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EFFECTS OF THINNING AT DIFFERENT GROWTH STAGES ON MORPHOLOGY AND YIELD OF GRAIN SORGHUM /*Sorghum bicolor* (L.) Moench/

by

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TITLE

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AND YIELD OF GRAIN SORGHUM [*Sorghum bicolor* (L.) Moench]

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INTRODUCTION

Plant physiology investigations which have as their ultimate aim the improvement of yield in economic crops such as grain sorghum /*Sorghum bicolor* (L.) Moench/ must be based on an understanding of how physiologic factors relate to yield. One of the basic relationships to be considered in this respect is the interaction of morphogenetic and physiologic factors in determining the final form of the plant, i.e., how the dry matter produced during growth is distributed within the plant. In grain sorghum, the primary consideration for yield is generally the reproductive portion of the plant or the grain. Optimum partitioning of dry matter produced between vegetative and reproductive organs is as important in determining economic yield as the total amount of dry matter produced. Before an adequate distribution of dry matter into the grain can occur, an adequate sink (seed number and size) must be available.

Much of the commercial grain sorghum production in the United States is carried out under conditions which favor vegetative over reproductive development, particularly high nitrogen fertility and high plant populations. The use of combine height ("dwarf") hybrids has helped to alleviate the unfavorable effects of these factors on dry matter partitioning, but the plant populations currently used still represent a compromise between even higher populations which would increase total dry matter production and lower populations which would maximize the proportion of dry matter found in the grain (Loomis, Williams, and Hall, 1971). The suppression of reproductive development

as plant density increases is due to the reduction of available photosynthate per plant to limiting levels by increased mutual shading (Blackman and Black, 1959).

The restriction of plant development due to limiting levels of available photosynthate was utilized in this investigation to induce morphological changes in grain sorghum. The level of available photosynthate per plant was increased at different growth stages by thinning the crop stands from populations at or above that considered to be optimal for grain yield to levels 30 to 40 percent below the original population. Thus selected effects of changes in available photosynthate level during the development of different plant organs on the extent of development and final morphology of those organs and on the developmental inter-relationships between organs could be observed. In turn the relationship of grain yield to the induced morphological changes could be determined.

One factor of particular interest was the effect of altered photosynthate level on developmental relationships which affect seed number, i.e., sink size. Variations in grain sorghum yields are frequently correlated with variations in seed number indicating a direct relationship between factors which control the number of seed produced and those which determine yield. In addition, Eastin (1971) and Clegg (1971) have suggested means of increasing yield in grain sorghum which, if successful, will require an increase in seed number.

LITERATURE REVIEW

Population Density Effects on Grain Sorghum

The plant population at which grain sorghum is grown has marked effects on both leaf area index (LAI) and on leaf area per plant. Leaf area index increased with increasing plant density up to approximately 350,000 plants per hectare for five varieties studied by Schulze (1971). In the same study, leaf area per plant was found to decrease with increasing population up to approximately 400,000 plants per hectare for the same varieties.

Stem diameter and leaf width decrease with an increase in plant density (Schulze, 1971). Sinnott (1921, 1936) suggested that the size of a plant organ was related to the size of the meristem from which it originated and used stem diameter as an index to estimate the size of the apex from which the stem and the leaves on it developed. Leaf width in both corn (Abbe and Phinney, 1951; Abbe, Randolph, and Einset, 1941) and rice (Yamazaki, 1963) has been shown to be related to the circumference of the apex from which the leaves developed. Assuming, as suggested by Quinby (1970), that these relationships also hold for sorghum, then the circumference of the apex /and presumably apex volume since they are correlated in corn (Abbe and Phinney, 1951)/ also decreases with increased plant populations in grain sorghum.

Maturity length in sorghum does not seem to be changed to any large extent by changes in population. Maturity, measured as days to half bloom (Schulze, 1971) was negatively correlated to population

in long season hybrids and positively correlated in short season hybrids although these changes were relatively small. Days to panicle initiation for the hybrid RS 610 was not changed by changes in plant density (Fischer, 1972).

Grain yield increases with increasing population (Atkins and Martinez, 1971; Stickler and Laude, 1960; Stickler and Wearden, 1965) up to a maximum which then declines. There is a plateau effect at the peak where yield response to population change is relatively small (Atkins, Reich, and Kern, 1968; Fischer, 1972; Grimes and Musick, 1960; Robinson, et al., 1964; Schulze, 1971). The population suggested as optimum for yield under irrigated conditions is about the center of this plateau or approximately 250,000 plants per hectare (Clegg, 1971).

Seed number per head is negatively correlated with population (Atkins and Martinez, 1971; Atkins, et al., 1968; Fischer, 1972; Schulze, 1971; Stickler and Wearden, 1965) while seed number per unit area is positively correlated with grain yield and responds in much the same way as yield to changes in population (Clegg, 1971; Fischer, 1972; Schulze, 1971). Changes in seed size due to population are usually quite small (Atkins and Martinez, 1971; Atkins, et al., 1968; Fischer, 1972; Goldsworthy and Tayler, 1970; Stickler and Wearden, 1965) and are usually negatively correlated with population.

