area	Indirect effect of primary trait on rep. node number per area via: Node number per area	Indirect effect of primary trait on rep. node number per area via: Fraction rep. nodes
Node number per area	0.96 * * *	0.95	___	-0.01
Fraction. Rep. nodes	0.27 *	0.22	- 0.05	___

Coefficient of determination $R^2 = 0.98$. Residual effect = 0.14

*, **, *** represent significance at 0.05, 0.01 and 0.001 levels of probability, respectively.

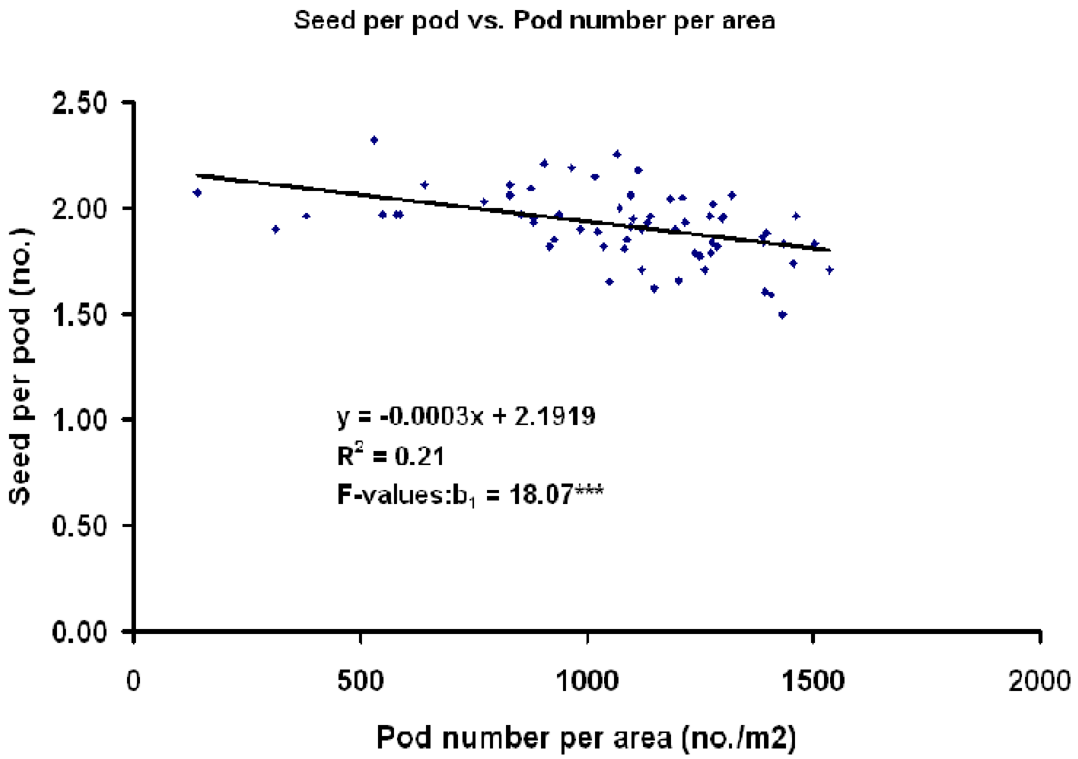

Fig. 15. Regression of seed per pod on pod number per area for soybean planted across a range of cultural and environmental conditions near Baton Rouge, LA, 1987 – 1996. *,,*** Significant at the 0.05, 0.01, and 0.0001 probability levels, respectively.**

The direct effect for seed per pod (0.36) was negated by a large indirect path effect of seed per pod on seed number per area via pod number per area (-0.51) (Table. 1). Yield showed very little linear relationship with seed per pod (Fig. 16; r^2 = 0.14). In contrast, yield and pod number per area showed a strong linear relationship (Fig. 17; r^2 = 0.90).

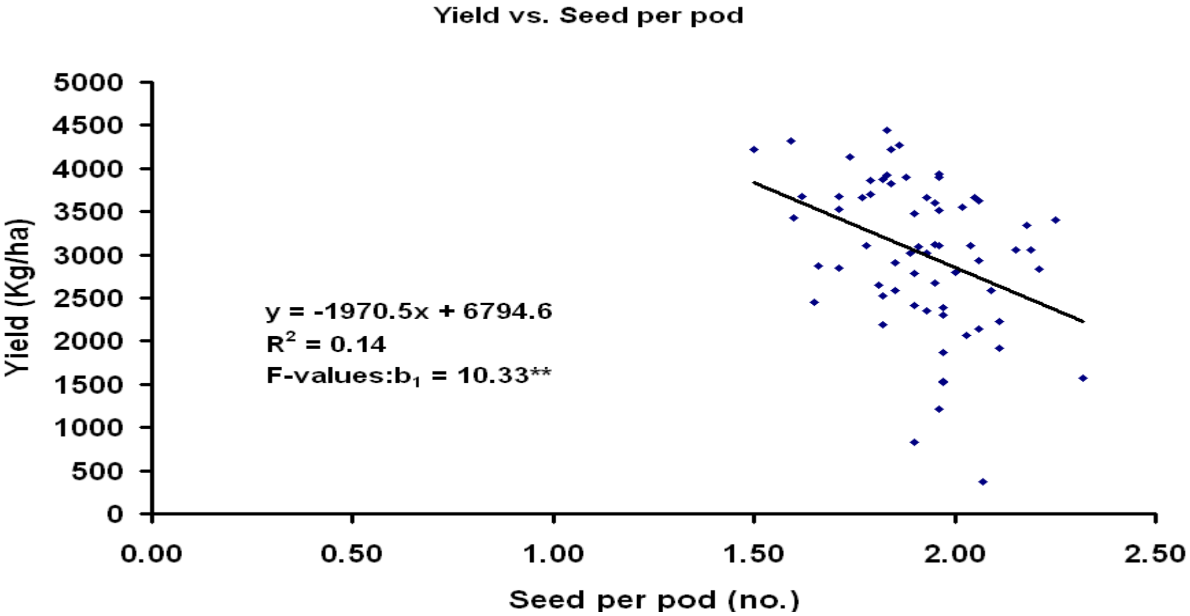

Fig. 16. Regression of yield on seed per pod for soybean planted across a range of cultural and environmental conditions near Baton Rouge, LA, 1987 – 1996. *,,*** Significant at the 0.05, 0.01, and 0.0001 probability levels, respectively.**

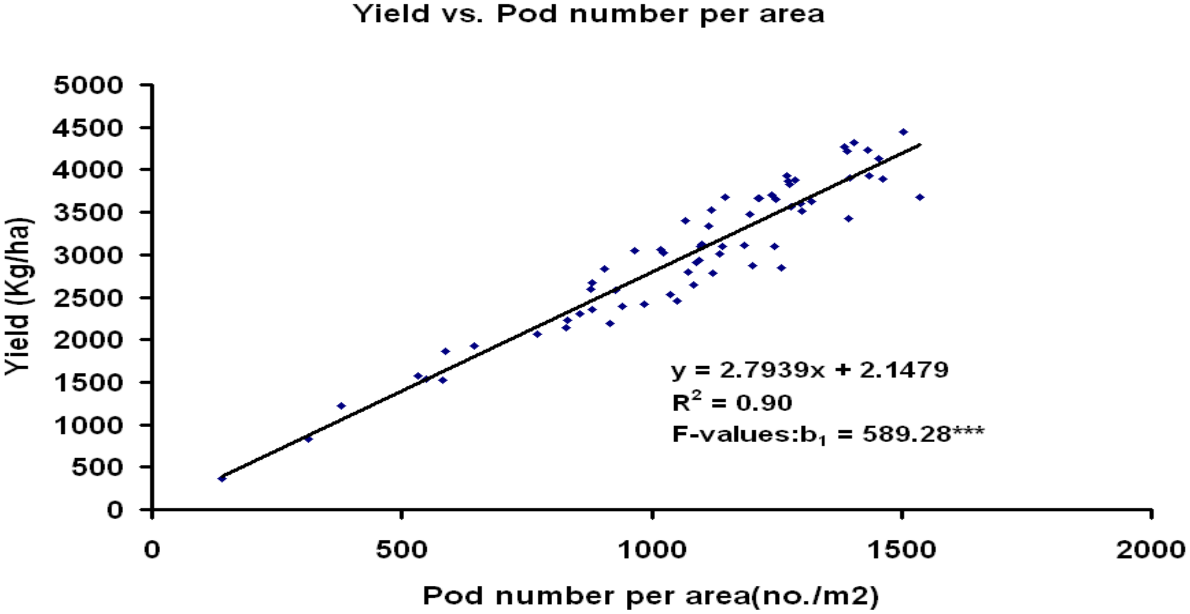

Fig. 17. Regression of yield on pod number per area for soybean planted across a range of cultural and environmental conditions near Baton Rouge, LA, 1987 – 1996. *,,*** Significant at the 0.05, 0.01, and 0.0001 probability levels, respectively.**

Pod number per area showed a strong quadratic relationship with reproductive node number per area (Fig. 18; $r^2 = 0.73$). Up to 400 reproductive nodes m^{-2}, pod number per area increases were large. Pod number per area increases were smaller above this level and plateaud at 600 reproductive nodes m^{-2}. However, pod number per area was only slightly related to pods per reproductive node (linear relationship $r^2 = 0.26$; Fig. 19). Pods per reproductive node and reproductive node number per area were not related (Fig. 20). Path coefficient analysis revealed that reproductive node number per area had a slightly larger direct effect on pod number per area vs. pods per reproductive node (0.85 vs. 0.59) (Table. 1). Indirect effects of reproductive node number per area and pods per reproductive node on pod number per area were negligible (-0.08 and -0.05, respectively).

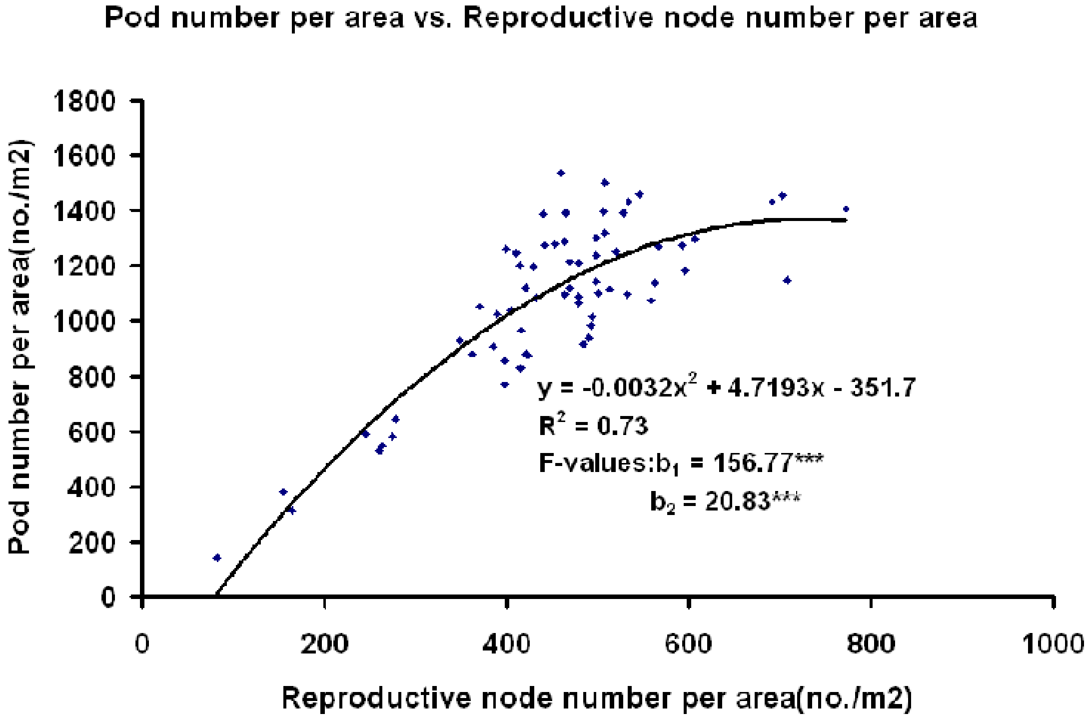

Fig. 18. Regression of pod number per area on reproductive node number per area for soybean planted across a range of cultural and environmental conditions near Baton Rouge, LA, 1987 – 1996. *,**,*** Significant at the 0.05, 0.01, and 0.0001 probability levels, respectively.

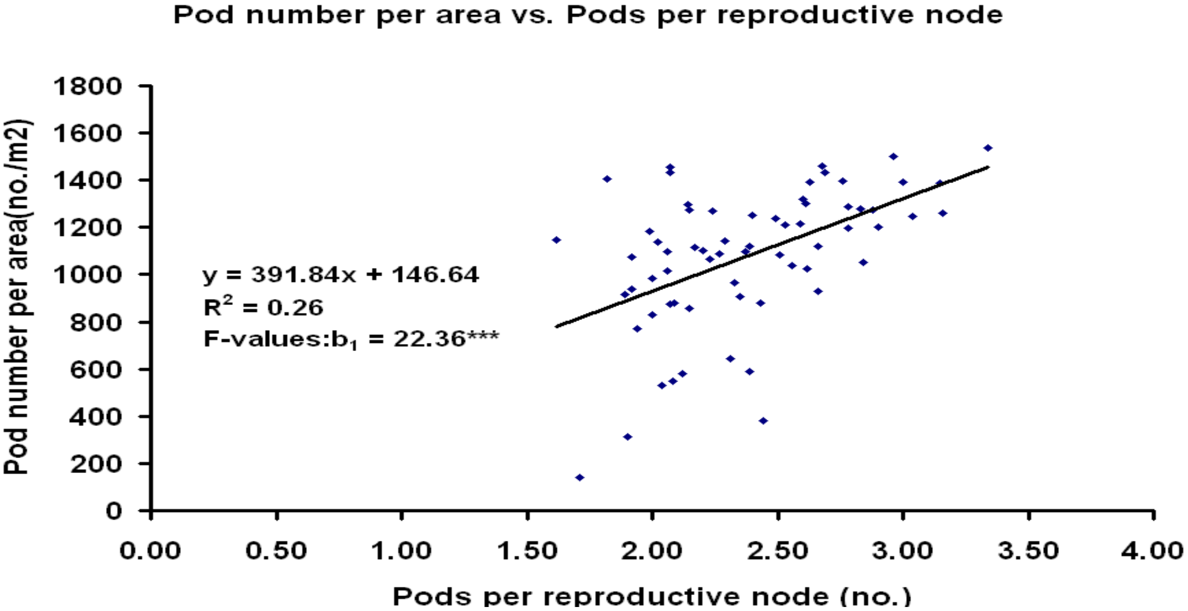

Fig. 19. Regression of pod number per area on pods per reproductive node for soybean planted across a range of cultural and environmental conditions near Baton Rouge, LA, 1987 – 1996. *,**,*** Significant at the 0.05, 0.01, and 0.0001 probability levels, respectively.

