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Influence of Indeterminate Growth Habit on Yield and Irrigation Water-use Efficiency in Upland Cotton[1]

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ABSTRACT

Based on their growth habit, 12 cultivars of upland cotton (*Gossypium hirsutum* L.) were placed in four groups designated as 1) High Plains-determinate, 2) High Plains moderately determinate, 3) High Plains-indeterminate, and 4) non High Plains-indeterminate. These cultivar groups were grown at three moisture levels at Lubbock, Texas, and evaluated for their degree of indeterminate growth habit, earliness of crop maturity, lint yield, and irrigation water-use efficiency. The purpose of our study was to determine the relationships between indeterminacy, lint yield, and irrigation water-use efficiency.

The indeterminate groups of cultivars had higher lint yields at all moisture levels than did the determinate groups. Irrigation water-use efficiency of all cultivars was higher at the intermediate moisture level (preplant irrigation) than at the higher moisture level (full irrigation). At the intermediate moisture level, the indeterminate cultivars had a higher irrigation water-use efficiency than did the determinate cultivars. The determinate cultivars had a higher irrigation water-use efficiency than the indeterminate cultivars at the higher moisture level. Correlation analyses between individual cultivar indeterminacy values and lint yield and irrigation water-use efficiency suggested that a cotton cultivar with a relatively inteterminate growth habit is better adapted in an environment with seasonally limited soil moisture than a cotton cultivar with a relatively determinate growth habit.

Additional index words:* Gossypium hirsutum *L., Earliness of crop maturity, Dryland cotton production.

THE Texas High Plains is a semiarid region that annually averages about 40 to 50 cm of rainfall, but annual variations from 21 to 103 cm have been recorded. In most years, cotton (*Gossypium hirsutum* L.) can be grown economically without supplemental irrigation, although irrigation is generally beneficial to yield and is widely used where it is available.

Irrigation water on the Texas High Plains is pumped from wells drilled into the Ogallala aquifer. Since this aquifer is isolated from significant sources of recharge, the amount of available irrigation water has declined. The region will return to nonirrigated, semiarid agriculture as the irrigation water declines. The return to nonirrigated cotton production will benefit from new cultivars that are better adapted to a semiarid climate.

One approach to developing cotton (*Gossypium hirsutum* L.) cultivars that are adapted to a nonirrigated, semiarid environment is to establish relationships between plant characteristics that are associated with efficient water use and yield. Such relationships should aid in the definition of the plant type that is most desirable when grown under moisture stress and could provide a better selection criteria than yield.

The 1974 growing season at Lubbock,Texas presented an unusual opportunity to evaluate the growth and yield response of different cotton cultivars grown under various amounts of soil moisture. The season was low in preplant and early season rainfall and was marginal for cotton growth and development. The purpose of this study was to evaluate the relationships between the degree of indeterminate growth habit, irrigation water-use efficiency, and lint yield in upland cotton.

Literature Review

The growth of the cotton plant is indeterminate, but there are variations in growth behavior which have led to the classification of some cultivars as "determinate" and others as "indeterminate" (Eaton, 1955; Quisenberry, 1975). Determinate cultivars fruit heavily during the early season, after which the terminal buds become dormant, the growth of fruiting branches and rate of flower production decline, and all or most of the late flowers are shed. This phenomenon is often referrred to as "cut out." With the opening of the first bolls, these determinate cultivars will usually renew their growth and flowering and, if environmental conditions are favorable and adequate season remains, a new crop of fruit may be set. The indeterminate cultivars, on the other hand, continue to flower throughout the summer, but usually do not carry enough fruit to stop growth (Tharp, 1960).

Determinate cultivars are generally classed as "early" and indeterminate as "late" in crop maturity. In longer seasons, determinate cultivars usually do not produce as much yield as indeterminate cultivars; but the determinate cultivars in short seasons, or when frost occurs early, will have a higher percentage of mature fruit (Brown and Ware, 1958).

