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RESEARCH ON DROUGHT TOLERANCE IN COMMON BEAN

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INTRODUCTION

Although precise estimates of effects of drought on bean production are difficult to obtain, moderate to severe drought stress is thought to occur in over 60% of bean production regions in developing countries, and drought is probably rivaled in importance only by problems of soil fertility as a factor limiting bean yields. Although nobody expects that common beans (*Phaseolus vulgaris*) will grow in the complete absence of water, there is much interest in trying to increase bean yields under drought conditions. Many national bean programs are involved in drought research, and CIAT has studied drought tolerance almost since the onset of its research on bean physiology.

Recognizing this interest and the need to bring researchers together to discuss results of their efforts and to suggest priorities for future work, a workshop was organized to review research on drought tolerance in common beans. The original objectives of the workshop were stated as:

1. Review drought problems in beans, considering the following:

   a) Characterization of drought in different regions
   b) The farmer's view of drought problems
   c) Drought physiology
   d) Solutions to drought problems
      - drought tolerance
      - agronomic practices

2. Formulate strategies for reducing the impact of drought in bean production, including plans for collaboration among national programs.

How well these objectives were met may be determined from the papers presented and from the conclusions provided at the end of this document.

Regrettably, funds were not available to invite a larger number of participants. In one case a paper was prepared, but the participant could not attend for lack of travel support; this paper, by R. Rodriguez, has also been included.

Jeffrey W. White
Workshop Coordinator

ACKNOWLEDGMENTS

The editors extend their sincerest thanks to María Eugenia Cobo and Adriana María Velasco for their invaluable assistance in the organization and administration of the workshop. We also acknowledge the efforts of Patricia Zamorano de Montoya and Ligia García in typinging the manuscripts, and of the CIAT print shop for the actual publication of the document.

EFECTOS DE SEQUIA EN CARACTERISTICAS MORFOFISIOLOGICAS EN GENOTIPOS DE FRIJOL EN DOS LOCALIDADES DE DURANGO, MEXICO[1]

Francisco Ibarra*

Introducción

La agricultura de secano de la zona semiárida de altura del Norte Centro de México, se caracteriza por tener bajas producciones con alta variabilidad a través de la zona y del tiempo. Esto es debido principalmente, a la escasez de agua de lluvia y su mala distribución, así como también a la degradación del suelo. Bajo estas condiciones anualmente se siembran 1'250,000 hectáreas en los estados de Zacatecas, Durango, Chihuahua, Aguascalientes y San Luis Potosí. En años cuando la escasez de agua de lluvia es severa, se puede perder hasta el 60% de la superficie sembrada.

Para resolver el problema de sequía se requiere de un enfoque multidisciplinario con el objeto de aumentar la producción y productividad del frijol mediante el uso eficiente del agua de lluvia disponible durante el ciclo de cultivo (mayo-octubre). Así, el Campo Agrícola Experimental "Valle del Guadiana" (CAEVAG) del Instituto Nacional de Investigaciones Forestales y Agropecuarias (INIFAP) está llevando a cabo un proyecto de investigación, el cual considera alternativas de solución que incluyen aspectos tanto de mejoramiento genético-fisiológico, donde se pretende seleccionar plantas resistentes a sequía, como aspectos de manejo de suelo

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[1] Como parte del proyecto cooperativo INIFAP/MSU/CRSP.

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que favorezcan la captación, conservación y aprovechamiento del agua de lluvia.

Para resolver los problemas de sequía desde el punto de vista planta, se ha optado principalmente, por trabajar en mejoramiento genético-fisiológico, con un esquema de trabajo que permita por una parte evaluar y seleccionar una gran cantidad de plasma germinal, así como el entendimiento de los mecanismos de resistencia a sequía de los genotipos seleccionados. Así pues, mientras se lleva a cabo la evaluación extensa de germoplasma, tanto mexicano como de otras fuentes en la búsqueda de progenitores y/o variedades resistentes a sequía, se tienen estudios para determinar los efectos del tipo de sequía que las plantas de fríjol enfrentan en la zona semiárida de altura de México.

Como parte de este proyecto se estableció un estudio con 12 genotipos, para determinar los efectos de sequía inducida en la etapa de floración sobre caracteres fenológicos, morfológicos, fisiológicos, así como en algunos componentes de rendimiento. Además, se esperaba determinar la relación de los caracteres estudiados con los mecanismos de resistencia a sequía y con rendimiento en fríjol.

Revisión de Literatura

Bajo condiciones de campo, muchos cultivos experimentan efectos negativos durante alguna etapa de su ciclo de vida, debido a la sequía. Consecuentemente, incrementando la adaptación de las plantas a sequía sería un componente importante en el mejoramiento de los programas de investigación agrícola. Adaptación de las plantas es definido en diferentes formas dependiendo del tipo de planta, ambiente y el uso que tendrá dicha especie. Hall (1981) define adaptación como la producción de altos promedios de rendimiento de grano, así como alta estabilidad del mismo en especies como chícharo de vaca (Vigna unguiculata).

Para definir el concepto de sequía, hay que considerar la especie de planta que se trata, de las condiciones ambientales del lugar y de las interacciones importantes de la relación agua-suelo-planta-atmósfera. Una definición de sequía muy amplia, y que es consistente con los conceptos ampliamente usados de escape, evasión y tolerancia a sequía la sugiere Hall (1981) como la ocurrencia de un déficit substancial de agua en el suelo, planta y atmósfera.

Una aproximación empírica, basada en la evaluación de rendimiento bajo condiciones de campo, son componentes esenciales en los programas de mejoramiento de cultivares. Hurd (1974) desarrolló cultivares mejorados de trigo seleccionando por rendimiento en localidades libres de lluvia. Desafortunadamente, evaluación de rendimiento en condiciones semiáridas es menos exitosa que en una agricultura intensiva, debido principalmente a variaciones substanciales tanto en severidad y período de la sequía. Mejoramiento convencional de los cultivos pudieran ser suplementados usando índices de adaptación a sequía basados en características fenológicas, morfológicas, anatómicas, fisiológicas, y bioquímicas para facilitar la selección de progenitores, así como material segregante, (Hall, 1981).

La resistencia a sequía se puede considerar como una acción combinada de tolerancia, evasión y escape. Escape a la sequía, se manifiesta cuando las plantas completan su ciclo de vida durante cortos períodos cuando el agua es disponible en ambientes semiáridos. Las plantas que utilizan el mecanismo de evasión intentan mantener un nivel normal de agua en los tejidos en la presencia de sequía ambiental. La planta que mantiene mas alto el potencial hídrico (el valor mas cercano a 0) tiene un valor mas alto de evasión a sequía. Tolerancia a sequía es definido en el sentido de que el funcionamiento de la planta es mantenido en presencia de déficits hídricos. Por lo tanto, se puede decir que las plantas adaptadas exhibirían un balance entre los niveles de tolerancia a sequía y evasión a sequía. Así, una planta que exhibe poca evasión a sequía sería benéfica por su habilidad para mantener el funcionamiento de la planta a pesar de estar desarrollando deificiencias hídricas en su sistema, (Hall, 1981).

En lo que respecta a las respuestas de las plantas a condiciones de sequía, la magnitud de la reducción en la producción de grano así como materia seca, depende en buena extensión de la etapa fenológica más susceptible del cultivo, como el espigamiento en maíz (Slatyer, 1967) y pocos días antes de la antesis en trigo (Fisher, 1973), para cultivos indeterminados como el fríjol y chícharo de vaca, los efectos de la sequía en el rendimiento de grano durante etapas específicas de crecimiento, dependen de subsecuentes condiciones ambientales. Turk et al. (1980) utilizando la especie Vigna unguiculata observaron que una sequía moderada durante la floración causó una substancial abscisión de flores y pequeñas vainas; también, las plantas rápidamente entraron a senescencia para producir un temprano y reducido rendimiento de grano, situación que es muy similar en el fríjol común (Phaseolus vulgaris L.) como se demuestra en los estudios de Acosta et al. (1981).

Cuando las plantas son expuestas a un amplio rango de condiciones atmosféricas y edáficas, ciertos procesos fisiológicos y características morfológicas proporcionan un amortiguamiento en contra de condiciones ambientales extremosas. Así, cuando una planta pierde agua hacia la atmósfera, el potencial hídrico disminuye en el sitio de evaporación. Los estomas generalmente no responden a las reducciones en el potencial hídrico necesario para mantener el flujo de transpiración, a menos que el potencial hídrico de la hoja caiga por debajo de un punto crítico (umbral). Entonces el estoma comienza a cerrarse. Este umbral puede ser a potenciales hídricos típicos en plantas mesófitas que están entre -7 y -18 barias (Hsiao, 1973; Raschke, 1976). Así pues, el potencial hídrico de la hoja y la conductancia estomatal son usados solos o en combinación como importantes indicadores de sequía en el suelo. La relación entre estos dos parámetros no es única entre especies o aún dentro de especies, sino que depende de las condiciones del medio ambiente.

Carlson et al. (1979) llevaron a cabo estudios en soya tratando de correlacionar el potencial hídrico y la resistencia difusiva de la hoja con mediciones en campo; no fue factible establecer una relación lineal, ya que el potencial hídrico de la hoja no influyó sobre la resistencia difusiva, sino hasta que los valores del potencial fueron muy bajos -13 a -14 barias. La resistencia difusiva aumentó rápidamente despuées de que el valor crítico fue excedido.

Materiales y Métodos

El estudio consistió de un experimento de campo establecido en dos localidades del estado de Durango, México. En la localidad del Campo Agrícola Experimental "Valle del Guadiana" (CAEVAG) se sembró el 12 de junio de 1986 en un suelo arcillo-arenoso con una precipitación acumulada de 695 mm durante el ciclo de cultivo. La fecha de siembra en la localidad de Francisco I. Madero fue el 9 de julio del mismo año, en un suelo migajón arcillo-arenoso, acumulándose 677 mm de mayo a octubre.

Los genotipos utilizados en este estudio fueron previamente seleccionados a partir de un grupo de 1,500 genotipos evaluados en varias localidades de la zona semiárida de altura de México, tanto por su rendimiento, sanidad, adaptación y estabilidad en diferentes condiciones de humedad a través de localidades y años. En el Cuadro 1 se pueden observar algunas características agronómicas, así como la fuente genética de procedencia.

Los 12 genotipos se distribuyeron en cuatro repeticiones, dos de las cuales se cubrieron con plástico negro entre los surcos y así evitar el agua de lluvia a partir de los 45 días despúes de la siembra (DDS) en la localidad del CAEVAG. En Francisco I. Madero se utilizaron estructuras metálicas de 4 m x 6 m cubiertas con polietileno transparente para evitar el agua de lluvia y así inducir sequía a partir de los 39 DDS. Las dos repeticiones restantes recibieron un riego de auxilio durante el período de floración para utilizarse como control.

Se utilizó fertilizante comercial para la fórmula 35-50-00, la cual fue aplicada al momento de la siembra. La parcela experimental fue de 3 surcos de 5 m y 0.76 m entre surcos; de los surcos laterales se tomaron muestras para materia seca y del central para rendimiento de grano.

Se tomaron datos en los 12 genotipos sólo en aquellas características que resultaron ser importantes de acuerdo al análisis multivariado realizado en 1985, sobre fenología, morfología, fisiología y de componentes de rendimiento.

Los datos fenológicos fueron días a floracion, a madurez fisiológica y la diferencia entre estas dos etapas denominado período efectivo de reproducción.

Datos morfológicos como materia seca total en floración y en madurez fisiológica, separando la materia seca de hojas, tallos y vainas cuando las hubo, siendo de 1 m el tamaño de la muestra. Además, se determinó la tasa de crecimiento en la etapa reproductiva (g/pl/día) y del fruto también, así como el factor de remobilización de la siguiente manera:

Tasa de crec. (etapa rep.) = M.S. Total a M.F./Período efectivo de rep.
Tasa de crec. del fruto = Peso de vainas/período efectivo de rep.
Factor de remobilización = Peso del grano/M.S. total a M.F.

Solamente en la localidad de Francisco I. Madero se determinaron como caracteres fisiológicos la conductancia estomatal (Automatic Porometer MK3) y el potencial hídrico de la hoja (usando la bomba de presión de Scholander), solamente en 4 de los 12 genotipos en tres ocasiones durante el período de sequía; la determinación de estos parámetros se llevó a cabo cada hora durante el día de muestreo entre las 7 y 19 horas, tanto en la condición de riego como en sequía. La conductancia estomatal se determinó en cuatro trifolios, dos en la parte inferior y dos en la parte superior de la planta. El potencial hídrico se determinó inmediatamente después de usar el porómetro en 4 trifolios utilizando el mismo criterio que para la determinación de la conductancia estomatal.

Con respecto a los componentes de rendimiento, sólo se determinó el peso de 100 semillas y el rendimiento de grano.

Finalmente, se llevaron a cabo muestreos durante el ciclo para determinar la humedad del suelo en diferentes estratos 0-15, 15-30 y 30-45 cm por el método gravimétrico. Además, en Francisco I. Madero se utilizó el método radioactivo de dispersor de neutrones para determinar el contenido de agua del suelo en diferentes estratos hasta una profundidad de 1.05 m, en sólo 3 de los 16 genotipos en 4 ocasiones durante el período de sequía. Para estimar el contenido volumétrico de agua (θ_v) se utilizó el conteo relativo (CR), registrado en el dispersor, con la siguiente ecuación de regresión :

$$\theta_v = 119.56 + 0.163\ (CR)$$

El % de agua del suelo se determinó por medio de la relación del 0_v y la densidad aparente promedio del suelo (1.6) bajo la siguiente fórmula:

$$\%\ \text{de agua} = \frac{\theta_v}{Da}$$

Donde:

Da = Densidad aparente del suelo

θ_v = Contenido volumétrico de agua

Resultados y Discusión

Con los datos obtenidos en campo se llevó a cabo el análisis estadístico como bloques al azar de un factorial 2x2. El factor A se refiere a dos condiciones de humedad (riego y sequía) y el factor B para genotipos con 12 niveles. Además, para el análisis de varianza se consideraron dos localidades. Los resultados del análisis están descritos en el Cuadro 2 solamente de aquellas variables que fueron comunes para las dos localidades.

Con relación a los caracteres fenológicos días a madurez fisiológica (MF) y período efectivo de reproducción (PER), el análisis estadístico indicó significancia ($p = 0.01$) entre condiciones de humedad (C) y para genotipos (G). La interacción CxG no fue significativa, pero la interacción LxG fue altamente significativa para las dos variables; sin embargo, la triple interacción LxCxG sólo fue altamente significativa para MF.

El promedio de MF en la condición de riego fue similar para las dos localidades, encontrándose significancia ($p = 0.01$) entre localidades bajo sequía. En Francisco I. Madero la sequía propició que los genotipos aceleraran su MF en forma significativa como es el caso de A 59 y BAT 477 (Cuadro 3). Por otra parte, al combinar las dos localidades se detectaron genotipos que aceleraron su MF al ser sometidos a sequía con respecto a riego. Esta respuesta se observó en tipos precoces como A 59 y tardíos como Tlax-475. Lo anterior representa para algunos genotipos reducciones en el PER hasta de 9 días como en BAT 477 (Cuadro 4). Seleccionar genotipos precoces tiende a incrementar los rendimientos de grano durante años relativamente secos, pero reduce el potencial de rendimiento y la producción de grano durante años mas húmedos, situación que se debe considerar en el intento de seleccionar progenitores y/o variedades para la zona semiárida de altura de México, donde algunas veces es posible obtener lluvias en los meses de septiembre y octubre al final del ciclo de cultivo.

Con respecto a la producción de biomasa (B) y al factor de remobilización (FR), el análisis estadístico indicó significancia entre condiciones (C), entre genotipos (G), para la interacción CxG y LxCxG solamente para la variable biomasa (Cuadro 2).

La biomasa total es uno de los caracteres cuantitativos que son afectados por déficits hídricos y en este estudio no fue la excepción. En el Cuadro 5 se puede observar que genotipos como Pinto Nacional-1, CIAT 131/84, V 8025 y Bayo Durango tuvieron reducciones significativas cuando se combinaron los datos obtenidos en las dos localidades. También hubo genotipos que respondieron similarmente al testigo Durango-222 que tuvieron reducciones en biomasa, pero no en forma significativa. En el mismo Cuadro 5 se presentan los resultados combinados del factor remobilización, detectándose genotipos como Pinto Nacional-1 que remobiliza significativamente, tanto bajo riego (44%) como bajo sequía (43%), al igual que A 322 (41%) en ambas condiciones. Por otra parte, hay genotipos que si fueron afectados severamente por la sequía inducida para este carácter, tal es el caso de Negro Argel, A 59 y Tlax-475.

Caracteres morfológicos

La tasa de crecimiento del cultivo y del fruto en la etapa reproductiva, fueron afectadas por la sequía inducida, cuando se comparó con el promedio de riego (Cuadro 6). Solamente A 59 y Negro Puebla tuvieron tasas de crecimiento ligeramente mas altas bajo sequía que en riego. Además, fue notorio que Pinto Nacional-1, Negro Argel y A 322 se vieron mas afectados que el testigo Durango-222. Por otra parte, la pérdida de peso en hojas y tallos en el período comprendido entre 55 DDS y M.F., se utilizó para determinar la capacidad de remobilización de carbohidratos. El promedio en la pérdida de peso en hojas y tallos fue mas alto en riego (5.10 y 1.23 g/planta, respectivamente) que bajo sequía (3.46 y 0.76 g/planta, respectivamente); sin embargo, Pinto Nacional-1 y BAT 477 perdieron más peso en hojas y tallos tan pronto se les sometió a sequía en comparación con riego (Cuadro 7).

Componentes de rendimiento

El análisis estadístico señaló significancia para peso de 100 semillas y rendimiento de grano entre condiciones de humedad (C), entre genotipos (G) y para la interacció CxG, y solamente para la variable rendimiento se detectó significancia para la interacción de tercer orden LxCxG, no así para el peso de 100 semillas (Cuadro 2).

Fisher and Wood (1979) han definido un índice de intensidad de sequía en trigo, como la unidad menos la relación entre el promedio de rendimiento bajo sequía y el promedio de rendimiento bajo no sequía. Usando este índice, las intensidades de sequía fueron de 0.50 y 0.25 para CAEVAG y Madero, respectivamente (Cuadro 6). Ya que las intensidades de sequía fueron muy diferentes para cada localidad, esto permitió que los rendimientos de grano fueran afectados también diferentemente para cada uno de los genotipos. La respuesta de cada uno de los genotipos se determinó utilizando un índice de sequía, basado en el rendimiento bajo ambas condiciones de humedad. De acuerdo a Fisher et al. (1983) el índice de sequía (IS) para cada uno de los genotipos sería la relación entre su rendimiento bajo sequía y no sequía, relativo a la relación entre el promedio de rendimiento de todos los genotipos bajo sequía y no sequía. Así, el índice de sequía mayor de 1.0 sugiere resistencia relativa a sequía, y un índice menor de 1.0, susceptibilidad relativa a sequía.

En el Cuadro 8 se presentan los datos de rendimiento por localidad por condición; se puede notar que A 424, Durango-222 (t) y BAT 477 forman un grupo de genotipos relativamente resistentes a sequía, ya sea cuando ésta es intermedia (D = 0.50) o cuando es moderada (D = 0.25), ya que en ambas localidades mantienen un índice de sequía IS $\geq$ 1.0. Por otra parte, se detectaron genotipos como Pinto Nacional-1, A 322, CIAT 131/84 y Negro Puebla que son relativamente resistentes cuando la sequía es moderada, pero si ésta se agudiza, estos genotipos tienden a ser relativamente susceptibles de acuerdo al índice de sequía.

Mas aún, cuando se considera el promedio de las dos localidades, varios genotipos mostraron un alto potencial de rendimiento bajo la condición de riego de auxilio. En el Cuadro 9 se puede observar que la media geométrica ($\bar{X}_G$) permite detectar genotipos con valores mas altos que el testigo Durango-222 (1,185 kg/ha), pero que no necesariamente tienen resistencia relativa a sequía, ya que sus IS fueron menores de 1.0, como Pinto Nacional-1 (1,242 kg/ha) y Tlax-475 (1,336 kg/ha). Sin embargo, si fue posible detectar genotipos con respuesta similar al testigo, es decir, alto valor en la $\bar{X}_G$ de rendimiento y valores de IS > 1.0, combinación deseable para que los genotipos A 424, A 322 y CIAT 131/84 se consideren como resistentes a sequía. Sin embargo, V 8025 y BAT 477 que tienen resistencia relativa a sequía no disponen de alto potencial de rendimiento.

Se llevó a cabo un análisis de correlación lineal (r) entre el rendimiento de grano bajo sequía y las variables discutidas hasta ahora. Así, el análisis indicó que la relación entre el rendimiento de grano bajo ambas condiciones de humedad fue alta y positiva ($r = 0.78$), lo que sugiere que aquellos genotipos que se comportaron bien bajo riego, lo hicieron relativamente bien bajo sequía. Esto fue posible ya que los genotipos utilizados han sido seleccionados por su buena adaptación a sequía basada ésta, principalmente, en rendimiento de grano bajo una amplia gama de condiciones ambientales. Considerando que en este estudio no se incluyeron genotipos susceptibles a sequía, no se puede considerar la posibilidad de seleccionar para sequía en base a alto potencial de rendimiento bajo riego como se ha sugerido en otros estudios.

Por otra parte, la correlación entre el período efectivo de reproducción y el rendimiento de grano, ambos bajo sequía, no fue significativa, a pesar de que mostró un valor intermedio ($r = 0.50$), lo que permitiría hacer algunas inferencias acerca de la respuesta de los genotipos bajo sequía (Cuadro 10).

La ausencia de correlación entre el rendimiento de grano en sequía y el resto de las variables, hacen suponer que éstas no permiten explicar el comportamiento de los genotipos a las condiciones de humedad impuestas en este estudio.

Caracteres fisiológicos

Por razones de equipo, solamente en la localidad de Francisco I. Madero se hicieron mediciones en el potencial hídrico, conductancia estomatal, y temperatura del follaje en 4 de los 12 genotipos en estudio.

Las primeras mediciones se llevaron a cabo 57 días después de la siembra en Bayo Durango; la conductividad estomatal fue menor bajo sequía que bajo riego, ocasionando incrementos hasta el 10 C en la temperatura del follaje, principalmente entre las 12:00 y 15:00 horas. Sin embargo, el potencial hídrico de la hoja fue mayor (mas cercano a cero) bajo sequía que en riego, respuesta inversa a lo que se esperaría (Figuras 1A, B, C).

A los 62 días después de la siembra se determinaron los mismos parámetros en los genotipos Bayo Durango y Durango-222, detectándose la misma respuesta 5 días antes. Se mantuvo alto el potencial hídrico de la hoja en ambos genotipos (-0.5 y -1.5 barias) a través del día bajo sequía, mientras en la condición de riego los valores fueron tan bajos como -4.5 a -5.5 barias, salvo en horas del día cuando se ocultaba el sol y la demanda atmosférica permitía la recuperación de las plantas aún bajo riego. La respuesta de los genotipos a la sequía inducida en este estudio, fue incrementando la temperatura del follaje, debido principalmente al cierre estomatal, ya que la conductividad estomatal disminuía conforme el déficit hídrico avanzaba a través del día, siendo mas severo en el lapso entre 12:00 y 15:00 horas (Figuras 2A, B, C).

Con los genotipos A 322 y Pinto Nacional-1 se llevaron a cabo estas mediciones a los 70 días después de la siembra, y a pesar de tener períodos con nublados a través del día, se detectaron las mismas tendencias que con Bayo Durango y Durango-222 en lo que se refiere a la conductividad estomatal y el potencial hídrico de la hoja. Pinto Nacional-1 siempre mantuvo el potencial hídrico mas bajo en sequía (-3.0 a -4.5 barias) que A 322 (-1.5 a -2.5 barias); sin embargo, el diferencial en potencial hídrico entre riego y sequía fue mayor en el Pinto Nacional-1, ya que este genotipo tuvo valores hasta -8.2 barias, mientras que A 322 no fue mas allá de -4.5 barias bajo riego. Con respecto a la conductividad estomatal el efecto de la sequía no fue tan drástico en estos genotipos como en Bayo Durango y Durango-222, pero fue claro que A 322 mantuvo mas cerrado los estomas (0.050 cm/s) que Pinto Nacional-1 (0.150 cm/s) en sequía, a pesar de los nublados momentáneos que se presentaron el día de muestreo (Figuras 3A, B).

Ya que las respuestas de los genotipos a la sequía inducida en este estudio, estaba siendo diferente a lo que la literatura reporta en lo que respecta al potencial hídrico de la hoja, se dicidió determinar estos parámetros a los 75 días después de la siembra en Durango-222 y en Qro-3-B-1 a pesar de que este último genotipo no se incluyó en el grupo de 12 genotipos. Se detectó que Durango-222 permanecía con potenciales hídricos (-1.5 a -2.5 barias) mas altos bajo sequía que en riego (-3.0 a -5.0 barias) a través del día, notando que en esta etapa la sequía estaba avanzando pues los valores del potencial hídrico eran mas bajos en Durango-222 que 15 días atrás. Con respecto a la conductividad estomatal, los períodos nublados no permitieron detectar respuestas claras en los genotipos (Figuras 4A, B).

El potencial hídrico de la hoja ha sido utilizado para detectar respuestas de las plantas a déficits hídricos, ya que el potencial hídrico puede ser descrito como una función del potencial del suelo, el flujo de agua a través de la transpiración, y la resistencia en su fase líquida al flujo de agua del suelo a un punto de evaporación dentro de la hoja (Kaufmann, 1981). Esto sugiere que los potenciales hídricos bajo la sequía inducida en este estudio debieron ser mas bajos que bajo riego; sin embargo, Hall (1981) estudiando con chícharo de vaca (*Vigna unguiculata*) encontró que durante el medio día, plantas de esta especie que no habían recibido agua de lluvia o riego por 2 ó 3 meses mostraron potenciales hídricos que fueron solamente 2 barias más negativos que plantas irrigadas semanalmente, siendo el mecanismo responsable de esta respuesta una expansión de área foliar lenta, cierre estomatal y movimiento de foliolos que resultó en bajas cargas de irradiación. Todos estos mecanismos resultarían en menos asimilación de CO_2 y su valor de adaptación dependería en el balance entre la regulación de pérdida de agua y el mantenimientode la asimilación de CO_2 (Hall and Schultze, 1980). Así, con referencia a este estudio, las plantas que se pudieron desarrollar bajo las estructuras metálicas cubiertas con polietileno transparente, parece ser que no fueron lo suficientemente vigorosas para experimentar una sequía severa repentina, sino que el déficit hídrico en el suelo (Fig. 5) fue avanzando lentamente lo que permitió que plantas con mucho menor área foliar presentaran potenciales hídricos mas altos en sequía que bajo riego donde el vigor de las plantas así como la demanda atmosférica resultara en el tipo de respuesta detectada en este estudio.

Conclusiones

Con los datos obtenidos en este estudio se llegó a las siguientes conclusiones.

1. Los genotipos mostraron diferente respuesta al tipo de sequía inducida en cada localidad.

2. No todos los genotipos aceleraron su madurez fisiológica tan pronto se les expuso a sequía, principalmente cuando ésta fue inducida como en la localidad de Francisco I. Madero.

3. El crecimiento y desarrollo de las plantas fue reducido en los genotipos debido a la sequía inducida en ambas localidades.

4. Pinto Nacional-1 y BAT 477 mostraron en este estudio la capacidad de removilizar fotosintatos provenientes de hojas y tallos a las fuentes de demanda.

5. Los genotipos en los que se realizaron mediciones fisiológicas, mostraron respuestas similares a sequía indicando capacidad de conservar humedad en la hoja, debido al cierre estomatal usando esto como medio de adaptación a sequía.

6. A 424, A 322 y el testigo Durango-222 mostraron una respuesta en el rendimiento de grano mas estable en ambas condiciones de humedad y localidades. Esto sugiere que estabilidad del rendimiento es un componente importante en los genotipos de frijol resistentes a sequía.

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Cuadro 1. Características agronómicas y fuente genética de 12 genotipos de fríjol sembrados bajo dos condiciones de humedad en dos localidades de Durango, Mex. 1986.

	Nombre	Color grano[1]	Tipo	M.F[2]	Tamaño[3]	Fuente genética	País
				días	g		
1	Pinto Nacional-1	P	3	90	34	CAEVAG	Méx.
2	Negro Argel	N	2	89	20	INIA	Chile
3	A 424	P	3	94	28	CIAT	Col.
4	A 59	C	2	85	26	CIAT	Col.
5	A 322	C	3	100	28	CIAT	Col.
6	CIAT 131/84	C	3	89	26	CIAT	Col.
7	Tlax-475	B	3b	110	29	URG	Méx.
8	Durango-222 (t)	B	3	100	40	CAEVAG	Méx.
9	V 8025	N	3	88	22	CIAT	Col.
10	Negro Puebla	N	3b	110	26	URG	Méx.
11	BAT-477	C	2	88	21	CIAT	Col.
12	Bayo Durango	B	3	105	45	CAEVAG	Méx.

[1] P = Pinto, N = Negro, C = Crema, B = Bayo.
[2] Días a madurez fisiológica.
[3] Peso de 100 semillas.

Cuadro 2. Análisis de varianza como bca factorial en 12 genotipos de fríjol bajo dos condiciones de humedad en dos localidades de Durango, Mex. 1986.

Variable	Cuadros medios								Error
	Loc.	R(L)	Cond.	L x C	Gen.	L x G	C x G	L x C x G	
Días a madurez fisiológica	42*	2	384**	70**	980*	83**	5NS	19*	9
Período efectivo de rep.	52NS	0.43	219**	33NS	369*	161**	17NS	26NS	15
Factor de removilización	24448**	323	513**	2NS	260*	26NS	52NS	42NS	50
Biomasa a M.F.	913399**	19129	99813**	32243**	17880*	12187**	9717**	10826**	3913
Peso de 100 semillas	1197**	28	663**	1325**	4977*	121**	124**	29NS	43
Rend. de grano	613879**	1784	854249**	276992**	33836*	17143*	6775**	7120**	1811

Loc. = CAEVAG y Madero.
Cond. = Riego de auxilio y sequía inducida.
*, ** = Diferencia significativa al 0.05 y 0.01 de probabilidad, respectivamente.
NS = No significativo.

Cuadro 3. Madurez fisiológica de 12 genotipos de fríjol bajo dos condiciones de humedad en dos localidades de Durango, Mex. 1986.