Head number per unit area increases with increased population while yield per head decreases and the two are strongly and negatively correlated (Schulze, 1971; Stickler and Wearden, 1965).

Panicle morphology changes with changes in population. Blum (1967) found that, for RS 610, increased competition due to higher plant densities caused a shorter panicle, with fewer branches per whorl in

the upper whorls and more branches per whorl in the lower whorls, and caused a decreased seed number per panicle primarily through lower seed number per panicle branch. Goldsworthy and Tayler (1970) found for NK 300, a commercial American hybrid, that increased population led to a very small change in the number of primary panicle branches and a decrease in both the number of secondary panicle branches and the number of grains per secondary panicle branch. However, most of the change in seed number per panicle was due to the change in seed number per panicle branch.

Total dry matter production increases with increasing population up to a peak and then declines. This peak occurs at a higher population than the peak for grain yield (Fischer, 1972), thus the grain to stover ratio declines at high populations (Schulze, 1971).

Effects of Altered Available Photosynthate Level Per Plant at Different Stages of Plant Development

Many treatments which could be expected to alter the level of photosynthate available to a developing plant have been applied at different growth stages to crop species. Shading, carbon dioxide enrichment, thinning, and variation of spacing of single plants in containers have all been utilized and presumably exert their primary effects by altering the amount of photosynthate available per plant for its development.

Hardman and Brun (1971) provided field grown soybeans with carbon dioxide at a concentration of approximately 1200 parts per million for five-week periods corresponding to vegetative, flowering, and pod-filling stages. There were no noticeable effects on yield components at maturity when the high carbon dioxide concentration was provided

during the vegetative phase. Increased carbon dioxide concentration during the flowering period resulted in an increased number of nodes, increased leaf and stem dry weights, and an increased number of pods. However, seed size decreased and yield was not altered. If the high level of carbon dioxide was provided during the pod-filling stage, there was a slight increase in the number of pods and a marked increase in seed size and seed yield, but there was no noticeable effect on vegetative characteristics. The level of available photosynthate apparently limited development of both sink capacity and yield since sink size did not appear to be limiting at any stage of development.

Effects of shading, thinning, and moving plants grown in tubes to different densities at different growth stages have been studied in wheat. Pendleton and Weibel (1965) submitted wheat to ten-day periods of 60 to 90 percent shading during the pre-heading, heading, and post-heading stages. All shading resulted in some yield reduction regardless of amount or duration of shade. The growth stage at which the 60 percent shade was applied had no apparent effect on yield. Plots which receive the 90 percent shade ten days prior to heading had the lowest yield while those which received the 90 percent shade ten days after heading had the highest yield.

Puckridge (1968) attributed the effects of changing plant density, obtained by moving wheat plants grown in tubes from high to low density arrangements, to competition for light. The number of spikelets per ear was increased by transfer to the low density between the formation of double ridges on the plant apex and ear emergence. The time of transfer had no effect on the number of primordia formed but did affect the number which developed into fertile flowers. There was no density

effect on the number of leaves formed. Individual leaves were reduced in both area and weight by transfer of plants from high to low density during the period from initiation of growth of the leaf on the apex to its appearance above the sheath. Apparently the relationship between organ size and the size of the apex on which it was initiated can be altered in wheat by changes in the environment under which the leaf develops after initiation (Sinnott, 1921, 1936; Abbe and Phinney, 1951; Abbe, et al., 1941; Yamazaki, 1936).

Both shading (to 72 and 46 percent of sunlight) and thinning treatments were applied to a range of plant populations of wheat during different periods of plant development by Willey and Holliday (1971b). During ear development shading caused a decreased number of grains per ear and a decrease in grain yield. Shading during the grain filling period reduced grain size and yield. Thinning prior to anthesis showed that competition progressively reduced the storage capacity of the head, through progressively reduced grain numbers per head. Apparently both the number of primordia formed and the number of primordia which developed into fertile flowers were reduced by increased competition. When thinning was carried out after anthesis in order to increase the photosynthate available for grain filling in the remaining plants, no change in seed size occurred. Higher populations accelerated the effects of competition. These results suggested that sink capacity may limit yield in wheat.

Barley is also responsive to treatments which alter the level of available photosynthate at different stages of growth. Green, Finkner, and Duncan (1971) removed border rows at various times during the development of two cultivars of barley. Removal of border rows up to

two to three weeks prior to heading caused an increase in the number of spikelets per unit row length. After this stage the more favorable environment produced no response in this component. Average kernel weights were small for all treatments. Yield differences were attributable to the number of heads per unit row length and this factor was more closely related to tiller mortality than to the total number of tillers formed.

Leakey (1971) found that changing density at various times during the growth of barley did not affect the stage of development, except for changes due to differences in tillering. The factor most affected by treatments was the number of shoots per plant although both the number of spikelets formed per ear and the number of surviving spikelets per ear were affected by density.