Metzer (1973) provided a classification of cultivars according to their degree of indeterminacy, as determined by field experience. He contended that the degree of indeterminacy plays an important role in the earliness of crop maturity and that it gives some indication of regrowth ability and sensitiveness to moisture. Metzer stated that indeterminate cultivars tend to develop larger plants than determinate cultivars under high moisture conditions.

Generally, indeterminate cultivars are considered to be more drought resistant than determinate cultivars (Ware, 1936; Metzer, 1973; Ray, et al., 1974). J. W. Neely observed that indeterminate cultivars withstood drought better than determinate cultivars in the Mississippi Delta (Eaton and Rigler, 1945). Eaton and Rigler (1945) suggested that this response

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Table 1. Groups and cultivars/group values for indeterminacy and earliness of crop maturity.

Groups and cultivars/groups	Indeterminacy	Earliness
	cm ht/cm water	days
HP†-determinate ‡	0.5242 a*	148.5 a
Tamcot SP-37	0.5426	144.8
Lan. LX571	0.5870	152.4
Paymaster Dwarf	0.4430	148.5
HP-moderately determinate	0.5944 a	150.4 ab
Tamcot 788	0.5630	146.4
Lockett 4789	0.6191	152.0
Paymaster 111A	0.6162	153.0
HP-indeterminate	0.7448 b	152.7 bc
Coker 5110	0.7182	154.4
Western 44	0.8069	152.0
Blightmaster A-5	0.7093	151.6
Non-HP-indeterminate	0.6975 b	154.0 c
Coker 201	0.6650	150.8
Deltapine 16	0.7093	156.7
Acala 1517-70	0.7182	154.5

* Means within columns followed by a different letter are significantly different at the 0.05 level, according to a Duncan's multiple range test. † HP = cultivars grown on the Texas High Plains; Non-HP = cultivars not grown on Texas High Plains. ‡ Indicates type of growth habit.

was due to the greater root system developed by the indeterminate cultivars. However, Murray and Verhalen (1970) suggested that early-maturing, determinate cultivars tend to be the most productive in the nonirrigated, semiarid areas in Oklahoma.

Few quantitative studies on cultivar-water use relationships have been conducted in cotton. Eaton and Belden (1929) and Gustein (1969) found that the water requirement for 'Acala' (*G. hirsutum* L.) was less than that for 'Pima' (*G. barbadense* L.). Wendt (1971) studied the relationships between transpiration and plant height in five cultivars of upland cotton. He found that 'Paymaster III' transpired more water per unit height than either 'Acala 1517 BR-2' or 'Stoneville 7A.' Jackson and Tilt (1968) demonstrated a significant cultivar by moisture level interaction in tests conducted on eight cultivars in three years.

MATERIALS AND METHODS

Based on Metzer's (1973) classification, 12 cultivars of upland cotton were selected for their degree of indeterminate growth habit and grouped into four categories of 1) High Plains-determinate, 2) High Plains-moderately determinate, 3) High Plains-indeterminate, and 4) non High Plains-indeterminate (Table 1). The "High Plains" designation refers to the general cotton production area where the cultivars are grown and the "determinate" or "indeterminate" refers to their type of growth habit. The selected cultivars cover the approximate range of indeterminacy in the commercial germplasm of upland cotton; however, there is a predominance of stormproof, short-fibered High Plains cultivars. The extent to which the data can be applied to all cotton germplasm and to the same cultivars grown in other areas or environments is unknown.

Three replications of each cultivar were planted on 15 May 1974, in three moisture regimes at Lubbock, Texas. The experimental design was a split-plot with moisture levels as whole plots and the cultivars as the sub-plots. Four rows (12 m long) with 1 m between rows were planted to each cultivar within each replication and moisture level. Stands were thinned to 71,040 plants/ha. The soil type was an Olton loam (Aridic Paleustolls).