		Días a madurez fisiológica					
		CAEVAG			Madero		
	Nombre	R[1]	S	Dif.	R	S	Dif.
1	Pinto Nacional-1	85	87	2	91	84	-7
2	Negro Argel	85	84	-1	93	86	-7
3	A 424	89	91	2	95	89	-6
4	A 59	82	81	-1	86	76	-10
5	A 322	101	100	-1	100	95	-5
6	CIAT 131/84	82	81	-1	90	85	-5
7	Tlax-475	120	109	-11	113	109	-4
8	Durango-222 (t)	105	104	-1	99	93	-6
9	V 8025	83	84	1	89	83	-6
10	Negro Puebla	119	114	-5	110	109	-1
11	BAT-477	85	83	-2	93	84	-9
12	Bayo Durango	116	106	-10	95	94	-1
	Promedio	96	94	-2	96	90	-6

DMS $_{0.01}$ genotipos = 2.6 días
DMS $_{0.01}$ genotipo/loc. = 3.7 días
DMS $_{0.01}$ genotipo/loc./cond. = 5.2 días
DMS $_{0.01}$ condición = 1.5 días

R[1] = Riego de auxilio.
S = Sequía inducida 49 DDS (CAEVAG) y 39 DDS (Madero).

Cuadro 4. Caracteres fenológicos de 12 genotipos de fríjol bajo dos condiciones de humedad combinando dos localidades de Durango, Mex. 1986.

	Nombre	Días a M.F.			Período efectivo de reproducción[1]		
		R[1]	S	Dif.	R	S	Dif.
1	Pinto Nacional-1	88	86	-2	46	43	-3
2	Negro Argel	89	85	-4	39	37	-2
3	A 424	92	90	-2	43	46	3
4	A 59	84	79	-5	44	36	-8
5	A 322	101	98	-3	46	45	-1
6	CIAT 131/84	86	83	-3	43	40	-3
7	Tlax-475	117	109	-8	57	54	-3
8	Durango-222 (t)	102	99	-3	55	52	-3
9	V 8025	86	84	-2	40	37	-3
10	Negro Puebla	114	112	-2	57	53	-4
11	BAT 477	89	83	-6	46	37	-9
12	Bayo Durango	106	100	-6	56	55	-1
	Promedio	96	92	-4	48	45	-3
	DMS $_{0.01}$ condiciones	1.6			1.3		
	DMS $_{0.01}$ genotipos	2.6			3.3		
	DMS $_{0.05}$ genotipos/loc/ cond.	4.2			-		

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[1] Días entre floración y madurez fisiológica.

Cuadro 5. Producción de biomasa de 12 genotipos de frijol bajo dos condiciones de humedad en dos localidades de Durango, Mex. 1986.

	Nombre	Biomasa g/m^2 R	S	Pérdida	Factor de removilizacion[1] R	S	Pérdida
1	Pinto Nacional-1	276.9	103.4	173.5	44	43	1
2	Negro Argel	149.2	143.2	6.0	53	45	8
3	A 424	182.5	132.7	49.8	47	43	4
4	A 59	127.2	111.0	16.2	54	38	16
5	A 322	229.9	191.2	38.7	41	41	0
6	CIAT 131/84	127.7	50.7	77.0	56	51	5
7	Tlax-475	168.2	119.6	48.6	63	52	9
8	Durango-222 (t)	183.6	164.7	18.9	43	40	3
9	V 8025	169.1	71.1	98.0	50	48	2
10	Negro Puebla	172.0	118.5	53.5	56	58	+2
11	BAT 477	205.9	149.7	56.2	45	41	4
12	Bayo Durango	366.6	149.0	217.6	47	43	4
	Promedio	189.9	125.4	64.5	50	45	5
	DMS $_{0.01}$ condiciones	21.5			0.72		
	DMS $_{0.01}$ genotipos	52.8			1.76		
	DMS $_{0.01}$ gen/cond.	74.5			-		

[1] Peso de grano/M.S total a M.F.

Cuadro 6. Características de crecimiento y desarrollo de 12 genotipos de fríjol bajo dos condiciones de humedad de Durango, Mexico. 1986.

		Tasa de crecimiento en g/planta/día					
		Etapa reproductiva[1]			del fruto[2]		
	Nombre	R	S	Pérdida	R	S	Pérdida
1	Pinto Nacional-1	1.05	0.46	0.59	2.05	0.96	1.09
2	Negro Argel	0.68	0.53	0.15	1.67	0.79	0.88
3	A 424	0.74	0.57	0.17	1.41	1.04	0.37
4	A 59	0.41	0.55	+0.14	0.78	0.98	+0.20
5	A 322	1.14	0.63	0.51	1.95	0.40	1.55
6	CIAT 131/84	0.58	0.34	0.24	1.45	0.95	0.50
7	Tlax-475	0.51	0.68	+0.17	1.71	1.52	0.19
8	Durango-222 (t)	0.65	0.55	0.10	1.00	0.62	0.38
9	V 8025	0.70	0.49	0.21	1.32	1.25	0.07
10	Negro Puebla	0.35	0.41	+0.07	0.76	1.15	+0.39
11	BAT 477	0.60	0.51	0.09	0.70	0.51	0.19
12	Bayo Durango	0.95	0.42	0.53	0.89	0.40	0.49
	Promedio	0.70	0.51	0.19	1.31	0.88	0.43

[1] Materia seca a M.F./período efectivo de reproducción.
[2] Peso de grano/período efectivo de reproducción.

Cuadro 7. Pérdida de peso en hojas y tallos como indicador de removilización en 12 genotipos de fríjol bajo dos condiciones de humedad de Durango, México. 1986.

		Peso seco en g/planta[1]					
		Riego			Sequía		
	Nombre	Hojas	Tallos	Vainas	Hojas	Tallos	Vainas
1	Pinto Nacional-1	4.63	0.37	31.4	4.74	2.32	19.7
2	Negro Argel	4.59	1.48	28.3	0.57	0.38	15.3
3	A 424	6.29	1.29	33.0	2.84	0.83	27.9
4	A 59	6.47	2.99	40.6	2.43	1.61	12.3
5	A 322	4.42	0.02	65.2	3.28	+1.48	22.6
6	CIAT 131/84	5.06	3.22	22.7	2.77	1.17	15.4
7	Tlax-475	6.12	0.30	37.8	4.78	0.50	24.1
8	Durango-222 (t)	4.74	+0.60	26.5	2.74	0.67	21.1
9	V 8025	5.38	1.74	21.6	4.90	1.46	25.2
10	Negro Puebla	5.07	0.61	19.5	4.67	+0.10	20.1
11	BAT 477	2.91	1.53	19.8	4.61	1.92	10.0
12	Bayo Durango	5.49	0.57	51.7	3.16	+0.18	12.4
	Promedio	5.10	1.23	33.2	3.46	0.76	18.8

[1] Pérdida de peso entre 55 DDS y madurez fisiológica.

Cuadro 8. Rendimiento de grano de 12 genotipos de frijol bajo dos condiciones de humedad en dos localidades de Durango, Mex. 1986.

		Rendimiento en kg/ha							
		CAEVAG				Madero			
		R	S	$\overline{X}_G$[1]	IS[2]	R	S	$\overline{X}_G$	IS
1	Pinto Nacional-1	2045	860	1326	0.84	1248	1013	1140	1.09
2	Negro Argel	1579	734	1076	0.93	692	449	493	0.87
3	A 424	1786	1192	1459	1.34	820	672	719	1.10
4	A 59	1379	658	952	0.96	662	445	522	0.90
5	A 322	1715	797	1169	0.93	1474	1098	1272	1.00
6	CIAT 131/84	2677	1267	1841	0.95	932	839	884	1.20
7	Tlax-475	2577	1082	1670	0.84	1245	786	989	0.84
8	Durango-222 (t)	1819	987	1340	1.09	1055	967	1010	1.23
9	V 8025	1491	1077	1236	1.45	902	448	636	0.66
10	Negro Puebla	1953	666	1140	0.68	1177	1040	1117	1.18
11	BAT 477	1536	899	1175	1.18	830	684	753	1.10
12	Bayo Durango	1847	934	1313	1.02	1222	719	937	0.79
	Promedio	1867	929	1316		1021	763	883	
	D[3]		0.50				0.25		

$DMS_{0.01}$ entre genotipos = 113

$DMS_{0.01}$ genotipo/loc. = 160

$DMS_{0.01}$ genotipo/cond. = 160

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[1] Media geométrica = $\sqrt{R.S}$

[2] Indice de sequía = $\left(\frac{\overline{Ys}}{\overline{Yr}} \right) / \left(\frac{\overline{XS}}{\overline{Xr}} \right)$

[3] Intensidad de sequía = $1 - \frac{\overline{Xs}}{\overline{Xr}}$

Cuadro 9. Rendimiento de grano de 12 genotipos de frījol bajo dos condiciones de humedad combinando dos localidades de Durango, Mex. 1986.

		Rend. kg/ha				
	Nombre	R	S	X_G[1]	IS[2]	Pérdida
1	Pinto Nacional-1	1647	936	1242	0.97	711
2	Negro Argel	1136	591	792	0.89	545
3	A 424	1303	932	1102	1.22	371
4	A 59	1020	551	750	0.92	469
5	A 322	1594	947	1230	1.02	647
6	CIAT 131/84	1804	1053	1379	1.00	751
7	Tlax-475	1911	934	1336	0.84	977
8	Durango-222 (t)	1437	977	1185	1.16	460
9	V 8025	1196	763	956	1.09	433
10	Negro Puebla	1565	853	1155	0.93	712
11	BAT-477	1183	791	968	1.14	392
12	Bayo Durango	1535	826	1127	0.92	709
	Promedio	1436	839	1098		597
	D[3]	0.41				

DMS $_{0.01}$ entre genotipos = 113
DMS $_{0.01}$ genotipo/condición = 160
DMS $_{0.01}$ genotipo/cond./loc. = 227

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[1] Media geométrica = $\sqrt{\overline{Ys} \quad \overline{Yr}}$

[2] Indice de sequía = $\left(\frac{\overline{Ys}}{\overline{Yr}}\right) / \left(\frac{\overline{Xs}}{\overline{Xr}}\right)$

[3] Intensidad de sequía = $1 - \frac{\overline{Xs}}{\overline{Xr}}$

Cuadro 10. Coeficiente de correlación lineal (r) entre rendimiento de grano y otras características de 12 genotipos de fríjol bajo dos condiciones de humedad en Durango, Mex. 1986.

Variable	Rendimiento kg/ha	
	R	S
Rendimiento grano (sequía)	0.78**	1.0**
Madurez fisiológica (sequía)	0.59*	0.39
Período efectivo de rep. (sequía)	0.62*	0.50
Biomasa total (sequía)	-0.16	-0.08
Factor de removilización (sequía)	0.52	0.26
Indice de sequía	-0.32	0.31

*, ** Significativo al 0.05 y 0.01 de probabilidad, respectivamente.

Figuras

Fig. 1.A. Potencial hídrico de la hoja del genotipo Bayo Durango bajo dos condiciones de humedad 57 días después de la siembra. Fco. L. Madero, Dgo. 1986.

Fig. 1.B. Conductividad estomatal del genotipo Bayo Durango bajo dos condiciones de humedad 57 días después de la siembra. Fco. L. Madero, Dgo. 1986.

Fig. 1.C. Temperatura del follaje del genotipo Bayo Durango bajo dos condiciones de humedad 57 días después de la siembra. Fco. L. Madero, Dgo. 1986.

Fig. 2.A. Potencial hídrico de la hoja de los genotipos Bayo Durango y Durango 222 bajo dos condiciones de humedad 62 días después de la siembra. Fco. I. Madero, Dgo. 1986.

Fig. 2.B. Conductividad estomatal de los genotipos Bayo Durango y Durango 222 bajo dos condiciones de humedad 62 días después de la siembra. Fco. I. Madero, Dgo. 1986.

Fig. 2.C. Temperatura del follaje de los genotipos Bayo Durango y Durango 222 bajo dos condiciones de humedad 62 días después de la siembra. Fco. I. Madero, Dgo. 1986.

Fig. 3.A. Potential hídrico de la hoja de los genotipos A 322 y Pinto Nacional-1 bajo dos condiciones de humedad 70 días después de la siembra. Fco. I. Madero, Dgo. 1986.

Fig. 3.B. Conductividad estomatal de los genotipos A 322 y Pinto Nacional-1 bajo dos condiciones de humedad 70 días después de la siembra. Fco. I. Madero, Dgo. 1986.

Fig. 4.A. Potencial hídrico de la hoja de los genotipos Queretoro 3-B-1 y Durango 222 bajo dos condiciones de humedad 75 días después de la siembra. Fco. I. Madero, Dgo. 1986.

Fig. 4.B. Conductividad de los genotipos Qro-3-B-1 y Dgo. 222 bajo dos condiciones de humedad 75 días después de la siembra. Fco. I. Madero, Dgo. 1986.

Fig. 5. Muestreos de humedad del suelo en dos condiciones (riego y sequía) bajo condiciones de Fco. I. Madero, Dgo. 1986.

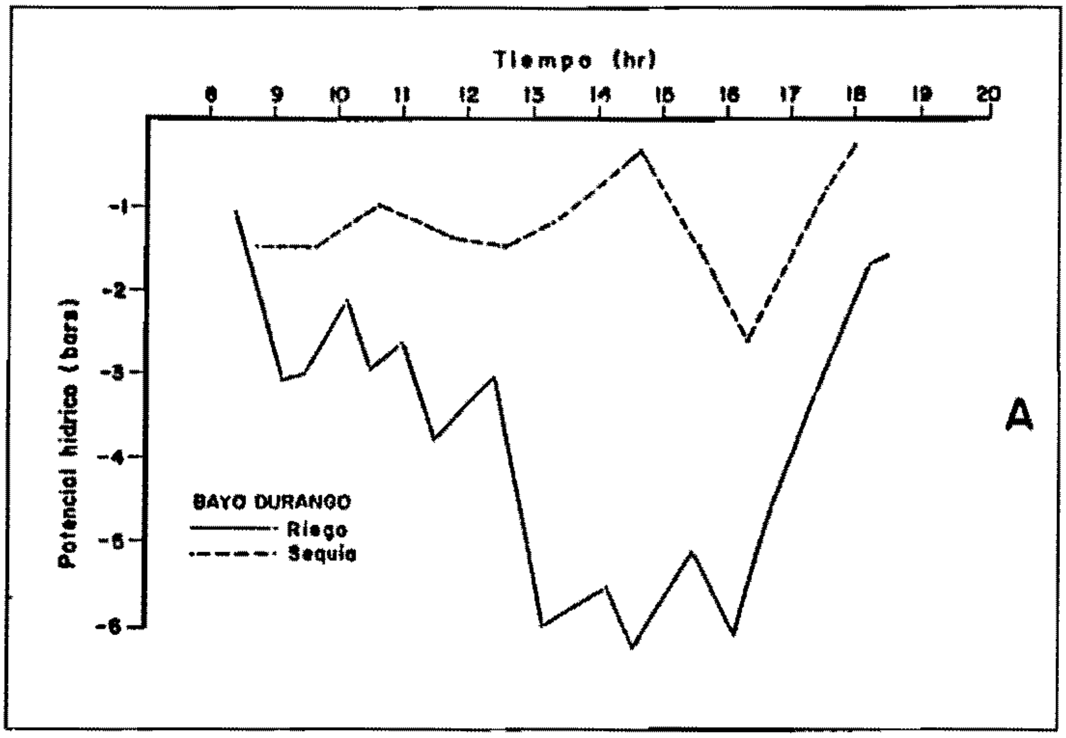

Figura 1.A Potencial hídrico de la hoja del genotipo Bayo Durango bajo dos condiciones de humedad 57 días después de la siembra. Fco. L. Madero, Dgo. 1986.

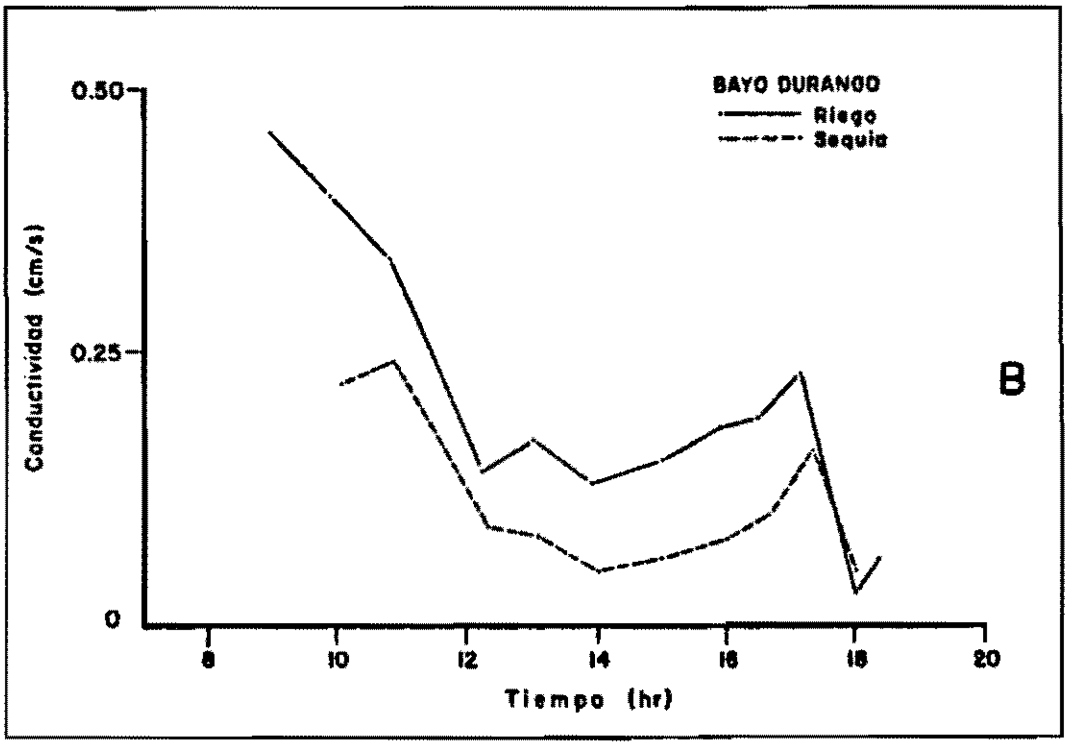

Figura 1.B Conductividad estomatal del genotipo Bayo Durango bajo dos condiciones de humedad 57 días después de la siembra. Fco. L. Madero, Dgo. 1986.

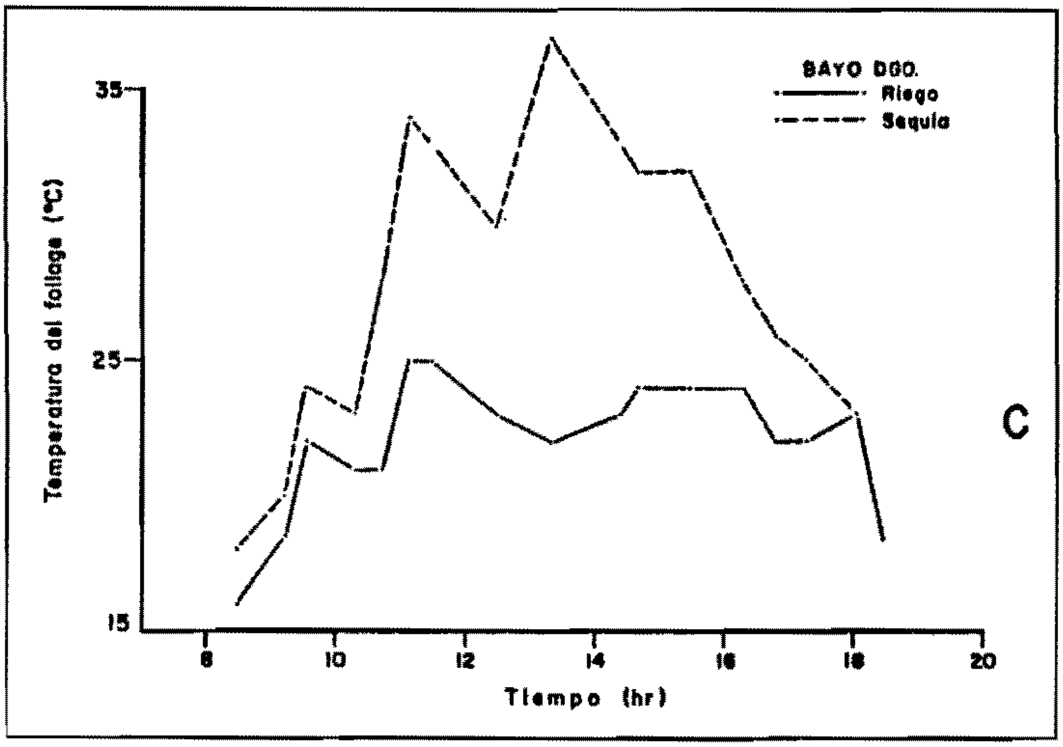

Figura 1.C Temperatura del follaje del genotipo Bayo Durango bajo dos condiciones de humedad 57 días después de la siembra. Fco. L. Madero, Dgo. 1986.

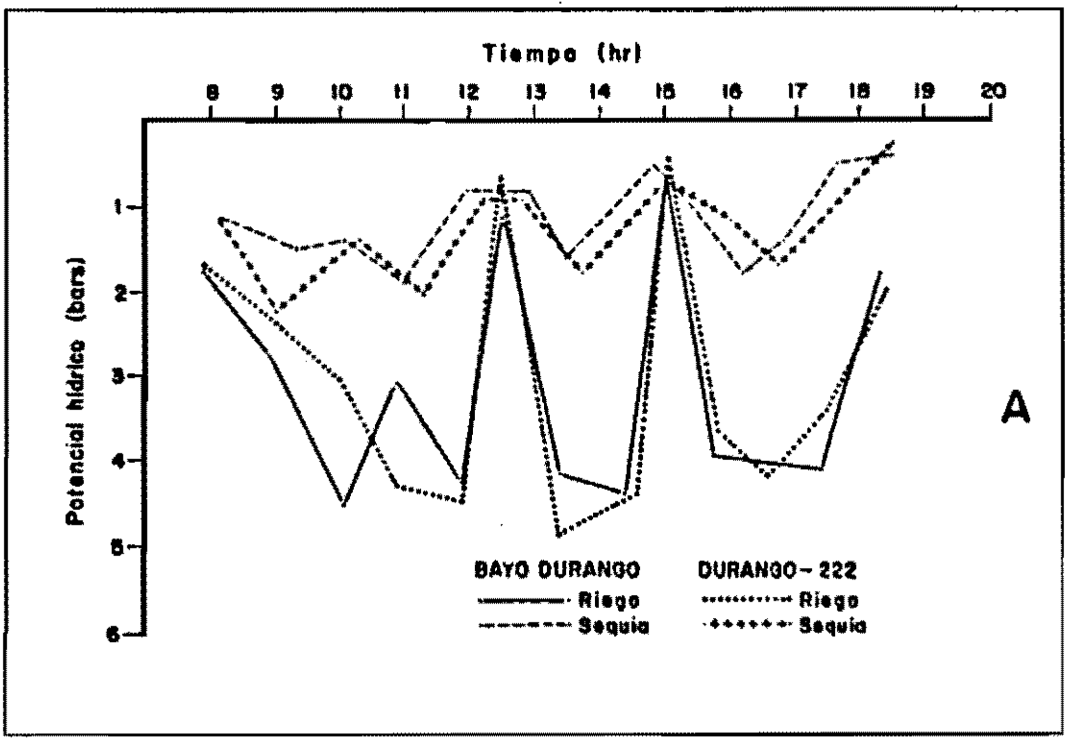

Figura 2.A Potencial hídrico de la hoja de los genotipos Bayo Durango y Durango 222 bajo dos condiciones de humedad 62 días después de la siembra. Fco. I. Madero, Dgo. 1986.

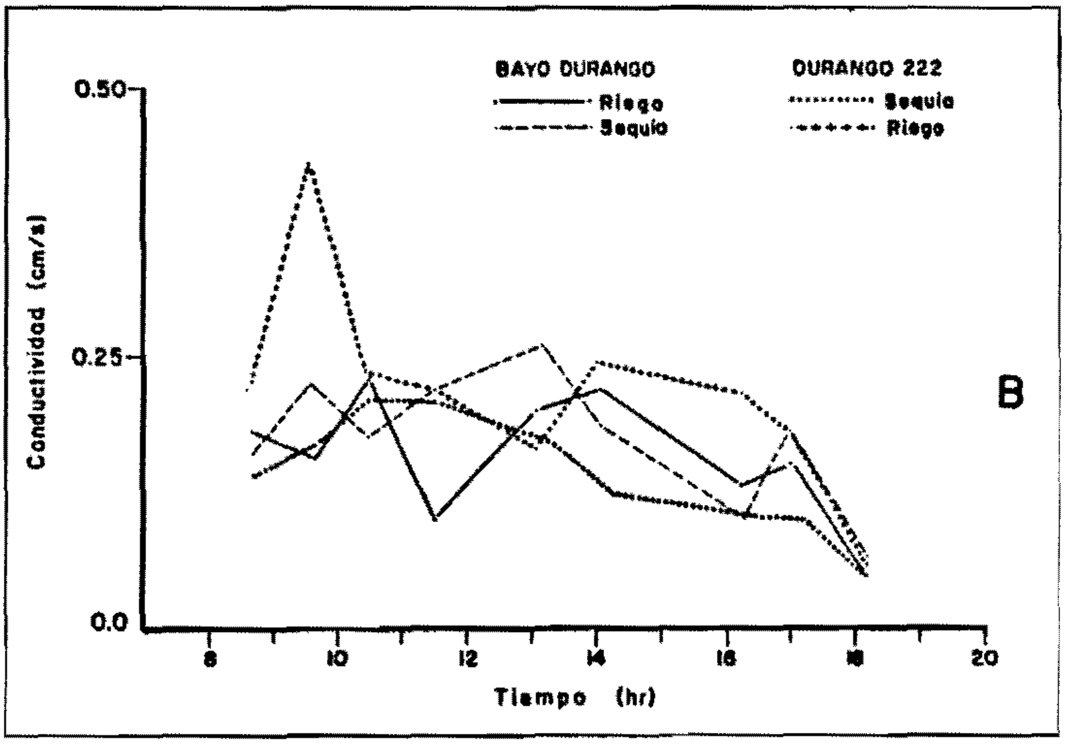

Figura 2.B Conductividad estomatal de los genotipos Bayo Durango y Durango 222 bajo dos condiciones de humedad 62 días después de la siembra. Fco. I. Madero, Dgo. 1986.

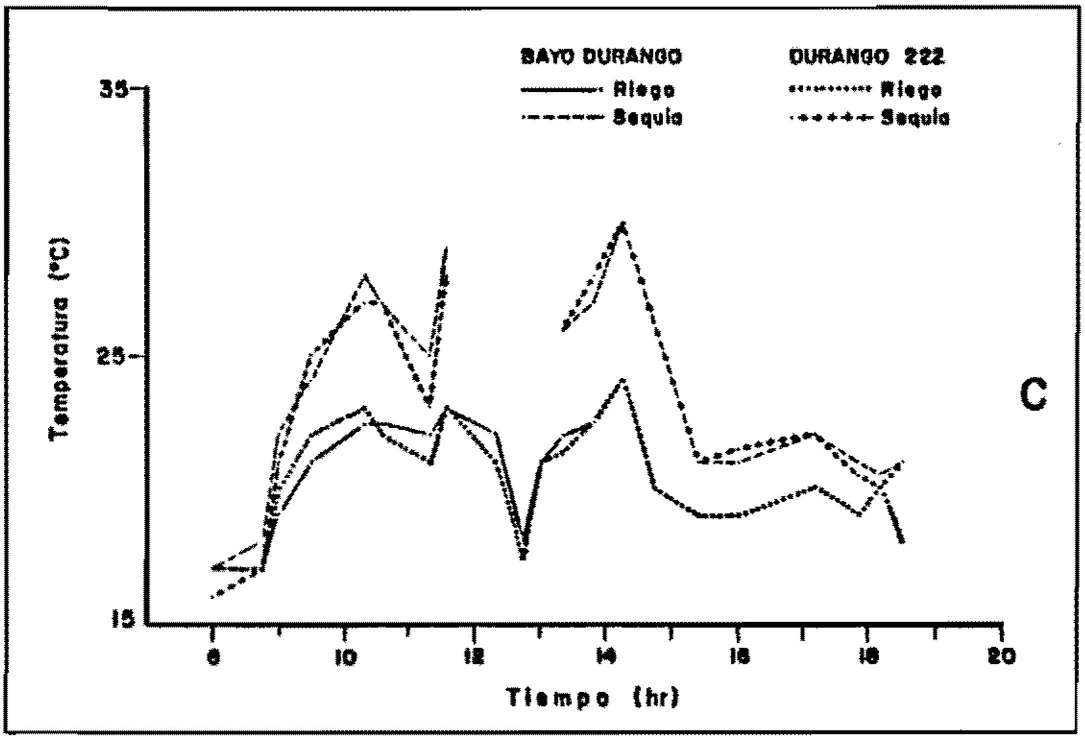

Figura 2.C Temperatura del follaje de los genotipos Bayo Durango y Durango 222 bajo dos condiciones de humedad 62 días después de la siembra. Fco. I. Madero, Dgo. 1986.

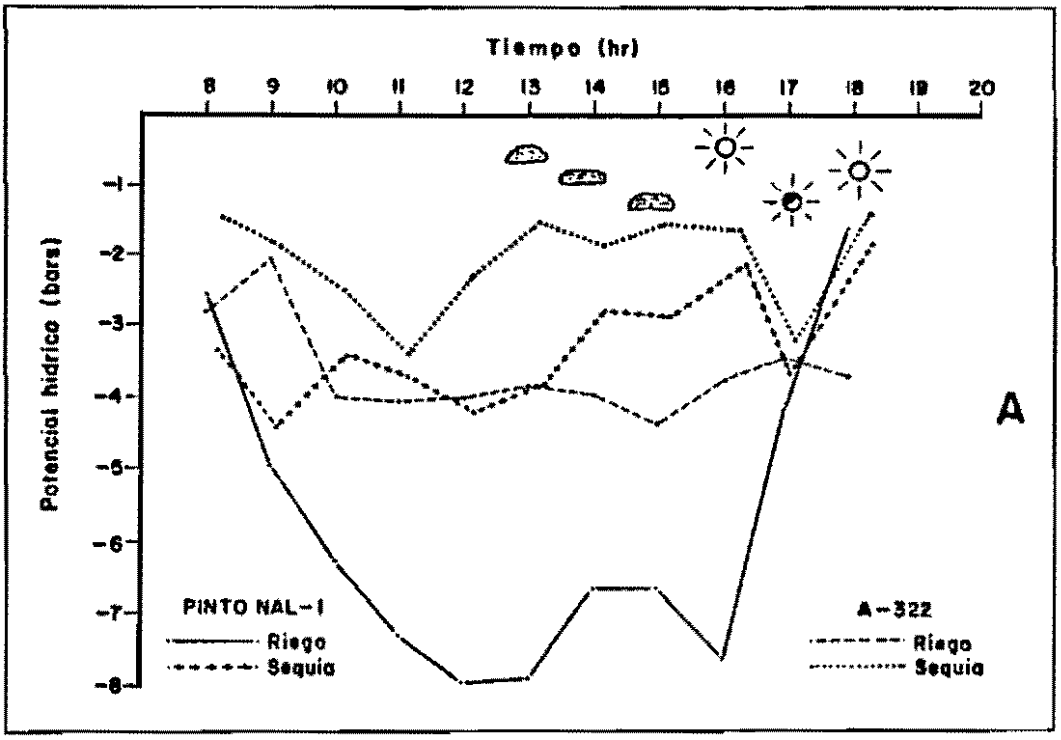

Figura 3.A Potential hídrico de la hoja de los genotipos A 322 y Pinto Nacional-1 bajo dos condiciones de humedad 70 días después de la siembra. Fco. I. Madero, Dgo. 1986.