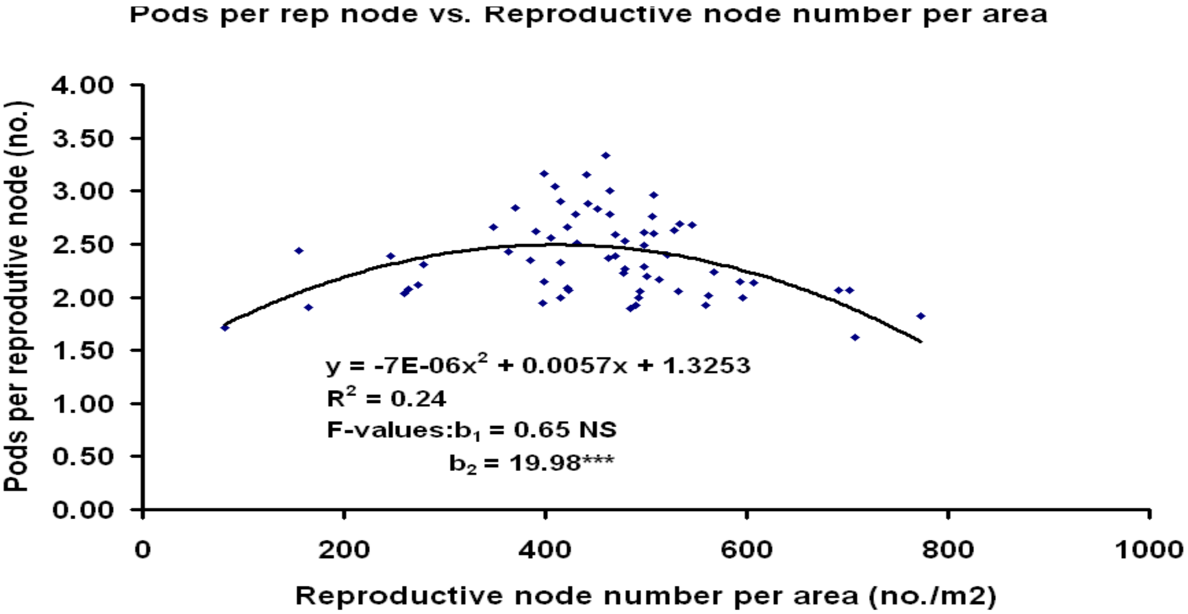

Fig. 20. Regression of pods per reproductive node on reproductive node number per area for soybean planted across a range of cultural and environmental conditions near Baton Rouge, LA, 1987 – 1996. *,**,*** Significant at the 0.05, 0.01, and 0.0001 probability levels, respectively.

Seed number per area vs. reproductive node number per area (Fig. 21) and yield vs. reproductive node number per area (Fig. 22) were related in strong cubic ($r^2 = 0.78$) and quadratic ($r^2 = 0.70$) relationships, respectively. In contrast, seed number per area and yield were only weakly linked with pods per reproductive node in weak linear relationships ($r^2 = 0.21$ and $r^2 = 0.17$, respectively) (Fig. 23 and 24, respectively).

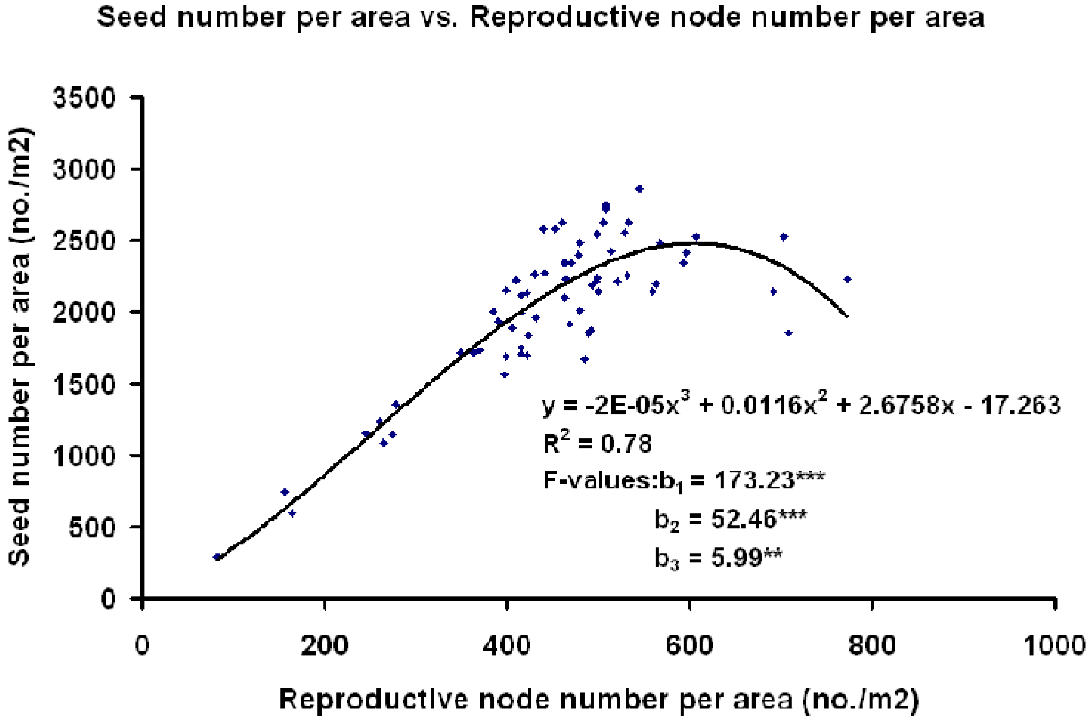

Fig. 21. Regression of seed number per area on reproductive node number per area for soybean planted across a range of cultural and environmental conditions near Baton Rouge, LA, 1987 – 1996. *,**,*** Significant at the 0.05, 0.01, and 0.0001 probability levels, respectively.

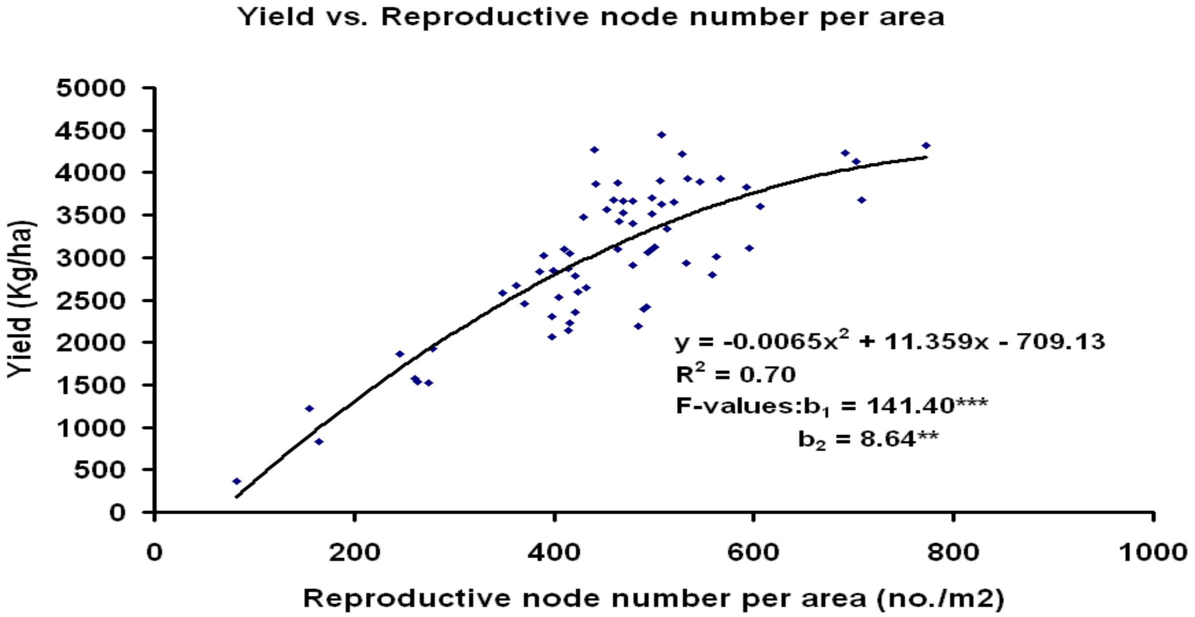

Fig. 22. Regression of yield on reproductive node number per area for soybean planted across a range of cultural and environmental conditions near Baton Rouge, LA, 1987 – 1996. *,**,*** Significant at the 0.05, 0.01, and 0.0001 probability levels, respectively.

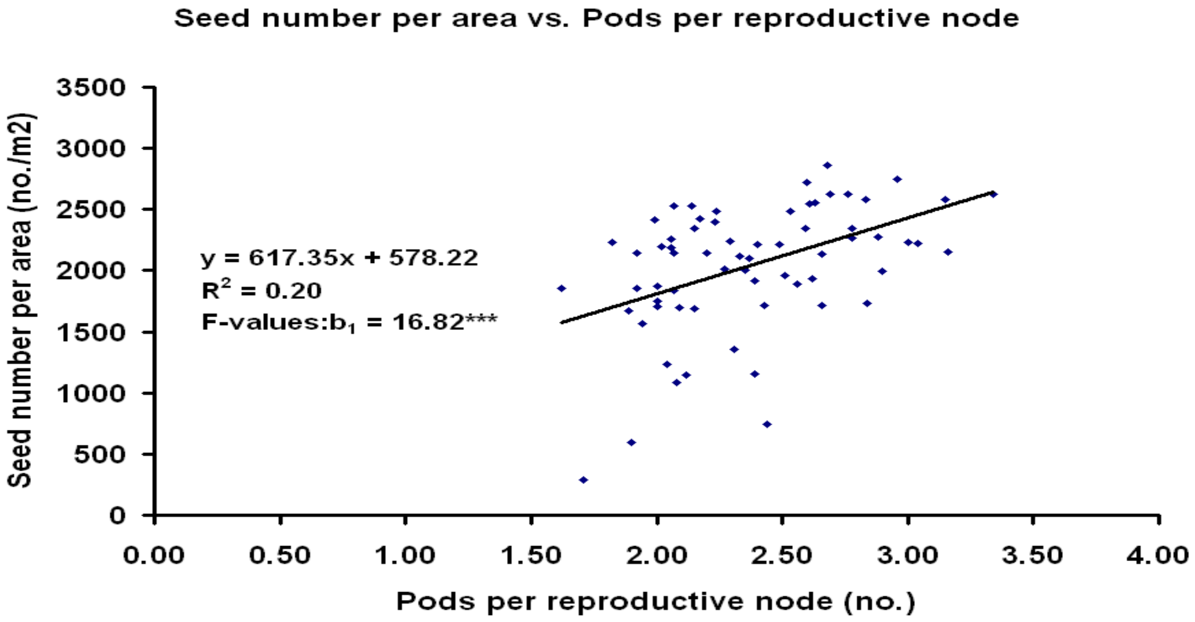

Fig. 23. Regression of seed number per area on pods per reproductive node for soybean planted across a range of cultural and environmental conditions near Baton Rouge, LA, 1987 – 1996. *,**,*** Significant at the 0.05, 0.01, and 0.0001 probability levels, respectively.

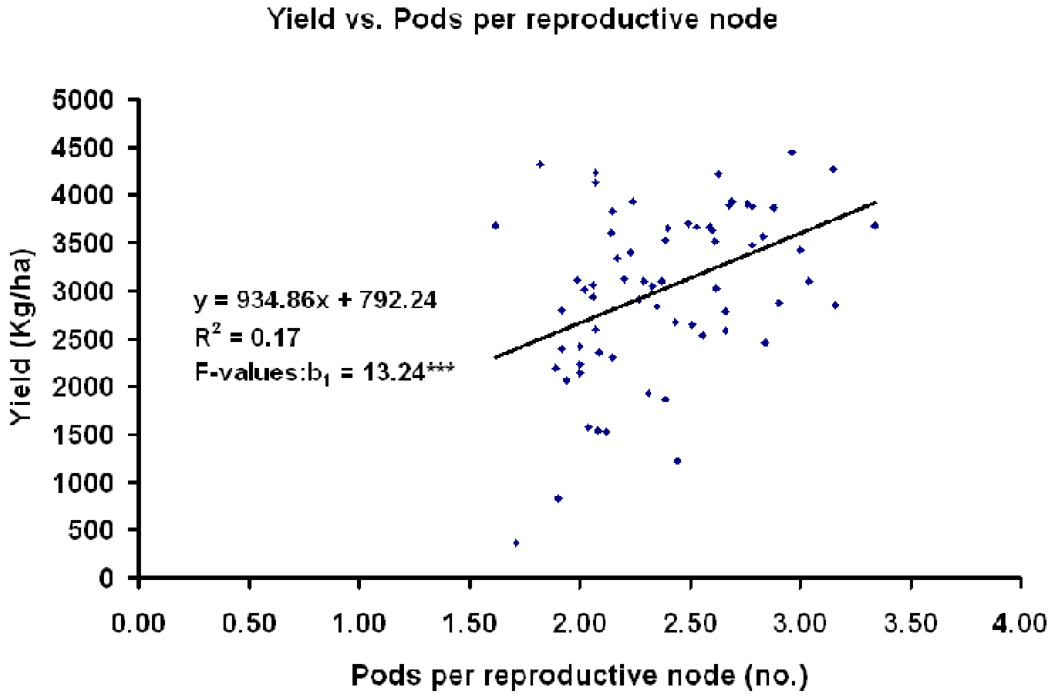

Fig. 24. Regression of yield on pods per reproductive node for soybean planted across a range of cultural and environmental conditions near Baton Rouge, LA, 1987 – 1996. *,,*** Significant at the 0.05, 0.01, and 0.0001 probability levels, respectively.**

Reproductive node number per area demonstrated only a slightly positive correlation with fraction of nodes becoming reproductive (Fig. 25). In contrast, reproductive node number per area was strongly positively correlated with node number per area in a cubic fashion (Fig. 26; $r^2 = 0.93$). Node number per area and percent of nodes becoming reproductive were not related strongly (Fig. 27). Supporting these trends, the direct path effect for node number per area on reproductive node number per area was almost three times greater than that for percent of nodes becoming reproductive (0.95 vs. 0.27; Table.1). Indirect path effects between the two yield components on reproductive node number per area were small (0.01 and 0.05). Regression analysis revealed that node number per area played an important role in formation of yield components that controlled yield formation.