The three moisture regimes used were: 1) *Dryland* — nonirrigated plots that received 56-cm of rainfall during the growing season (November 1973, to October 1974); however, 41 cm or 73% of the rainfall occurred after 21 Aug. 1974, and was not available to the plants during the major portion of the growing season (plants grown in this moisture regime were stunted, with small leaves and short internodes, and grew slowly from the time of their emergence until 21 August); 2) *Preplant irrigation* — these plots received one 15-cm supplemental irrigation in April 1974, before planting (leaf wilting due to moisture stress was frequent before the August rainfall); and 3) *full irrigation* — these plots received a 15-cm supplemental irrigation before planting plus two 10-cm irrigations during the growing season (8 July and 2 Aug. 1974). The summer irrigations were applied with a trickle irrigation system in an attempt to make water distribution more uniform from plot to plot. These irrigations were applied when tensiometer readings reached —50 centibars potential at the 46-cm depth. Leaf wilting symptoms were limited to extremely hot afternoons.

Table 2. Analyses of variance for lint yield and irrigation water use efficiency (IWUE).

SOV	Lint yield, kg/ha		IWUE, kg/ha/cm	
	df	MS	df	MS
Moisture level (ML)	2	2,312,202**	1	1,885**
Reps/ML	6	20,526**	4	44**
Groups (Gps)	3	59,316**	3	22
Cultivars/Gps	8	8,188	8	20
Gps × ML	6	5,300**	3	73**
Cult./Gps × ML	16	3,351*	8	9
Residual	66	1,490	44	6

*,** Statistically significant at the 0.05 level and 0.01 level, respectively.

Soil moisture was monitored in each moisture regime with soil tensiometers placed in the row at the 46 and 91-cm depths. Tensiometer readings above —50 centibars at the 46-cm depth were considered to indicate that soil moisture was adequate for plant growth (Harbert et al., 1973). The tensiometer readings showed that the dryland plots had an inadequate soil moisture between the date of planting and 24 Aug. 1974, that the preplant irrigation plots had adequate soil moisture until 23 July 1974, and that the full irrigation plots had adequate soil moisture throughout the growing season.

Four characters were evaluated: 1) The response of plant height to the addition of irrigation water (degree of indeterminacy), 2) earliness of crop maturity, 3) lint yield, and 4) irrigation water use efficiency. The degree of indeterminacy was the linear regression coefficient (b_i) obtained from the regression of plant height on the centimeters of applied irrigation water. A large positive regression coefficient indicated a large response in plant height to the addition of irrigation water and suggested a relatively indeterminate growth habit, while a small positive coefficient suggested a more determinate growth habit. Earliness of crop maturity was calculated from periodic open boll counts as the mean maturity date (MMD) (Christidis and Harrison, 1955). Lint yield was determined by hand harvesting the seedcotton from the plots, separating the lint from the seed, and converting the lint weights per plot into kg/ha. Irrigation water-use efficiency (IWUE) was calculated for both the preplant and full irrigation regimes. For the preplant irrigation regime, IWUE was calculated as the mean lint yield on the dryland plots subtracted from the lint yields from each replication in the preplant plot divided by the amount of irrigation water applied (15-cm). Irrigation water-use efficiency on the full irrigation plots was calculated as the mean lint yield on the preplant plots subtracted from the replication lint yield of the full irrigated plot divided by the amount of additional irrigation water applied (20-cm) (Newman, 1967).

RESULTS AND DISCUSSION

The cultivar groups differed in the degree of indeterminate growth habit and in earliness of crop maturity (Table 1). The indeterminate groups (High Plains-indeterminate and non-High Plains-indeterminate) were later in crop maturity than the determinate groups. The linear correlation (r) between the response of plant height to irrigation water (degree of indeterminacy) and earliness of crop maturity was 0.65 and statistically significant. An analysis of variance on earliness showed that the interaction be-

Table 3. Mean separation of groups for lint yield and irrigation water use efficiency (IWUE) and linear correlation coefficients (r) between indeterminacy of the individual cultivars and their lint yield and IWUE for the three moisture levels.