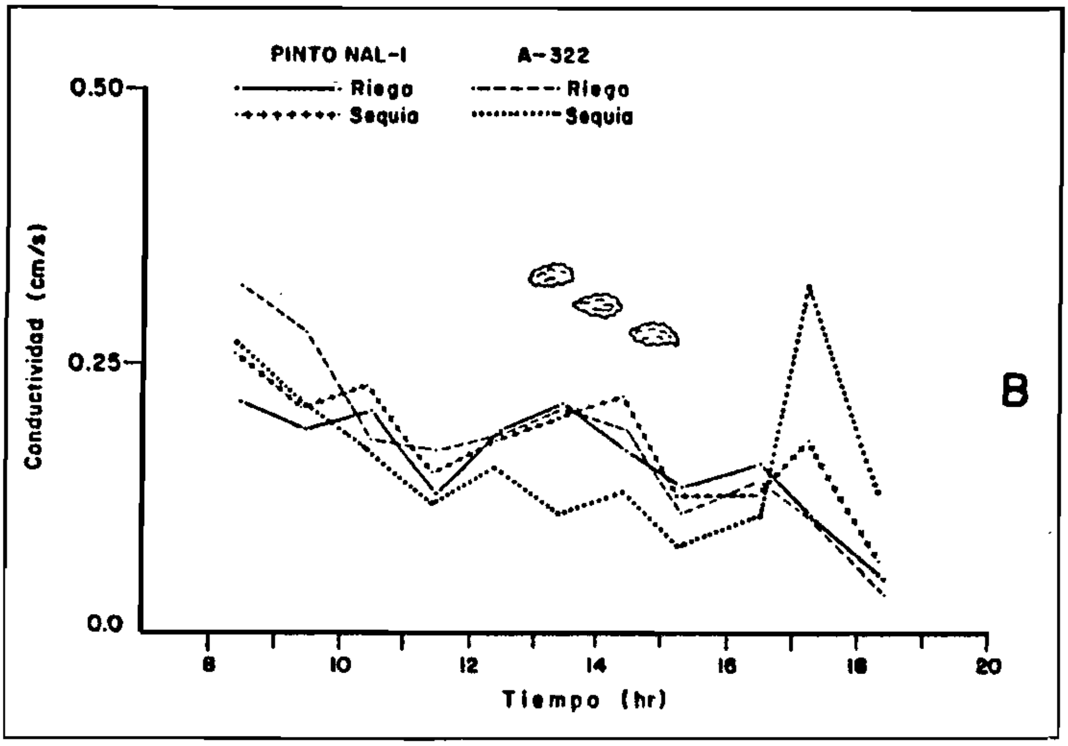

Figura 3.B Conductividad estomatal de los genotipos A 322 y Pinto Nacional-1 bajo dos condiciones de humedad 70 días después de la siembra. Fco. I. Madero, Dgo. 1986.

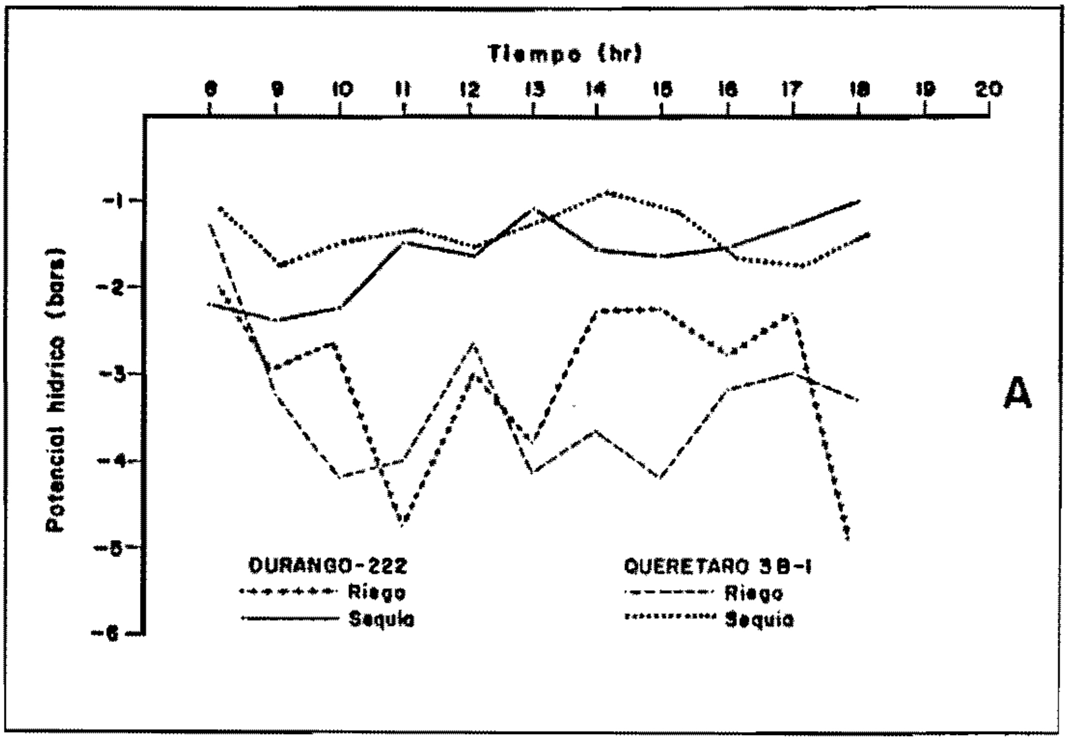

Figura 4.A Potencial hídrico de la hoja de los genotipos Queretoro 3-B-1 y Durango 222 bajo dos condiciones de humedad 75 días después de la siembra. Fco. I. Madero, Dgo. 1986.

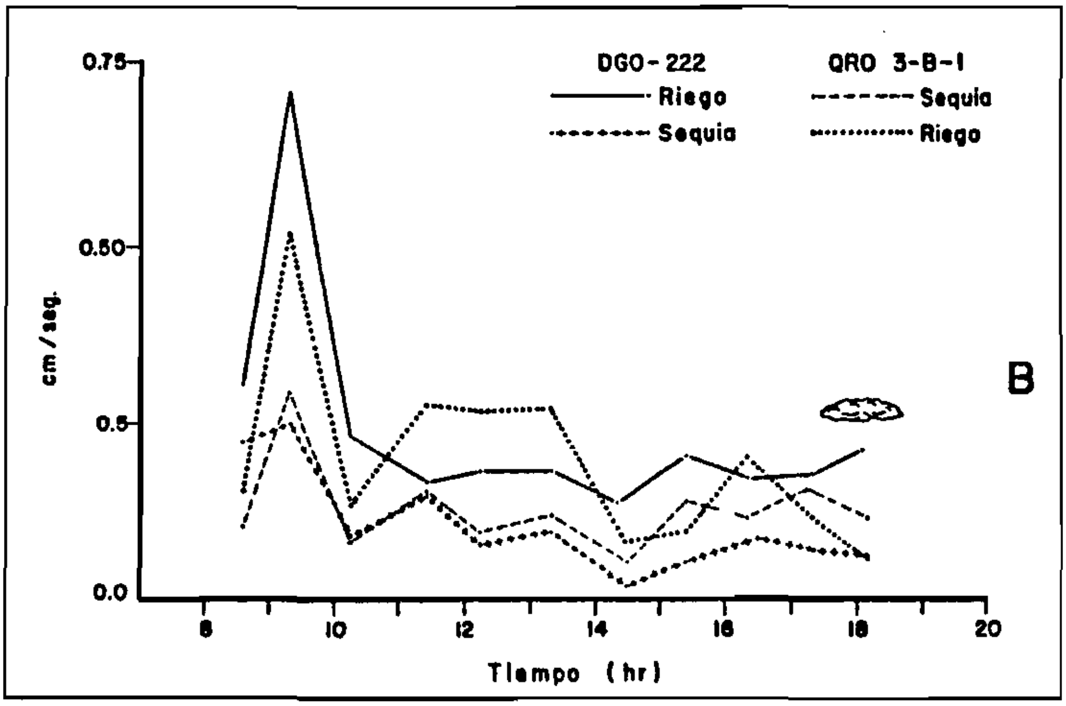

Figura 4.B Conductividad de los genotipos Qro-3-B-1 y Dgo. 222 bajo dos condiciones de humedad 75 días después de la siembra. Fco. I. Madero, Dgo. 1986.

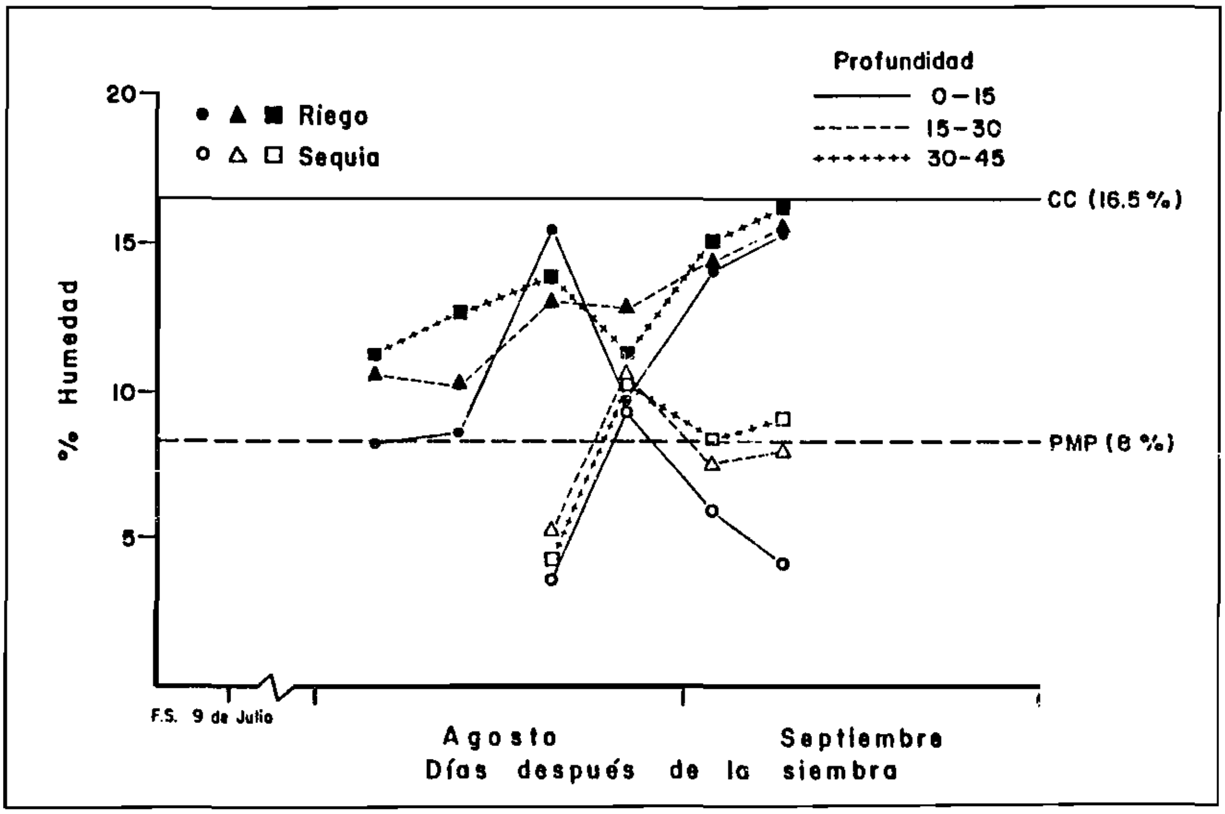

Figura 5. Muestreos de humedad del suelo en dos condiciones (riego y sequía) bajo condiciones de Fco. I. Madero, Dgo. 1986.

INVESTIGACION PARA TOLERANCIA A SEQUIA EN FRIJOL (Phaseolus vulgaris L.) EN GUATEMALA

Rafael Raúl Rodríguez C.*

Resumen

La investigación para tolerancia a sequía en fríjol (Phaseolus vulgaris L.) en Guatemala, no ha sido suficiente. Sin embargo, desde 1976 el tema ya fue de preocupación para algunos técnicos nacionales. Así, a la fecha se han elaborado ya algunos estudios que pueden dar la pauta para la investigación futura en este campo. Se dá una breve descripción de los trabajos mencionados.

1. Problemática

En el Sur-Oriente de Guatemala, la región más productora de fríjol en el país, ocurre cada año una época seca dentro del período de lluvias llamada "canícula" la cual se presenta a mediados de julio, prolongándose a veces hasta agosto y pudiendo llegar a durar hasta un mes (Rodríguez, 1986).

Si se considera que la siembra de "primera" se realiza a mediados de mayo para ser cosechada en agosto, y la de "segunda" se siembra a mediados de septiembre para ser cosechada en noviembre, es fácil ver que la sequía puede afectar el cultivo de fríjol en un estado tan crítico como puede ser la floración u otro estado de desarrollo contiguo a éste, cuando la siembra es de "primera", mientras que para la "segunda", es el final del ciclo vegetativo el afectado por la falta de lluvia. Las Figuras 1 y 2 pueden

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ilustrar mejor la situación descrita.

En la Figura 3, puede verse la precipitación ocurrida en la región durante el ciclo agrícola de 1986. Para 1987, la Figura 4 muestra los respectivos datos.

De los cuatro casos presentados puede verse que para 1987 ocurrió un corrimiento en cuanto al inicio de la temporada de lluvias, lo cual también incidió para que la canícula se presentara tardíamente respecto a otros años. En cualquier caso, también las dos siembras principales se retrasaron, con lo cual todo el fenómeno tuvo un movimiento relativo.

Adicionalmente, a la mala distribución de la precipitación pluvial, debe agregarse el hecho de que los suelos de la región poseen bajo promedio de infiltración y son poco profundos, por lo que no almacenan agua en cantidades suficientes (Simmons et al., 1959). Ya Piant (1979) había mencionado que la mayor cantidad de agua llovida en la región al final se acumulaba en el Océano Pacífico.

Considerando el problema desde el punto de vista de la investigación agrícola, es interesante señalar que según el Catálogo de Tesis 1955-1985 de la Facultad de Agronomía de la Universidad de San Carlos de Guatemala, publicado por el Centro de Documentación e Información Agrícola CEDIA, fueron elaboradas en la Facultad de Agronomía, 850 investigaciones de tesis, de las cuales solamente siete fueron sobre el tema de sequía; a la vez, únicamente tres de ellas se relacionan con el cultivo de fríjol.

Para julio de 1987 el número de tesis ha aumentado a 1019 aunque no se tenga un dato exacto de si ha habido incremento de aquellas relacionadas con sequía en fríjol.

2. Antecedentes

Como se ha señalado, la investigación para tolerancia a sequía en fríjol realizada hasta el momento en Guatemala, no ha sido suficiente como para poder presentar en esta oportunidad logros concretos. Sin embargo, examinando la trayectoria que el tema ha tenido desde 1976, es posible observar que aunque en casos muy esporádicos, la tolerancia a sequía en fríjol ya ha sido considerada por algunos investigadores nacionales.

En lo que sigue, se hará una breve descripción de los trabajos realizados a la fecha:

2.1 En 1976, Figueroa Muñoz, realiza un estudio de Tesis sobre Predicción de fechas de siembra para seis variedades de fríjol (*Phaseolus vulgaris* L.) en el Valle de Monjas, departamento de Jalapa, en función de la distribución de lluvias, durante los años 1966 - 1973. En este trabajo se analizó estadísticamente la distribución de las lluvias por un período de 8 años, como principal parámetro ecológico en la producción de fríjol, con el fin de determinar la gráfica de precipitación pluvial probable en el Valle de Monjas, aspecto que correlacionado con las curvas de crecimiento, podría definir las fechas más adecuadas para la siembra.

El sitio experimental se ubicó a 964 m.s.n.m., con una precipitación anual promedio de 924 m.m y una temperatura media de 21.5°C. Las variedades estudiadas fueron: Turrialba-1, Jamapa, San Pedro Pinula-72, Cuilapa-72, Porrillo-1 y Local Monjas. En el Cuadro 1 aparecen algunos de los resultados observados en esta investigación.

En el peso vegetativo, no se incluyeron las hojas porque la pérdida en cantidad de éstas, durante el ciclo vegetativo del cultivo, hubiese dado resultados no representativos.

Con los resultados anteriores, se integraron las curvas individuales de crecimiento, tomando éstos, como los puntos de importancia definida para los objetivos del estudio. La información para el ploteo de los puntos intermedios no se tomó porque está comprobado según el autor que la curva general sigue la forma sigmoide.

Por esta misma razón y considerando que únicamente se requería información sobre el período de floración y madurez de corte, no se usó ningún diseño experimental, sólo parcelas de observación.

Las conclusiones de este trabajo fueron:

a. La cantidad y distribución de la precipitación pluvial, como factor climático por sí sólo, no es determinante para definir la fecha de siembra más adecuada para el fríjol.

b. El conocimiento del comportamiento de las variedades, resulta de capital importancia, para correlacionarlo con la gráfica de precipitación probable y definir con más probabilidades de éxito, las fechas de siembra.

c. La correlación del crecimiento de las variedades estudiadas, con la gráfica de precipitación pluvial probable, sirvió para determinar las siguientes fechas de siembra, que satisfacen los requerimientos del cultivo, a traves de su ciclo vegetativo, (adecuada humedad para germinación, crecimiento y desarrollo primarios, llenado de vaina; período sin lluvias a la cosecha)

22 de julio :	Turrialba-1 Jamapa San Pedro Pinula-72 Cuilapa-72 Porrillo-1

31 de mayo y 23 de julio : Local Monjas

2.2 Leiva (1977) propuso tres probables soluciones para atacar el problema de la mala distribución de la precipitación en la región, a saber:

a. Obtener variedades tolerantes a la sequía.

b. Anticipar la fecha de la siembra de "segunda".

c. Obtener variedades precoces que escapen a la sequía, manteniendo un buen potencial de rendimiento.

Para el autor citado, lo ideal sería optar por la primera solución, aunque acepta que sería un proceso complicado y a muy largo plazo ya que habría que comenzar con detectar las fuentes de tolerancia a la sequía. Con todo es importante señalar la importancia que como solución a la sequía se le da al mejoramiento por tolerancia a la misma.

2.3 En marzo de 1984, Ruano publicó su trabajo de tesis en donde estudió el efecto del Cycocel (Cloruro de 2 cloroetiltrimetilamonio) sobre la resistencia a sequía edáfica en plántulas de fríjol bajo condiciones de invernadero.

Se pretendía con el estudio determinar la concentración que indujera el óptimo de resistencia a la sequía edáfica en la fase de plántula y también la variedad que en tal fase superará el mayor período de sequía edáfica cuando fuera tratada con Cycocel.

En el trabajo se consideraron como importantes dos respuestas características de las plantas al Cycocel: a) mejor tolerancia a la sequía y temperaturas altas y b) reducción de la transpiración y pérdida de agua. Lo anterior, quizá basado en que este inhibidor puede retrasar la actividad meristemática de crecimiento en general.

El estudio se realizó bajo condiciones de 1500 m.s.n.m., temperatura promedio de 34°C, 55% de humedad relativa y alta intensidad lumínica.

Se regó diariamente hasta los diez días, las aplicaciones del inhibidor fueron foliares, y se hicieron al suspender el riego. Se usaron 4 dosis de Cycocel: 200, 500, 1000 y 2000 ppm más un testigo con agua. Las variedades empleadas fueron ICTA-Tamazulapa, ICTA-Quetzal e ICTA-Jutiapán.

En la Figura 5 se observa que la dosis de 500 ppm indujo la mayor resistencia a la sequía edáfica, a los 21 días en ICTA-Quetzal y a los 17 días en ICTA-Tamazulapa. (Estos días fueron medidos como los días que tardaron las plántulas en marchitarse después del último riego al suelo).

En las líneas de tendencia (Figura 6) se observa que la resistencia a la sequía es menor cuando se emplean dosis inferiores o superiores a 500 ppm, especialmente en las variedades ICTA-Quetzal e ICTA-Jutiapán, pués los tratamientos obtuvieron respuestas similares y deficientes.

Los promedios de resistencia a la sequía, debido a tratamientos con Cycocel, con respecto a un mes fueron de 47% en la variedad ICTA-Quetzal, 40% en la variedad ICTA-Tamazulapa y 12% en la variedad ICTA-Jutiapán (Cuadro 2).

Por otro lado, los promedios de resistencia provocados por cada dosis fueron de 27%, 47%, 37% y 20% para 200, 500, 1000 y 2000 ppm respectivamente. El promedio de los testigos fue de 20% (Cuadro 3).

Se concluyó que :

Los mayores períodos de resistencia a la sequía se obtuvieron con la dosis de 500 ppm, 21 y 17 días en las plántulas de ICTA-Quetzal e ICTA-Tamazulapa, respectivamente. En estas variedades la respuesta a cada dosis de Cycocel fue diferente mientras que en la variedad ICTA-Jutiapán no se encontró respuesta favorable ni significancia en los tratamientos pués las plántulas se marchitaron severa y prematuramente hasta secarse debido a las condiciones experimentales.

Las medias de resistencia a la sequía, debido a los tratamientos con Cycocel, en cada una de las variedades fueron de 14 días en las plántulas de ICTA-Quetzal, 12 días en las plántulas de ICTA-Tamazulapa y 3.5 días en las plántulas de ICTA-Jutiapán.

Por otro lado las mejores medias de resistencia, por dosis de Cycocel, se lograron con 500 ppm (14 días) y 1000 ppm (11 días).

2.4 Beebe et. al. en 1984 publicaron un trabajo acerca de dos estudios sobre el efecto de sequía en el fríjol con variedades precoces y tardías en Jutiapa, Guatemala. Las condiciones experimentales fueron 960 m.s.n.m. y temperatura promedio de 27°C.

Se utilizaron cinco genotipos:

BAT 41 : Intermedio a florecer, maduración precoz, corto período de floración a madurez, rojo opaco, semilla pequeña.
P006 : Precoz a floración período de maduración largo, negro opaco, semilla pequeña.
RABIA DE GATO : Precoz a floración, período corto a maduración, negro opaco, semilla pequeña.
CENTA-IZALCO : Precoz a floración, con posible tolerancia a sequía, rojo opaco, semilla grande.
ICTA-TAMAZULAPA : Floración intermedia, negro opaco, semilla pequeña.

El objetivo de este trabajo fue determinar si los diferentes componentes de rendimiento y diferentes genotipos de fríjol común

(Phaseolus vulgaris L.) responden igual a la sequía impuesta en varias fechas después de la floración.

Se utilizó un arreglo en parcelas divididas con distribución en bloques al azar, con 3 repeticiones.

Las variedades constituyeron las parcelas menores. Las parcelas mayores se distribuyeron por la fecha del último riego, o sea, la fecha de aplicación de la sequía (Figura 7).

El segundo ensayo se sembró en agosto de 1983, y se establecieron tratamientos de sequía variando la fecha de siembra, cada 10 días a partir del 24 de agosto hasta el 13 de septiembre (3 fechas de siembra). En este ensayo P006 se reemplazó por ICTA-Jutiapán, y se agregó Pata de Zope (criollo, muy precoz).

Aquí, las parcelas mayores fueron las fechas de siembra, y las menores, las variedades.

El objetivo fue determinar si las variedades precoces tienen ventajas sobre las tardías en condiciones de períodos cortos de lluvias.

De ambos trabajos se concluyó lo siguiente:

- En el primer ensayo la variedad ICTA-Tamazulapa, superó a las precoces cuando no hubo presión de sequía. Con sequía, perdió su ventaja pero no cayó por debajo de las precoces.

- Sin embargo, en el segundo ensayo con presión moderada de sequía, CENTA-Izalco y Pata de Zope superaron a ICTA-Tamazulapa (no significativamente) sugiriendo esto una ventaja de la precocidad.

- De acuerdo con experiencias en ensayos de finca, ICTA-Jutiapán fue más sensible a la sequía que ICTA-Tamazulapa.

- BAT 41, que es intermedio en días a floración y precoz para madurar, fue más sensible a la sequía que las precoces criollas Pata de Zope y CENTA-Izalco, que son precoces para florear y madurar.

- El patrón de precocidad de BAT 41 no parece ser el mejor para proteger al cultivo contra la sequía.

- Entre los componentes de rendimiento, vainas por planta fue el más sensible a la sequía.

2.5 Con base en el primer ensayo realizado en el estudio anterior por Beebe *et. al.* (1984), Vásquez (1984) publicó su tesis sobre el efecto de sequía impuesta en distintas épocas en el rendimiento y sus componentes en cinco genotipos precoces e intermedios de fríjol (*Phaseolus vulgaris* L.).

El mérito de este trabajo estuvo en que profundizó los análisis estadísticos de los datos.

El objetivo fue determinar el comportamiento de diferentes componentes de rendimiento y diferentes genotipos de fríjol común (*Phaseolus vulgaris* L.) bajo condiciones de sequía impuesta en distintas fechas.

Se efectuaron análisis de varianza para cada componente de rendimiento. Además análisis de correlación lineal simple, correlación logarítmica y cuadrática entre el rendimiento y los diferentes tratamientos de riego. Por otro lado, se efectuaron las mismas correlaciones entre cada uno de los componentes del rendimiento (número de vainas por planta, número de semillas por vaina y peso de cien semillas) y los diferentes tratamientos de riego. Correlación lineal simple entre rendimiento y componentes de rendimiento en los diferentes tratamientos de riego. El análisis estadístico anterior se efectuó para cada una de las variedades evaluadas.

El análisis de regresión múltiple se aplicó entre el rendimiento y sus componentes tomando en cuenta los diferentes tratamientos de riego.

Analizando la Figura 8 se observa que el comportamiento en general de las variedades en estudio fue similar en el sentido de mantener la tendencia a incrementar el rendimiento de acuerdo al incremento en el número de riegos. Unicamente Rabia de Gato tiene un decremento en rendimiento después del octavo riego, lo que podría deberse a una cantidad de agua excesiva (demás), en una época en que ya estaba de cosecha, pues es una variedad de madurez precoz (55 a 58 días).

Esta misma Figura 8 permite observar que variedades precoces como Rabia de Gato y BAT 41 son inferiores en rendimiento a las intermedias aún cuando se hagan pocos riegos. Estos resultados son contrarios a lo que se suponía, es decir, que las variedades precoces rendirían más que las intermedias cuando se les suprimiera el agua en una época en que ambas estuvieran en diferente etapa de desarrollo. En otras palabras, las variedades intermedias mantienen su potencial de rendimiento superior a las precoces bajo condiciones de sequía, según los resultados obtenidos.

En la Figura 9 se puede ver que el comportamiento del componente número de vainas por planta no se mantuvo estable a través de los tratamientos de riego ya que hubo una notable variación; por lo tanto, se le considera como uno de los componentes más afectados por la sequía impuesta.

En el Cuadro 4 se presentan los resultados de la regresión múltiple entre el rendimiento y sus componentes, por cada variedad y a través de los tratamientos de riego, se puede observar ahí que el componente más importante y más afectado por la sequía impuesta en todas las variedades a excepción de CENTA-Izalco, es el número de vainas por planta, debido a su valores altos de "F".

En la variedad CENTA-Izalco resultó ser el componente número de semillas por vaina el más afectado por la sequía. El rendimiento de ICTA-Tamazulapa depende del número de semillas por vaina y del número de vainas por planta, que son los más afectados por la sequía impuesta en esta variedad. Al realizar este mismo análisis para todas las variedades, resultó que el componente del cual más depende el rendimiento y es mayormente afectado por la sequía es el número de vainas por planta, en función de su alto valor de "F".

Como conclusiones se tienen las siguientes:

- Las variedades en estudio mostraron un aumento en rendimiento conforme su aumento en el número de riegos, exceptuando la variedad Rabia de Gato cuyo mayor rendimiento se observó a los ocho riegos.

- El componente número de vainas por planta fue el que más se redujo, bajo condiciones de humedad limitada, para todas las variedades en general; el peso de cien semillas fue menos afectado que el anterior y el número de semillas por vaina, el último afectado de los componentes.

- El número de vainas por planta, en las variedades mejoradas fue el componente que más contribuyó al rendimiento, seguido del peso de cien semillas.

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Cuadro 1. Comportamiento de cada variedad en el estudio de Muñoz (1976) sobre fechas de siembra en el Valle de Monjas.

Variedades	Días a floración	Días a madurez de corte	Peso tallo y raíces kg/ha	Peso grano kg/ha	Peso total kg/ha
Turrialba	47	86	1640	2360	4000
Jamapa	48	86	1800	2200	4000
San Pedro Pinula 72	45	86	2000	2000	4000
Cuilapa 72	45	94	2080	1920	4000
Porrillo-1	46	93	1760	2240	4000
Local Monjas	42	81	2120	1880	4000

Cuadro 2. Medias de resistencia a la sequía en tres variedades de fríjol tratadas con Cycocel.

Variedad	$\bar{X}$ Cycocel		$\bar{X}$ Testigos	
	Días	%	Días	%
Quetzal	14	-	8	27
Tamazulapa	12	-	5	17
Jutiapán	3.5	12	4	13

% = Porcentaje respecto a un mes.

$\bar{X}$ = Medias.

Cuadro 3. Medias de resistencia a la sequía inducida por cada dosis de Cycocel (Ruano, 1984).

Cycocel (ppm)	Días	% Respecto a un mes
0	6	20
200	8	27
500	14	47
1000	11	37
2000	6	20

Cuadro 4. Coeficientes de regresión de determinación y constantes para las variables peso de 100 semillas, número de vainas por planta, número de semillas por vaina para las 5 variedades evaluadas (Vasquez, 1984).

				Peso de 100 semillas		Vainas por planta		Semillas por vaina	
Variedade	r	R^2	b_0	b1	F	b_2	F	b_3	F
Rabia de Gato	0.99992	0.99984	14232.86	-571.4416	488.140	312.9605	3315.777	- 804.375	172.709
Centa Izalco	0.99984	0.99968	-13096.78	181.3436	83.039	8.894245	0.335	1679.159	549.882
P-006	0.99630	0.99262	1991.875	-278.9044	1.695	304.0941	37.583	193.6987	0.299
BAT 41	0.98981	0.97973	1955.149	-413.8619	12.164	476.3476	32.029	290.0511	1.288
ICTA Tamazulapa	0.95653	0.91496	- 5959.758	33.71154	0.011	227.3389	11.544	707.4630	2.544
Todas las vars.	0.88181	0.77759	- 3242.586	51.52668	11.164	174.8202	42.349	322.3512	7.501

r = Coeficiente de regresión.
R^2 = Coeficiente de determinación.
b_0, b_1, b_2, b_3 = constantes de regresión

Figuras

Figura 1. Distribución de la lluvia en mm por mes, y en días por cada mes en el Sur-oriente de Guatemala. (Promedio de 6 años y 3 localidades).