Lee (1960) compared competitive and non-competitive barley genotypes in mixed and pure stands. Competition effects were first evident at the tillering stage. Seed yield in the non-competitive genotype declined markedly from that of the pure stand if the competitive genotype was not thinned from the mixed stand plots prior to the joint stage. When the competitive variety was thinned after the jointing stage some decrease in seed size from that of a thinned pure stand was noted.

A range of plant populations of a single barley hybrid was shaded during different periods of development by Willey and Holliday (1971a). Shading during ear development caused considerable yield reduction associated with a reduction in the number of grains per ear, while shading during the grain filling period caused no reduction in yield. These researchers felt there was a potential surplus of photosynthate available for grain filling and grain yield was limited by the storage capacity of the ears.

Corn responds strikingly to both shading and thinning treatments during different development stages. Early, et al. (1967) applied 30, 60, 70, 80, and 90 percent shading to two corn hybrids for 21 days during vegetative, reproductive, and maturation phases of growth. Shading during vegetative growth delayed tassel, anther, and silk emergence, while shading during the reproductive phase delayed silk emergence only. Yield was reduced by shading at all stages but shading during the reproductive stage was most detrimental. Reduced vegetative growth, noted when shade was applied during the vegetative stage, did not reduce yield and the authors suggested that restriction of early growth might reduce mutual shading during the reproductive phase which might lead to greater grain production. Shading with covers that transmitted 40 percent or less of the incident light during the reproductive stage limited the number of kernels initiated and developed. Similar shading during the maturation stage caused lower yields with very little change in kernel numbers. Shade treatments after the vegetative stage produced only minimal changes in stover production and leaf area.

Prine (1971) changed the light environment of semi-prolific corn by removing every other plant at various times through the growing season. A "critical" period for ear development was found during and just following silking at which time rapid abortion of ears took place at the high population. Ear size did not increase enough to compensate for the loss in yield due to the decreased ear number caused by delayed thinning. The plant response was attributed primarily to competition for light.

The time at which both thinning and shading treatments are applied to grain sorghum has marked effects on both yield and morphology in sorghum. Delay of early season thinning until the plants were 23 centimeters high reduced yield in two varieties of grain sorghum (Clegg and Maranville, 1972). The effects of delayed thinning on plant morphology were found to be similar to those of high populations, i.e., reduced stem diameter, increased plant height and reduced seed number per plant.

Goldsworthy and Tayler (1970) thinned the hybrid NK 300 from 100,000 to 55,000 or 10,000 plants per acre and from 55,000 to 10,000 plants per acre at panicle initiation and at heading. Thinning from both 100,000 and 55,000 plants per acre to 10,000 plants per acre at heading and from 100,000 to 55,000 plants per acre at initiation or heading did not affect yield. Yield per head was reduced at either 55,000 or 10,000 plant population if thinning was delayed until panicle initiation. This was reduced even further by delaying thinning until heading. Effects on yield per head were closely correlated with effects on seed number per head. Seed number was changed very little regardless of whether a stand of 10,000 or 55,000 plants per acre was established or obtained by thinning from a higher population at initiation. However, thinning from either higher populations at heading to 10,000 plants per acre caused a reduction of seed number per head and an associated increase in seed size. Similar though reduced effects on seed size and number per head were noted by thinning at heading from 100,000 to 55,000 plants per acre. Changes in grain number per head due to thinning were primarily due to a change in seed number on the secondary branches and, to a lesser extent, to a change in the number of these branches.

Pepper and Prine (1972) shaded (75 percent reduction of sunlight) a single grain sorghum variety, Georgia 615, for weekly periods during development. Although most shading treatments resulted in some yield reduction, two periods of development were most affected by low light intensity. Shading from pre-boot to full panicle expansion resulted in a lower seed number per panicle and an increase in seed weight. Shading during the milk and soft dough stages did not change seed number but did decrease seed size. When seed number was decreased by shading, seed size increased which compensated for some, but usually not all, of the potential yield decrease.

Morphology and Development in Relation to Yield in Grain Sorghum

This is not a comprehensive review of all studies which relate to morphology and morphogenesis in grain sorghum. It has been restricted to studies pertaining to a limited number of relationships which influenced the design of the experiments to be reported in this thesis and relate, more or less directly, to their interpretation.

Seed Number

In grain sorghum the single morphological characteristic most often associated and correlated with increased yield is higher seed number. This relationship has been shown for yield differences between varieties (Clegg, 1970, as cited by Eastin, 1971), for yield differences due to changes in row spacing and population (Atkins and Martinez, 1971; Blum, 1967; Clegg 1971; Fischer, 1972; Goldsworthy and Tayler, 1970; Schulze, 1971) and for yield differences between hybrids and their parents (Arnon and Blum, 1962; Beil and Atkins, 1967; Blum, 1970; Doggett, 1967;