Groups	Dryland Yield	Preplant irrigation Yield	Preplant irrigation IWUE	Full irrigation Yield	Full irrigation IWUE	Average Yield	Average IWUE
	kg/ha		kg/ha/cm	kg/ha	kg/ha/cm	kg/ha	kg/ha/cm
HP†determinate‡	184 b§	446 b	17.2 b	677 b	11.4 a	436 b	14.3 a
HP-moderately determinate	199 ab	469 b	17.7 b	664 b	9.6 ab	444 b	13.7 a
HP-indeterminate	224 a	551 a	21.8 a	741 a	9.3 ab	506 a	15.5 a
Non-HP-indeterminate	234 a	589 a	23.3 a	773 a	8.7 b	532 a	16.0 a
Average	210	514	20.0	714	9.8	479	14.9
r between indeterminacy (cm/cm) and:	0.59*	0.72**	0.64*	0.46	−0.36	0.69*	0.43

*,** Significantly different from zero at the 0.05 and 0.01 levels, respectively. † HP = cultivars grown on the Texas High Plains; Non-HP = cultivars not grown on Texas High Plains. ‡ Indicates type of growth habit. § Means within columns followed by different letter are significantly different at the 0.05 level, based on a Duncan's multiple range test.

tween moisture level and the cultivar groups was nonsignificant, thus demonstrating that moisture level had a relatively small effect on the earliness relationships among the cultivar groups. The cultivar values calculated to quantify indeterminacy and earliness closely agreed with Metzer's (1973) cultivar classification (Table 1); therefore, we accepted our cultivar groupings as being representative of different degrees of indeterminacy.

Lint yield was significantly affected by moisture level and groups with a significant interaction between groups and moisture level (Table 2). Irrigation water-use efficiency was affected by moisture level, but not by groups or cultivars within groups. A significant interaction was observed between groups and moisture levels.

In the dryland moisture level, small but significant differences in lint yield occurred among the cultivar groups (Table 3). The indeterminate groups tended to yield slightly more than the determinate groups. These yield differences probably reflect the harvest method. Since all bolls were harvested from the plants and the seedcotton was hand separated from the burrs, small bolls that would not ordinarily be included in yield were broken cpen and used in the yield estimate. More of this type of boll was associated with the indeterminate cultivars than with the determinate cultivars. Thus, lint yield estimates from the dryland moisture level were probably biased upward more for the indeterminate cultivars than for the determinate cultivars.

At the preplant irrigation moisture level, the indeterminate cultivar groups yielded significantly more than did the determinate groups (Table 3). Irrigation water-use effeciency was also higher for the indeterminate groups than for the determinate groups. Since the yield estimates from the dryland may have been biased upward for the indeterminate groups, the estimated irrigation water use efficiencies were probably biased downward for these groups.

In the full irrigation moisture level, the indeterminate groups again outyielded the determinate groups; however, the determinate groups had a higher irrigation water-use efficiency than did the indeterminate groups.

Averaged over all moisture levels, the indeterminate groups produced more lint than did the determinate groups, but the irrigation water-use efficiency was statistically the same for all groups.

The linear correlation coefficients (r) between the cultivar indeterminacy values and the cultivar lint yields showed a significant correlation between indeterminacy and yield for the dryland and preplant moisture levels, but not for the full irrigation moisture level (Table 3). Likewise, the cultivar indeterminacy values and irrigation water-use efficiency were correlated at the preplant moisture level, but not in the full irrigation moisture level.

We concluded that in cotton there exists a positive relationship between the indeterminate growth habit and yield in a nonirrigated semiarid environment. As the amount of seasonally available soil moisture increases, this relationship tends to become less important. In terms of evolution, Stebbins (1974) has concluded that inherent in an indeterminate growth habit is a flexibility that enables individual plants to form few or many flowers depending upon the length of the favorable season. Consequently, natural selection should favor this kind of growth habit in a plant adapted to a semiarid climate with great variation in rainfall from one season to the next.

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