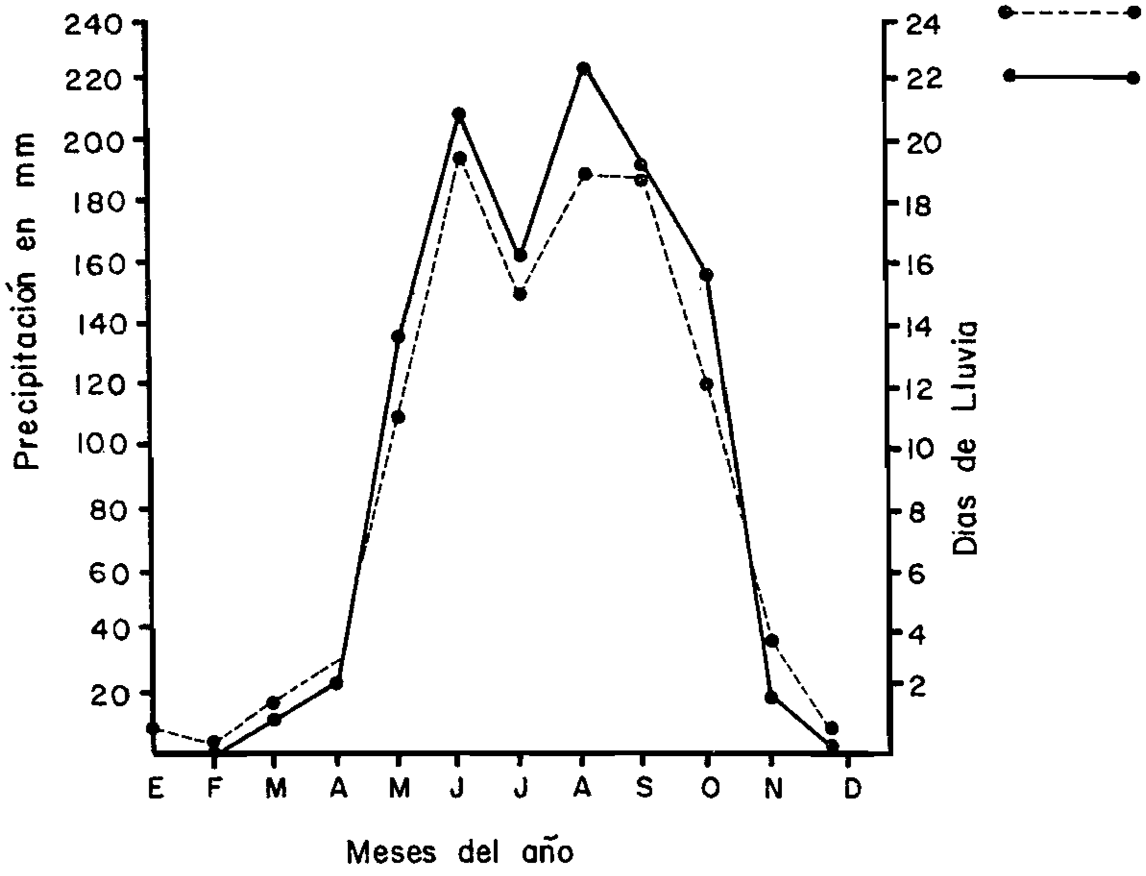


Figura 2. Cantidad de lluvia distribuída cada 6 días durante el trimestre Septiembre-Noviembre en el Sur-oriente de Guatemala. (Promedio de 6 años y 3 localidades).

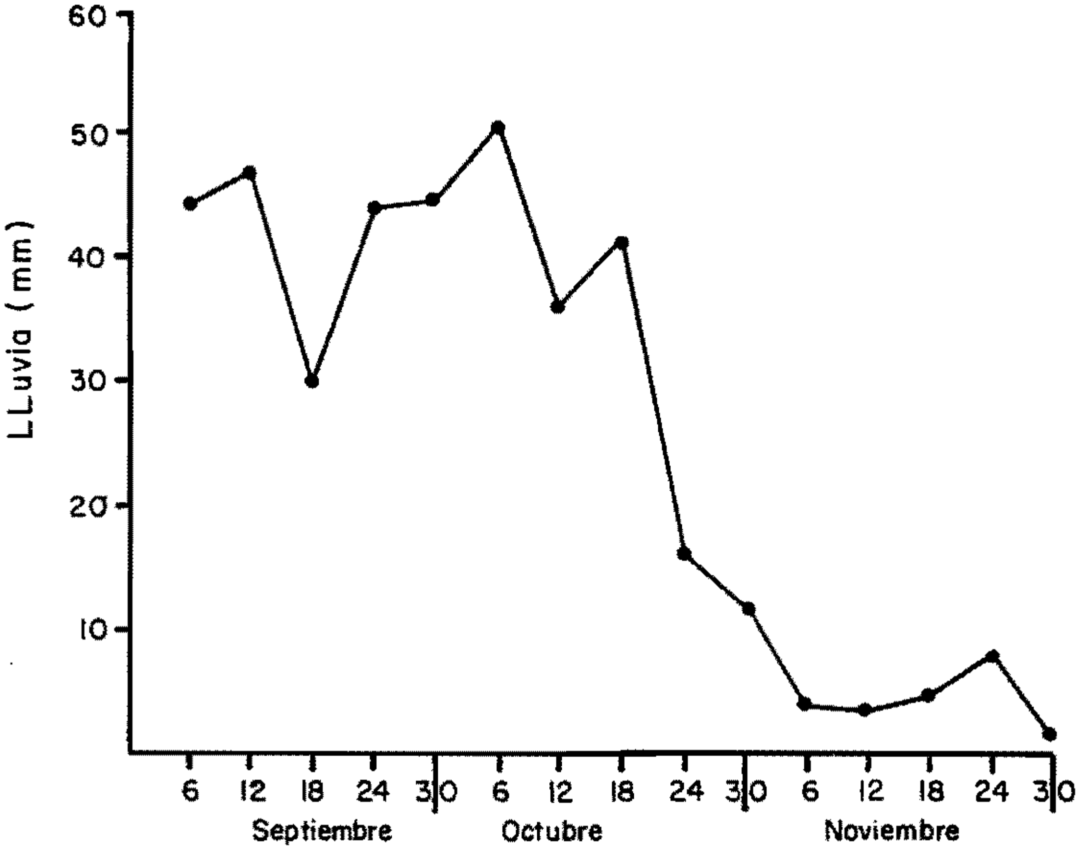


Figura 3. Climograma para siembras de 1ra. y 2da. región VI, Jutiapa, 1986.

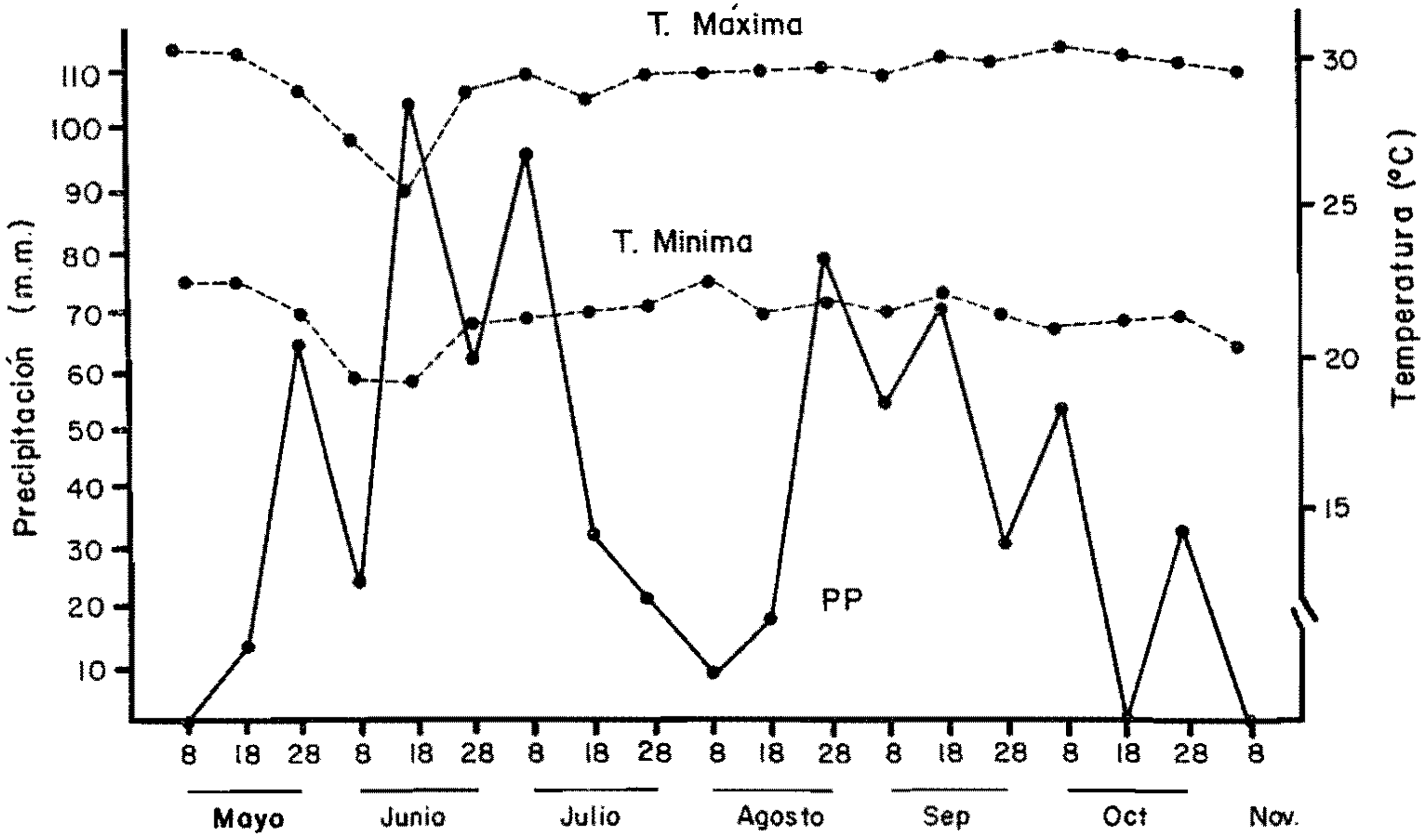


Figura 4. Precipitación para 1987.

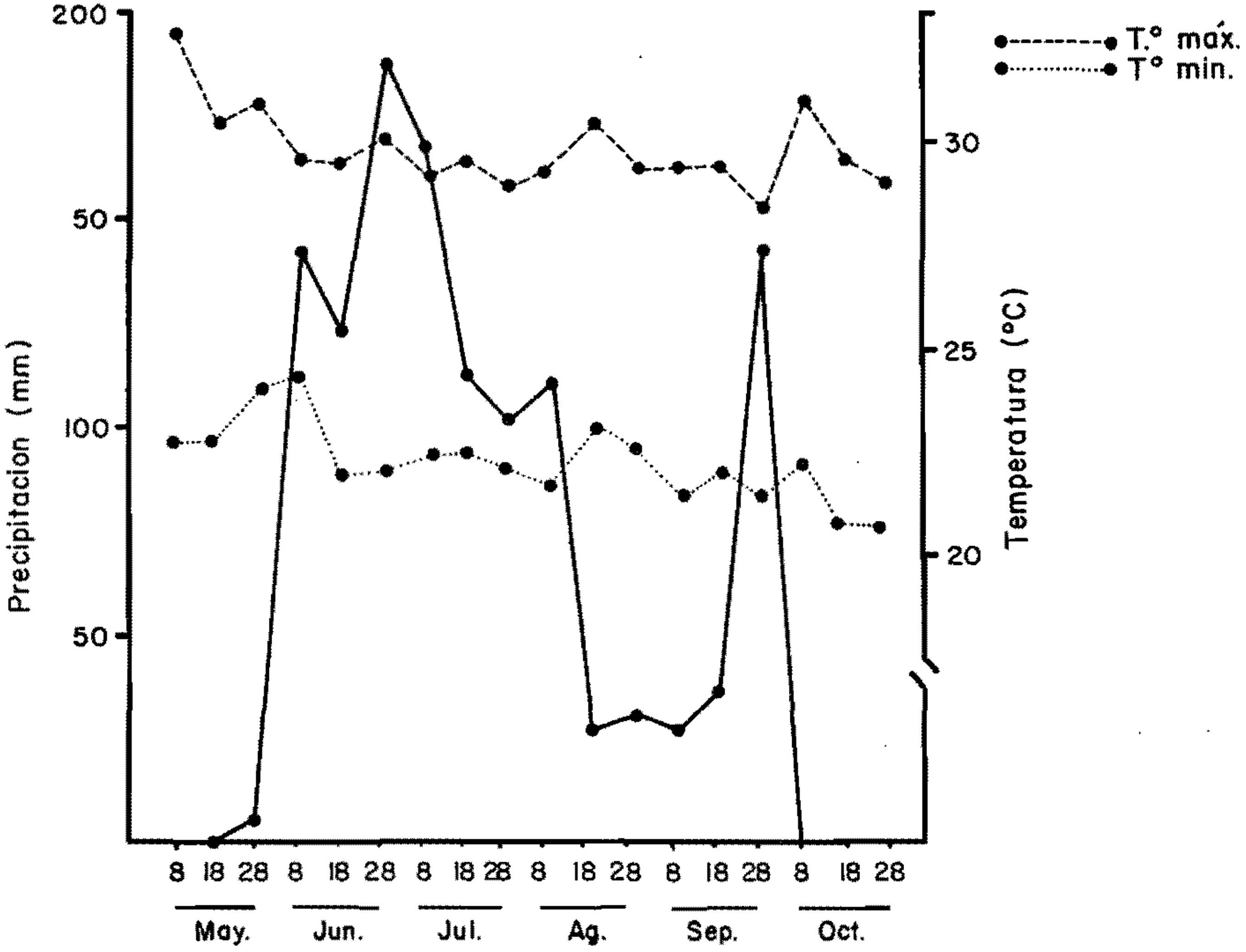


Figura 5. Resistencia a la sequía edáfica. Plántulas de fríjol tratadas con Cycocel (Ruano, 1984).

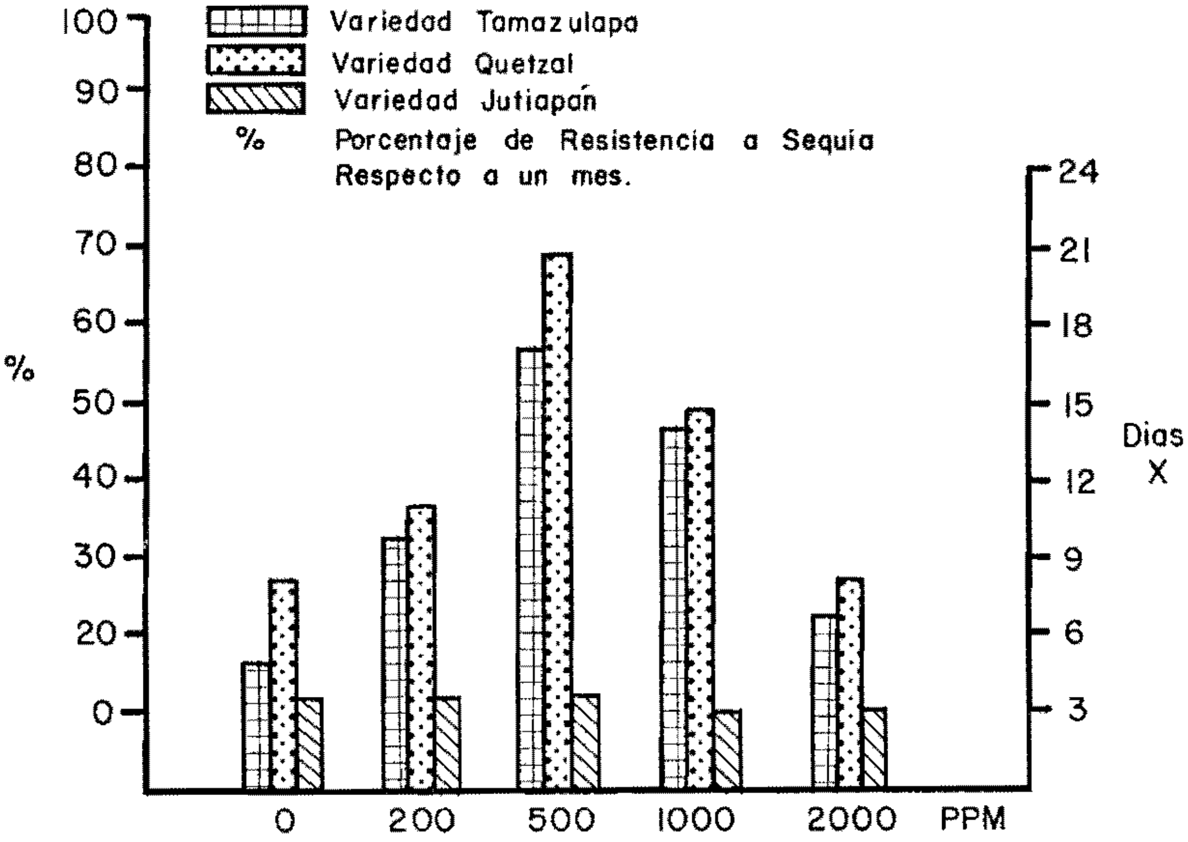


Figura 6. Líneas de tendencia dosis de Cycocel vs resistencia a sequía (Ruano, 1984).

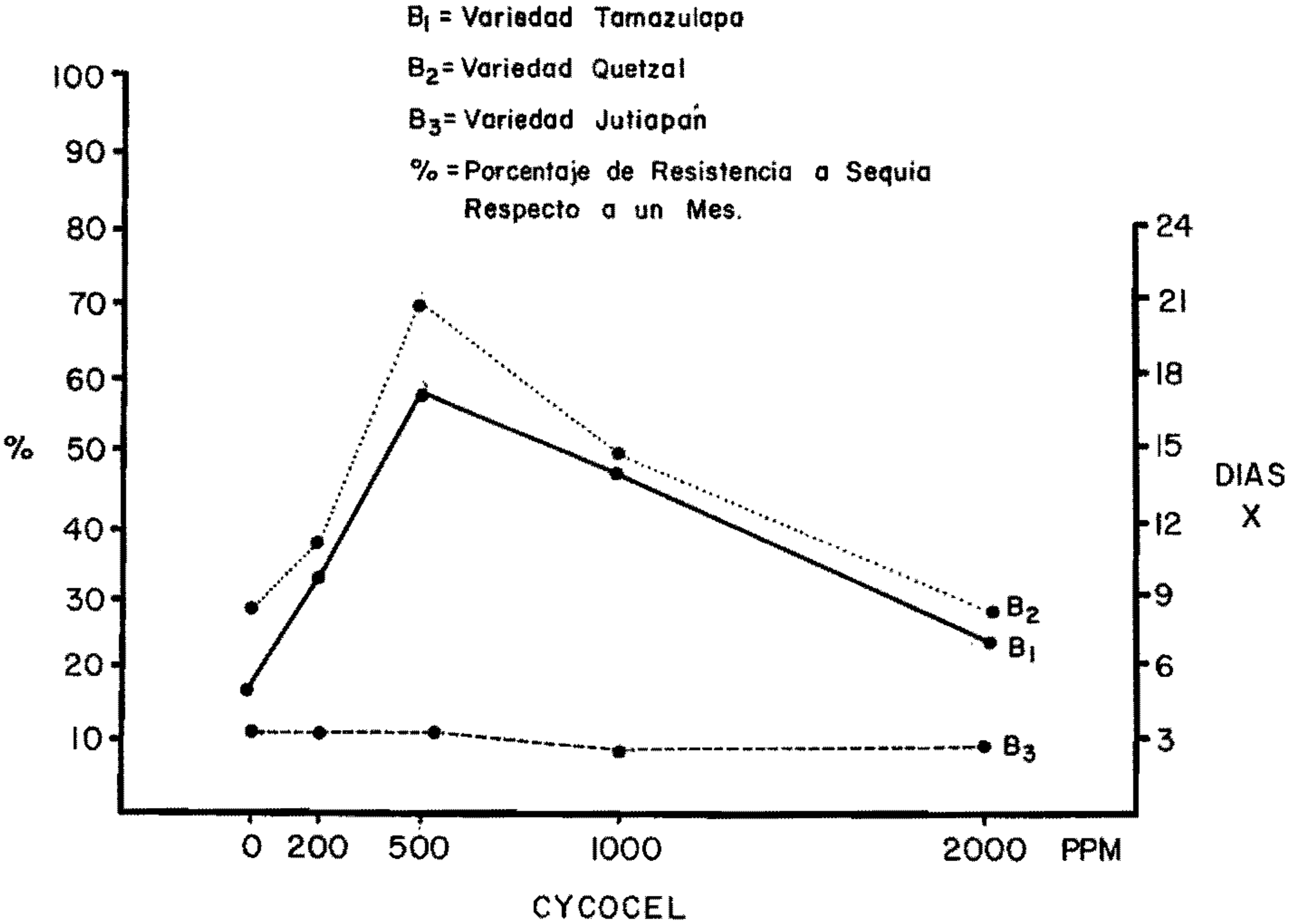


Figura 7. Plano de campo.

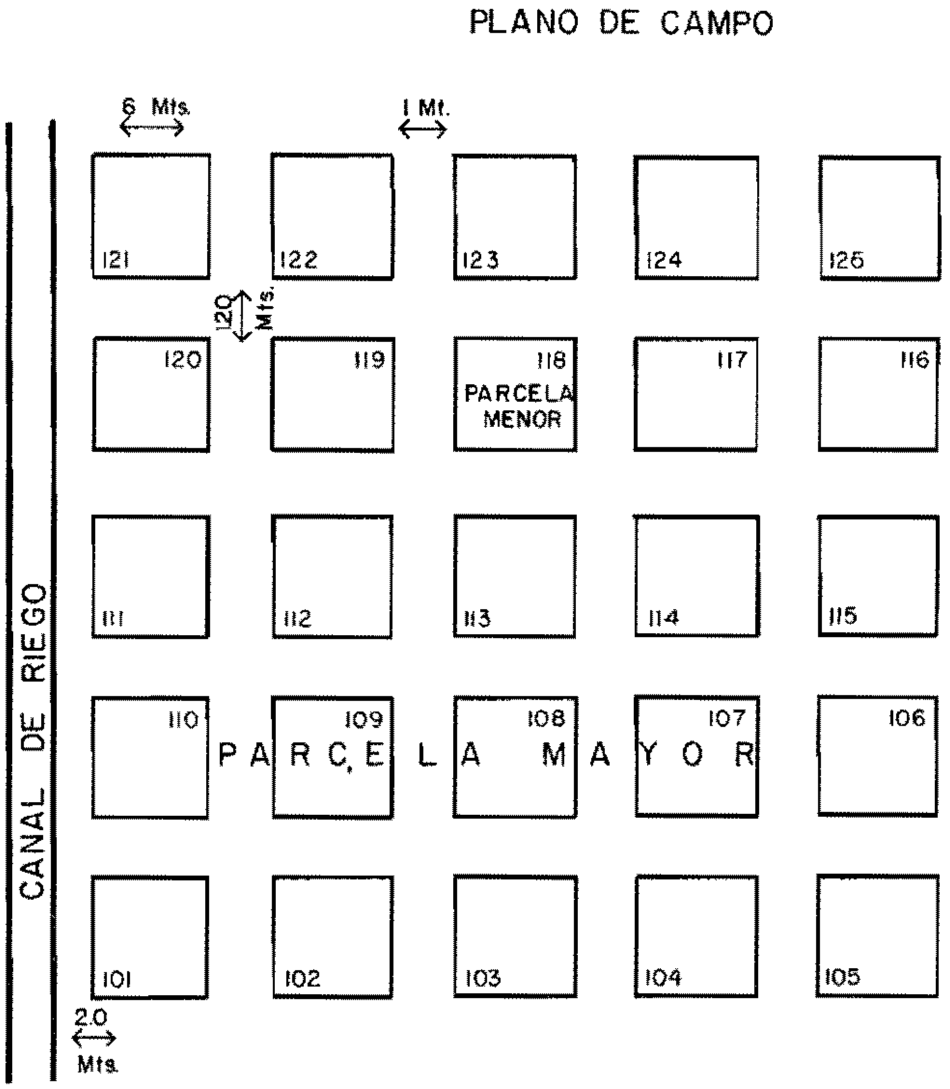


Figura 8. Rendimiento de 5 variedades de frijol a través de 5 tratamientos de riego (Vasquez, 1984).

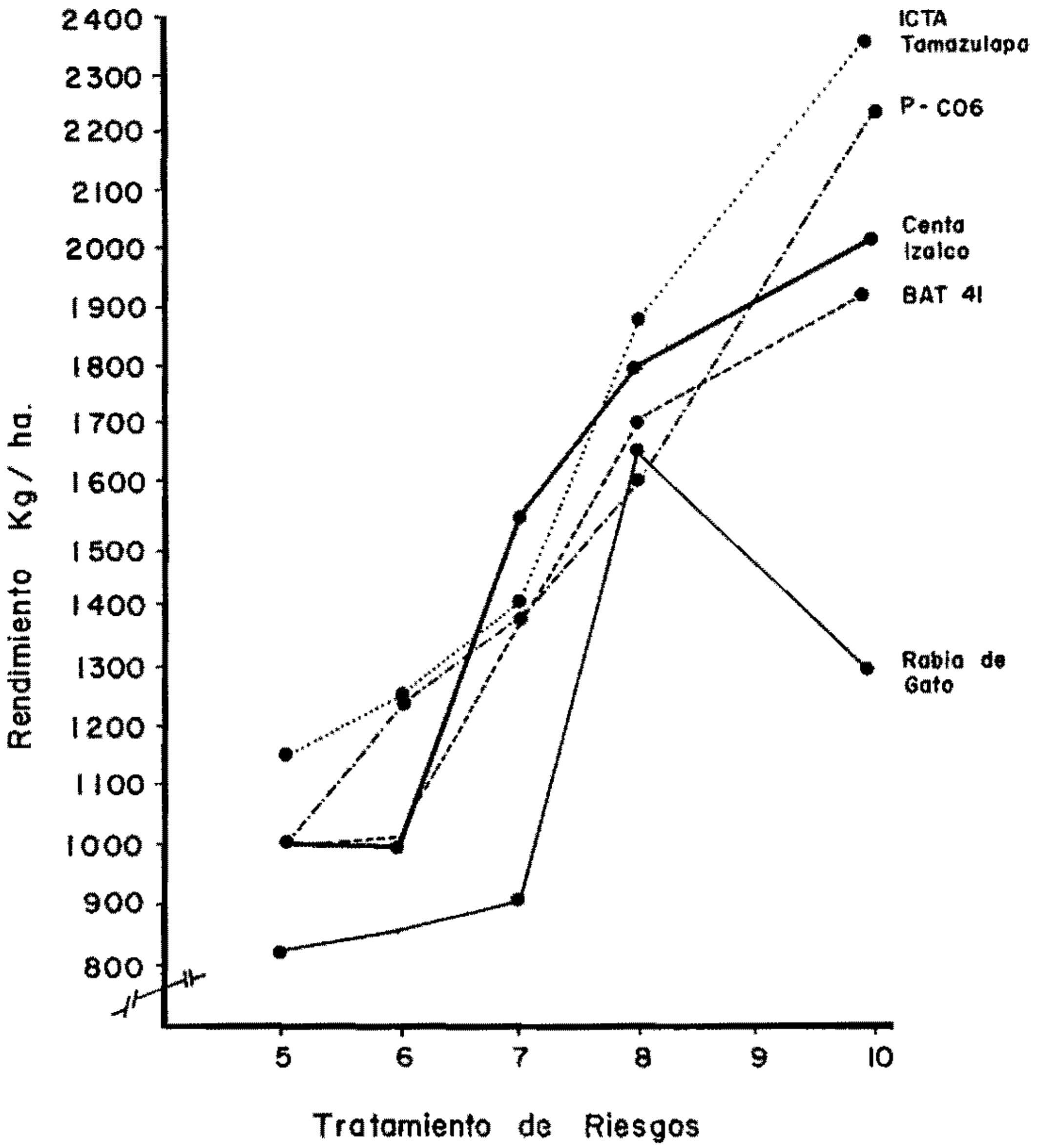
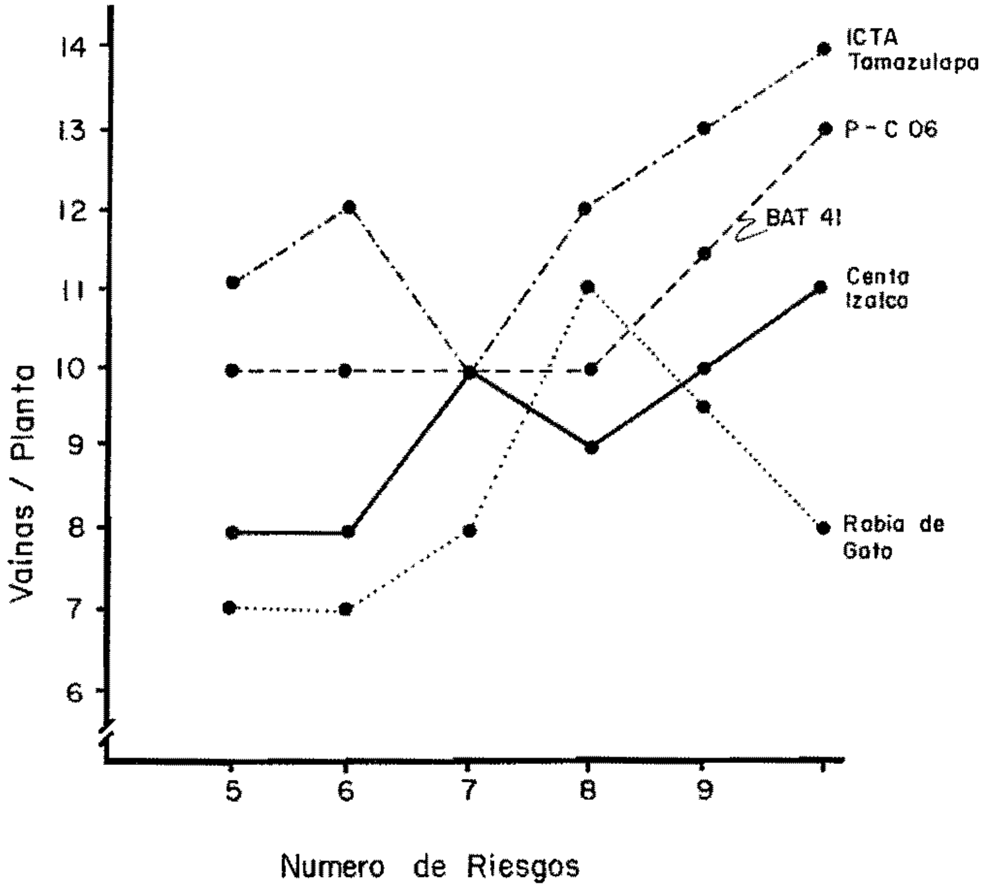


Figura 9. Comportamiento del no. de vainas por planta en 5 variedades de fríjol a través de 5 tratamientos de riego (Vasquez, 1984).