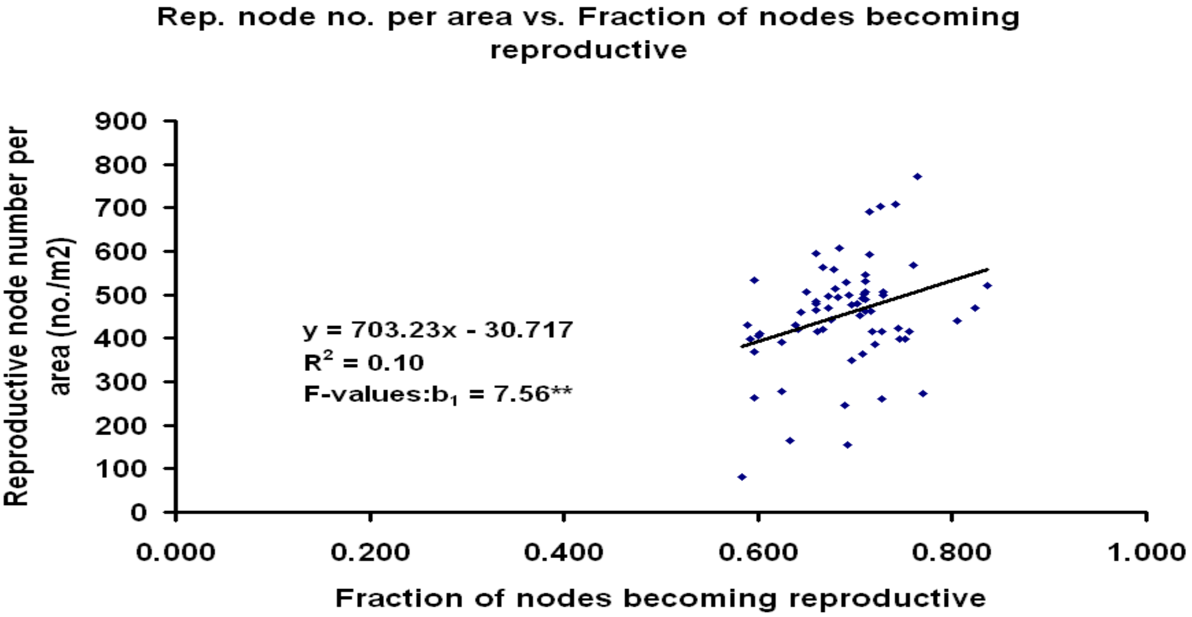

Fig. 25. Regression of reproductive node number per area on fraction of nodes becoming reproductive for soybean planted across a range of cultural and environmental conditions near Baton Rouge, LA, 1987 – 1996. *,,*** Significant at the 0.05, 0.01, and 0.0001 probability levels, respectively.**

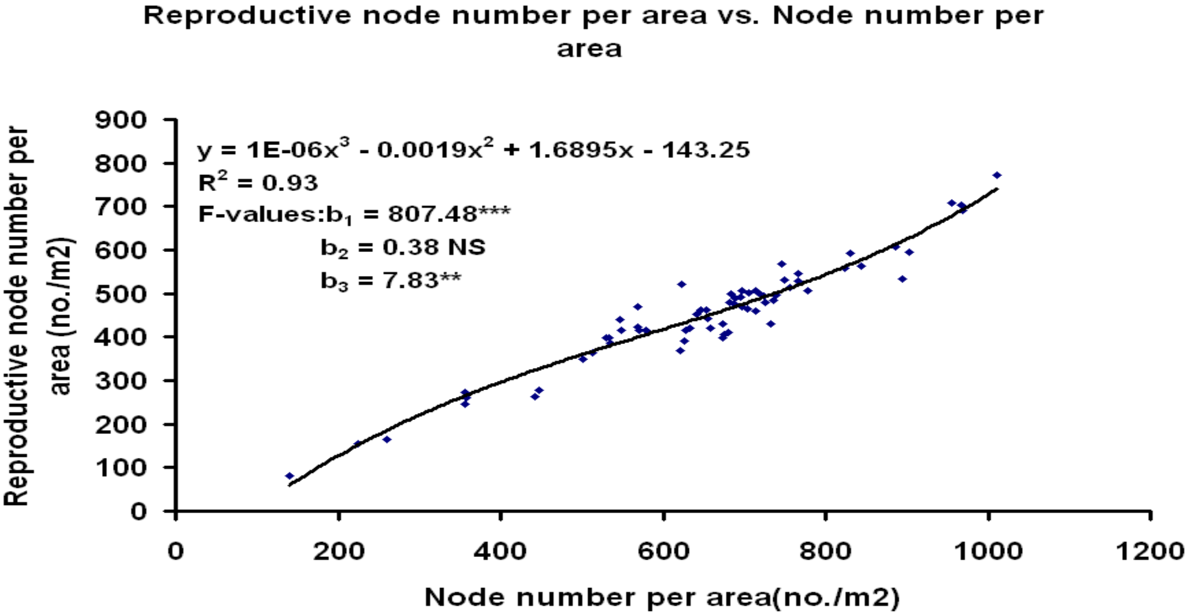

Fig. 26. Regression of reproductive node number per area on node number per area for soybean planted across a range of cultural and environmental conditions near Baton Rouge, LA, 1987 – 1996. *,,*** Significant at the 0.05, 0.01, and 0.0001 probability levels, respectively.**

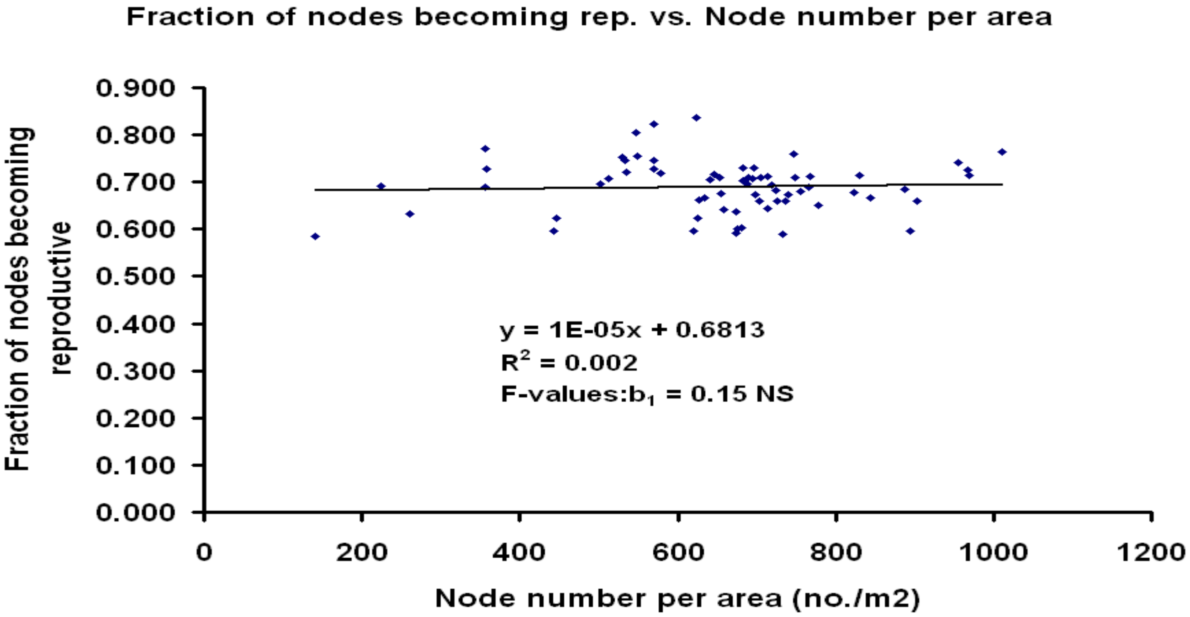

Fig. 27. Regression of fraction of nodes becoming reproductive on node number per area for soybean planted across a range of cultural and environmental conditions near Baton Rouge, LA, 1987 – 1996.

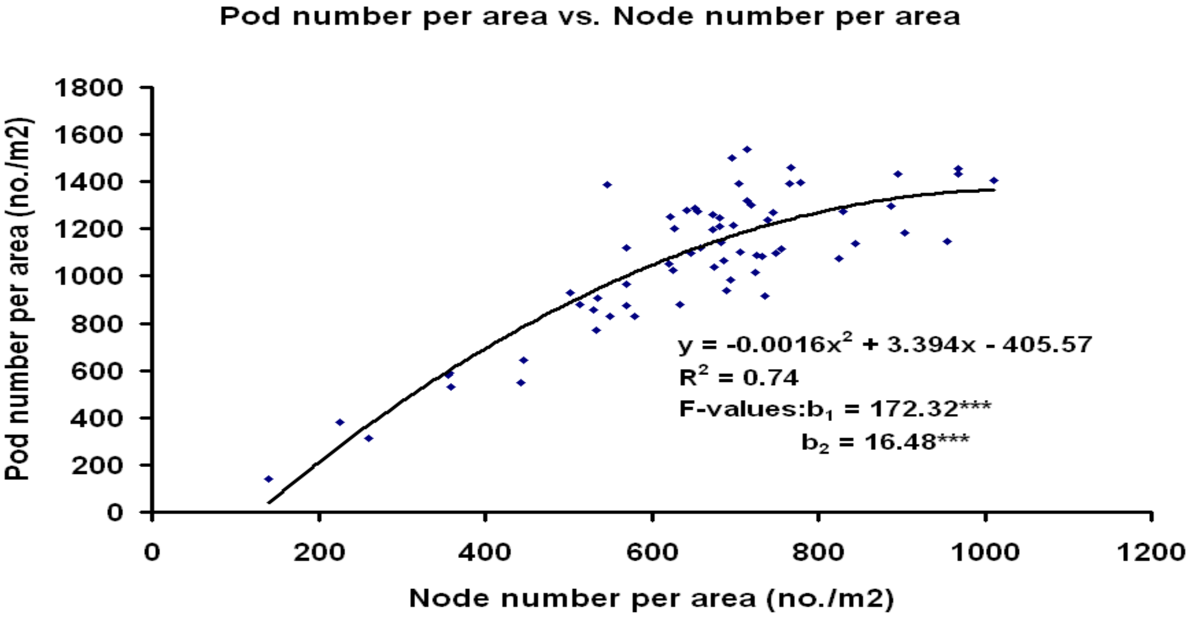

Fig. 28. Regression of pod number per area on node number per area for soybean planted across a range of cultural and environmental conditions near Baton Rouge, LA, 1987 – 1996. *,,*** Significant at the 0.05, 0.01, and 0.0001 probability levels, respectively.**

Pod number per area responded to node number per area in a quadratic relationship (Fig. 28; r^2 = 0.74). Pod number per area increased linearly with node number per area up to about 600 pods m^{-2}, slowed above this level, and then plateaud at about 800 nodes m^{-2}. Seed number per area showed a similar response with node number per area in a cubic relationship (Fig. 29; r^2 = 0.76). Reflecting these trends, yield responded to node number per area in a quadratic fashion (Fig. 30; r^2 = 0.64). Yield increased linearly as node number per area advanced to 600 nodes m^{-2}. Above this point, incremental yield increases progressively declined as nodes m^{-2} rose to about 1000 nodes m^{-2}.

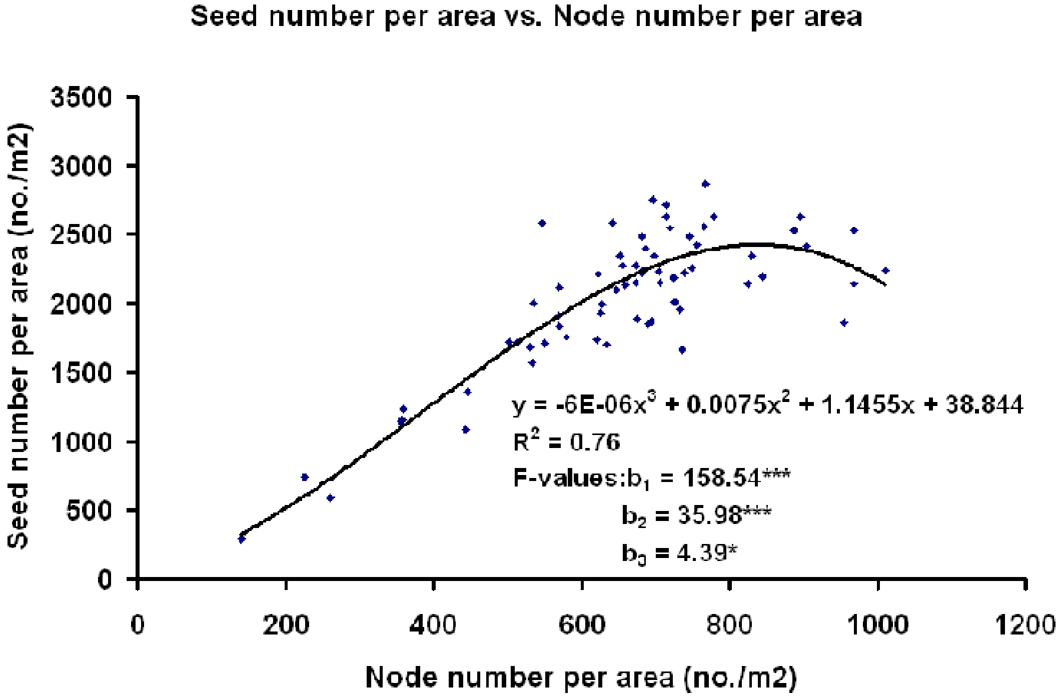

Fig. 29. Regression of seed number per area on node number per area for soybean planted across a range of cultural and environmental conditions near Baton Rouge, LA, 1987 – 1996. *,**,*** Significant at the 0.05, 0.01, and 0.0001 probability levels, respectively.