INVESTIGACIONES SOBRE TOLERANCIA A SEQUIA EN FRIJOL EN HONDURAS

Silvio Zuluaga, Concha M. Elvir, Carlos Rodríguez Serrano y
José David Erazo*

Resumen

La sequía es un factor limitante de la producción de fríjol en Honduras, principalmente en las siembras realizadas en el segundo semestre de cada año. El país es ideal para realizar, a nivel de campo, trabajos de tolerancia a sequía, ya que se tienen pocas probabilidades de precipitación en los cuatro primeros meses del año. En 1986, con la siembra del Vivero Internacional de Tolerancia a Sequía (BIDYT), se iniciaron, en la Escuela Agrícola Panamericana, investigaciones sobre tolerancia a estrés hídrico en fríjol. Bajo condiciones extremas de sequía, las entradas del BIDYT redujeron sus rendimientos entre 69% y 98%. En 1987, se continuaron los estudios con la siembra de diferentes ensayos. La variedad de grano negro, ICTA Ostúa mostró ser muy promisoria; en contraste, RAB 50 y la variedad local Zamorano, resultaron ser altamente susceptibles. Líneas derivadas de cruces interespecíficos entre _P. vulgaris_ x _P. acutifolius_ indicaron una alta tolerancia, aunque la respuesta pudo ser debida a precocidad. Los planes futuros incluyen estudios de osmorregulación, pubescencia foliar y cruces interespecíficos, con el objeto de identificar mecanismos fisiológicos de tolerancia que puedan ser utilizados en programas de mejoramiento.

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Introducción

En Honduras, el fríjol es un cultivo de pequeños agricultores que dependen de la lluvia para obtener su cosecha. Por las épocas de siembra utilizadas, principalmente en el segundo semestre del año, las probabilidades de lluvia se disminuyen cuando el cultivo está entrando a su etapa reproductiva, limitando grandemente los rendimientos.

No existe una cuantificación de las pérdidas en rendimiento debidas a estrés hídrico. Sin embargo, son considerablemente altas y contribuyen en buena parte al bajo rendimiento promedio, 550 kg/ha, que se obtiene en el país (Ramos, 1986). Hay épocas en que la sequía es de tal magnitud que se pierde un alto porcentaje de la producción en algunas zonas, como ocurrió en la postrera de 1984 en la Región Centro Oriental. Alrededor del 30% de la producción de fríjol se perdió en la Escuela Agrícola Panamericana (EAP), en primera de 1985, debido a dos semanas de estrés hídrico en la etapa de establecimiento de vainas.

A través de los años, los agricultores han aminorado el problema de la sequía, mediante el uso de variedades precoces. Con buena razón, todas las variedades criollas del país como : cuarenteños, cincuenteños, chingos, etc., tienen 60 días a 65 días a madurez fisiológica. La preferencia por variedades muy precoces limita la adopción, por parte de los agricultores, de variedades mejoradas con superiores rendimientos a las tradicionales. En la EAP, se ha observado que variedades precoces, bajo adecuada irrigación, retrazan su madurez fisiológica y presentan un potencial de rendimiento más alto que el normal. Esto demuestra, que aún para variedades precoces, existe la posibilidad de incrementar sus rendimientos, si se les lograra introducir resistencia genética a la sequía.

Honduras es un país ideal para hacer trabajos de sequía a nivel de campo. Se tienen muy buenas probabilidades de carencia de lluvias en los primeros cuatro meses del año. Disponiendo de riego, se puede aprovechar este período para identificar germoplasma tolerante, hacer selecciones en un programa de mejoramiento y para el estudio, a nivel de campo, de mecanismos fisiológicos de tolerancia. Otra manera de inducir estrés hídrico a nivel de campo, es sembrando a fines de octubre (un mes más tarde de la fecha normal de siembra) lo que permite humedad suficiente para el establecimiento del cultivo y se garantiza estrés en las etapas de floración, establecimiento y llenado de vainas.

En 1986, se iniciaron formalmente investigaciones de sequía en la EAP, con la siembra del BIDYT (Ensayo Internacional de Rendimiento de Fríjol Bajo Sequía), distribuido por el Programa de Fisiología de Fríjol de CIAT. En 1987 se montaron una serie de ensayos, cuyos resultados se reportan en este trabajo. En 1988, con financiamiento externo, se iniciarán estudios del mecanismo fisiológico de osmorregulación, la pubescencia foliar y el comportamiento de líneas derivadas de cruces interespecíficos entre *P. vulgaris* y *P. acutifolius*.

Análisis de la Precipitación Pluvial

Las lluvias en Honduras tienen una distribución bimodal. Generalmente, se inician en mayo y se terminan a fines de noviembre o principios de diciembre. La precipitación es menor en Julio y Agosto, en lo que se conoce como la "canícula". La Figura 1 ilustra esta distribución para tres zonas frijoleras del país: El Valle del Zamorano, donde se produce semilla certificada de fríjol; la Región Centro Oriental donde se siembra el 32% del área en fríjol del país (23000 hectáreas aproximadamente) y la Región Norte donde se cultiva el 20% del área total (15000 hectáreas aproximadamente).

Se hacen generalmente dos siembras al año. En la estación de "primera", se siembra a mediados de mayo y se cosecha en Agosto, durante la "canícula. En esta época, el cultivo presenta altas probabilidades de obtener la precipitación adecuada para establecer buenos rendimientos

(Fig. 1). En la estación de "postrera", se siembra a fines de septiembre; la probabilidad de buena precipitación se disminuye durante la etapa reproductiva del cultivo. Por ejemplo, si un agricultor de la Región Centro Oriental siembra las variedades Danlí 46 o Zamorano, con 38 a 40 días a floración, su cultivo entraría a la etapa reproductiva a principios de noviembre. En noviembre, como norma general caen menos de 100 mm de lluvia (Fig. 1). Si el suelo no tiene buena capacidad de retener humedad, el cultivo sufrirá estrés hídrico durante toda la etapa reproductiva, lo que disminuirá los rendimientos.

Para ilustrar mejor el problema de la sequía en "postrera" se analizó la precipitación quincenal, reportada por la Estación Metereológica de Villa Ahumada, Danlí, Región Centro Oriental, para el período 1975 a 1985 (Cuadro 1). En 6 de los 11 años analizados, la precipitación entre el 15 de septiembre y el 15 de diciembre estuvo por debajo de los 300 mm, los cuales son insuficientes para generar un buen rendimiento. También, en 6 de los 11 años, se presentó una precipitación de menos de 100 mm en la etapa de post-floración, asumiendo que la misma se inicia a principios de noviembre. Se puede concluir que en más del 50% de los años, hay problemas graves de sequía en las siembras de "postrera" en la Región Centro Oriental. A pesar de que solo se obtuvieron estadísticas de rendimiento promedio para la zona en el período 1975 a 1980, se puede ver que hay una tendencia a que sean mas bajos cuando la precipitación es mas baja (Cuadro 1).

Aunque no existen buenas estadísticas de producción y rendimiento en el país, los rendimientos promedios de producción reportados para la Región Norte, en el período 1973 a 1979, fueron de 660 kg/ha. Ellos son significativamente más altos que para la Región Central Oriental, que fueron de 440 kg/ha para el mismo período (Torchelli y Narváez, 1980). Quizás, esta diferencia pueda explicarse por una precipitación pluvial mas alta en a Región Norte en comparación con la Región Centro Oriental en el mes de noviembre (Fig. 1).

Resultados del BIDYT

El 10 de marzo de 1986, se sembró el BIDYT 1984-85. Constaba de 23 materiales élites de CIAT y 2 variedades locales. Se sembró bajo dos tratamientos, con y sin riego. Cada tratamiento se consideró como un ensayo diferente, establecido en un diseño de bloques al azar con 4 repeticiones. Para establecer el experimento a nivel de campo, se regó por aspersión hasta los 23 días después de la siembra. Posteriormente, el tratamiento húmedo se regó cuando se consideró necesario para evitar estrés. El tratamiento seco no recibió lluvia hasta los 60 días después de la siembra, implicando que los períodos críticos como floración, establecimiento y llenado inicial de vainas transcurrieron bajo estrés hídrico. Las lluvias presentadas después de los 60 días de la siembra, reactivaron el desarrollo vegetativo de las parcelas del tratamiento seco, por lo cual se aplicó un defoliante, cuando el tratamiento húmedo tenía madurez fisiológica. Así, solo se consideró como rendimiento en el tratamiento seco, la semilla formada durante el período de estrés de agua. Es necesario anotar que el grado de estrés que sufrió el ensayo fue más severo del que normalmente se presenta en las siembras comerciales en el país (Cuadro 1, Fig. 1). Los rendimientos en el tratamiento seco se redujeron entre 69% y 98%, en comparación con el tratamiento húmedo, siendo San Cristóbal 83, un genotipo originario de la República Dominicana, el que presentó la menor reducción. Los testigos locales Danlí 46 y Zamorano se ubicaron en las posiciones 4 y 23, respectivamente, por su rendimiento bajo condiciones secas (Cuadro 2).

Genotipos reportados como tolerantes en CIAT, tales como A 195, BAT 1289, V 8025 y BAT 477 (White y Singh, 1985) ocuparon las posiciones 3, 12, 17 y 18 respectivamente (Cuadro 2). Esto sugiere que la tolerancia a sequía de algunos genotipos, en una zona ecológica determinada, se enmascara con problemas de adaptación y condiciones edáficas en otras zonas. Por lo tanto, las selecciones de genotipos de fríjol tolerantes a sequía deben hacerse en las mismas zonas con problemas de estrés hídrico.

Resultados de los Ensayos de 1987

En febrero de 1987 se sembraron una serie de ensayos para evaluar el efecto de sequía en diferentes genotipos. Cuando se inició el período de estrés en el tratamiento respectivo, se notó que los ensayos quedaron mal ubicados a nivel de campo, debido a grandes gradientes de humedad presentes en el suelo, que no se removieron con la ubicación de los bloques. Una lluvia de 70 mm caída a los 29 días después de la siembra inundó varias parcelas. Además, el terreno donde se sembró presentaba compactación a los 30 cm de la superficie, por lo que se hacía difícil detectar diferencias entre genotipos.

Por los problemas enumerados, se decidió repetir la siembra de los diferentes ensayos el 20 de marzo. El terreno donde se ubicó esta segunda siembra no presentaba compactación como ocurría con el anterior. Los diferentes ensayos incluían un tratamiento seco y uno con riego, manejados como experimentos independientes, en un diseño de bloques al azar, con 3 a 4 repeticiones, dependiendo del ensayo.

El último riego de establecimiento de los tratamientos secos se dio a los 19 días después de la siembra. Posteriormente, se regaron los tratamientos húmedos cuando se consideró necesario para que no sufrieran estrés de agua. Cayeron 12 mm de precipitación hasta los 28 días después de la siembra. A partir de este día hasta los 43, cuando ya todos los genotipos habían florecido, hubo estrés hídrico. De aquí, hasta la madurez fisiológica, cayeron 100.5 mm de lluvia. Las condiciones de estrés que sufrieron los ensayos fueron muy similares a las que se presentan en las siembras de "postrera" en Honduras (Fig. 1, Cuadro 1). Dichas condiciones fueron suficientes para generar hasta 75% de reducción de rendimiento en el tratamiento seco, con respecto al húmedo, en algunos genotipos.

Rendimiento y Componentes de Rendimiento de 10 Genotipos de Phaseolus Sembrados Con y Sin Estrés Hídrico

Utilizando un diseño de bloques al azar, para cada tratamiento, con cuatro repeticiones, se sembraron 9 genotipos de *P. vulgaris* y uno de *P. acutifolius* para estudiar el efecto de la sequía en el rendimiento y sus componentes. Las entradas se seleccionaron por su respuesta diferencial a sequía en el BIDYT sembrado en 1986 o por ser variedades comerciales o líneas promisorias en América Central.

Como era de esperarse, el genotipo de *P. acutifolius* fue el que presentó los mas altos rendimientos en el tratamiento seco y el que presentó menor reducción del rendimiento por efecto de la sequía (Cuadro 3). *P. acutifolius* ha sido reportado como una especie tolerante al estrés hídrico (Nabhan y Felger, 1978 como ejemplo).

De los 9 genotipos de *P. vulgaris*, ICTA Ostúa fue el material que mejor se comportó bajo condiciones de estrés. Esta variedad, ha sido observada, en diferentes países Centroamericanos como tolerante a sequía (Silvio Hugo Orozco, comunicación personal). Vale la pena destacar los bajos rendimientos obtenidos, bajo condiciones de estrés, por las líneas RAB 58, RAB 204 Y RAB 50 que junto al cultivar local Zamorano fueron las mas susceptibles, con reducciones de rendimiento superiores al 60% (Cuadro 3). En observaciones preliminares en 1986, las líneas hermanas RAB 50 y RAB 205 indicaron la misma susceptibilidad a sequía. En 1987, RAB 205 fue liberada como variedad en Honduras, con el nombre de "Catrachita". Se utilizó RAB 50 porque repetidamente, en el Valle del Zamorano, presenta mejor potencial de rendimiento.

Materiales que el año anterior mostraron cierta tolerancia a sequía como Danlí 46 y San Cristóbal 83 (Cuadro 2), mostraron, una vez más, cierta tolerancia (Cuadro 3). Esto sugiere que independientemente del grado de estrés establecido, puede existir repetición de la respuesta de año a año en algunos genotipos.

Un análisis de los componentes de rendimiento indica que, en general, todos son reducidos por el efecto de la sequía (Cuadro 3). Sin embargo, el componente que mas sufrió fue el número de semillas/vaina, que presentó una reducción del 40%. Considerando que los componentes de rendimiento se determinan en una forma secuencial, se puede explicar la baja reducción en el número de vaina/m^2 y la alta reducción en el número de semillas/vaina, mediante el análisis de la precipitación pluvial. Entre los 43 y 46 días después de la siembra, cayeron 52.7 mm suficientes para fijar un alto número de vainas. Cuando las plantas entraron de nuevo en estrés, respondieron disminuyendo el número de semillas/vaina y el tamaño de la semilla.

Los coeficientes de variación para los rendimientos del tratamiento seco y el tratamiento húmedo indican que un diseño de bloques al azar, funciona bien para el tratamiento con riego (CV = 8.26%), pero no para el tratamiento seco (CV = 39.39). Esto mismo se observó en el BIDYT sembrado en 1986 (Cuadro 2). En el futuro, se utilizarán látices que han sido reportados más eficientes para remover variabilidad en trabajos de tolerancia a sequía (White y Singh, 1985).

Respuesta a Sequía de Algunas Líneas Derivadas de Cruces Entre P. vulgaris y P. acutifolius

Hasta la fecha, líneas derivadas de cruces interespecíficos *P. vulgaris* x *P. acutifolius* han mostrado pobre adaptación a condiciones tropicales y subtropicales (líneas XAN 159, XAN 160, XAN 161, como ejemplo). Quizás, esto se deba a que los progenitores de *P. vulgaris* usados, tienen adaptación específica a regiones templadas. Parece ser que utilizando progenitores de *P. vulgaris* adaptados al trópico, se pueden generar líneas con buena adaptación a dicha región.

En 1986, se recibió semilla de cruces interespecíficos hechos por el Dr. Richard Pratt (Departamento de Horticultura, Purdue University, West Lafayette, Indiana 47907). En los cruces iniciales utilizó Jamapa, Puebla 152, Ex-Rico 23 y Porrillo Sintético como algunos de los progenitores de *P. vulgaris*. Esta semilla, con abundante segregación para color y tipo de planta, se sembró durante la época normal de siembra y se seleccionaron algunas líneas.

Cuatro líneas que presentaban semilla suficiente para montar, a nivel de campo, un ensayo replicado de rendimiento con y sin riego, se compararon con un genotipo de *P. acutifolius*, A 76-2 y uno de *P. vulgaris*, PI 312-302, reportado por Mosjidis y Waines (1985) como capacitado para sobrevivir tanto como *P. acutifolius*, bajo condiciones extremas de sequía y producir vainas con al menos una semilla bien desarrollada.

Los rendimientos de las líneas en el tratamiento húmedo estuvieron entre 2126 y 2714 kg/ha (Cuadro 4), lo que demuestra su buena adaptación y potencial de rendimiento. Estos rendimientos son comparables a los obtenidos con los mejores genotipos de *P. vulgaris* sembrados en la misma fecha, en ensayos aledaños (Cuadro 3). La reducción en rendimiento en el tratamiento seco, con respecto al húmedo, estuvo entre 21 y 36%, lo que indica un alto nivel de tolerancia a sequía, comparable al presentado por *P. acutifolius*. El genotipo de *P. vulgaris*, PI 312-302, redujo el rendimiento en solo 27%. En contraste, el *P. acutifolius*, A76-2, incrementó el rendimiento en un 10% en el tratamiento seco (Cuadro 4). Otros investigadores, han reportado que *P. acutifolius* rinde mejor bajo condiciones de estrés hídrico que cuando se siembra bajo regímenes de humedad adecuada (Peterson y Davis, 1982).

La tolerancia a sequía expresada por las líneas bajo estudio, se podría explicar por precocidad ya que todas florecen entre 31 y 33 días (Cuadro 4). Sin embargo, dadas las condiciones del ensayo, estos materiales florecieron bajo pleno estrés hídrico, el cual se prolongó hasta los 44 días después de la siembra. Es necesario obtener más información para determinar si además de precocidad, presentan otras características fisiológicas que las hacen tolerantes a sequía.

Estudio de Selección Fenotípica por Tolerancia a Sequía

Por definición, una línea o variedad de un cultivo de polinización autógama, como es el caso de fríjol, es una mezcla de genotipos homocigotos con similar fenotipo. Bajo ciertas condiciones, por ejemplo estrés hídrico, esos genotipos pueden mostrar fenotipos diferentes. Es muy posible que dentro de una población fenotípicamente igual, existan genotipos con tolerancia a sequía que solo aparecen cuando el cultivo está sometido a estrés hídrico. De hecho, se notan plantas dentro de las parcelas con un estatus hídrico superior y con rendimientos aceptables. Del BIDYT de 1986 se seleccionaron las 5 mejores plantas del centro de la parcela del tratamiento seco, de algunas entradas. Se hizo un ensayo para determinar si esas plantas seleccionadas, generaban poblaciones mas tolerantes a sequía que la población de la cual se hizo la selección. Se usaron 4 genotipos (Cuadro 5) los que se ubicaron en un ensayo en bloques divididos, bajo un solo tratamiento, el seco.

Los resultados demostraron que los grupos seleccionados rinden, en general, un poco mejor que los cultivares originales, pero estas diferencias no fueron estadísticamente significativas (Cuadro 5).

Análisis Conjunto de los Genotipos Ensayados en 1987

El uso del rendimiento diferencial, como criterio de selección de genotipos de fríjol con tolerancia a sequía, puede dar lugar a la selección de genotipos con bajo potencial de rendimiento. Samper y Adams (1985), sugirieron el uso de la media geométrica (raíz cuadrada del producto de los rendimientos obtenidos con y sin estrés hídrico) como criterio, ya que considera el rendimiento potencial y el rendimiento diferencial. Cuando se estimó la media geométrica, en general, los genotipos que presentaron baja reducción en rendimiento, presentaban una alta media geométrica, con la excepción de algunos materiales precoces, de bajo potencial de rendimiento, como el PI 312-302 y el Cuarenteño. Para el análisis de la respuesta a sequía de los diferentes genotipos de fríjol ensayados en 1987, se utilizó el porcentaje de reducción en rendimiento en el tratamiento con estrés hídrico.

El porcentaje de reducción en rendimiento estuvo altamente correlacionado con los días a floración (r = 0.74, eliminando RAB 50), tal como lo indica la Figura 2. Esto implica que la precocidad es importante de considerar en trabajos de sequía en fríjol en Honduras. Sin embargo, existen genotipos precoces a floración, como el RAB 50, que mostraron ser altamente susceptibles. Cuando se analiza la relación entre los rendimientos absolutos en el tratamiento seco y los días a floración (Fig. 3), se puede notar que los mayores rendimientos correspondieron a los genotipos de P. acutifolius y a las líneas derivadas de cruces interespecíficos que son precoces. Sin embargo, materiales como la ICTA Ostúa, que es más tardía a floración (Fig. 3), presentó altos rendimientos en el tratamiento seco, indicando que debe poseer algun mecanismo fisiológico de tolerancia a estrés hídrico, diferente al "escape" dado por la precocidad.

Planes Futuros

En 1988, además de los esfuerzos para identificar germoplasma tolerante, se iniciarán estudios en tres áreas específicas, con el objeto de entender algunos mecanismos de tolerancia a sequía en fríjol.

Las áreas a estudiar son :

1. Estudio detallado de la presencia y el efecto de la osmorregulación en fríjol. Estos estudios se harán colaborativos con la Universidad de

Rutgers-New Jersey.

2. Estudios de tolerancia a sequía y fijación biológica de nitrógeno bajo condiciones de estrés hídrico, de líneas derivadas de cruces interespecíficos entre *P. vulgaris* y *P. acutifolius*. Se harán en colaboración con la Universidad de Minnesota.

3. El efecto de la pubescencia foliar como mecanismo de tolerancia a sequía.

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Cuadro 1. Distribución quincenal de la precipitación pluvial, en mm, durante la siembra de "postrera", en la Estación de Villa Ahumada, Danlí, Departamento del Paraíso, para el período 1975-1985.

Año	Septiembre 16-30	Octubre 1-15	Octubre 16-31	Noviembre 1-15	Noviembre 16-30	Diciembre 1-15	Precipitación total Sept.16-Dic.15	Precipitación en la etapa reproductiva Nov.1-Dic.15	Rendimiento promedio (kg/ha)
1975	110.3	83.0	94.3	80.2	71.1	12.3	451.2	163.6	459
1976	21.3	52.9	57.5	17.8	26.0	45.6	221.0	89.4	380
1977	131.5	11.5	27.4	12.6	66.1	44.4	293.5	123.1	631
1978	134.2	56.7	20.5	18.8	25.9	26.2	282.3	70.9	252
1979	62.5	111.9	65.6	67.3	13.8	57.2	378.3	138.3	360
1980	110.2	297.0	57.6	51.5	43.4	46.3	606.0	141.2	440
1981	33.0	105.8	108.9	0.1	15.4	30.0	293.2	45.5	ND[1]
1982	207.1	89.2	22.0	45.1	21.4	11.2	396.0	77.7	ND
1983	88.3	71.3	39.6	81.0	6.8	14.5	301.5	102.3	ND
1984	107.0	52.8	44.9	0.1	6.7	21.2	232.7	28.0	ND
1985	85.0	32.3	125.3	20.6	2.8	17.0	283.0	40.4	ND

[1] ND = No disponible

Cuadro 2. Características y rendimientos de los genotipos de frijol incluidos en el Vivero Internacional de Resistencia a sequía, BIDYT 1984-1985, sembrado en el Valle del Zamorano en 1986. Los materiales están organizados en orden descendente por su rendimiento bajo condiciones secas.

No.	Identificación	Color semilla	Hábito crecimiento	Peso 100 sems (g)	Días a floración		Días a madurez fisiológica		Rendimiento kg/ha - 14%H		% Reducción rendimiento
					Seco	Riego	Seco	Riego	Seco	Riego	
1	San Cristóbal 83	Rosado	3	26	41	40	78	77	698	2283	69.4
2	BAT 1393	Crema	1	36	38	35	77	78	671	2601	74.2
3	A 195	Crema	1	52	38	36	77	78	658	3098	78.7
4	Danlí 46	Rojo	2	25	42	41	78	78	559	2680	79.1
5	A 54	Crema	2	19	43	43	79	80	547	2556	78.6
6	A 97	Crema	2	23	43	42	78	80	468	2709	82.7
7	G 5201	Negro	2	18	44	41	81	78	445	2482	82.1
8	A 170	Crema	2	20	44	41	81	81	410	2971	86.2
9	G 4830 (Río Tibagi)	Negro	2	19	44	42	81	79	408	2926	86.1
10	BAT 336	Crema	2	21	44	42	79	78	362	2635	86.3
11	G 4454 (ICA Tui)	Negro	2	21	44	42	79	80	361	2539	85.8
12	BAT 1289	Rojo	3	21	42	41	79	77	355	2282	84.5
13	G 4523 (Línea 17)	Rojo Mot	1	40	38	37	78	77	352	2449	85.6
14	BAT 1298	Rosado	3	21	40	40	79	78	333	1864	82.2
15	BAT 798	Negro	3	23	44	41	78	78	331	2490	86.7
16	BAT 85	Crema	2	22	44	41	78	78	304	2686	88.7
17	V 8025	Negro	4	21	42	41	78	78	278	2668	89.6
18	BAT 477	Crema	3	24	41	38	79	79	255	2775	90.8
19	BAT 125	Crema	2	23	46	45	82	85	242	2461	90.1
20	A 59	Café	2	27	38	36	73	77	149	2148	93.1
21	EMP 105	Rojo	2	20	44	42	78	78	149	2406	93.8
22	G 5059	Crema	2	23	48	48	82	88	103	3125	96.7
23	Zamorano	Rojo	3	23	40	39	79	78	99	1988	95.0
24	BAT 868	Café	2	25	45	42	82	87	55	2733	98.0
25	G 4446	Café	3	28	44	43	82	88	54	2510	97.9
	$\overline{X}$					42	41	79	80	346	2562 86.5
	DMS (5%)				1.3	1.47	1.3	1.50	225	661	
	CV %				2.3	2.6	1.2	1.4	463	18.7	

Cuadro 3. Rendimiento y componentes de rendimiento de 9 genotipos de *Phaseolus vulgaris* y uno de *P. acutifolius* sembrados con y sin estrés de agua en el Valle del Zamorano, Honduras, en 1987A.

Genotipo	Días a floración	Rendimiento (kg/ha)		% de reducción de rendimiento	No. de vainas /m^2		No. semillas/ vaina		Peso seco semillas(mg)		Peso seco total (g/m^2)	
		Riego	Seco		Riego	Seco	Riego	Seco	Riego	Seco	Riego	Seco
A 80-10 (*P. acut.*)	30	2442	1888	23	476	424	3.5	2.6	148	158	356	284
ICTA Ostúa	39	2766	1777	36	284	233	5.6	3.7	173	174	453	289
Cuarenteño brillante	32	2056	1203	41	238	246	4.0	3.1	184	150	266	230
San Cristóbal 83	37	2343	1217	48	232	222	4.6	3.2	194	189	324	251
Danlí 46	38	2516	1217	52	235	253	5.2	3.1	192	176	364	273
Negro Huasteco	39	2822	1187	58	271	212	5.5	2.4	204	179	497	259
Zamorano	40	1577	604	62	134	124	5.2	3.2	184	159	254	160
RAB 58	39	2336	837	64	251	202	4.5	2.4	206	166	397	221
RAB 204	39	2445	706	71	254	183	5.7	2.8	169	135	382	189
RAB 50	34	2859	758	74	213	165	4.4	2.8	222	138	338	194
$\overline{X}$	37	2416	1139		259	226	4.8	2.9	188	162	363	235
DMS 5%		290	661		68.2	80.1	1.3	0.7	24.3	33.7	83.2	76.3
CV (%)		8.26	39.39		18.6	24.3	18.5	17.0	8.9	14.2	15.8	22.1
% reducción			53			8			40	14		

Cuadro 4. Fenología y rendimiento de un genotipo de *P. acutifolius*, uno de *P. vulgaris* y líneas derivadas de cruces interespecíficos entre ambas especies, sembradas con y sin estrés de agua, en el Valle del Zamorano, Honduras, en 1987A.

Genotipos	Días a floración	Días a madurez fisiológica	Rendimiento (kg/ha)		% de reducción de rendimiento
			Riego	Seco	
A 76-2	30	63	2355	2582	10
PI 312-302 (*P. vulgaris*)	31	56	2006	1468	27
Purdue 5A[1]	33	66	2272	1805	21
Purdue 9	33	67	2714	1762	35
Purdue 32	32	62	2126	1540	28
Purdue 35	32	67	2660	1697	36
$\bar{X}$	32	64	2356	1809	23
DMS			376	612	
CV			6.20	13.14	

[1] Pedigree de las líneas Purdue:
(((Sanilac x Puebla 152) x GN 1026) x (Jamapa x Ex-Rico 23)) x Pinquito.

GN 1026 = línea de *P. acutifolius*.

Cuadro 5. Rendimiento, bajo estrés hídrico de la población original, de la cual se seleccionaron visualmente las 5 mejores plantas en 1986 y rendimientos de las poblaciones originales y seleccionadas, sembradas bajo condiciones secas, en el Valle del Zamorano, Honduras, 1987A.

	Rendimiento en el tratam. seco 1986 (kg/ha)	Rendimiento de las 5 mejores plantas en 1986 (g)	Días a florac.	Días a madurez fisiológica	Rendimiento de la poblac. original (kg/ha)	Rendimiento de las seleccion. (kg/ha)
BAT 1289	355	50.5	37	72	1513	1700
G 4454 (ICA Tui)	361	54.9	39	75	1153	1243
G 5201	445	45.1	38	74	1903	1933
Cincuenteño	513	81.1	32	68	1500	1397
$\overline{X}$	419	57.9	36	72	1517	1568

Las medias de rendimiento no son estadísticamente diferentes.

Figuras

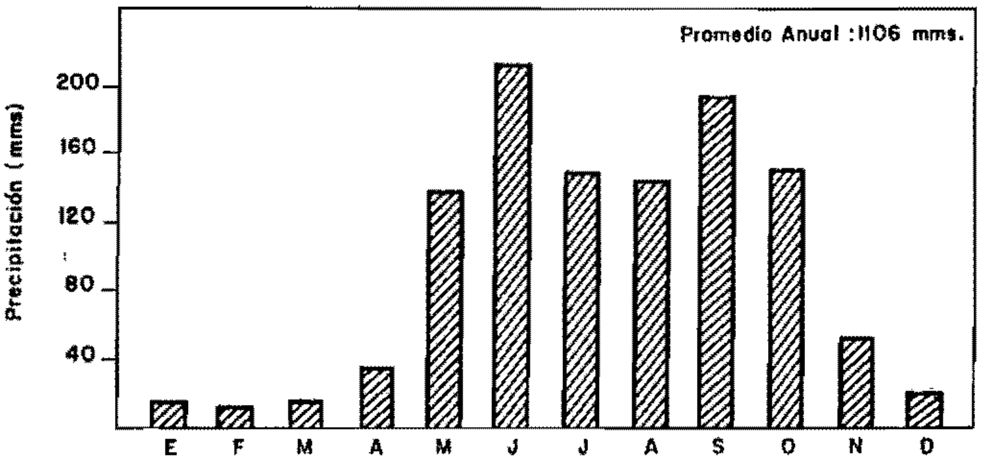
Fig. 1. Precipitación pluvial en tres zonas frijoleras de Honduras.

Fig. 2. Relación entre los días a de floración y el porcentaje de reducción en rendimiento de los genotipos de *Phaseolus* ensayados para tolerancia a sequía en el Valle del Zamorano, Honduras, 1987 A (⊙: *P. acutifolius*, * : líneas derivadas de cruces interespecíficos *P. vulgaris* x *P. acutifolius*, ●: *P. vulgaris*).

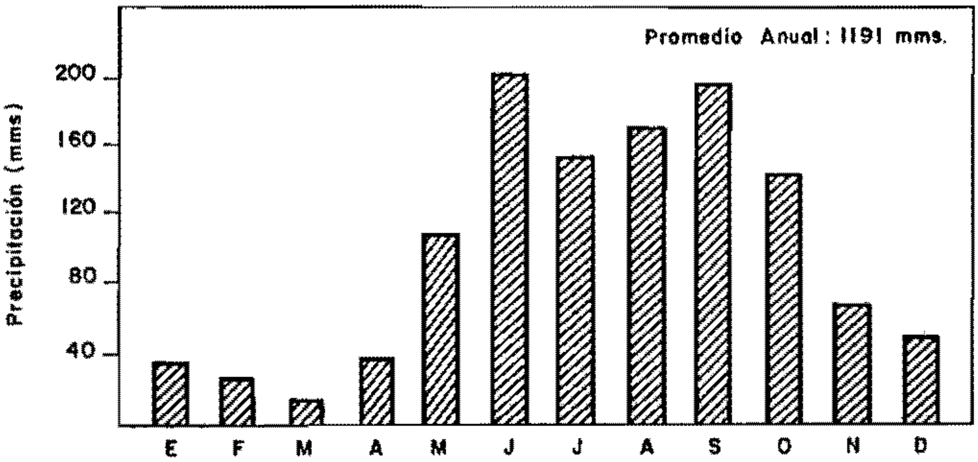
Fig. 3. Relación entre días a floración y el rendimiento, bajo condiciones de sequía, de los genotipos de *Phaseolus* ensayados en el Valle del Zamorano, Honduras, 1987A (⊙: *P. acutifolius*, *: Líneas derivadas de cruces *P. vulgaris* x *P. acutifolius*, ●: *P. vulgaris*).

Figura 1. Precipitación pluvial en tres zonas frijoleras de Honduras.

a) Precipitación pluvial en el Valle del Zamorano (44 años).



b) Precipitación pluvial en Villa Ahumada, Región Centro Oriental (12 años).



c) Precipitación pluvial en Yoro, Región Norete (13 años).

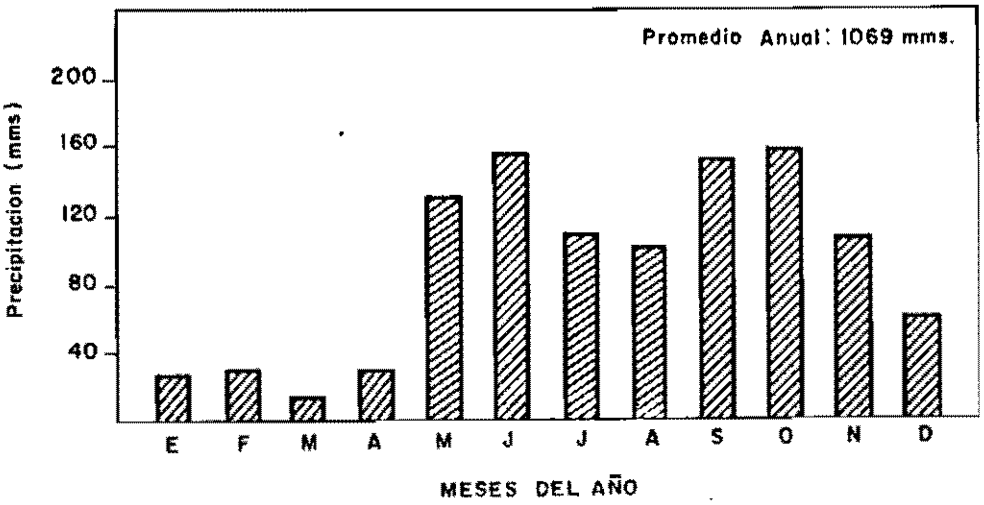


Figura 2. Relación entre los días a de floración y el porcentaje de reducción en rendimiento de los genotipos de *Phaseolus* ensayados para tolerancia a sequía en el Valle del Zamorano, Honduras, 1987 A (⊙: *P. acutifolius*, * : líneas derivadas de cruces interespecíficos *P. vulgaris* x *P. acutifolius*, ● : *P. vulgaris*).

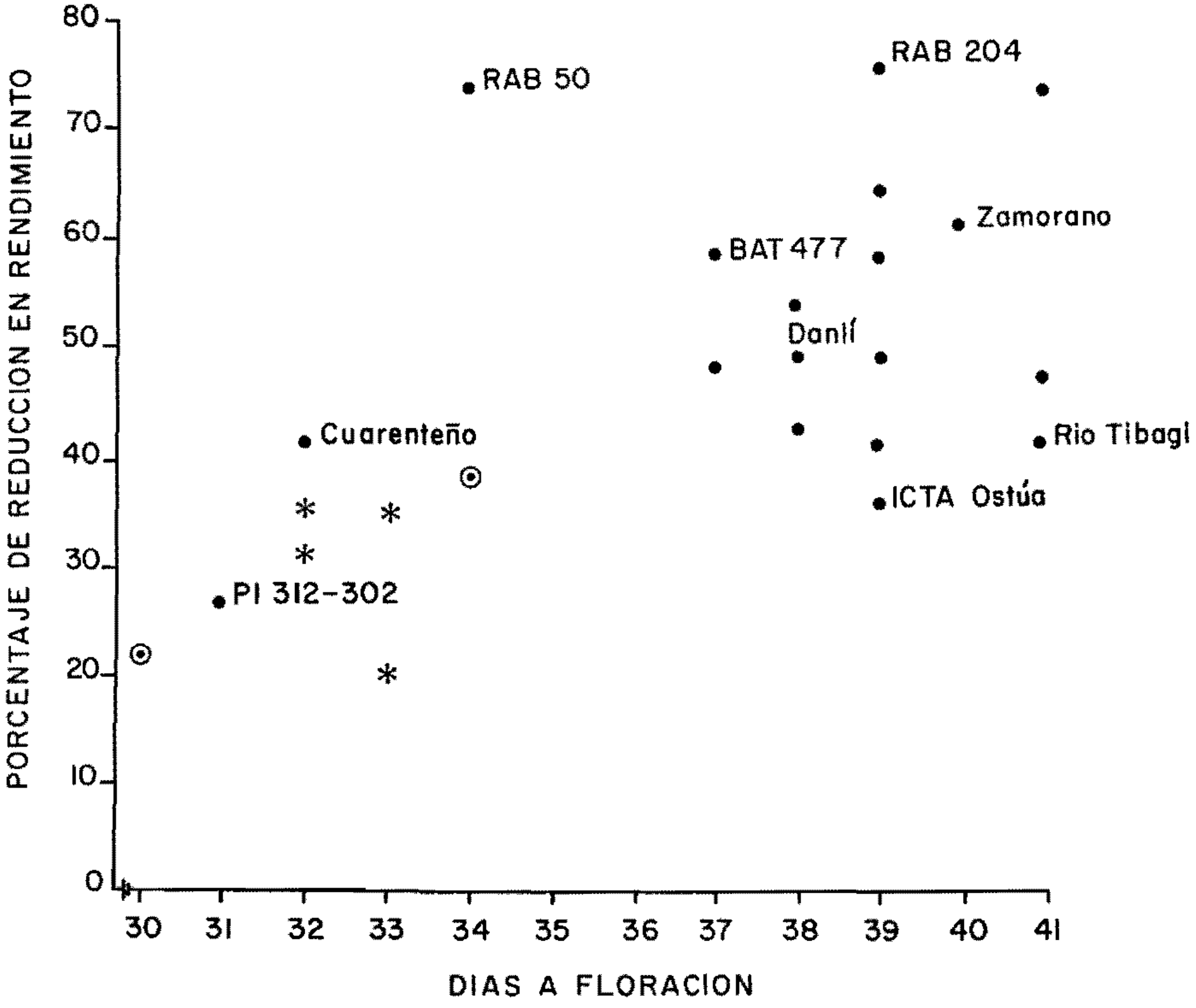
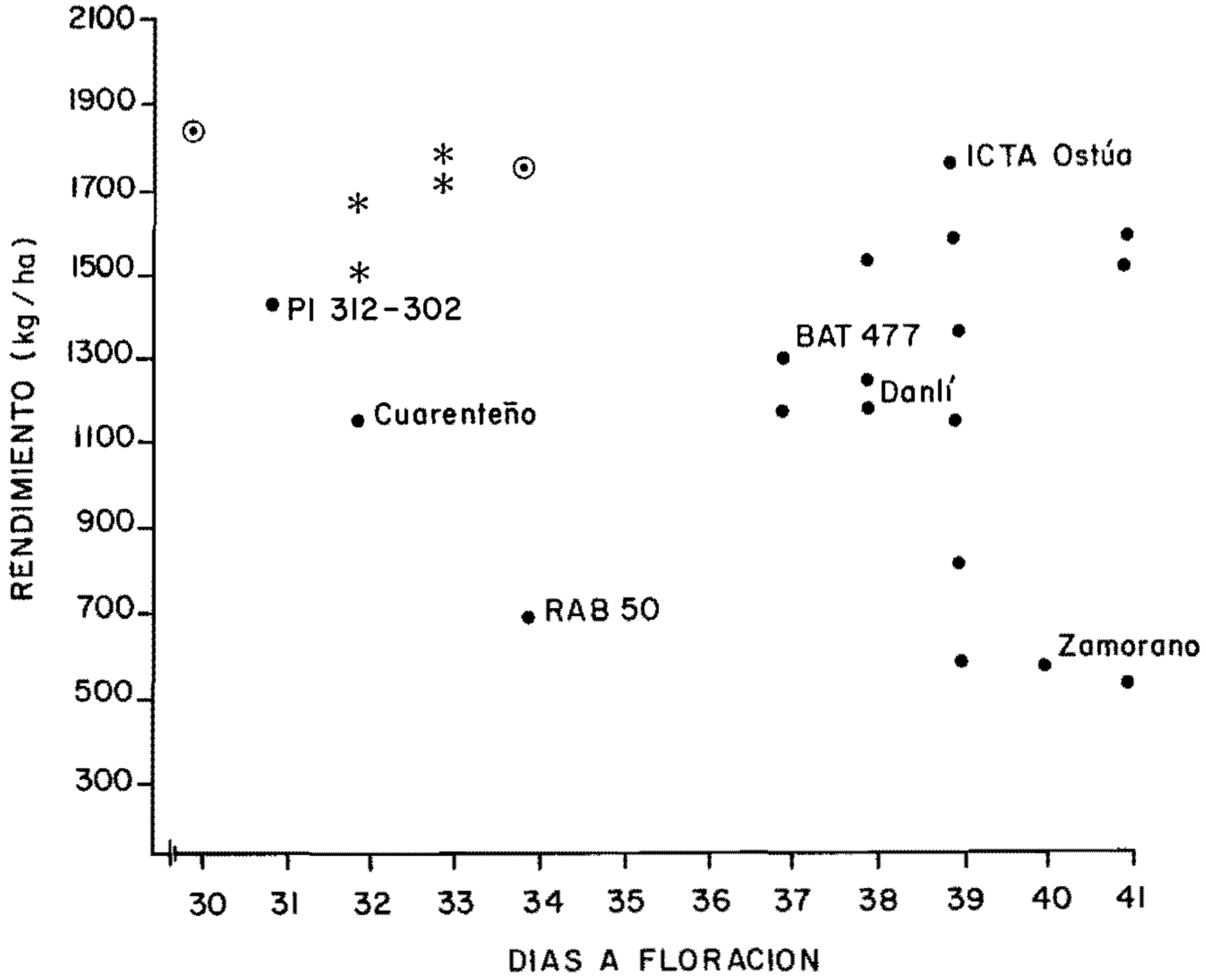


Figura 3. Relación entre días a floración y el rendimiento, bajo condiciones de sequía, de los genotipos de *Phaseolus* ensayados en el Valle del Zamorano, Honduras, 1987A (⊙: *P. acutifolius*, * : Líneas derivadas de cruces *P. vulgaris* x *P. acutifolius*, ● : *P. vulgaris*).



PROGRAMA DE RESISTENCIA DO FEIJOEIRO A SECA NO CNPAF

Cleber Guimaraes*

Introdução

As produtividades do feijão baixas e instáveis retratam bem as condições a que a cultura é submetida. A deficiência hídrica é um dos fatores que mais concorrem para o insucesso da cultura. Considerando-se que ela ocorre, em maior ou menor intensidade, em quase todas às regiões brasileiras produtoras de feijão e que a irrigação é altamente dispendiosa e às vezes impraticável recomenda-se que as novas cultivares apresentem adaptabilidade às condições de sequeiro. Para isto está sendo conduzido, no CNPAF, um programa de resistência do feijoeiro à seca, cujas linhas básicas e resultados são descritos a seguir.

Programa de Resistência à Seca

Objetivos

- Identificar progenitores promissores em condições de sequeiro;
- caracterizar os principais fatores fisiológicos e morfológicos responsáveis pela resistência à seca; e
- selecionar, em condições de sequeiro, linhagens comerciais.

Estratégia de ação

São efectuadas avaliações preliminares I e II, avançada, estudos de

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mecanismos de resistência a seca, hibridações intra e interespecíficas e avaliação de populações segregantes (Figura 1).

Avaliação preliminar I. A avaliação preliminar I é formada de aproximadamente 600 introduções, provenientes das coletas regionais, do ensaio preliminar e de linhagens dos cruzamentos direcionados para resistência à seca. Estes materiais são submetidos a boas condições de umidade, 0,036 MPa a 15 cm de profundidade, até aos 15 a 20 dias após a emergência, quando é aplicado um estresse severo de umidade, pela suspensão total da irrigação, até o fim do ciclo da cultura. As introduções são distribuídas aleatoriamente em dois blocos ou repetições, sendo plantada uma testemunha promissora, para as condições de sequeiro, a cada 10 introduções.

Avaliação preliminar II. A avaliação preliminar II é formada dos 200 melhores materiais provenientes da avaliação preliminar I, que são mantidos em condições hídricas ideais até aos 15 a 20 dias após a emergência, quando são implantados dois tratamentos hídricos: 1) manutenção das mesmas condições hídricas anteriormente implantadas; e 2) aplicação de um estresse hídrico severo, com a suspensão total da irrigação, até o fim do ciclo da cultura. Os materiais são distribuídos aleatoriamente em duas repetições ou blocos. A avaliação será baseada no índice de susceptibilidade a deficiência hídrica (S), conforme equações abaixo.

$D = 1 - Xp/Xw$ (1)

$Yd = Yw\ (1 - SD)$ (2)

D - Severidade da deficiência hídrica,
S - índice de susceptibilidade à seca,
X_p - produtividade média dos materiais com deficiência hídrica,
X_w - produtividade média dos materiais com boas condições hídricas,
Y_d - produtividade individual dos materiais com deficiência hídrica, e

Y_w - produtividade individual dos materiais com boas condições hídricas.

Os materiais terão a máxima resistência à seca quando

S = 0; no entanto, será tanto menor, quanto maior os valores de S.

Avaliação avançada. A avaliação é composta dos 30 melhores materiais provenientes da avaliação preliminar II e dos 70 materiais do BIDAN (Bean International Drought Adaptation Nursery), ensaio organizado pelo CIAT e distribuído de dois em dois anos a uma rede de cooperadores internacionais. Considerando-se que estes materiais enviados pelo CIAT são anteriormente testados para as condições de sequeiro, mas em condições climáticas diferentes, decidiu-se que este germoplasma fosse avaliado e reavaliado em dois anos consecutivos. No entanto, os trinta novos materiais provenientes da avaliação preliminar II são introduzidos e avaliados anualmente, de modo a manter um total de 100 materiais na avaliação avançada.

Este experimento, como os demais, é mantido em boas condições hídricas, até os 15 a 20 dias após a emergencia, quando é instalada a linha central de aspersores, planejada para produzir três níveis hídricos distintos: 1) estresse severo, 2) estresse moderado; e 3) sem estresse hídrico. A irrigação no nivel 3 é controlada com tensiômetros, ou seja, novas irrigações de aproximadamente 28 mm são efetuadas quando a tensão do solo, a 15 cm de profundidade, atingir 0,036 MPa, somando, ao fim do ciclo, aproximadamente 300 mm. O nível 2 recebe aproximadamente 150 mm e o nível 1, não recebe irrigações após a implantação dos tratamentos hídricos.

O coeficiente de regressão linear entre a produtividade e as lâminas de água dos três tratamentos hídricos é usado como escala de avaliação da resposta a irrigação. A produtividade dos níveis com estresse hídrico é usada na avaliação do potencial produtivo em condições de sequeiro. Estes parâmetros são representados graficamente, da seguinte maneira: a produtividade, na ordenada, e os coeficientes de regressão, na abscissa. Do ponto médio ($\bar{X}$) da abscissa e do ponto médio acrescido de 25% ($\bar{Y}$ x 1.25) da ordenada são traçadas linhas que dividem o germoplasma em quatro grupo. Nos grupos I e II são classificados os materiais que produzem acima da média do experimento, mas que diferem quanto ao potencial produtivo em boas condições hídricas. Os materiais do grupo I são responsivos a irrigação, e os do grupo II, não têm esta característica. Os materiais dos grupos III e IV apresentam produtividade abaixo do limite estipulado anteriormente, o grupo localizado à direita da linha média dos coeficientes de regressão, apesar de não apresentar resistência a seca é responsivo à irrigação.

Paralelamente, são efetuadas observações agronômicas, com o objetivo de contribuir, para a compreensão do comportamento dos materiais em estudo, nas condições hídricas do teste.

Avaliação de mecanismos. A avaliação de mecanismos é composta de um numero reduzido de progenitores comprovadamente promissores e uma testemunha não produtividade em condições de deficiência hídrica. Este germoplasma é estudado morfo-fisiologicamente, com o objetivo de avaliar suas fontes de resistência à seca. Uma vez conhecidos os principais fatores de resistência à seca, tem-se orientação para a escolha dos progenitores a comporem os cruzamentos para as regiões com provável ocorrência de deficiência hídrica. Este experimento é submetido a condições hídricas iguais as do experimento anterior. Suas parcelas são compostas de maior número de fileiras (15 fileiras), das quais seis são destinadas à avaliação de produtividade e seus componentes, e as demais, à avaliação de potencial hídrico foliar, resistência difusiva dos estômatos, temperatura do dossel, índice da área foliar, análise de crescimento, etc. Faz-se o acompanhamento da umidade do solo e densidade radicular, de 20 em 20 cm da superfície até 120 cm de profundidade e, das lâminas da irrigação, através de pluviômetros distribuídos no experimento.

Hibridações e seleção em populações segregantes. Os cruzamentos são efetuados pelo programa de melhoramento, utilizando as fontes de resistência à seca identificadas nos trabalhos mencionados antes, em *Phaseolus vulgaris* L. e *P. acutifolius* L., através dos cruzamentos intra e interespecíficos. As populações de F_2 dos cruzamentos intra-específicos para resistência à seca e populações F_2, F_3 e F_4 dos RC2 dos híbridos interespecíficos para *P. vulgaris* L., são conduzidos a campo, pela metodologia de descendência de uma única semente, modificada na forma exposta a seguir:

As populações mencionadas acima são semeadas no campo, em "blocos" sem repetições, em espaçamento de 0,5 m entre linhas; as populações de cruzamentos intra-específicos, em Goianîa, e as demais, em Porangatu, Goiás, (latitude 13° 27', longitude 49° 10', altitude 600 m, e temperatura suficientemente alta, para permitir boa adaptabilidade de plantas híbridas com *P. acutifolius* L.). Todas as populações são submetidas a estresse hídrico e, ao final (por ocasião da colheita), as plantas que tiverem menos de 4 vagens são eliminadas. Das demais, colhe-se uma vagem por planta, destinadas a formar três populações: a primeira, formada de uma semente de cada vagem, para compor a geração seguinte; uma segunda, formada de uma semente para ser entregue a outros programas que a solicitem, e as demais sementes das mesmas vagens sao reunidas numa "populaçao reserva", a ser mantida em câmara fria, para o caso de se necessitar delas. Na ocasião da seleção (F_4 e F_5) são colhidas, individualmente, as melhores plantas de cada população (100 ou mais de cada), e as demais, eliminadas. As linhas resultantes são semeadas a campo, em linhas de 5 m, sem repetições. A cada 20 linhas são plantados testemunhas intercaladas, as mesmas da avaliação preliminar. São eliminadas todas as linhas que ainda estejam segregantes e as inferiores as testemunhas. As linhas superiores, fixadas, são colhidas massalmente, e 80 de suas sementes são entregues para o EPL, e as demais passam a seguir o esquema das avaliações preliminares de resistência à seca.

Resultados de Trabalhos em Andamento

Avaliação preliminar I-1986

Avaliaram-se 597 entradas, a maioria das quais proveniente das coletas regionais de germoplasma tradicional. Esta avaliação foi conduzida durante os meses de maio-agôsto de 1986, período em que ocorreu deficiência hídrica severa, com uma precipitação total de 33 mm durante o período de contenção de umidade que se prolongou do 20^{o} dia após a emergência até a maturação das vagens. Do plantio até a implantação do tratamento hídrico, com a imposição de dificência hídrica aos 20 dias após a emergência, o experimento foi mantido em condições hídricas ideais. Durante este período ocorreram 50 mm de precipitação pluviomêtrica e foram aplicadas três irrigações com aproximadamente 60 mm.

A amplitude de variação da produtividade foi de 130 a 861 kg/ha. A classe mais frequente foi composta de 63% da população, e sa amplitude foi de 350 a 600 kg/ha. Acima dos 700 kg/ha foram registrados apenas 17 materiais, o que representa 2,8% do total (Figura 2). Para continuidade dos trabalhos do programa de resistência à seca selecionaram-se e incorporaram-se a avaliação preliminar II - 1987 todos os materiais com produtividade acima de 523 kg/ha, englobando todos os da classe de 550 a 900 kg/ha e alguns da classe de 500 a 550 kg/ha.

Avaliação avancada - 1986

Este experimento foi conduzido seguindo a metodologia descrita anteriormente. Após o período inicial irrigado, aplicaram-se os três tratamentos hídricos: estresse severo, moderado e sem estresse hídrico, com o uso de linha central de aspersores, os quais receberam, respectivamente 0, 107 e 311 mm de irrigação, e 26 mm de precipitação pluviomêtrica. O germoplasma avaliado nestas condições foi classificado em função da sua resistência à seca e da resposta a irrigação dadas pela produtividade com deficiência hídrica e coeficiente de regressão linear entre produtividade e lâminas de água aplicadas.

Estes parâmetros foram representados graficamente, estando as produtividades na ordenada, e os coeficientes de regressão, na abscissa. Do ponto médio dos coeficientes de regressão ($\bar{X}$ = 2,96) e do ponto médio das produtividades com deficiência hídrica mais 25% ($\bar{Y}$ x 1,25 = 806 kg/ha) foram traçadas linhas que dividem o germoplasma em quatro grupos com características próprias (Figura 3). Os materiais, A 285 (1), A 295 (2), A 319 (3), A 320 (4), BAT 53 (5), G 4446 (6), e GF 1138 (7) foram classificados no grupo 1, por produzirem em condições de deficiências hídricas e responderem a irrigação, conforme pressão de seleção aplicada, para as próximas etapas do programa de resistência à seca. Os materiais do grupo 2, por não apresentarem boa resposta a irrigação foram desclassificados. Os materiais dos grupos 3 e 4 também foram desclassificados, por não apresentarem boa produtividade em condições de deficiência hídrica.

Avaliação de mecanismos de resistência à seca - 1986

Estudaram-se alguns parâmetro morfo-fisiológicos relacionados com o comportamento, em condições hídricas diversas, de oito materiais, CNF 127, CF 830026, IPA 7419, BAT 477, BAT 258, Carioca e Moruna, classificados, conforme as avaliações anteriores, como promissores para resistência à seca, enquanto que A 170, como material sensivel do deficit hídrico. Neste experimento foram impostos três tratamentos hídricos conforme descrito, após um período inicial com irrigação adequada, que se prolongou até aos 20 dias após a germinação; durante este período registrou-se um total de 3.5 mm de precipitação pluviométrica, sendo efetuadas irrigações suplementares, para manter o solo em condições hídricas satisfatórias, ou seja, com tensão inferior a 0.036 MPa, controlada com tensiômetro na profundiade de 15 cm. Após este período foram implantados os tratamentos hídricos que perduraram até o fim do ciclo da cultura, tendo ocorrido 21 mm de precipitação pluviométrica. O tratamento 1 caracterizou-se por uma deficiência hídrica severa, não recebendo irrigação; o tratamento 2 foi mantido em condições hídricas moderadas, recebendo 123 mm, e o tratamento 3 foi matido em condições hídricas satisfatórias, recebendo 333 mm.

Os materiais BAT 258, CF 830026 e Moruna, embora não tenham apresentado produtividade significativa superior em relação aos demais, foram ligeiramente superiores em resistência a seca. Produziram 408, 359 e 333 kg/ha, sob deficit hídrico severo e 1198, 1202 e 1014 kg/ha, sob deficit hídrico moderado respectivamente (Figura 4). Os dois primeiros materiais, (BAT 258 e CF 830026) apresentaram, também, o maior coeficiente de regressão, (2.82), mostrando que, além de comportarem bem em condições hídricas deficitárias, foram os mais responsivos a irrigação. A testemunha susceptível à seca, quando submetida a deficiência severa produziu apenas 164 kg/ha, respondeu prontamente a irrigação moderada (21 mm de precipitação e 123 mm de irrigação), com uma produtividade de 772 kg/ha, o que corresponde um aumento da ordem de 371%. Seu coeficiente de regressão linear foi de 1.75, mostrando que não é um material de alto potencial de produção, comparativamente aos demais quando submetido a irrigação ideal (Figura 4).

Na tentativa de compreeder a variabilidade produtiva do germoplasma estudado nos diversos tratamentos hídricos, fez-se análise de regressão linear entre este parâmetro e o potencial hídrico foliar, resistência estomática das faces superior e inferior das folhas, temperatura do dossel e do índice de área foliar. Constatou-se que os componentes não explicaram a variabilidade produtiva nas condições hídricas favoráveis. Nos extresses hídricos severo e moderado foi explicada pela temperatura do dossel, pelo índice da área foliar, e pela resistência difusiva da face inferior das folhas apenas nas condições hídricas moderadas (Tabela 1).

Pela análise de regressão linear obtiveram-se equações com coeficientes diferentes, significando que a relação entre temperatura e produtividade varia com o estado hídrico das plantas. Analizando mais detalhadamente a relação entre temperatura e produtividade sob estresse hidrico moderado (Figura 5) verifica-se que existe um conjunto de 8 pontos que podem não representar o verdadeiro estado térmico das plantas no momento da leitura, ou que existem fator ou fatores interativos atuando sobre a temperatura do dossel, em condições moderadas de umidade do solo. Deve-se acrescentar que houve tendência de as cultivares BAT 477 e IPA 7419 concentrarem seus pontos neste grupo. Considerando-se que a temperatura representa, indiretamente, o estado hídrico da planta, seria difícil admitir que temperaturas iguais resultariam em produtividades diferentes. Neste caso, o conjunto de dados seria representado por um sistema de segundo grau. O intervalo de temperatura entre 20° a 23° C seria responsável por uma queda vertiginosa de produtividade. A partir de 24° C, a produtividade foi inferior a 400 kg/ha, com baixa sensibilidade a variação de temperatura, mas o suficiente para explicar a variação de produtividade neste nível hídrico (Tabela 1).

No entanto, deve-se considerar que os dados de temperatura foram obtidos durante horas de alta insolação (12:00 a 15:00) e que as plantas sob estresse moderado tem maior índice de área foliar que as sob estresse hídrico severo, logo, com provável maior ocorrência de estresse hídrico temporário (Figura 6, Tabela 2) consequentemente maiores temperaturas do dossel. Esta afirmativa não pode ser considerada como regra geral, pois a temperatura do dossel e a resistência difusiva dos estômatos diferiram significativamente entre estresse severo e moderado, apesar de o potencial hídrico não ter diferenciado significativamente (Tabela 2).

Feita a análise de regressão linear individual entre produtividade e temperatura do dossel, verificou-se que, exceto a cultivar BAT 258 o germoplasma promissor apresentou menor coeficiente de regressão, quando comparado com a testemunha susceptível, A 170 (Tabela 3). Estes dados sugerem que a temperatura atua diferentemente nos diversos materiais. Parece que o material susceptível e mais sensível ao efeito da temperatura.

As Figuras (4, 5 e 7) dão uma visão mais precisa sobre o parâmetro temperatura do dossel. O primeiro aspecto a ser notado é o gradiente inverso de temperatura em relação a produtividade; foram observada produtividade mais alta e temperatura mais baixa, no tratamento hídrico sem estresse; a medida que se desloca em direção ao estresse hídrico severo, a produtividade diminuiu e a temperatura do dossel aumentou. No entanto, observou-se, também, que as temperaturas variram entre cultivares no mesmo nível hídrico, explicando 14% a 23% de variação da produtividade dos tratamentos com estresse severo e moderado, respectivamente. Apesar de a temperatura, pela análise de regressão linear, não ter explicado a variação de produtividade do tratamento irrigado (Tabela 1), em algumas cultivares as temperaturas mais baixas no nível sem estresse hídrico correspondem a produtividades mais altas. Fazendo-se uma observação geral, conclui-se que os materiais BAT 258 e CF 830026 apresentaram temperatura mais baixa, independente dos níveis hídricos. As cultivares BAT 258 e CF 830026 apresentaram, uma temperatura média de 22.5 e 22.8°C, para produtividade 1006 e 978 kg/ha, o que difere das médias dos germoplasmas promissores restantes, com temperatura de 24.3°C, para produtividade de 756 kg/ha. A testemunha susceptível à seca apresentou temperatura média de 22.6°C, nos três níveis hídricos para a produtividade de 581 kg/ha, sugerindo-se que este material tem alguma característica, além de seu estado hídrico que controla sua produtividade.

Verificou-se que o IAF influenciou parcialmente a produtividade apenas nos níveis hídricos com estresse severo e moderado (Tabela 1). Aparentemente não houve diferenca de sensibilidade da produtividade por efeito do IAF, nos dois níveis hídricos, como pode ser visto pelos coeficientes de regressão linear das equações apresentadas na Figura 8. Sob estresses hídricos severo e moderado, os coeficientes de regressão linear foram, a 256, 336 e 285, 752, respectivamente. Pelos dados da análise individual de regressão linear, percebe-se que o germoplasma promissor apresentou menor sensibilidade ao índice de área foliar; o coeficiente de regressão médio dos materiais promissores foi de 378.60 e

506.32 para testemunha A 170 (Tabela 4).