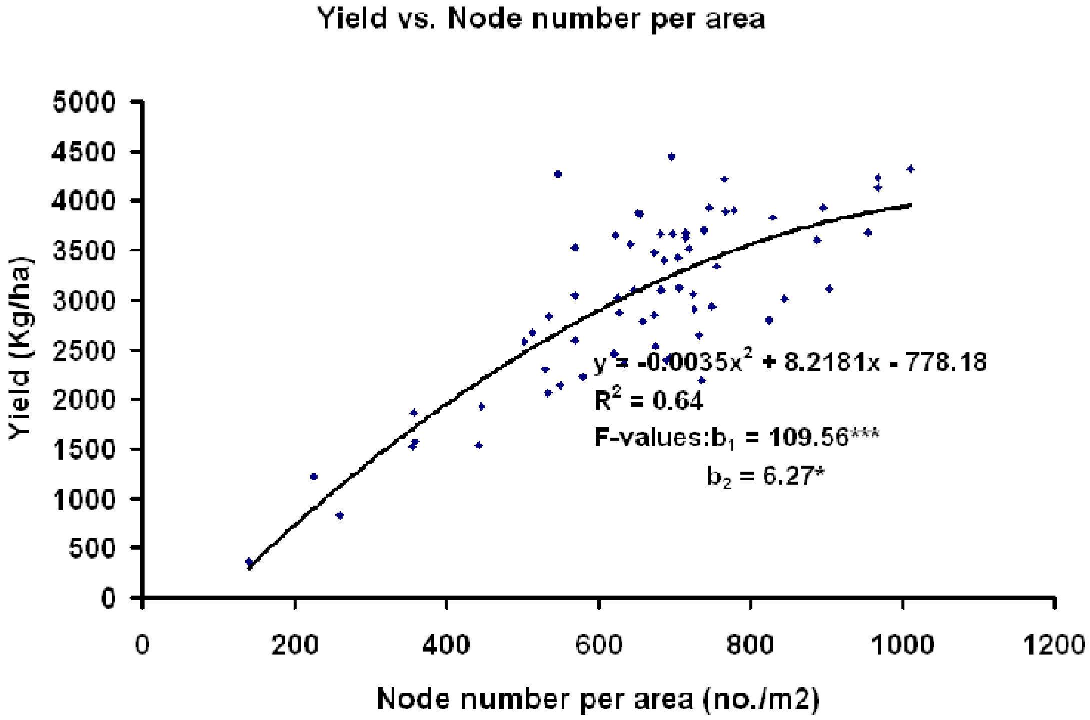

Fig. 30. Regression of yield on node number per area for soybean planted across a range of cultural and environmental conditions near Baton Rouge, LA, 1987 – 1996. *,,*** Significant at the 0.05, 0.01, and 0.0001 probability levels, respectively.**

2.4 Discussion

2.4.1 TDM(R5) as a Criterion for Optimum Yield

The results of the current study clearly indicate that TDM(R5) can be used as a criterion for predicting optimal yield in soybean. The existence of a negative relationship between yield and HI (Fig. 3) suggested that partitioning of dry matter into yield played a much smaller role compared with dry matter accumulation. This indicates that the cultural/environmental factors affect yield predominantly through dry matter accumulation rather than partitioning of dry matter into yield. A similar result, where yield was found to be more related to CGR than to partitioning of assimilate was reported by Egli (1988).

The relationship between TDM(R5) and yield was quadratic with a slight cubic component. Yield increased steeply with increased TDM(R5) at low dry matter levels. With further increases in level of TDM(R5), the yield increments declined until a plateau was reached at about 600 g m^{-2}. These results support the finding by Egli et al. (1987), except that they reported a linear relationship between dry matter and seed number per area rather than the nonlinear relationship observed in the current study. Duncan (1986) postulated that greater TDM(R5) resulted in higher seed yields of soybean. Egli and Yu (1991) have also reported a linear relationship between CGR and seed yield of soybean. The current study is more comprehensive than the previous studies and provides a stronger basis for establishing a TDM criterion for optimal yield.

Soybean producers now have an indicator for optimal yield that can be used for management decisions. Management decisions aimed at maintaining the CGR at a rate and for a sufficient period of time can achieve the required TDM(R5). Nonoptimal soybean yields are most likely to occur in conditions where the CGR and TDM are restricted between emergence and R5. Subcritical TDM(R5) in soybean may reflect adverse conditions caused by environmental factors, such as reduced light interception, mineral and moisture deficiencies, or adverse soil conditions. In such a case, farmers can rectify the environmental factor causing the subcritical TDM(R5). For example, if the length of the period between emergence and R5 was shorter and limited the LI of the crop, farmer can reduce the row spacing during the next growing season, which would enhance the CGR rates to make up for the loss of growth period between emergence and R5. If the farmers achieve the required TDM(R5), but fail to realize optimum yields, this would indicate that the factors that caused the reduced yield were operating during the seed-filling period (R5-R7). Suitability of TDM(R5) as a criterion for optimum yield is enhanced by other factors. The R5 stage is easily recognizable (Fehr and Caviness, 1977) and is highly predictable for a given cultivar/environment situation. Another advantage is that TDM(R5) can cheaply, quickly, and easily be determined through digital aerial photography (Printer et al., 1981). The leafiness of the crop (LAI) can be easily determined using the vegetative indices (NDVI and SR) using the photographs taken from a height over the crop area at R5 stage. This parameter can be easily correlated to TDM(R5) and the dry matter accumulated by the crop by that stage can be easily determined.

2.4.2 Yield Component Analysis

The importance of attaining the required TDM by R5 can be further strengthened by establishing the relationships between TDM(R5) and important yield components in the yield formation process. Regression of yield on individual yield components, regression of individual yield components between themselves, correlation analysis, and path coefficient analysis indicated that the yield components most important in yield formation were seed number per area, pod number per area, reproductive node number per area, and node number per area. Seed size, seed per pod, pods per reproductive node, and fraction of nodes becoming reproductive were not strongly linked with yield or dry matter accumulation.

Seed number per area was much more strongly related to yield than was seed size as shown by correlation coefficients and direct path effects. Little compensation occurred between seed number per area and seed size as indicated by indirect path effects. This shows that environmental/cultural factors can increase seed number per area without substantially decreasing seed size. This explains why we observed a linear relationship between seed number per area and yield (Fig. 11). The relationship between seed number per area and yield is further substantiated by the relationship between TDM(R5) and seed number per area (Fig. 4) which paralleled that between yield and TDM(R5) (Fig. 2). Importance of seed number per area vs. seed size as the yield component that mediates environmental/cultural influences on yield is similar to findings of previous research (Shibles et al., 1975; Egli and Yu, 1991; Egli, 1998).

Correlation and direct path coefficient analyses indicated that pod number per area was more important in determining seed number per area than was seed per pod. Pod number per area could increase the seed number per area without bringing about a decrease in seed per pod as indicated by the low indirect path effect of pod number per area on seed number per area via seed per pod. However, seed per pod had a large indirect path effect on seed number per area via pod number per area indicating that environmental/cultural factors that increased seed per pod caused compensatory decreases in pod number per area thus having no effect on seed number per area. Importance of pod number per area in yield formation is further explained by the strong linear relationship between pod number per area and yield (Fig. 17), which was similar to the relationship between seed number per area and yield. This was also substantially supported by the cubic relationship between TDM(R5) with pod number per area, which was similar to the one between TDM(R5) with seed number per area and yield; as well as the nearly linear relationship between pod number per area and seed number per area (Fig. 14).

The above results are supported by other research implicating pod number per area as an important factor for mediating environmental/cultural influences on yield (Schou et al., 1978; Kokuban and Watanabe, 1983; Board and Harville, 1993; Board and Tan 1995) indicated that reduced pod number per area played a prominent role in decreasing yield due to partial defoliations imposed from R1 to a few days after R5. Kokuban and Watanabe (1983) have indicated that seed yield was principally determined by pod number per area or seed number per area. Shibles et al. (1975) have stated that seed per pod was genetically influenced, and seed number per area is usually highly correlated with pod number per area.

Correlation analysis and direct path coefficients indicated that reproductive node number per area was somewhat more important than pods per reproductive node in affecting pod number per area, but both these yield components appeared to be important. Indirect path coefficients between pods per reproductive node and reproductive node number per area in affecting pod number per area were small, indicating that little compensation occurred between the two; that is, an increase in either yield component does not result in decrease in the other. Regression analysis revealed the greater importance of reproductive node number per area vs. pods per reproductive node. Previous research indicated that CGR during the early reproductive period affected pod number per area through regulation of reproductive node number per area (Board and Harville, 1993; Board et al., 1992; Board and Tan, 1995). Board et al. (1995) also stated that pod number per area was more responsive to source strength variations than was seed per pod or seed size.

Reproductive node number per area was strongly linked with pod number per area, seed number per area, and yield in nonlinear relationships (either quadratic or cubic, Figs. 18, 21, and 22, respectively) with high r^2 values (0.73, 0.78, and 0.70, respectively). Seed number per area was maximized at about 650 reproductive nodes m^{-2} above which the curve plateaud. The pod number per area and yield were also maximized at around 650 to 700 reproductive nodes m^{-2}. This indicates that pod number per area, seed number per area and yield are maximized by the regulation of reproductive node number per area. Pods per reproductive node on the other hand, was not strongly linked with pod number per area ($r^2 = 0.26$; Fig. 19), reproductive node number per area ($r^2 = 0.24$; Fig. 20), seed number per area ($r^2 = 0.20$; Fig. 23) and yield ($r^2 = 0.17$; Fig.

24). Further substantiation for the greater importance of reproductive node number per area is seen in the relationships with TDM(R5). Reproductive node number per area and TDM(R5) existed in a moderate cubic relationship ($r^2 = 0.49$; Fig. 9), which was similar to the relationship between TDM(R5) and yield, whereas pods per reproductive node showed only a slight linear relationship with TDM(R5) ($r^2 = 0.26$; Fig. 8).

Correlation analysis and direct path coefficients indicated that node number per area was more important than fraction of reproductive nodes in affecting pod number per area. Node number per area increased reproductive node number per area without bringing about a change in fraction of reproductive nodes as indicated by the low indirect path effect of node number per area on reproductive node number per area via fraction of reproductive nodes. Pod number per area increased linearly with node number per area up to about 600 nodes m^{-2}, slowed above this level, and then plateaud at about 800 nodes m^{-2}. Seed number per area also showed a similar response with node number per area in a cubic relationship ($r^2 = 0.76$; Fig. 29). Reflecting these trends, yield responded to node number per area in a quadratic fashion ($r^2 = 0.64$; Fig. 30). Yield increased linearly as the node number per area advanced to 600 nodes m^{-2}. Above this point, incremental yield increases progressively declined as node number per area rose to 1000 nodes m^{-2}. The importance of node number per area can be further substantiated by its relationship with TDM(R5). The node number per area and TDM(R5) existed in a moderate cubic relationship ($r^2 = 0.49$; Fig. 10), which was similar to the relationship between TDM(R5) and yield.

Formation periods for node number per area, reproductive node number per area, pod number per area, and seed number per area extend from emergence to shortly after R5 (Board and Settimi, 1986; Pigeaire et al., 1986; Peterson et al., 1992; Board and Tan, 1995). Thus it would be expected that integrated photosynthetic activity (emergence - R5) and hence TDM(R5) would need to be at a certain level to optimize these components and thus optimize yield. Based on the data presented, integrated photosynthetic activity during this period must be long enough to generate a TDM(R5) of 600 g m^{-2} to optimize levels of node number per area, reproductive nodes, pod number per area, and seed number per area. Yield plateaus at this level of TDM(R5), demonstrating the "Law of Diminishing Returns" response to TDM(R5) because all four important yield components responded to TDM(R5) in a similar fashion.

2.4.3 <u>Practical Applications for the Results</u>

The TDM(R5) criterion can be used as a good management tool by the farmers. They can assess the performance of the crop at R5 and effectively manipulate the cultural practices to realize optimum yields. Farmers achieving a TDM(R5) level of about 600 g m^{-2} would expect optimum yield and should guard against any stress during seed filling that limits this potential. Achievement of TDM(R5) below this level would indicate less yield potential and demonstrate that some environmental stress during the emergence to R5 period was operative (e.g., waterlogging, drought, etc.). Therefore, farmers should adjust their cultural practices in such fields to ensure that CGR and/or length of the emergence to R5 period is long enough to achieve the required TDM(R5) (e.g., reducing the row space or increasing the population). Also, selection of cultivars with a longer period from emergence to R5 and/or greater crop growth rate during this time would be advantageous.

We know that several factors that limit crop growth and development become operation at different stages of development. This differed timing of occurrence of these factors results in distortion of the regular sigmoid growth curve which could be plotted based on the timing of occurrence of growth limiting factors. By having a TDM(R5) criterion we can look at the level of TDM(R5) achieved by the farmer, and can assess the approximate timing of occurrence of the adverse effects on crop growth, i.e., whether the crop suffered long before R5 was reached or just prior to stage. Also having a TDM criterion by the start of flowering (R1) will further strengthen our cause to provide a better assessment of timing of occurrence of adverse growth limiting factors. A failure in achieving the required TDM(R1) levels will indicate that the factors that affected the crop occurred prior to R1 stage and such factors could be insufficient seed germination, or adverse soil pH etc. But failure to achieve the required TDM(R5), in spite of getting the optimum TDM(R1) indicates that the resources that were sufficient to the crop during the early stages of growth became insufficient after the R1 stage has been reached. Such factors could be mineral deficiencies, lack of light interception that limited the photosynthetic capacity.