Avaliação de mecanismo de resitência à seca - 1987

Na tentativa de compreender melhor o comportamento do material promissor decidiu-se trabalhar mais intensamente com um menor número de materiais. Desta maneira, em 1987, conduziu-se um ensaio com apenas quatro materiais, dois comprovadamente promissores, Carioca e BAT 477, e dois relativamente desconhecidos, em termos de resposta à deficiência hídrica, tidos apenas como exigentes. Os métodos de condução do experimento foram os descritos anteriormente. As avaliações foram feita a partir do início da floração, durante duas semanas consecutivas. Neste período, avaliaram-se a temperatura do dossel, a abertura estomática das faces superiores e inferiores e o potencial hídrico durante todo o dia. Avaliaram-se, também, o índice de área foliar, a umidade do solo, densidade radicular, etc.

Infelizmente, não se pôde apresentar uma análise global, pois alguns dados estão sendo analisados e, outros, calculados. Contudo, serão apresentados alguns gráficos sem qualquer tipo de análise, para dar uma idéia geral do que se pretende. A Figura 9 apresenta o desenvolvimento diurno do potencial hídrico, do dia 17 de julho de 1987, das cultivares Carioca e EMGOPA 201 Ouro, com estresse severo. Parece que houve uma tendência de nivelamento de comportanento durante as horas mais quentes do dia. No entanto, a partir das 15:00 horas, a cultivar EMGOPA 201-Ouro tendeu a recuperar mais rapidamente seu estado hídrico, com o aumento do seu potencial. Este comportamento inverteu no tratamento com estresse hídrico moderado, (Figura 10). Deve-se notar que a cultivar EMGOPA 201 Ouro apresentou tendência de manter o potencial hídrico foliar maior que a Carioca, durante as horas mais quentes (Figura 10). Observou-se também, diferença do potencial hídrico foliar entre os tratamentos com estresse hídrico severo e sem deficit hídrico, durante todo o dia. No entanto, não houve grande distanciamento, sugerindo que os mecanismos de deficit hídrico são acionados para ajustar as condições hídricas da planta, quando há iminência de estresse hídrico (Figura 11).

As temperaturas do dossel (cv. Carioca), dos tratamentos com estresses hídricos severo e moderado, foram semelhantes até as 9:00 horas, quando comecou o diferenciamento que perdurou ate o término das leituras, ao entardecer (Figura 12). Isto leva a crer que o período em que as plantas estressadas se mantém recuperadas, após o período noturno, perdura por poucas horas do dia, ou seja, até às 9:00 horas. No entanto, parece que não houve diferença clara entre as cultivares Carioca e EMGOPA 201 Ouro e BAT 477 durante as horas mais quentes. A diferença foi notada a partir das 16:00, (Figura 13 e 14). Observou-se que esta diferença desaparece no tratamento sem deficit hídrico (Figura 15).

O comportamento da abertura estomática, face inferior, não seguiu a tendência do potencial hídrico, temperatura do dossel e intensidade da radiação solar. O comportamento das duas cultivares foram semelhantes, nas condições hídricas ideais (Figura 16). Sob estresse hídrico severo, o comportamento estomatal foi semelhante, até às 10:00 horas; a partir deste ponto, houve intensa diferenciação, e a cultivar EMGOPA 201 Ouro manteve a resistência difusiva mais alta até o término das leituras, às 18:00 horas (Figura 16). Tendência semelhante ocorreu para resistência estomática da face superior (Figura 17).

Hibridação e seleçao em populações segregantes

Selecionaram-se linhagens em 28 populações de cruzamentos intraespecificos e 7 de cruzamentos interespecíficos para resistência à seca pela metodologia descrita anteriormente.

Em 1988 serão executados novos cruzamentos utilizando os progenitores até o momento identificados e combinando-os com linhagens do programa de melhoramento de alto potencial de rendimento ou linhagens que apresentam resistência mútua às doenças.

Tabela 1. Coeficiente de determinação entre produtividade e número de vagens/planta (NVAG), peso de 100 sementes (P100), potencial hídrico das folhas ($_f$), resistência estomática das faces superior (R_{fs}), e inferior (R_{fi}), temperatura do dossel (TD) e índice de área foliar (IAF), nos três níveis hídricos, estresse severo (1), moderado (2) e sem estresse hídrico (3).

Níveis hídricos	NVAG	P100 g	$_f$ MPa	R_{fs} cm/seg	R_{fi} cm/seg	TD °C	IAF
1	** 0.3718	*** 0.4523	0.0971	0.0128	0	0.1989	*** 0.2400
2	* 0.1477	0.0576	0.0047	0.0379	*** 0.3542	0.2621	** 0.1812
3	** 0.2275	* 0.1224	0.0412	0.0391	0.0963	0.0413	0.0410

Tabela 2. Temperatura do dossel. (TD), Indice de área foliar (IAF), potencial hídrico foliar ($_f$), resistência estomatica da faces superior (R_{fs}) e inferior (R_{fi}).

Tratamentos hídricos	TD °C	IAF	$_f$ MPa	R_{fs} cm/seg	R_{fi} cm/seg
Estresse severo	26.24 a	0.68 c	1.03 ab	4.77 a	2.14 a
Estresse moderado	23.13 b	1.82 b	1.05 a	2.37 b	1.01 b
Sem estresse	21.62 c	2.65 a	0.93 b	2.63 b	0.65 c

Tabela 3. Coeficiente de regressão entre produtividade e a temperatura do dossel, nos três níveis hídricos estresse severo, moderado e sem estresse hídrico.

Cultivares	Coeficiente de regressão linear (b)
BAT 258	- 210,837
BAT 477	- 103,977
Carioca	- 100,987
CF 830026	- 109,034
CNF 127	- 115,712
IPA 7419	- 116,135
Moruna	- 98,738
A 170 (testemunha)	- 177,458

Tabela 4. Coeficiente de regressão linear entre produtividade e índice de área foliar, nos três níveis hídricos, estesse severo, moderado e sem estresse.

Cultivares	Coeficiente de regressão linear (b)
BAT 258	383,57
BAT 477	398,53
Carioca	482,30
CF 830026	414,77
CNF 127	324,52
IPA 7419	352,47
Moruna	294,03
A 170 (testemunha)	506,32

Figuras

Fig. 1. Fluxograma do programa de resistência do feijão à seca.

Fig. 2. Distribuição das classes de produção da avaliação preliminar I.

Fig. 3. Distribuição do germoplasma da avaliação avançada, em 4 grupos: I - resistente à seca e responsivo à irrigação, II - resistente e não responsivo, III - não resistente e não responsivo e IV - não resistente e responsivo. 1 - A 285, 2 - A 295, 3 - A 319, 4 - A 320, 5 - BAT 53, 6 - G 4446 e 7 - GF 1138.

Fig. 4. Produtividade das cultivares promissoras e não promissora (A 170) para as condiçoes de severo, moderado e sem estresse hídrico.

Fig. 5. Efeito da temperatura do dossel sobre a produtividade em condições de deficiência severa (1) e moderada (2).

Fig. 6. Indice de área foliar (IAF) das cultivares promissoras e não promissora (A 170) para as condições de severo, moderado e sem estresse hidrico.

Fig. 7. Temperatura do dossel das cultivares promissoras e não promissora (A 170) para as condições de severo, moderado e sem estresse hídrico.

Fig. 8. Efeito do índice de área foliar sobre a produtividade em condições de deficiência hídrica severa (1) e moderada (2).

Fig. 9. Variação diurna do potencial hídrico foliar, das cultivares Carioca e EMGOPA 201-Ouro, em condições de estresse hídrico severo.

Fig. 10. Variação diurna do potencial hídrico foliar, das cultivares Carioca e EMGOPA 201-Ouro, em condições de estresse hídrico moderado.

Fig. 11. Variação diurna do potencial hídrico foliar, da cultivar Carioca, em condições de estresse hídrico severo e sem estresse.

Fig. 12. Variação diurna da temperatura do dossel, da cultivar Carioca, em condições de estresse hídrico severo e sem estresse.

Fig. 13. Variação da temperatura do dossel, das 16:00 às 18:00 horas, das cultivares Carioca e BAT 477, em condições de estresse hídrico severo.

Fig. 14. Variação da temperatura do dossel, das 16:00 às 18:00 horas, das cultivares Carioca e EMGOPA 201-Ouro, em condições de estresse hídrico severo.

Fig. 15. Variação da temperatura do dossel, das 16:00 às 18:00 horas, das cultivares Carioca e EMGOPA 201-Ouro, sem deficiência hídrica.

Fig. 16. Variação diurna da resistência difusiva estomatal da face inferior, das cultivares EMGOPA 201-Ouro e Carioca, em condições de estresse hídrico severo e sem estresse.

Fig. 17. Variação diurna da resistência estomatal da face superior, das cultivares EMGOPA 201-Ouro e Carioca, em condições de estresse hídrico severo e sem estresse.

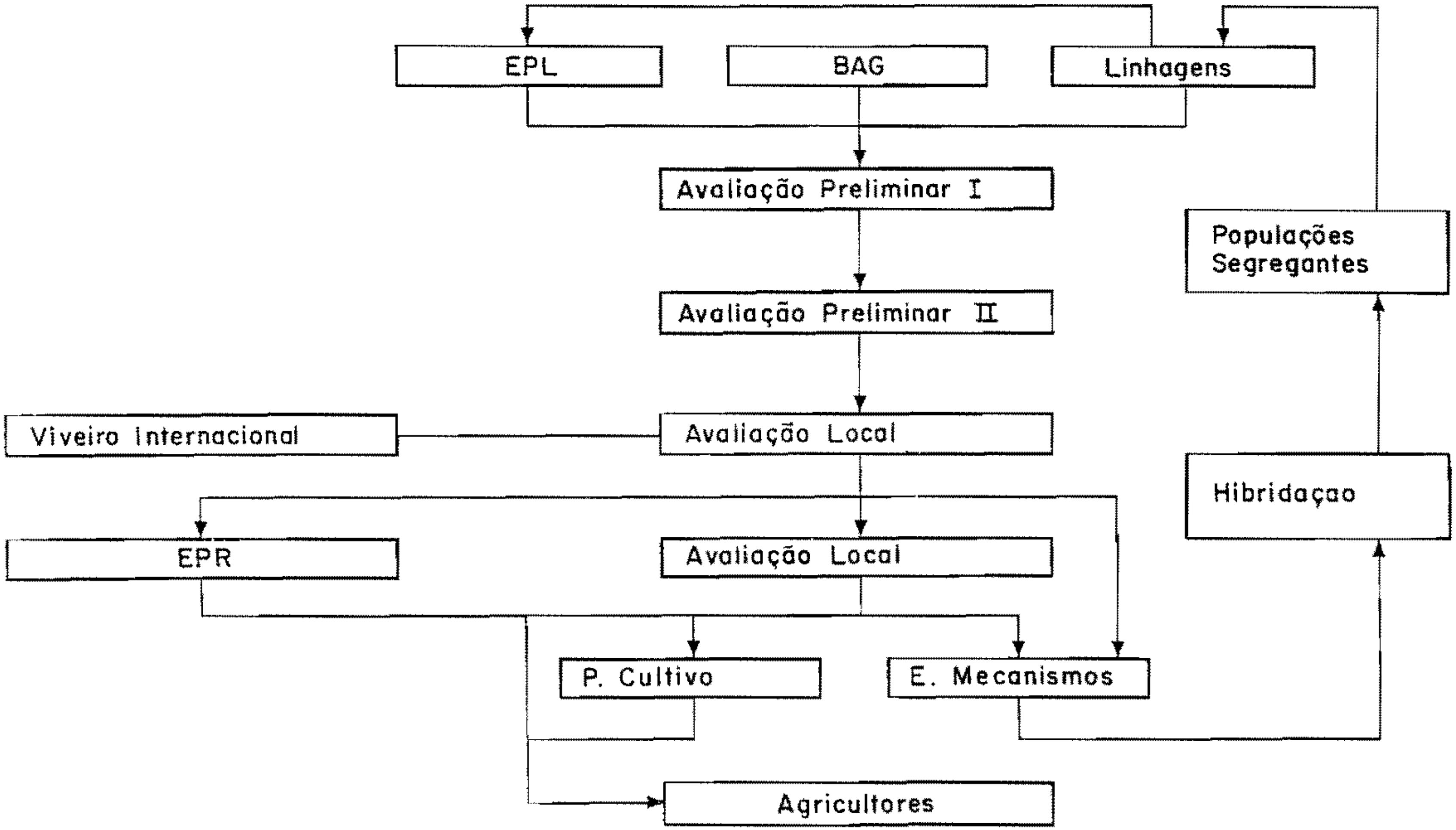

Figura 1. Fluxograma do programa de resistência do feijão à seca.

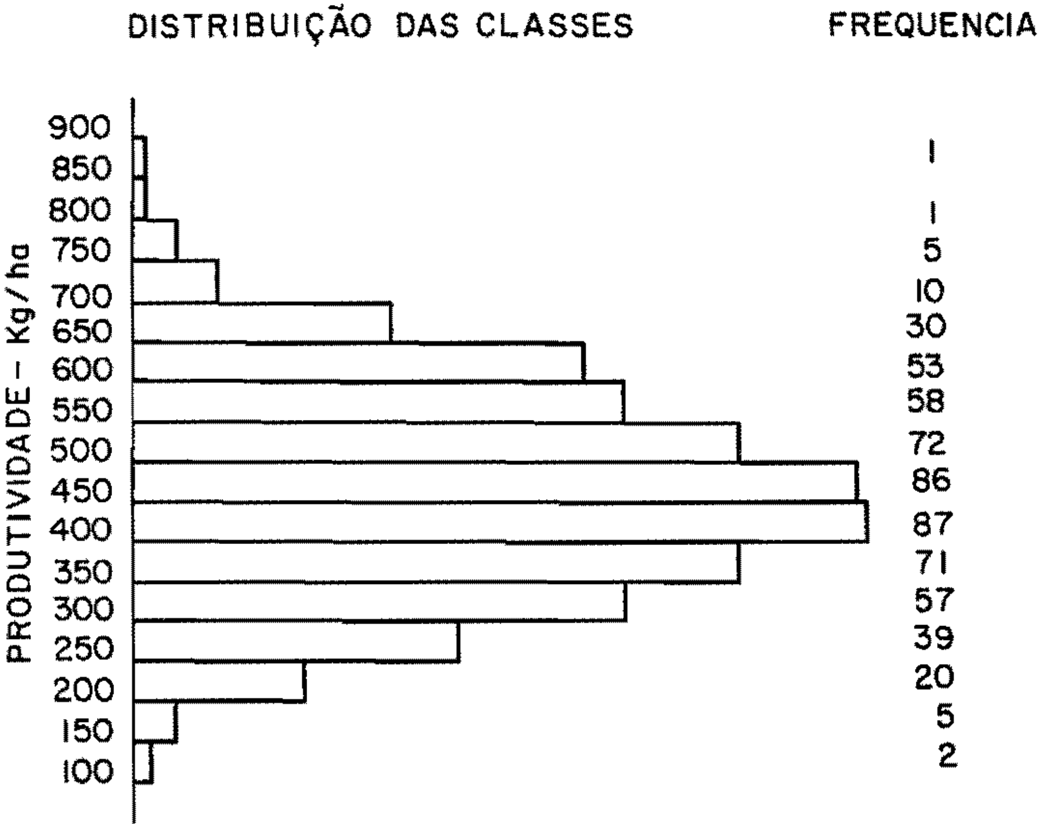

Figura 2. Distribuição das classes de produção da avaliação preliminar I.

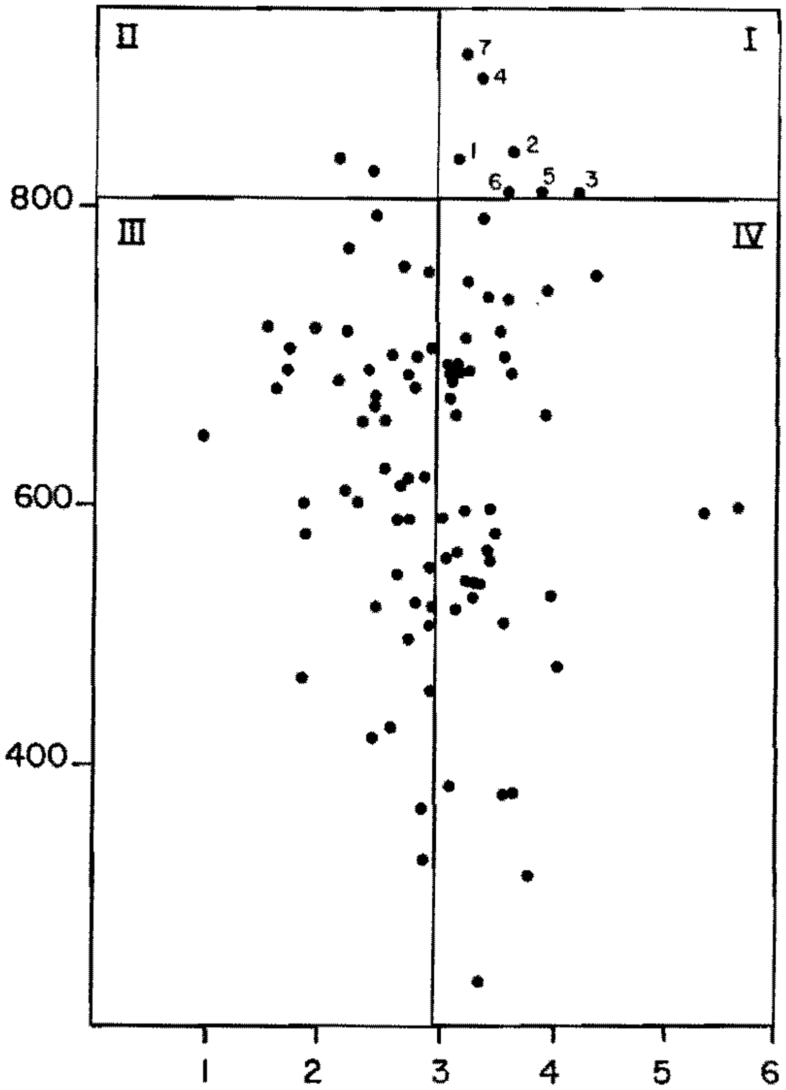

Figura 3. Distribuição do germoplasma da avaliação avançada, em 4 grupos: I - resistente à seca e responsivo à irrigação, II - resistente e não responsivo, III - não resistente e não responsivo e IV - não resistente e responsivo. 1 - A 285, 2 - A 295, 3 - A 319, 4 - A 320, 5 - BAT 53, 6 - G 4446 e 7 - GF 1138.

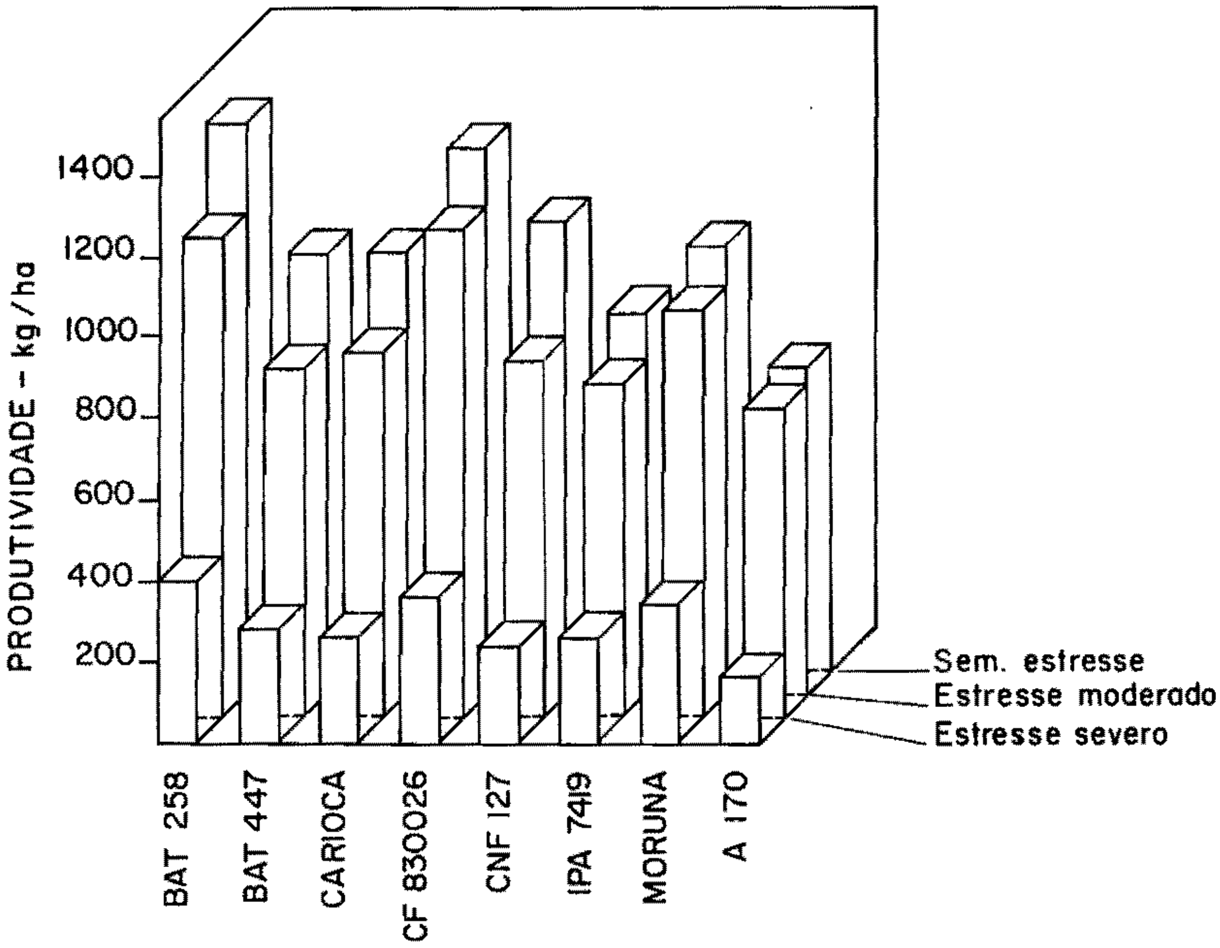

Figura 4. Produtividade das cultivares promissoras e não promissora (A 170) para as condições de severo, moderado e sem estresse hídrico.

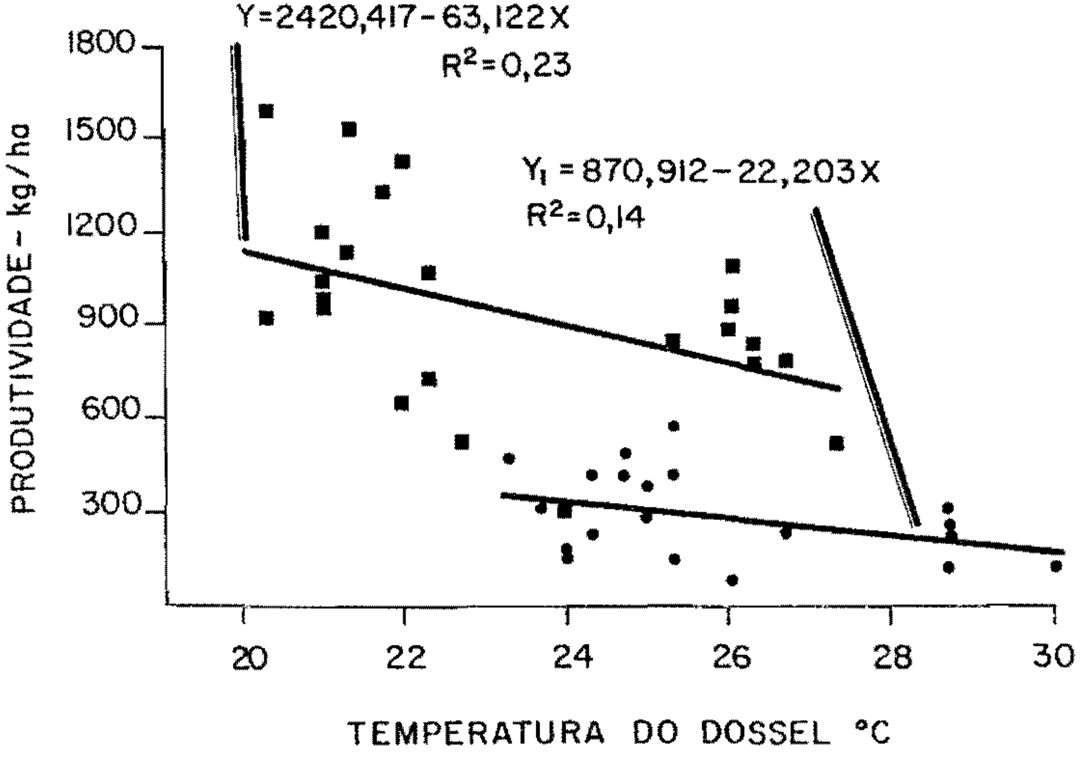

Figura 5. Efeito da temperatura do dossel sobre a produtividade em condições de deficiência severa (1) e moderada (2).

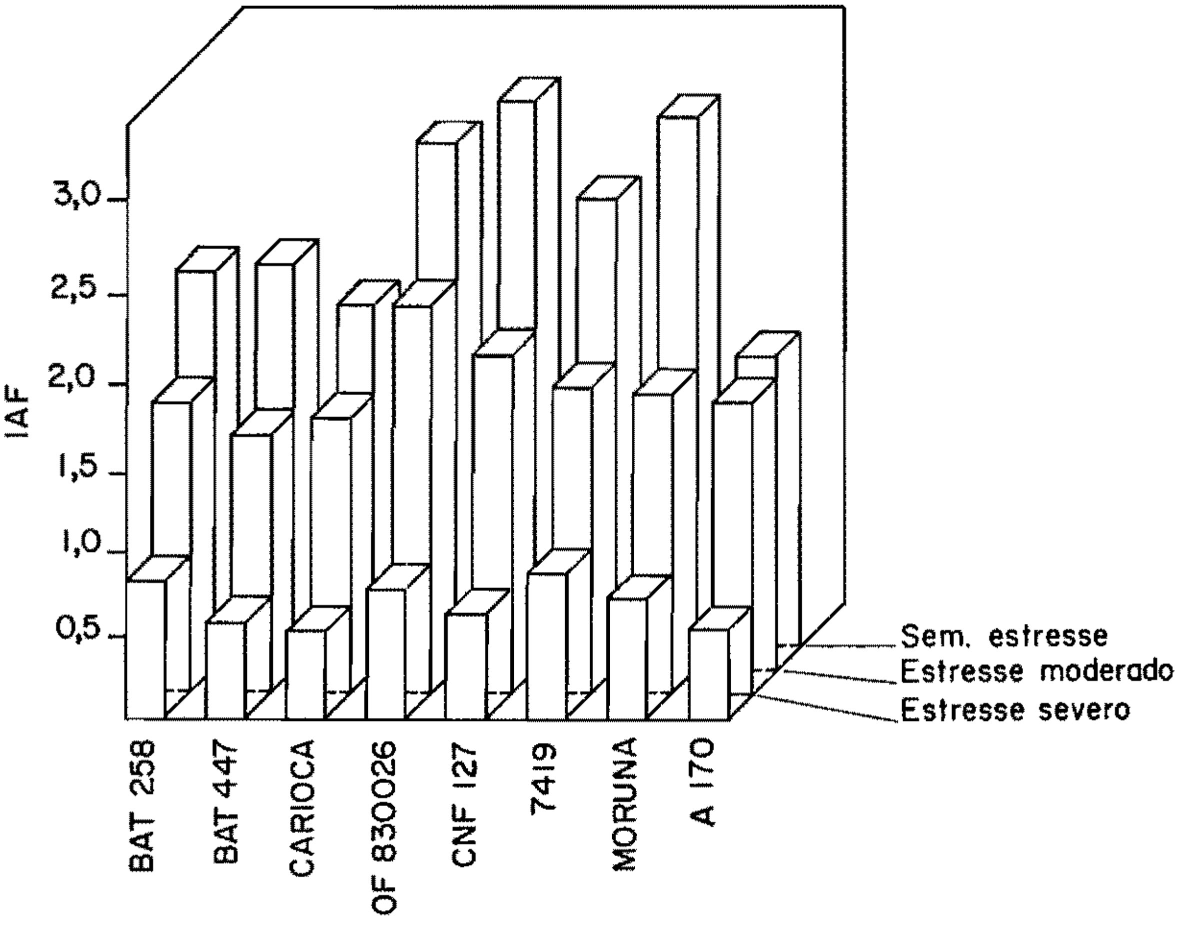

Figura 6. Indice de área foliar (IAF) das cultivares promissoras e não promissora (A 170) para as condições de severo, moderado e sem estresse hídrico.

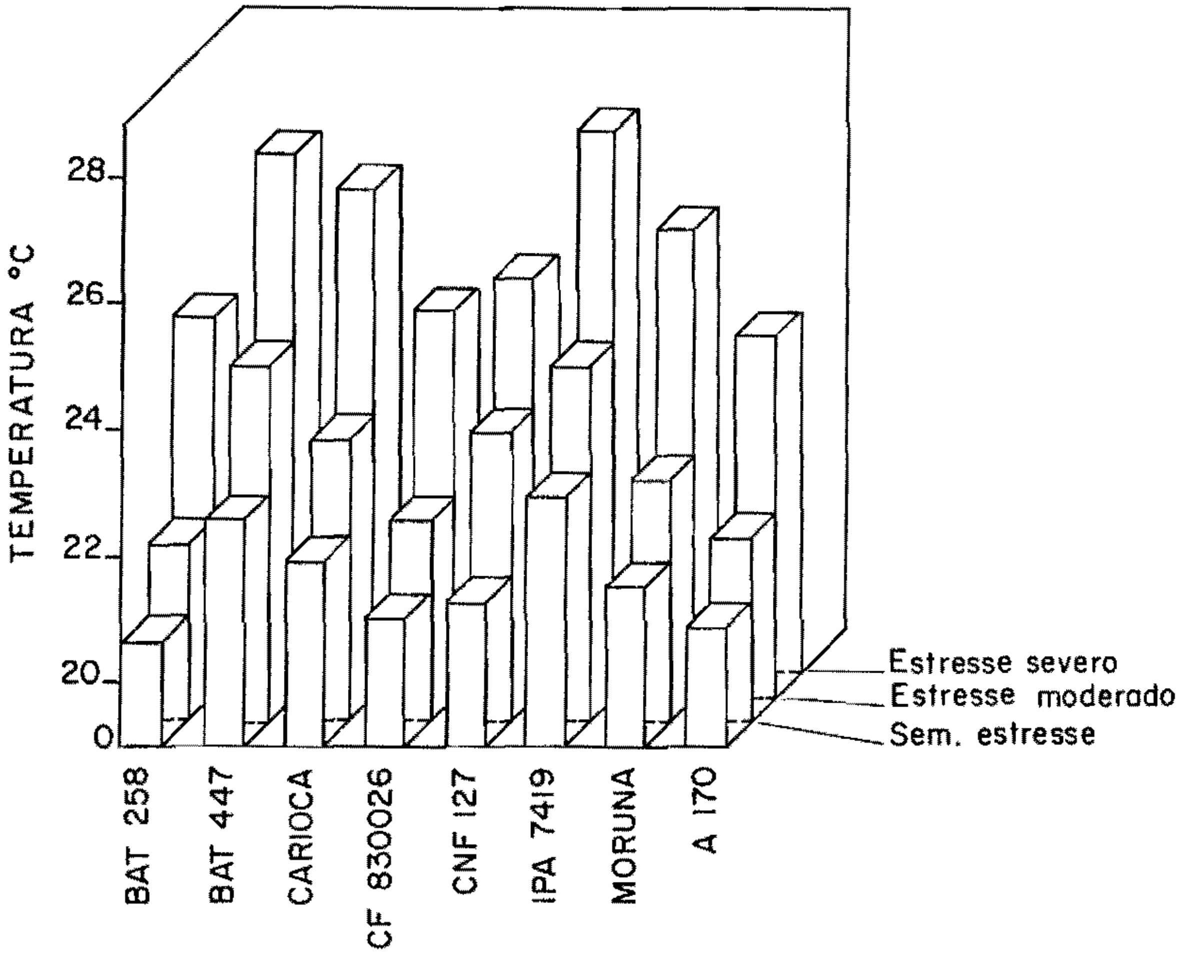

Figura 7. Temperatura do dossel das cultivares promissoras e não promissora (A 170) para as condições de severo, moderado e sem estresse hídrico.