The data indicated that in many cases, crop growth rate and/or length of the emergence to R5 period created greater TDM(R5) than was necessary to achieve optimum yield potential. This may have a negative effect on yield, if such “over growth” contributes to lodging, disease, or some other factor that negatively affects yield. Farmers could save money by reducing seeding rate in such cases. Achievement of suboptimal yields in spite of realizing the critical TDM(R5) level of about 600 g m^{-2} would suggest that the yield limiting factors, such as pests or diseases or severe moisture stress, affected by the crop during the seed-filling period (R5 - R7).

This study clearly outlines yield components that do and do not respond to increased photosynthetic capacity. Yield components, such as seed number per area, pod number per area, reproductive node number per area and node number per area, which responded strongly to CGR, are likely to be affected by environmental factors/ management practices of the farmer. Possibly, differences in these yield components may also explain genetic differences in yield. The other yield components that did not respond to photosynthetic capacity are likely to be controlled by genetic factors and could also be useful for genetic improvement of crops.

The yield component approach for genetic improvement would not be successful if factors such as yield component compensation, where selection for one component resulted in a decrease in some other component leaving yield unaffected. For example, a classic case of compensation was reported in previous research when selection for larger seeds increased seed size but seed number per area decreased thus maintaining a constant yield (Hartwig and Edwards, 1970). Our study showed that increasing seed size would result in decreased seed number per area and thus leaving yield unaffected. However, the reverse compensation did not occur so genetic selection for seed number per area or factors affecting it could genetically improve yield. Another example: seed per pod was reported to be genetically controlled (Shibles et al., 1975). In our study seed per pod had a large indirect path effect on seed number per area via pod number per area (path effect = -0.51) indicating that environmental/cultural factors that increased seed per pod caused compensatory decreases in pod number per area thus having no effect on seed number per area and yield. Therefore, it probably could not be used as a trait for genetic improvement in soybean. However our conclusions are based strictly on the environmental responses of the crops but not based on a vast genetic study, which would be otherwise be required to produce firm conclusions on use of the traits for genetic improvement.

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CHAPTER 3: SUMMARY AND CONCLUSIONS

Identification of criterion that indicates soybean [*Glycine max* (L.) Merril] yield would provide farmers with useful management tools as well as assess the effect of various environmental factors that limit crop yield. Possible yield criteria are yield components (e.g., seed number per area, seed size, etc.) and growth dynamic factors, such as total dry matter (TDM), leaf area index (LAI), and light interception (LI). The use of yield components, LAI or LI as criteria is not promising because of the variability and difficulty for assessing them in production environments. Since a certain TDM level is expected to optimize yield, and R5 marks the end of the period for vegetative TDM accumulation, TDM(R5) is a good putative criterion for optimum yield. Moreover, TDM(R5) can be easily determined and R5 stage can be easily predicted. Determination of yield components important in yield formation helps substantiate TDM(R5) as a criterion for optimum yield, since TDM accumulation during their formation periods would play an important role in yield formation. Adoption of TDM(R5) as a yield criterion would have greater efficacy if it were shown that these significant yield components responded to TDM(R5) in a manner similar to that shown for yield. Because TDM(R5) could be an efficient and accurate yield criterion and because little research has been done on this subject, our objectives were to use analyses of relationships between yield components, TDM, and yield to determine: 1. If TDM(R5) can be used as criterion for optimum yield; and 2. What level of TDM(R5) is required to optimize yield.

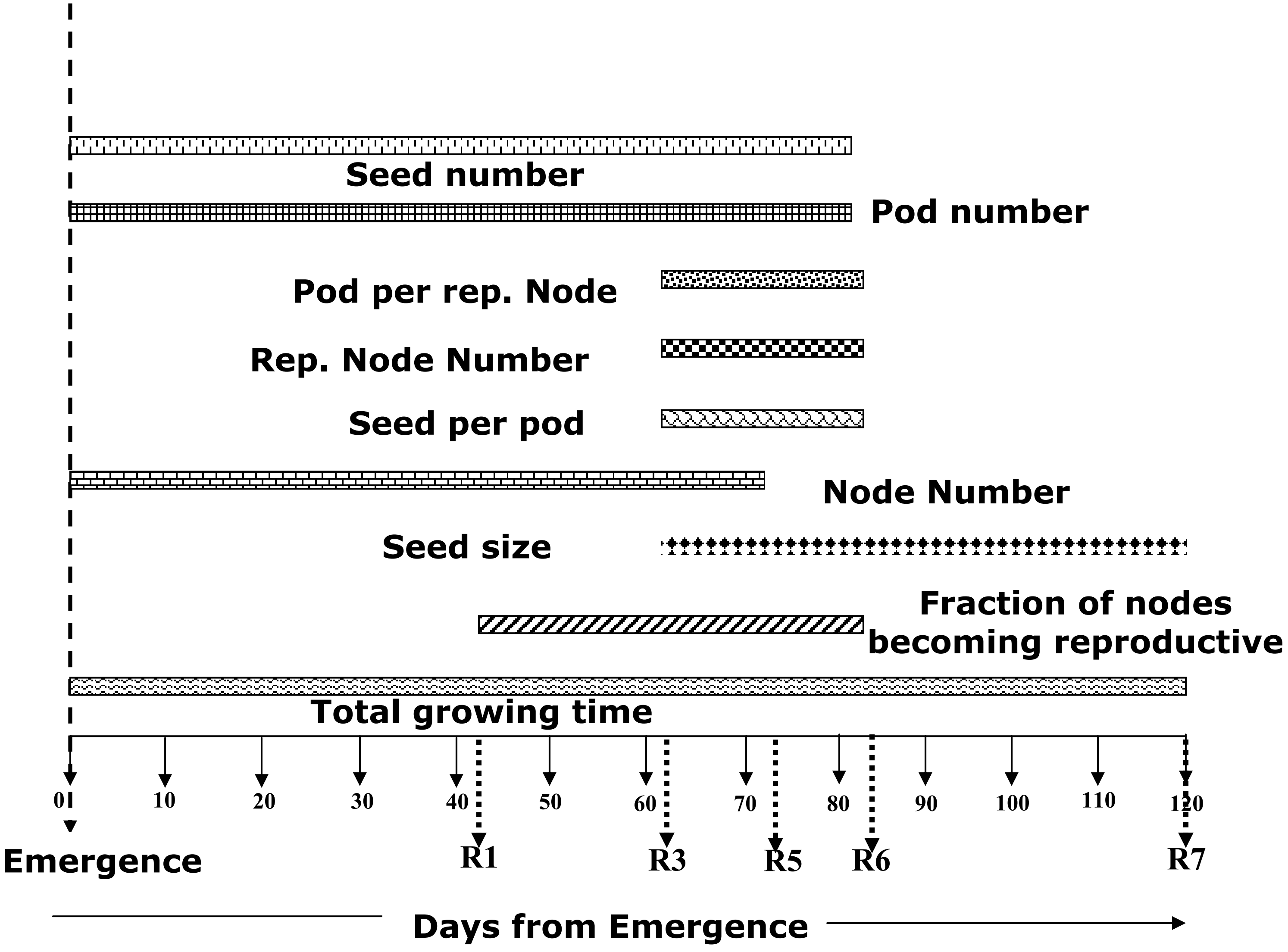
The data for this study were collected from previous studies conducted near Baton Rouge, LA (30^0 N Lat) between 1987 and 1996 and were combined to make a single data set. These studies contained a variety of cultural treatments that altered environmental growing conditions (planting dates, row spacings, plant populations, partial defoliation, and waterlogging stress). The data thus pooled were subjected to correlation, regression and path coefficient analyses to achieve our objectives.

The results of the study clearly indicated that TDM(R5) can be effectively used as a criterion for optimum yield. Critical TDM(R5) level of about 600 g m^{-2} must be achieved by the farmer to realize optimum yield in soybean. The regression analysis between the yield components, yield and TDM(R5) had clearly indicated as to why TDM(R5) could be effectively used as a criterion for optimum yield. Regression of yield on individual yield components, regression of individual yield components between themselves, correlation analysis, and path coefficient analysis indicated that the yield components most important in yield formation were seed number per area, pod number per area, reproductive node number per area, and node number per area. Seed size, seed per pod, pods per reproductive node, and fraction of nodes becoming reproductive were not strongly linked with yield or dry matter accumulation. The importance of TDM(R5) was further substantiated by its strong association with important yield components stated above and its weak association with yield components that were not strongly linked with yield.

The practical implications from the research are that farmers should adjust their cultural practices to ensure that crop growth rate and/or length of the emergence to R5 period is long enough to achieve this goal. Possible methods that help are reduced row spacing, greater plant population, and alleviation of environmental stresses prevalent during the emergence to R5 period. Also, selection of cultivars with a longer period from emergence to R5 and/or greater crop growth rate during this time would be advantageous. These results agree with some previous findings (Egli et al., 1987) but disagree with others claiming that seed number and yield had a linear relationship with crop growth rate prior to R5 (Egli and Yu, 1991). The Data indicated that in many cases, crop growth rate and/or length of the emergence to R5 period created greater TDM (R5) than was necessary to achieve optimum yield potential. This may have a negative effect on yield, if such “over growth” contributes to lodging, disease, or some other factor that negatively affects yield. In such cases, farmers can alleviate these problems, and increase profitability by reducing seeding rates.

This study clearly outlines yield components that do and do not respond to increased photosynthetic capacity. Yield components, such as seed number per area, pod number per area, reproductive node number per area and node number per area, which responded strongly to CGR, are likely to be affected by the environmental/ management factors practiced by the farmer. Possibly, differences in these yield components may also explain genetic differences in yield. The other yield components that did not respond to photosynthetic capacity are likely to be controlled by genetic factors and could also be useful for genetic improvement of crops. However, the yield component approach for genetic improvement would not be successful if factors, such as yield component compensation, where selection for one component resulted in a decrease in some other leaving yield unaffected

APPENDIX A: TIME LINE FOR THE FORMATION OF YIELD COMPONENTS IN A TYPICAL MATURITY GROUP V SOYBEAN CULTIVAR PLANTED AT AN OPTIMAL PLANTING DATE (MAY) AT BATON ROUGE, LA (30^0 N LAT).



APPENDIX B: STAGES OF DEVELOPMENT IN SOYBEAN

Stage	Description
	Vegetative stages
V1	Completely unrolled leaf at the unifoliate node.
V2	Completely unrolled leaf at the first node above the unifoliate leaf
V3	Three nodes on main stem beginning with the unifoliate node.
V (N)	N nodes on the main stem beginning with the unifoliate node
	Reproductive stages
R1	One flower at any node
R2	Flower at node immediately below the uppermost nodes with a completely unrolled leaf
R3	Pod 0.5 cm (1/4”) long at one of the four upper most nodes with a completely unrolled leaf
R4	Pod 2 cm (3/4”) long at one of the four upper most nodes with a completely unrolled leaf
R5	Beans beginning to develop (can be felt when the pod is squeezed) at one of the four upper most nodes with a completely unrolled leaf
R6	Pod containing full size green beans at one of the four upper most nodes with a completely unrolled leaf
R7	Pods yellowing; 50% of leaves yellow. Physiological maturity.
R8	95% pods brown. Harvest maturity.

APPENDIX C: ABBREVIATIONS

S.no	Abbreviation	Expansion	Units
1	**TDM**	Total dry matter	g m^{-2}
2	**LI**	Light interception	%
3	**PAR**	Photosynthetically active radiation	nm (400-700)
4	**LAI**	Leaf area index	No units
5	**LIE**	Light interception efficiency	%
6	**RUE**	Radiation use efficiency	g M J^{-1}
7	**RLAER**	Relative leaf area expansion rate	RGR (la), m^{2} m^{-2} day^{-1}
8	**CGR**	Crop growth rate	g m^{-2} (land area) day^{-1}
9	**RGR**	Relative growth rate	g g^{-1} day^{-1}
10	**NAR**	Net assimilation rate	g m^{-2} (leaf area) day^{-1}
11	**LAR**	Leaf area ratio	m^2 kg^{-1}(plant mass)
12	**SLR**	Specific leaf area	m^2 kg^{-1}(leaf mass)
13	**HI**	Harvest Index	%
14	**TDMR5**	TDM at R5	g m^{-2}
15	**R_{IR}**	Reflected infrared radiation	M J^{-1}
16	**R_{R}**	Reflected red radiation	M J^{-1}
17	**NDVI**	Normalized difference vegetative index	$(R_{IR} - R_R)/(R_{IR} + R_R)$ no.
18	**SR**	Simple ratio	(R_{IR}/R_R) no.

APPENDIX D: SIGNIFICANCE LEVELS OF CORRELATION AND REGRESSION ANALYSIS BETWEEN YIELD COMPONENTS AND DRY MATTER PARAMETERS

S No.	Parameters Tested	R^2 Statistics						Relationship
		X	Significance	X*X	Significance	X*X*X	Significance	
1	Seed No. Vs. TDM R1	0.4039	< 0.0001	0.5495	< 0.0001	0.5767	0.0465	Cubic
2	Seed No. Vs. TDM R5	0.4818	< 0.009	0.6328	< 0.009	0.7324	<0.0001	Cubic
3	Seed No. Vs. TDM R7	0.7403	< 0.009	0.8661	< 0.0001	0.8695	0.2008	Quadratic
4	Seed No. Vs. DTDM	0.4416	< 0.0001	0.5718	< 0.0001	0.6752	< 0.0001	Cubic
5	Seed No. Vs. EFFSEED	0.1075	< 0.0063	0.1108	0.6218	0.1308	0.2292	Linear
6	Seed No. Vs. DTDM R5R7	0.6293	< 0.0001	0.6624	0.0141	0.6701	0.2251	Quadratic
7	Seed No. Vs. HI	0.2762	< 0.0001	0.2826	0.4473	0.2868	0.5404	Linear
8	Seed Size. Vs. TDM R1	0.2009	< 0.0001	0.2131	0.3201	0.2735	0.0244	L & C
9	Seed Size. Vs. TDM R5	0.2181	< 0.0001	0.2582	0.0652	0.3132	0.0270	L & C
10	Seed Size. Vs. TDM R7	0.3052	< 0.0001	0.3454	0.0499	0.3576	0.2732	Quadratic
11	Seed Size. Vs. DTDM	0.1922	0.0002	0.2608	0.0167	0.2824	0.1700	Quadratic
12	Seed Size. Vs. EFFSS	0.0498	0.0671	0.1564	0.0056	0.1632	0.4743	Quadratic
13	Seed Size. Vs. DTDM R5R7	0.2303	< 0.0001	0.3096	0.0081	0.3290	0.1785	Quadratic

14	Seed Size. Vs. HI	0.1884	0.0002	0.2007	0.3912	0.3195	0.0014	L & C
S No.	**Parameters Tested**	**R^2 Statistics**						**Relationship**
		X	**Significance**	**X*X**	**Significance**	**X*X*X**	**Significance**	
15	Seed per pod. Vs. TDM R1	0.1494	0.0011	0.1832	0.1057	0.1883	0.5322	Linear
16	Seed per pod. Vs. TDM R5	0.1549	0.0009	0.1975	0.0682	0.2012	0.5856	Linear
17	Seed per pod. Vs. TDM R7	0.1760	0.0004	0.1796	0.5944	0.1840	0.5587	Linear
18	Seed per pod. Vs. DTDM	0.1339	0.0021	0.1947	0.3030	0.1951	0.8465	Quadratic
19	Seed per pod. Vs. EFFSEDPD	0.2034	0.0001	0.3014	0.0036	0.3165	0.2385	Quadratic
20	Seed per pod. Vs. DTDM R5R7	0.0961	0.0101	0.1172	0.2182	0.1489	0.1272	Linear
21	Seed per pod. Vs. HI	0.2403	< 0.0001	0.3319	0.0040	0.3776	0.0340	Cubic
22	Pod Number. Vs. TDM R1	0.4931	< 0.0001	0.6513	< 0.0001	0.6634	0.1339	Quadratic
23	Pod Number. Vs. TDM R5	0.5759	< 0.0001	0.7479	< 0.0001	0.8123	< 0.0001	Cubic
24	Pod Number. Vs. TDM R7	0.8380	< 0.0001	0.9150	< 0.0001	0.9157	0.4633	Quadratic
25	Pod Number. Vs. DTDM	0.5234	< 0.0001	0.6894	< 0.0001	0.7666	< 0.0001	Cubic
26	Pod Number. Vs. EFFPOD	0.1503	0.0011	0.1613	0.3581	0.2381	0.0135	L & C
27	Pod Number. Vs. DTDM R5R7	0.6654	< 0.0001	0.6733	0.2173	0.6733	0.8910	Linear
28	Pod Number. Vs. HI	0.4002	< 0.0001	0.4264	0.0897	0.4491	0.1088	Linear

29	PPRN. Vs TDMR1	0.2106	< 0.0001	0.2348	0.1564	0.2366	0.7023	Linear
S No.	**Parameters Tested**	**R^2 Statistics**						**Relationship**
		X	**Significance**	**X*X**	**Significance**	**X*X*X**	**Significance**	
30	PPRN. Vs. TDM R5	0.2606	< 0.0001	0.2902	0.1050	0.2925	0.6467	Linear
31	PPRN. Vs. TDM R7	0.2131	< 0.0001	0.2245	0.3323	0.2260	0.7216	Linear
32	PPRN. Vs. DTDM	0.2424	< 0.0001	0.2685	0.1326	0.2721	0.5758	Linear
33	PPRN. Vs. EFFPDRPND	0.1012	0.0082	0.1061	0.5522	0.1750	0.0240	L & C
34	PPRN. Vs. DTDM R5R7	0.0547	0.0548	0.0917	0.1088	0.1013	0.4094	N S
35	PPRN. Vs. HI	0.1543	0.0009	0.1733	0.2269	0.1733	0.9502	Linear
36	Rep. Node No. Vs. TDM R1	0.2272	< 0.0001	0.3805	0.0002	0.4100	0.0783	Quadratic
37	Rep. Node No. Vs. TDM R5	0.2547	< 0.0001	0.4109	< 0.0001	0.4920	0.0002	Cubic
38	Rep. Node. No.Vs. TDM R7	0.5350	< 0.0001	0.6293	< 0.0001	0.6372	0.2415	Quadratic
39	Rep. Node No. Vs. DTDM	0.2276	< 0.0001	0.3825	< 0.0001	0.4721	0.0016	Cubic
40	Rep. Node No. Vs. EFFREPND	0.0057	0.5390	0.0156	0.4214	0.0272	0.3854	N S
41	Rep. Node No. Vs. DTDM R5R7	0.6287	< 0.0001	0.6295	0.7039	0.6429	0.1268	Linear
42	Rep. Node No. Vs. HI	0.1964	0.0020	0.2078	0.3368	0.2451	0.0802	Linear
43	Node No. Vs. TDM R1	0.2852	< 0.0001	0.4263	0.0002	0.4694	0.0259	Cubic
44	Node No. Vs. TDM R5	0.2729	< 0.0001	0.3863	0.0009	0.4933	0.0005	Cubic

45	Node No. Vs. TDM R7	0.4990	< 0.0001	0.6193	< 0.0001	0.6278	0.2306	Quadratic
S No.	**Parameters Tested**	**R^2 Statistics**						**Relationship**
		X	**Significance**	**X*X**	**Significance**	**X*X*X**	**Significance**	
46	Node No. Vs. DTDM	0.2273	< 0.0001	0.3336	0.0020	0.4467	0.0006	Cubic
47	Node No. Vs. EFFNOD	0.0096	0.4255	0.0417	0.1448	0.0487	0.4945	N S
48	Node No. Vs. DTDM R5R7	0.5141	< 0.0001	0.5247	0.2342	0.5366	0.2045	Linear
49	Node No. Vs. HI	0.2032	0.0001	0.2157	0.3140	0.2500	0.0917	Linear
50	Frac RPND. Vs. TDM R1	0.0058	0.5340	0.0186	0.3609	0.0188	0.9031	N S
51	Frac RPND. Vs. TDM R5	0.0040	0.6077	0.0657	0.0423	0.0660	0.8788	Quadratic *
52	Frac RPND. Vs. TDM R7	0.0559	0.0520	0.0581	0.6979	0.0721	0.3297	N S
53	Frac RPND Vs. DTDM	0.0137	0.3406	0.0928	0.0202	0.0928	0.9968	Quadratic *
54	Frac RPND Vs. EFFRAC	0.0043	0.5943	0.0437	0.1066	0.0437	0.9737	N S
55	Frac RPND Vs. DTDM R5R7	0.1562	0.0008	0.1594	0.6229	0.1713	0.3423	Linear
56	Frac RPND Vs. HI	0.0005	0.8540	0.0009	0.8722	0.0053	0.5960	N S
57	Yield. Vs. TDM R1	0.5445	< 0.0001	0.6753	< 0.0001	0.6764	0.6548	Quadratic
58	Yield. Vs. TDM R5	0.6322	< 0.0001	0.7978	< 0.0001	0.8231	0.0036	Cubic
59	Yield. Vs. TDM R7	0.9316	< 0.0001	0.9678	< 0.0001	0.9678	0.8609	Quadratic
60	Yield Vs. DTDM	0.5733	< 0.0001	0.7427	< 0.0001	0.7839	0.0009	Cubic

61	Yield Vs. DTDM R5R7	0.7525	< 0.0001	0.7525	0.8894	0.7537	0.5861	Linear
S No.	**Parameters Tested**	**R^2 Statistics**						**Relationship**
		X	**Significance**	**X*X**	**Significance**	**X*X*X**	**Significance**	
62	Yield Vs. HI	0.4069	< 0.001	0.4208	0.2153	0.4675	0.0208	L & C
63	DTDM R1R5 Vs TDMR1	0.5531	< 0.001	0.5532	0.8770	0.5537	0.7910	Linear
64	DTDM R1R5 Vs TDMR5	0.9561	< 0.0001	0.9561	0.8816	0.9570	0.2504	Linear
65	DTDM R1R5 Vs TDMR7	0.7665	< 0.0001	0.8113	0.0002	0.8117	0.7150	Quadratic
66	DTDM R1R5 Vs DTDMR5R7	0.1850	0.0003	0.2073	0.1808	0.2103	0.6252	Linear
67	HI Vs. Seed Number	0.2761	< 0.0001	0.3416	< 0.0134	0.3458	< 0.5251	Quadratic
68	HI Vs. Seed Size	0.1884	< 0.0002	0.1999	< 0.3366	0.2151	< 0.2698	Linear
69	HI Vs. Seed per pod	0.2402	< 0.0001	0.2624	< 0.1670	0.2633	< 0.7807	Linear
70	HI Vs. Pod Number	0.4002	< 0.001	0.5058	< 0.004	0.5161	< 0.2480	Quadratic
71	HI Vs. PPRN	0.1543	< 0.009	0.1579	< 0.6024	0.2606	< 0.0041	Linear
72	HI Vs. Rep Node No.	0.1964	< 0.0002	0.2004	< 0.5686	0.2142	< 0.2940	Linear
73	HI Vs. Frac Rep Node	0.0052	< 0.8540	0.0909	< 0.4560	0.0092	< 0.9561	N S
74	HI Vs. Node Number	0.2032	< 0.0001	0.2084	< 0.5163	0.2178	< 0.3846	Linear
75	HI Vs. TDMR1	0.3993	< 0.0001	0.4191	< 0.1405	0.4415	< 0.1138	Linear
76	HI Vs. TDMR5	0.5906	< 0.0001	0.6349	< 0.0066	0.7144	< 0.0001	Cubic

77	HI Vs. DTDM	0.5869	< 0.0001	0.6241	< 0.0137	0.6858	< 0.0007	Cubic
78	HI Vs. TDMR7	0.6217	< 0.0001	0.7165	< 0.0001	0.7165	< 0.9311	Quadratic

S No.	**Parameters Tested**	**R^2 Statistics**						**Relationship**
		X	**Significance**	**X*X**	**Significance**	**X*X*X**	**Significance**	
79	HI Vs. DTDMR5R7	0.2948	< 0.0001	0.3651	< 0.0092	0.3698	< 0.4928	Quadratic
80	HI Vs. EFFSEED	0.5039	< 0.0001	0.5632	< 0.0042	0.5672	< 0.4445	Quadratic
81	HI Vs. EFFSS	0.3679	< 0.0001	0.5818	< 0.0001	0.6035	< 0.0655	Quadratic
82	HI Vs. EFFSEDPD	0.4249	< 0.0001	0.6446	< 0.0001	0.6561	< 0.1486	Linear
83	HI Vs. EFFPOD	0.4329	< 0.0001	0.4907	< 0.0082	0.4976	< 0.3511	Quadratic
84	HI Vs. EFFREPND	0.4278	< 0.0001	0.4920	< 0.0056	0.5027	< 0.2461	Quadratic
85	HI Vs. EFFPDRPND	0.4069	< 0.0001	0.5719	< 0.0001	0.5903	< 0.0957	Quadratic
86	HI Vs. EFFRAC	0.4385	< 0.0001	0.6179	< 0.0001	0.6292	< 0.1682	Quadratic
87	HI Vs. EFFNOD	0.4232	< 0.0001	0.5009	< 0.0022	0.5197	< 0.1196	Quadratic

APPENDIX E: SIGNIFICANCE LEVELS OF CORRELATION AND REGRESSION ANALYSIS BETWEEN YIELD COMPONENTS AND YIELD

S No	**Parameters Tested**	**R^2 Statistics**						**Relationship**
		X	**Significance**	**X*X**	**Significance**	**X*X*X**	**Significance**	
1	Seed number Vs. Seed size	0.0238	0.2088	0.0267	0.6642	0.0342	0.4824	N S
2	Seed number Vs. Seed per pod	0.2308	0.2162	0.0244	0.7674	0.0255	0.7920	N S
3	Seed number Vs. Pod no.	0.8931	< 0.0001	0.9052	0.0055	0.9054	0.6802	Quadratic
4	Seed number Vs. PPRN	0.2053	< 0.0001	0.2162	0.3457	0.2188	0.6426	Linear
5	Seed number Vs. Rep. Node no.	0.5859	< 0.0001	0.7633	< 0.0001	0.7836	0.0171	Cubic
6	Seed number Vs. Frac. Rep. Nodes	0.0315	0.1473	0.0714	0.0997	0.1019	0.1449	N S
7	Seed number Vs. Node no.	0.6030	< 0.0001	0.7398	< 0.0001	0.7566	0.0400	Cubic
8	Seed size Vs. Seed per pod	0.3606	< 0.0001	0.4168	0.0149	0.4191	0.6117	Linear
9	Seed size Vs. Pod no.	0.1189	0.0040	0.1559	0.0960	0.1582	0.6797	Linear
10	Seed size Vs. PPRN	0.6067	0.5057	0.6081	0.7669	0.6842	0.0243	Cubic

11	Seed size Vs. Rep. Node no.	0.1509	0.0011	0.2887	0.0007	0.3500	0.0168	Cubic
S No.	**Parameters Tested**	**R^2 Statistics**						**Relationship**
		X	**Significance**	**X*X**	**Significance**	**X*X*X**	**Significance**	
12	Seed size Vs. Frac. Rep. Nodes	0.1112	0.0055	0.1246	0.3213	0.1427	0.2499	Linear
13	Seed size Vs. Node no.	0.0844	0.0162	0.1738	0.0100	0.2890	0.0020	Cubic
14	Seed per pod Vs. Pod no.	0.2103	< 0.0001	0.2552	0.0521	0.2554	0.8915	Linear
15	Seed per pod Vs. PPRN	0.1018	0.0080	0.2051	0.0050	0.2512	0.0514	Quadratic
16	Seed per pod Vs. Rep. Node no.	0.1238	0.0033	0.1595	0.1010	0.1926	0.1104	Linear
17	Seed per pod Vs. Frac. Rep. Nodes	0.0096	0.4276	0.0907	0.0188	0.1110	0.2319	Quadratic
18	Seed per pod Vs. Node no.	0.1520	0.0010	0.1793	0.1466	0.1903	0.3544	Linear
19	Pod no. Vs. PPRN	0.2586	< 0.0001	0.2596	0.7614	0.2598	0.9210	Linear
20	Pod no. Vs. Rep. Node no.	0.6466	< 0.0001	0.7325	< 0.0001	0.7360	0.3625	Quadratic
21	Pod no. Vs. Frac. Rep. Nodes	0.0180	0.2746	0.0254	0.4863	0.0609	0.1248	N S
22	Pod no. Vs. Node no.	0.6785	< 0.0001	0.7434	0.0001	0.7480	0.2826	Quadratic

23	PPRN. Vs. Rep. Node no.	0.0076	0.4794	0.2431	< 0.0001	0.2453	0.6700	Quadratic
24	PPRN. Vs. Frac. Rep. Nodes	0.0545	0.0553	0.0731	0.2579	0.1214	0.0652	N S
S No.	**Parameters Tested**	**R^2 Statistics**						**Relationship**
		X	**Significance**	**X*X**	**Significance**	**X*X*X**	**Significance**	
25	PPRN Vs. Node no.	0.0001	0.9383	0.2131	< 0.0001	0.2356	0.2183	Quadratic
26	Rep. Node no. Vs. Frac. Rep. Nodes	0.1009	0.0083	0.1409	0.0865	0.1458	0.5467	Linear
27	Rep. Node no. Vs. Node no.	0.9179	< 0.0001	0.9183	0.5610	0.9272	0.0068	L & C
28	Frac. Rep. Nodes Vs. Node no.	0.0020	0.7144	0.0095	0.4854	0.1520	0.0017	Cubic

APPENDIX F: POOLED DATA COLLECTED FROM THE STUDIES CONDUCTED NEAR BATON ROUGE, LA, 1987-1996

YEAR	PLT.DATE	CULTIVAR	TRT	TDM R1	TDM R5	DTDM	YIELD	SEED SIZE	SeedNo
				g/m2	g/m2	g/m2	*kg/ha*	g/100seed	no/m2
1987	J	FORREST	100	57.8	166.7	108.9	1576	11.51	1232
1987	J	FORREST	50	89.2	227.5	138.3	2139	11.27	1708
1987	J	FORREST	50H	112.3	330.2	217.9	2416	11.63	1870
1987	J	CENTENNIAL	100	73.0	153.8	80.8	1524	11.99	1144
1987	J	CENTENNIAL	50	82.6	251.7	169.1	2304	12.30	1686
1987	J	CENTENNIAL	50H	85.8	229.9	144.1	2388	11.61	1851
1988	M	FORREST	100	73.7	614.3	540.6	3558	12.39	2585
1988	M	FORREST	50	120.3	670.6	550.3	3662	13.27	2484
1988	M	FORREST	50H	171.6	774.8	603.2	3896	12.24	2865
1988	M	CENTENNIAL	100	222.6	811.6	589.0	3476	13.78	2270
1988	M	CENTENNIAL	50	320.7	1029.1	708.4	3924	13.45	2626
1988	M	CENTENNIAL	50H	380.1	1260.0	879.9	3898	13.36	2626
1988	J	FORREST	100	117.1	277.3	160.2	2835	12.75	2001
1988	J	FORREST	50	156.1	362.4	206.3	3339	12.38	2427
1988	J	FORREST	50H	178.5	427.2	248.7	3399	12.75	2399
1988	J	CENTENNIAL	100	114.3	327.5	213.2	2591	12.72	1833
1988	J	CENTENNIAL	50	119.9	304.1	184.2	3054	12.98	2118
1988	J	CENTENNIAL	50H	142.2	426.5	284.3	3058	12.59	2186
1989	J	CENTENNIAL	100	130.0	332.0	202.0	2587	13.56	1717
1989	J	CENTENNIAL	75	113.0	276.0	163.0	2670	13.98	1719
1989	J	CENTENNIAL	50	170.0	397.0	227.0	3662	14.05	2346
1989	J	CENTENNIAL	25	174.0	420.0	246.0	3021	14.07	1932
1990	J	CENTENNIAL	100	122.0	416.0	294.0	2873	12.95	1997
1990	J	CENTENNIAL	75	161.0	569.0	408.0	3431	13.85	2230
1990	J	CENTENNIAL	50	199.0	586.0	387.0	3672	12.59	2625
1990	J	CENTENNIAL	25	149.0	496.0	347.0	2851	11.91	2154

1989	J	CENTENNIAL	CONT	74.0	232.0	158.0	3095	13.29	2096
1989	J	CENTENNIAL	R3	76.0	205.0	129.0	3118	13.07	2147
1989	J	CENTENNIAL	R4	81.0	204.0	123.0	2905	12.99	2013
1989	J	CENTENNIAL	R5	79.0	174.0	95.0	2349	12.43	1701
1989	J	CENTENNIAL	R6.5	87.0	192.0	105.0	2194	11.84	1668
1990	J	CENTENNIAL	CONT	169.0	486.0	317.0	3103	12.59	2218
1990	J	CENTENNIAL	R3	151.0	378.0	227.0	2785	11.76	2131
1990	J	CENTENNIAL	R4	151.0	327.0	176.0	2646	12.15	1960
1990	J	CENTENNIAL	R5	153.0	301.0	148.0	2529	12.06	1887
1990	J	CENTENNIAL	R6.5	167.0	364.0	197.0	2456	12.75	1734
1993	J	CENTENNIAL-D	10"	207.0	437.0	230.0	3622	11.99	2719
1993	J	CENTENNIAL-D	40"	150.0	365.0	215.0	3103	12.49	2236
1993	J	CENTENNIAL-UD	10"	67.0	267.0	200.0	2937	11.71	2257
1993	J	CENTENNIAL-UD	40"	70.0	204.0	134.0	2062	11.85	1566
1994	J	CENTENNIAL-D	10"	50.0	126.0	76.0	1867	14.52	1157
1994	J	CENTENNIAL-D	40"	47.0	122.0	75.0	1217	14.72	744
1994	J	CENTENNIAL-UD	10"	56.0	107.0	51.0	835	12.63	595
1994	J	CENTENNIAL-UD	40"	41.0	101.0	60.0	366	11.34	290
1994	M	DP415	25	145.0	526.0	381.0	3523	16.55	1916
1994	M	DP415	64	208.0	506.0	298.0	4226	17.72	2146
1994	M	DP415	75	188.0	584.0	396.0	4324	17.41	2235
1994	M	DP415	113	210.0	609.0	399.0	3679	17.82	1858
1995	M	DP415	25	137.0	621.0	484.0	3658	14.89	2211
1995	M	DP415	64	170.0	632.0	462.0	3933	14.22	2489
1995	M	DP415	75	215.0	722.0	507.0	3830	14.69	2346
1995	M	DP415	113	190.0	656.0	466.0	4131	14.69	2531
1995	M	DP3606	LOW	210.0	685.0	475.0	4264	14.88	2579
1995	M	DP3606	MED	284.0	752.0	468.0	4446	14.55	2750
1995	M	DP3606	HIGH	322.0	779.0	457.0	4222	14.86	2557
1996	M	DP3606	LOW	238.0	747.0	509.0	3873	14.87	2344
1996	M	DP3606	MED	277.0	788.0	511.0	3864	15.27	2277
1996	M	DP3606	HIGH	362.0	759.0	397.0	3701	15.02	2218

1993	J	CENTENNIAL	Control	172.0	407.0	235.0	3600	12.80	2531
1993	J	CENTENNIAL	Lf Rem	134.0	281.0	147.0	3016	12.38	2193
1994	J	CENTENNIAL	Control	89.0	172.0	83.0	1922	12.74	1358
1994	J	CENTENNIAL	Lf Rem	108.0	134.0	26.0	1536	12.78	1082
1992	J	CENTENNIAL	100	104.2	215.7	111.5	2233	11.46	1754
1992	J	CENTENNIAL	50	108.9	254.0	145.1	2796	11.73	2145
1992	J	CENTENNIAL	25	115.1	301.4	186.3	3105	11.56	2417
1993	J	CENTENNIAL	100	132.8	364.8	232.0	3103	12.49	2236
1993	J	CENTENNIAL	50	229.7	426.0	196.3	3514	12.40	2550
1993	J	CENTENNIAL	25	192.3	436.5	244.2	3622	11.99	2719

YEAR	PLT.DATE	CULTIVAR	Seed per pod	PodNo.	POD/REP ND	REPND	Frac RpNd	NODNO	HI
			no.	No/m2	no.	No./M2		No/M2	%
1987	J	FORREST	2.32	531	2.04	260	0.727	358	65.7
1987	J	FORREST	2.06	829	2.00	415	0.755	549	57.6
1987	J	FORREST	1.90	984	2.00	492	0.708	695	56.1
1987	J	CENTENNIAL	1.97	581	2.12	274	0.770	356	61.2
1987	J	CENTENNIAL	1.97	856	2.15	398	0.752	529	59.5
1987	J	CENTENNIAL	1.97	940	1.92	489	0.710	689	59.8
1988	M	FORREST	2.02	1279	2.83	452	0.705	641	48.3
1988	M	FORREST	2.05	1212	2.53	479	0.702	682	54.7
1988	M	FORREST	1.96	1462	2.68	545	0.711	767	41.6
1988	M	CENTENNIAL	1.90	1195	2.78	430	0.638	674	44.4
1988	M	CENTENNIAL	1.83	1435	2.69	533	0.596	895	48.9
1988	M	CENTENNIAL	1.88	1397	2.76	506	0.650	779	54.5
1988	J	FORREST	2.21	906	2.35	385	0.721	534	61.8
1988	J	FORREST	2.18	1113	2.17	513	0.679	756	60.6
1988	J	FORREST	2.25	1066	2.23	478	0.696	687	62.8
1988	J	CENTENNIAL	2.09	877	2.07	424	0.745	569	60.0
1988	J	CENTENNIAL	2.19	967	2.33	415	0.728	570	58.4
1988	J	CENTENNIAL	2.15	1017	2.06	494	0.682	724	64.5
1989	J	CENTENNIAL	1.85	928	2.66	349	0.696	501	57.1

1989	J	CENTENNIAL	1.95	881	2.43	363	0.707	513	58.1
1989	J	CENTENNIAL	1.93	1215	2.59	469	0.673	697	57.8
1989	J	CENTENNIAL	1.89	1022	2.62	390	0.624	625	57.5
1990	J	CENTENNIAL	1.66	1203	2.90	415	0.661	627	56.1
1990	J	CENTENNIAL	1.60	1393	3.00	464	0.660	704	57.0
1990	J	CENTENNIAL	1.71	1535	3.34	460	0.644	714	54.4
1990	J	CENTENNIAL	1.71	1260	3.16	399	0.592	673	53.8
1989	J	CENTENNIAL	1.91	1097	2.37	463	0.716	647	58.3
1989	J	CENTENNIAL	1.95	1101	2.20	500	0.709	706	59.8
1989	J	CENTENNIAL	1.85	1088	2.27	479	0.660	726	57.1
1989	J	CENTENNIAL	1.93	881	2.09	422	0.666	633	65.5
1989	J	CENTENNIAL	1.82	916	1.89	485	0.659	736	65.0
1990	J	CENTENNIAL	1.78	1246	3.04	410	0.602	681	57.0
1990	J	CENTENNIAL	1.90	1122	2.66	422	0.641	658	56.8
1990	J	CENTENNIAL	1.81	1083	2.51	431	0.589	732	56.5
1990	J	CENTENNIAL	1.82	1037	2.56	405	0.600	675	56.1
1990	J	CENTENNIAL	1.65	1051	2.84	370	0.596	621	55.8
1993	J	CENTENNIAL-D	2.06	1320	2.60	508	0.711	714	57.0
1993	J	CENTENNIAL-D	1.96	1141	2.29	498	0.729	683	59.7
1993	J	CENTENNIAL-UD	2.06	1096	2.06	532	0.710	749	61.0
1993	J	CENTENNIAL-UD	2.03	771	1.94	398	0.746	533	61.2
1994	J	CENTENNIAL-D	1.97	587	2.39	246	0.689	357	62.4
1994	J	CENTENNIAL-D	1.96	380	2.44	156	0.692	225	62.4
1994	J	CENTENNIAL-UD	1.90	313	1.90	165	0.633	260	59.3
1994	J	CENTENNIAL-UD	2.07	140	1.71	82	0.584	141	58.0
1994	M	DP415	1.71	1120	2.39	469	0.823	570	56.7
1994	M	DP415	1.50	1431	2.07	691	0.714	968	51.7
1994	M	DP415	1.59	1406	1.82	772	0.764	1011	52.4
1994	M	DP415	1.62	1147	1.62	708	0.741	955	52.1
1995	M	DP415	1.77	1249	2.40	520	0.836	623	52.4
1995	M	DP415	1.96	1270	2.24	567	0.760	746	51.1
1995	M	DP415	1.84	1275	2.15	593	0.715	830	49.7

1995	M	DP415	1.74	1455	2.07	703	0.726	968	48.2
1995	M	DP3606	1.86	1387	3.15	440	0.805	547	54.5
1995	M	DP3606	1.83	1503	2.96	508	0.729	696	51.0
1995	M	DP3606	1.84	1390	2.63	528	0.690	766	51.9
1996	M	DP3606	1.82	1288	2.78	463	0.710	653	48.7
1996	M	DP3606	1.79	1272	2.88	442	0.675	654	50.3
1996	M	DP3606	1.79	1239	2.49	498	0.673	739	46.6
1993	J	CENTENNIAL	1.95	1298	2.14	607	0.684	887	57.0
1993	J	CENTENNIAL	1.93	1136	2.02	562	0.666	844	56.6
1994	J	CENTENNIAL	2.11	643	2.31	279	0.624	446	60.9
1994	J	CENTENNIAL	1.97	549	2.08	264	0.596	443	60.1
1992	J	CENTENNIAL	2.11	831	2.00	416	0.718	579	57.9
1992	J	CENTENNIAL	2.00	1073	1.92	559	0.678	824	57.3
1992	J	CENTENNIAL	2.04	1185	1.99	595	0.659	904	57.6
1993	J	CENTENNIAL	1.96	1141	2.29	498	0.729	683	59.7
1993	J	CENTENNIAL	1.96	1301	2.61	499	0.693	719	56.5
1993	J	CENTENNIAL	2.06	1320	2.6	508	0.711	714	57.0

YEAR	PLT.DATE	CULTIVAR	LFWT(R5)	PETWT(R5)	TDM(R7)	DTDMR5R7	HI-2	EFFSEED	EFFSS
			g/m2	g/m2	g/m2	g/m2	%	no/g	mg/g
1987	J	FORREST	64.2	21.3	443	277	32.0	7.39	0.690
1987	J	FORREST	88.0	29.0	644	416	29.9	7.51	0.495
1987	J	FORREST	113.4	39.1	758	427	28.7	5.66	0.352
1987	J	CENTENNIAL	62.2	21.8	445	291	30.8	7.44	0.780
1987	J	CENTENNIAL	100.4	34.4	691	439	30.0	6.70	0.489
1987	J	CENTENNIAL	92.1	33.2	700	470	30.7	8.05	0.505
1988	M	FORREST	217.9	142.0	1343	729	23.8	4.21	0.202
1988	M	FORREST	227.9	140.4	1300	630	25.3	3.70	0.198
1988	M	FORREST	267.1	162.9	1624	849	21.6	3.70	0.158
1988	M	CENTENNIAL	242.8	160.3	1421	609	22.0	2.80	0.170
1988	M	CENTENNIAL	238.5	185.9	1500	471	23.5	2.55	0.131
1988	M	CENTENNIAL	285.1	184.0	1464	204	24.0	2.08	0.106

1988	J	FORREST	106.6	48.4	823	546	31.0	7.22	0.460
1988	J	FORREST	134.7	62.6	994	631	30.2	6.70	0.342
1988	J	FORREST	153.7	76.6	1023	596	29.9	5.62	0.298
1988	J	CENTENNIAL	110.1	53.7	786	458	29.7	5.60	0.388
1988	J	CENTENNIAL	136.3	65.1	947	643	29.0	6.96	0.427
1988	J	CENTENNIAL	131.5	63.5	897	470	30.7	5.13	0.295
1989	J	CENTENNIAL	125.8	62.1	828	496	28.1	5.17	0.408
1989	J	CENTENNIAL	111.2	51.2	816	540	29.4	6.23	0.507
1989	J	CENTENNIAL	148.9	75.6	1124	727	29.3	5.91	0.354
1989	J	CENTENNIAL	159.1	77.2	981	561	27.7	4.60	0.335
1990	J	CENTENNIAL	144.3	81.0	945	529	27.4	4.80	0.311
1990	J	CENTENNIAL	187.0	120.6	1158	589	26.7	3.92	0.243
1990	J	CENTENNIAL	197.3	116.9	1252	666	26.4	4.48	0.215
1990	J	CENTENNIAL	166.1	90.9	991	495	25.9	4.34	0.240
1989	J	CENTENNIAL	103.3	36.9	897	665	31.1	9.03	0.573
1989	J	CENTENNIAL	90.6	35.5	876	671	32.0	10.47	0.638
1989	J	CENTENNIAL	82.9	36.0	838	634	31.2	9.87	0.637
1989	J	CENTENNIAL	68.8	30.3	633	459	33.4	9.77	0.714
1989	J	CENTENNIAL	78.5	34.0	614	422	32.2	8.69	0.617
1990	J	CENTENNIAL	172.4	87.0	1029	543	27.2	4.56	0.259
1990	J	CENTENNIAL	126.5	69.0	887	509	28.2	5.64	0.311
1990	J	CENTENNIAL	96.8	62.5	819	492	29.1	5.99	0.372
1990	J	CENTENNIAL	89.2	56.8	779	478	29.2	6.27	0.401
1990	J	CENTENNIAL	98.4	68.6	784	420	28.2	4.76	0.350
1993	J	CENTENNIAL-D	159.5	84.4	1142	705	28.6	6.22	0.274
1993	J	CENTENNIAL-D	144.6	73.2	965	600	28.9	6.13	0.342
1993	J	CENTENNIAL-UD	114.1	50.3	862	595	30.7	8.45	0.439
1993	J	CENTENNIAL-UD	90.6	45.3	625	421	29.7	7.68	0.581
1994	J	CENTENNIAL-D	63.6	31.8	533	407	31.5	9.18	1.152
1994	J	CENTENNIAL-D	58.1	29.1	372	250	29.4	6.10	1.207
1994	J	CENTENNIAL-UD	51.0	25.5	278	171	27.0	5.56	1.180
1994	J	CENTENNIAL-UD	32.1	16.1	138	37	23.9	2.88	1.123

1994	M	DP415	215.0	92.8	1184	658	26.8	3.64	0.315
1994	M	DP415	201.0	96.3	1413	907	26.9	4.24	0.350
1994	M	DP415	220.7	108.8	1461	877	26.6	3.83	0.298
1994	M	DP415	219.2	107.9	1294	685	25.6	3.05	0.293
1995	M	DP415	230.0	115.0	1303	682	25.3	3.56	0.240
1995	M	DP415	219.0	129.3	1395	763	25.4	3.94	0.225
1995	M	DP415	239.0	140.0	1417	695	24.3	3.25	0.203
1995	M	DP415	228.0	127.0	1498	842	24.8	3.86	0.224
1995	M	DP3606	207.2	145.2	1440	755	26.6	3.77	0.217
1995	M	DP3606	224.6	159.1	1568	816	25.5	3.66	0.193
1995	M	DP3606	228.0	147.1	1487	708	25.5	3.28	0.191
1996	M	DP3606	220.6	154.8	1440	693	24.2	3.14	0.199
1996	M	DP3606	211.4	158.5	1409	621	24.7	2.89	0.194
1996	M	DP3606	209.2	137.8	1395	636	23.9	2.92	0.198
1993	J	CENTENNIAL	153.1	68.6	1114	707	29.1	6.22	0.314
1993	J	CENTENNIAL	78.8	49.5	879	598	30.9	7.80	0.441
1994	J	CENTENNIAL	79.6	25.4	562	390	30.8	7.89	0.741
1994	J	CENTENNIAL	50.5	18.8	438	304	31.6	8.07	0.954
1992	J	CENTENNIAL	94.1	33.5	676	460	29.7	8.13	0.531
1992	J	CENTENNIAL	111.0	40.1	842	588	29.9	8.45	0.462
1992	J	CENTENNIAL	136.4	44.8	946	644	29.5	8.02	0.384
1993	J	CENTENNIAL	144.6	73.2	965	600	28.9	6.13	0.342
1993	J	CENTENNIAL	158.6	84.4	1119	693	28.3	5.99	0.291
1993	J	CENTENNIAL	159.5	85.8	1143	707	28.5	6.23	0.275

YEAR	PLT.DATE	CULTIVAR	EFFSEDPD	EFFPOD	EFFREPND	EFFPDRPND	EFFFRAC	EFFNOD
			(sedpd/g)x100	no./g	no/g	no/gx100	fr/g*100	no/g
1987	J	FORREST	1.392	3.19	1.56	1.224	0.436	2.15
1987	J	FORREST	0.905	3.64	1.82	0.879	0.332	2.41
1987	J	FORREST	0.575	2.98	1.49	0.606	0.214	2.10
1987	J	CENTENNIAL	1.281	3.78	1.78	1.378	0.501	2.31
1987	J	CENTENNIAL	0.783	3.40	1.58	0.854	0.299	2.10

1987	J	CENTENNIAL	0.857	4.09	2.13	0.835	0.309	3.00
1988	M	FORREST	0.329	2.08	0.74	0.461	0.115	1.04
1988	M	FORREST	0.306	1.81	0.71	0.377	0.105	1.02
1988	M	FORREST	0.253	1.89	0.70	0.346	0.092	0.99
1988	M	CENTENNIAL	0.234	1.47	0.53	0.343	0.079	0.83
1988	M	CENTENNIAL	0.178	1.39	0.52	0.261	0.058	0.87
1988	M	CENTENNIAL	0.149	1.11	0.40	0.219	0.052	0.62
1988	J	FORREST	0.797	3.27	1.39	0.847	0.260	1.93
1988	J	FORREST	0.602	3.07	1.42	0.599	0.187	2.09
1988	J	FORREST	0.527	2.50	1.12	0.522	0.163	1.61
1988	J	CENTENNIAL	0.638	2.68	1.29	0.632	0.227	1.74
1988	J	CENTENNIAL	0.720	3.18	1.36	0.766	0.239	1.87
1988	J	CENTENNIAL	0.504	2.38	1.16	0.483	0.160	1.70
1989	J	CENTENNIAL	0.557	2.80	1.05	0.801	0.210	1.51
1989	J	CENTENNIAL	0.707	3.19	1.31	0.880	0.256	1.86
1989	J	CENTENNIAL	0.486	3.06	1.18	0.652	0.170	1.76
1989	J	CENTENNIAL	0.450	2.43	0.93	0.624	0.149	1.49
1990	J	CENTENNIAL	0.399	2.89	1.00	0.697	0.159	1.51
1990	J	CENTENNIAL	0.281	2.45	0.82	0.527	0.116	1.24
1990	J	CENTENNIAL	0.292	2.62	0.78	0.570	0.110	1.22
1990	J	CENTENNIAL	0.345	2.54	0.80	0.637	0.119	1.36
1989	J	CENTENNIAL	0.823	4.73	2.00	1.022	0.309	2.79
1989	J	CENTENNIAL	0.951	5.37	2.44	1.073	0.346	3.44
1989	J	CENTENNIAL	0.907	5.33	2.35	1.113	0.324	3.56
1989	J	CENTENNIAL	1.109	5.06	2.42	1.201	0.383	3.64
1989	J	CENTENNIAL	0.948	4.77	2.53	0.984	0.343	3.83
1990	J	CENTENNIAL	0.366	2.56	0.84	0.626	0.124	1.40
1990	J	CENTENNIAL	0.503	2.97	1.12	0.704	0.170	1.74
1990	J	CENTENNIAL	0.554	3.31	1.32	0.768	0.180	2.24
1990	J	CENTENNIAL	0.605	3.45	1.35	0.850	0.199	2.24
1990	J	CENTENNIAL	0.453	2.89	1.02	0.780	0.164	1.71
1993	J	CENTENNIAL-D	0.471	3.02	1.16	0.595	0.163	1.63

1993	J	CENTENNIAL-D	0.537	3.13	1.36	0.627	0.200	1.87
1993	J	CENTENNIAL-UD	0.772	4.10	1.99	0.772	0.266	2.81
1993	J	CENTENNIAL-UD	0.995	3.78	1.95	0.951	0.366	2.61
1994	J	CENTENNIAL-D	1.563	4.66	1.95	1.897	0.547	2.83
1994	J	CENTENNIAL-D	1.607	3.11	1.28	2.000	0.567	1.84
1994	J	CENTENNIAL-UD	1.776	2.93	1.54	1.776	0.592	2.43
1994	J	CENTENNIAL-UD	2.050	1.39	0.81	1.693	0.578	1.39
1994	M	DP415	0.325	2.13	0.89	0.454	0.156	1.08
1994	M	DP415	0.296	2.83	1.37	0.409	0.141	1.91
1994	M	DP415	0.272	2.41	1.32	0.312	0.131	1.73
1994	M	DP415	0.266	1.88	1.16	0.266	0.122	1.57
1995	M	DP415	0.285	2.01	0.84	0.386	0.135	1.00
1995	M	DP415	0.310	2.01	0.90	0.354	0.120	1.18
1995	M	DP415	0.255	1.77	0.82	0.298	0.099	1.15
1995	M	DP415	0.265	2.22	1.07	0.316	0.111	1.48
1995	M	DP3606	0.272	2.02	0.64	0.460	0.118	0.80
1995	M	DP3606	0.243	2.00	0.68	0.394	0.097	0.93
1995	M	DP3606	0.236	1.78	0.68	0.338	0.089	0.98
1996	M	DP3606	0.244	1.72	0.62	0.372	0.095	0.87
1996	M	DP3606	0.227	1.61	0.56	0.365	0.086	0.83
1996	M	DP3606	0.236	1.63	0.66	0.328	0.089	0.97
1993	J	CENTENNIAL	0.479	3.19	1.49	0.526	0.168	2.18
1993	J	CENTENNIAL	0.687	4.04	2.00	0.719	0.237	3.01
1994	J	CENTENNIAL	1.227	3.74	1.62	1.343	0.363	2.60
1994	J	CENTENNIAL	1.470	4.10	1.97	1.552	0.445	3.31
1992	J	CENTENNIAL	0.978	3.85	1.93	0.927	0.333	2.68
1992	J	CENTENNIAL	0.787	4.22	2.20	0.756	0.267	3.24
1992	J	CENTENNIAL	0.677	3.93	1.98	0.660	0.219	3.00
1993	J	CENTENNIAL	0.537	3.13	1.37	0.628	0.200	1.87
1993	J	CENTENNIAL	0.460	3.05	1.17	0.613	0.163	1.69
1993	J	CENTENNIAL	0.472	3.02	1.16	0.596	0.163	1.64

VITA

Harikrishna Modali was born at Nellore, Andhra Pradesh, India, on June 26, 1975. He attended primary school, secondary school, and intermediate in Nellore, Andhra Pradesh, India, from 1980 to 1992. He completed his bachelor of science in agriculture at Acharya N. G. Ranga Agricultural University, Andhra Pradesh, India, from 1992 to 1996 after which he went on to complete his Master of Science in agronomy in the same university. He was admitted into doctoral program in the Department of Agronomy at Louisiana State University, Baton Rouge, Louisiana, USA, during the Fall 2000, and he completed the graduate studies in May 2004.