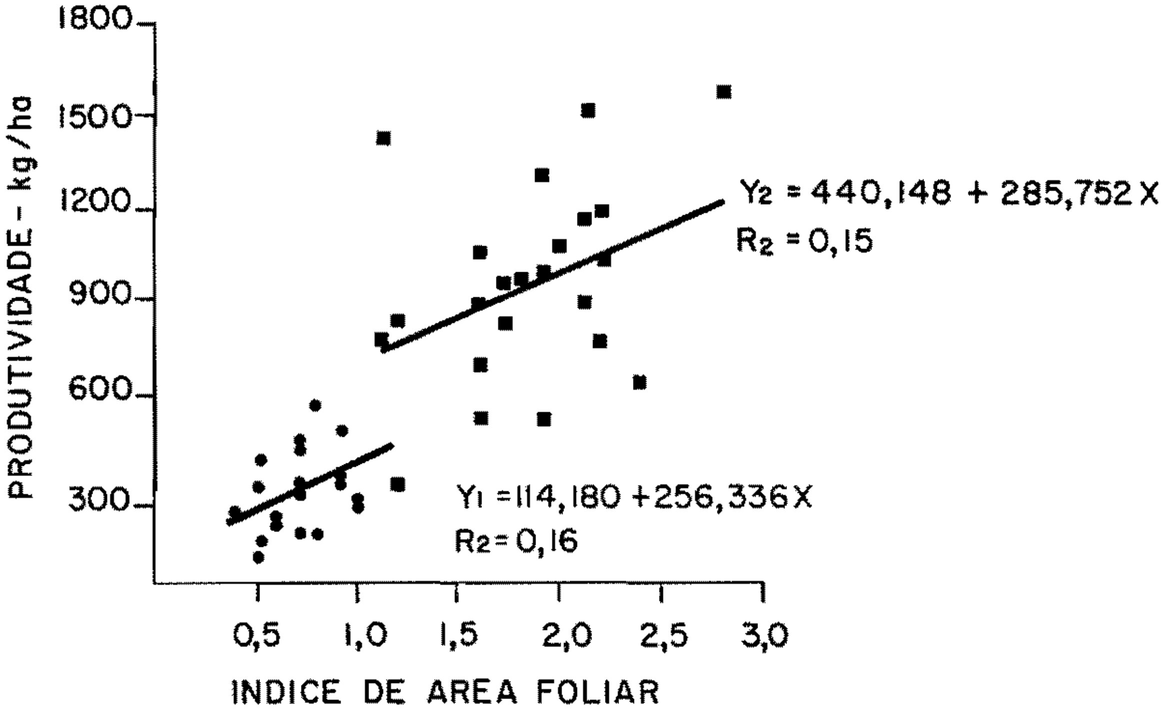

Figura 8. Efeito do índice de área foliar sobre a produtividade em condições de deficiência hídrica severa (1) e moderada (2).

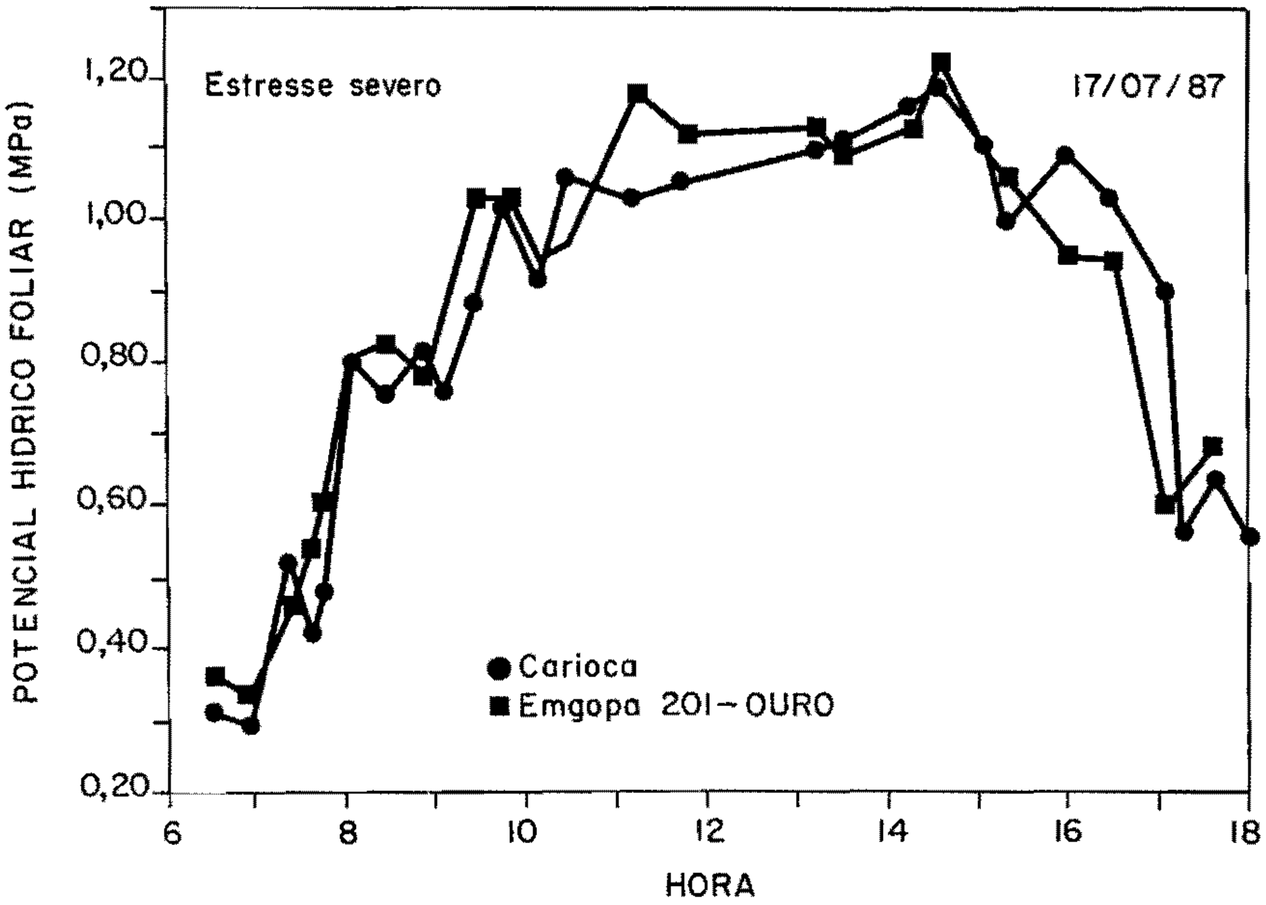

Figura 9. Variação diurna do potencial hídrico foliar, das cultivares Carioca e EMGOPA 201-Ouro, em condições de estresse hídrico severo.

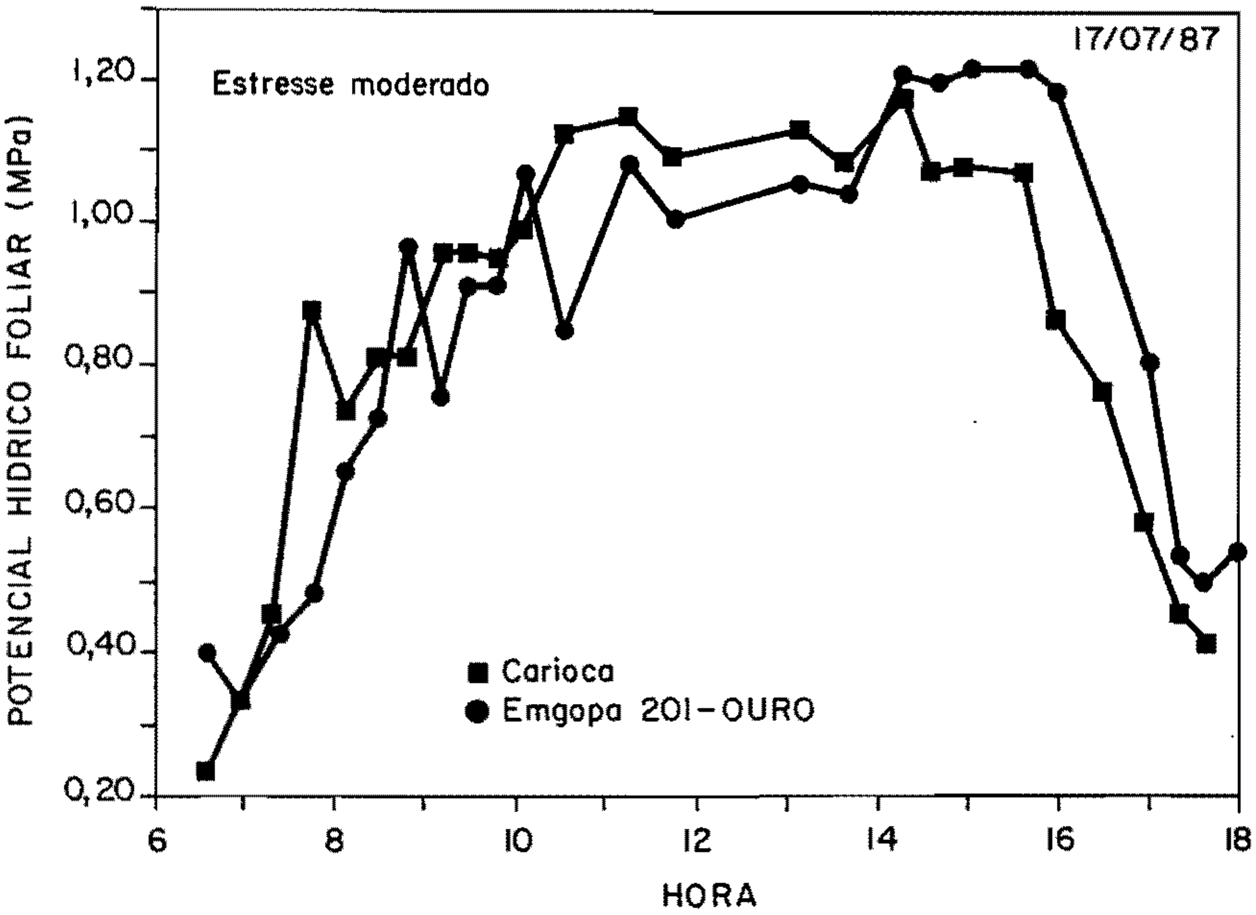

Figura 10. Variação diurna do potencial hídrico foliar, das cultivares Carioca e EMGOPA 201-Ouro, em condições de estresse hídrico moderado.

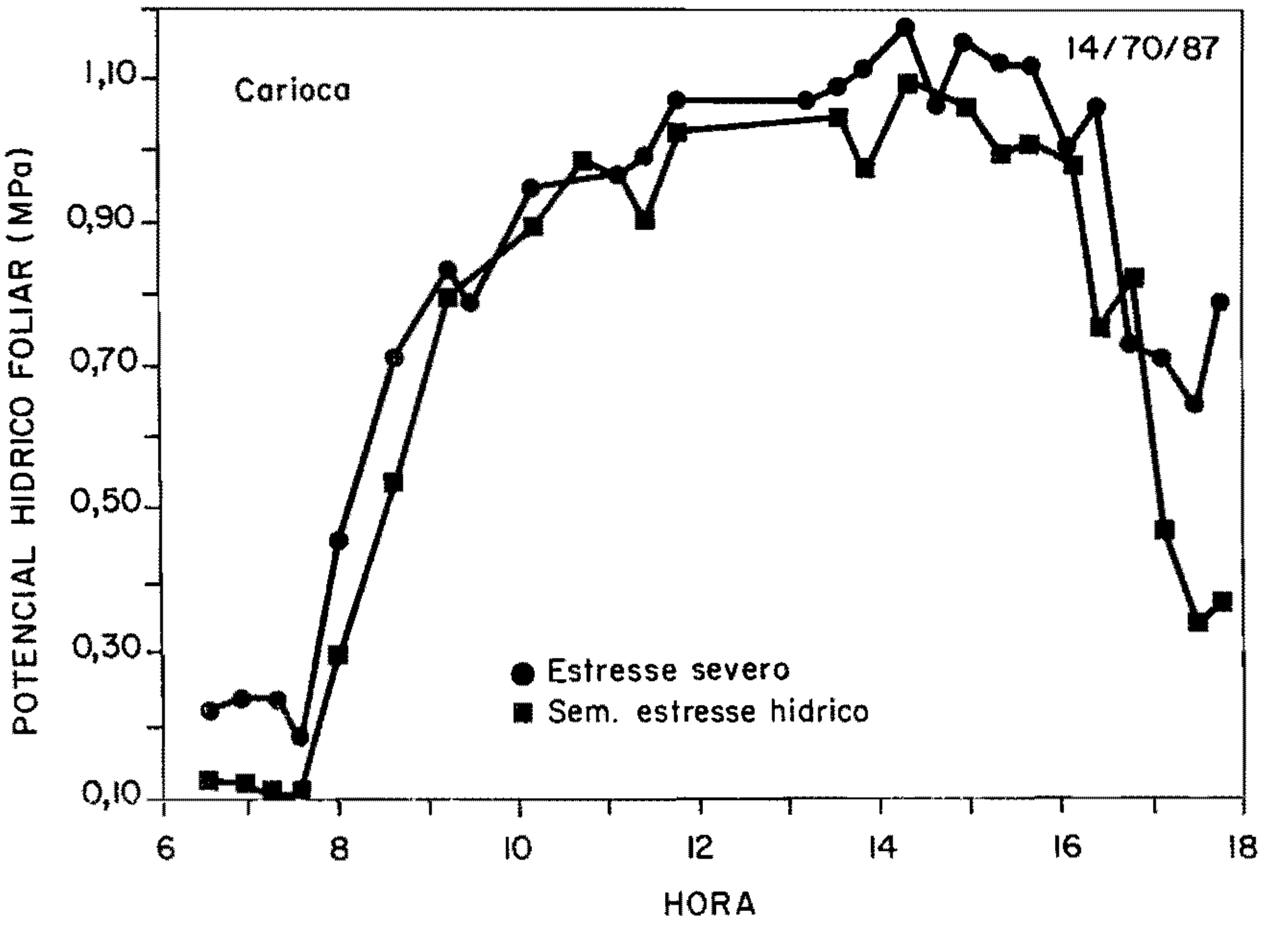

Figura 11. Variação diurna do potencial hídrico foliar, da cultivar Carioca, em condições de estresse hídrico severo e sem estresse.

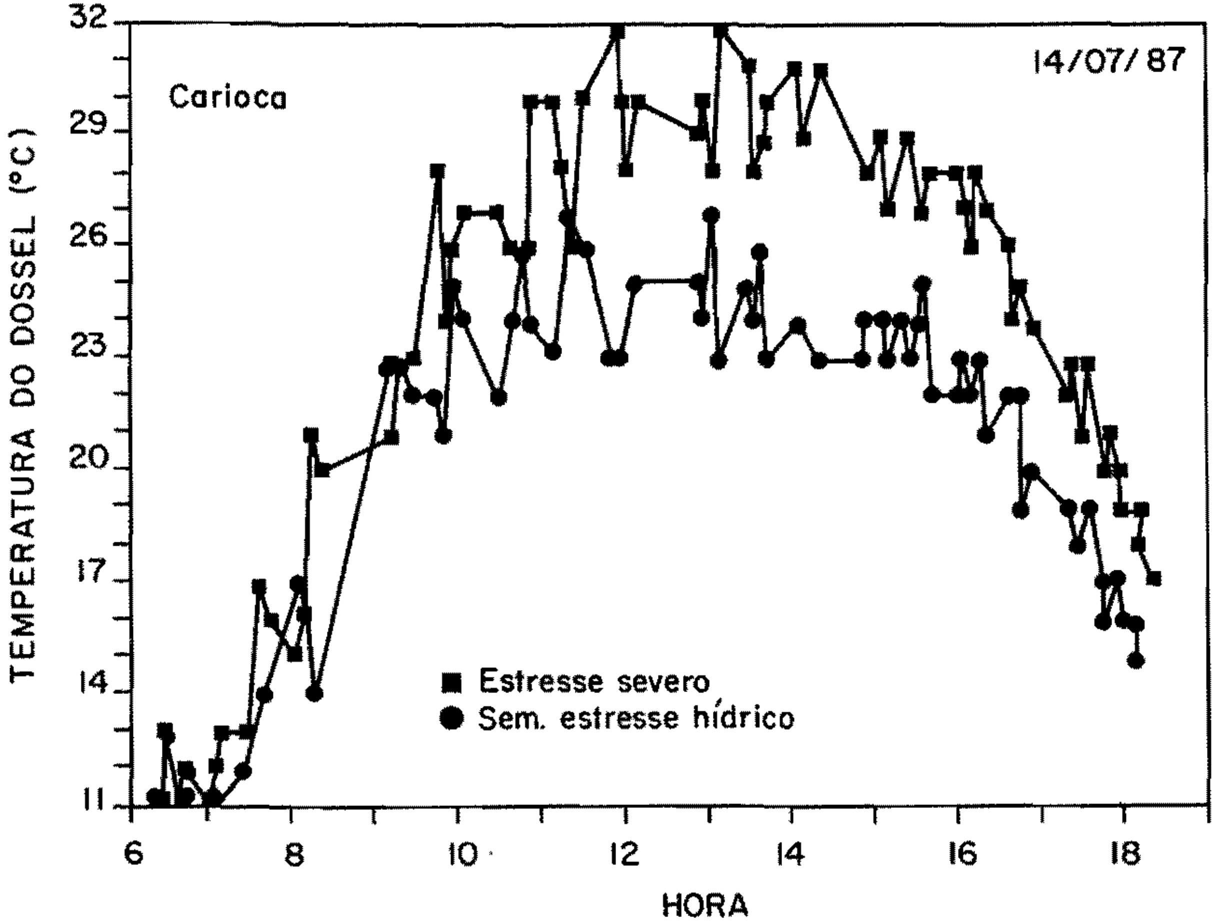

Figura 12. Variação diurna da temperatura do dossel, da cultivar Carioca, em condições de estresse hídrico severo e sem estresse.

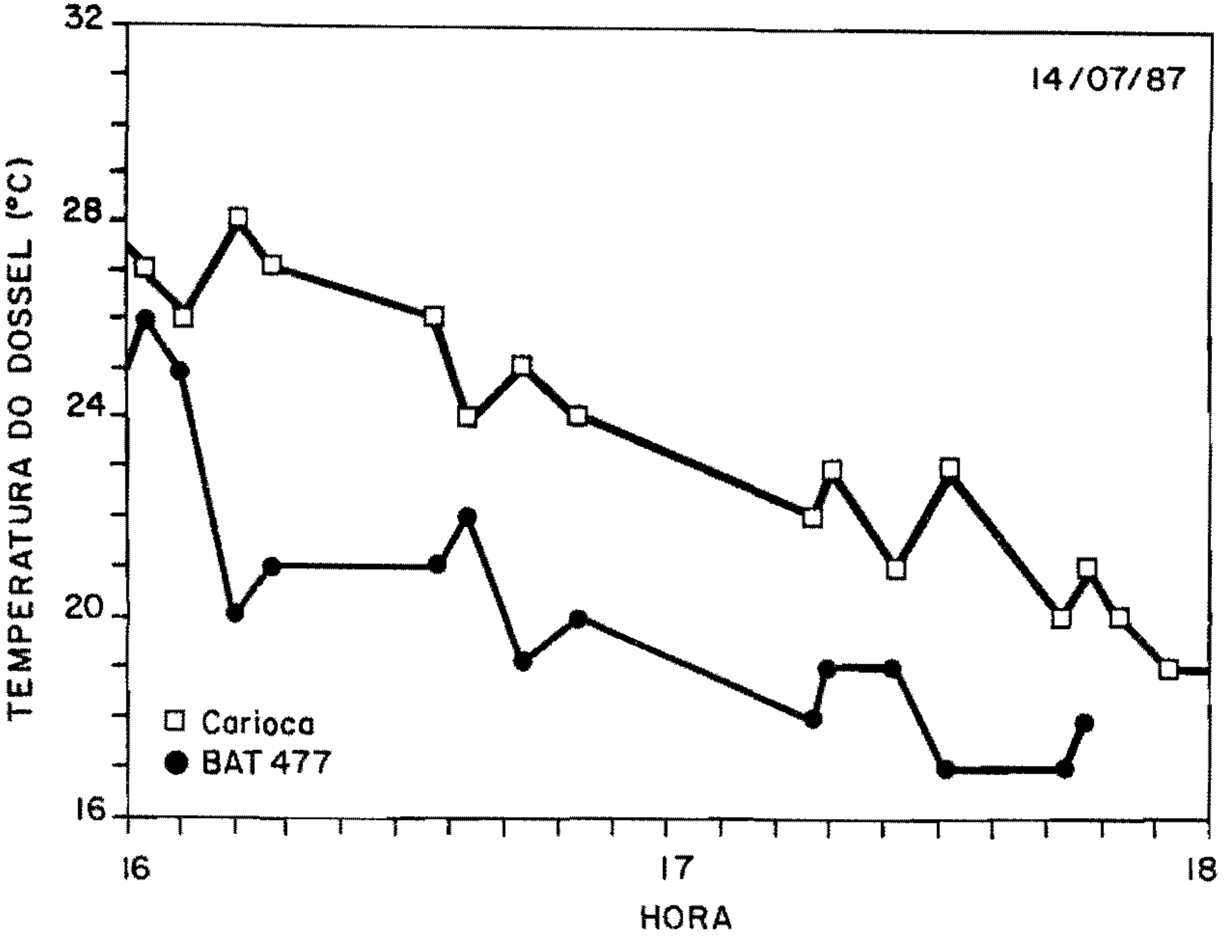

Figura 13. Variação da temperatura do dossel, das 16:00 as 18:00 horas, das cultivares Carioca e BAT 477, em condições de estresse hídrico severo.

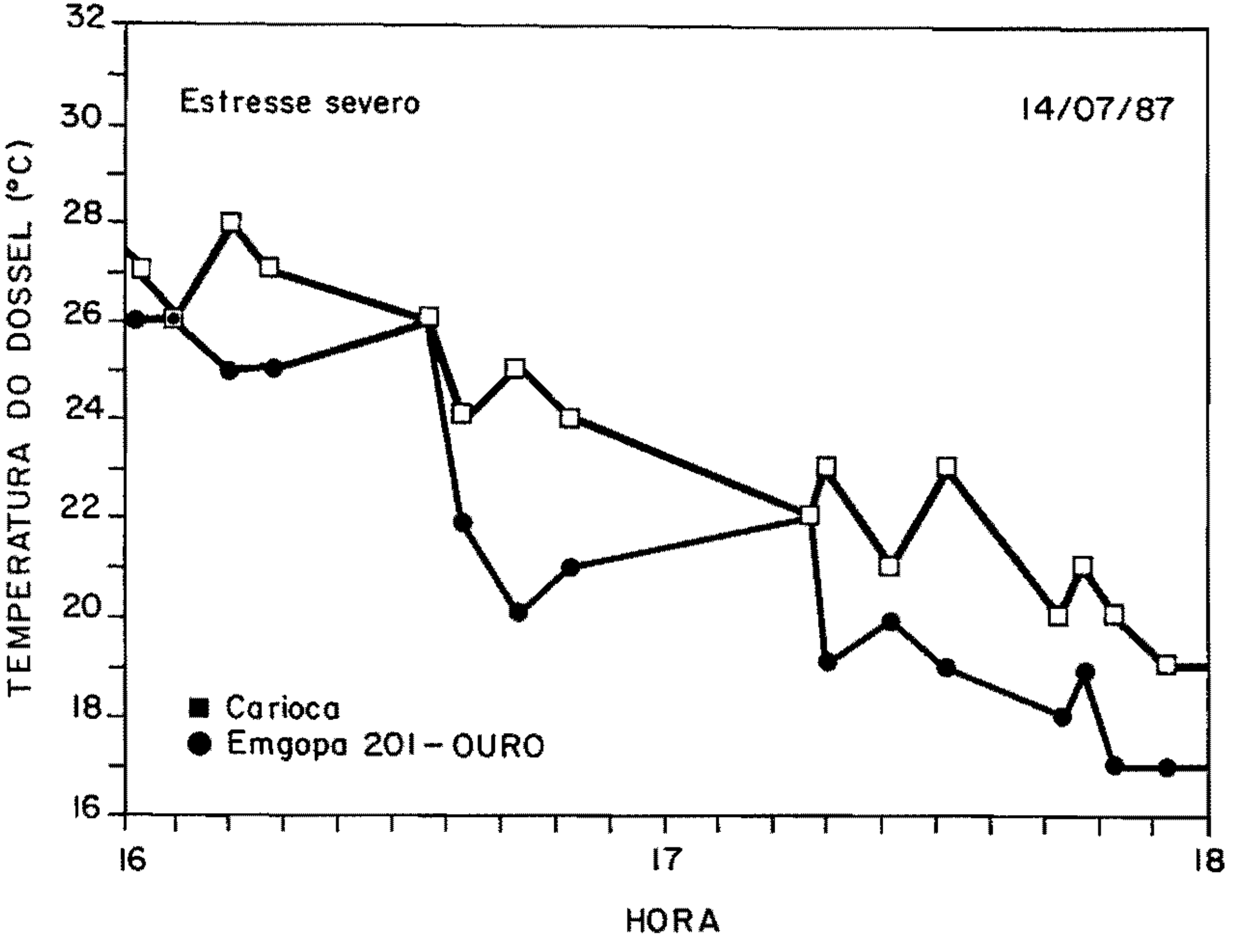

Figura 14. Variação da temperatura do dossel, das 16:00 as 18:00 horas, das cultivares Carioca e EMGOPA 201-Ouro, em condições de estresse hídrico severo.

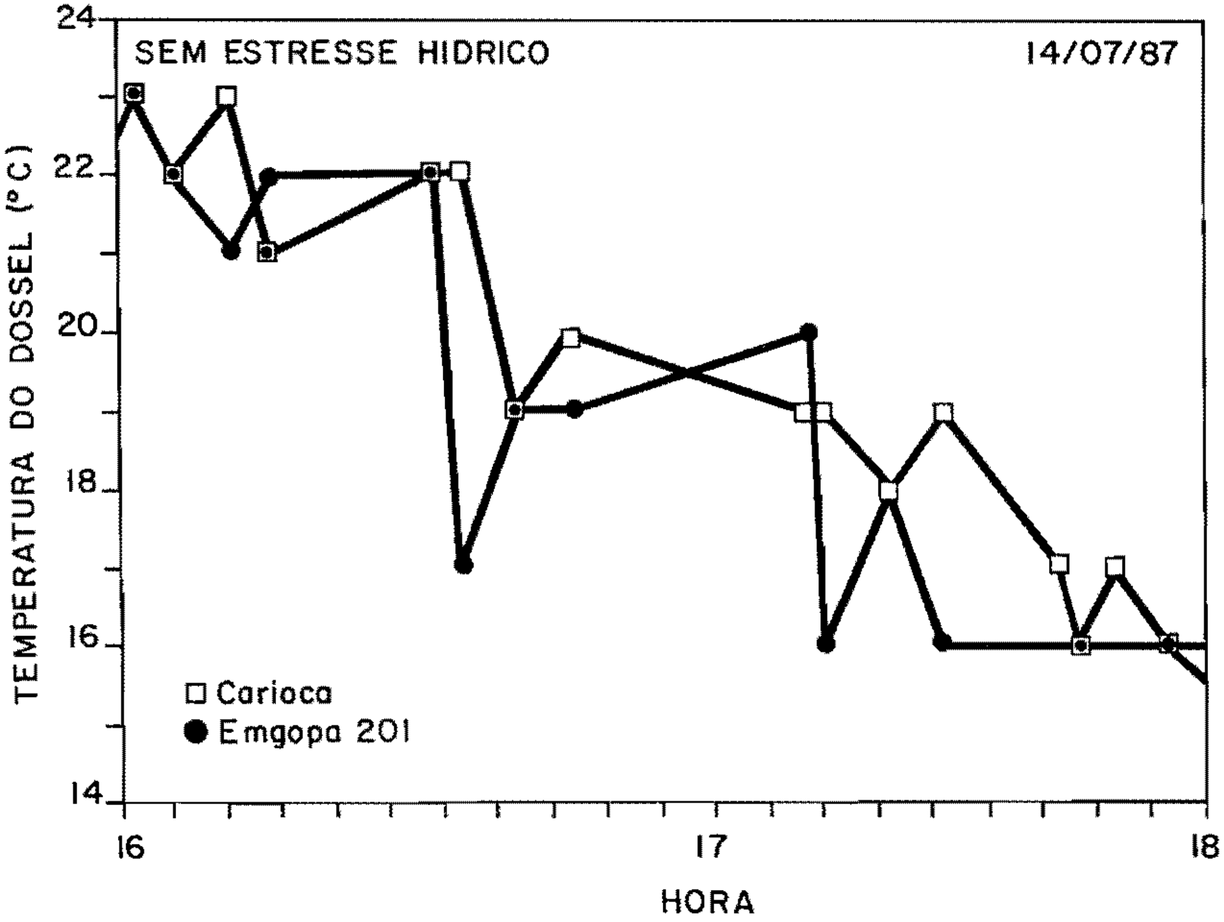

Figura 15. Variação da temperatura do dossel, das 16:00 às 18:00 horas, das cultivares Carioca e EMGOPA 201-Ouro, sem deficiência hídrica.

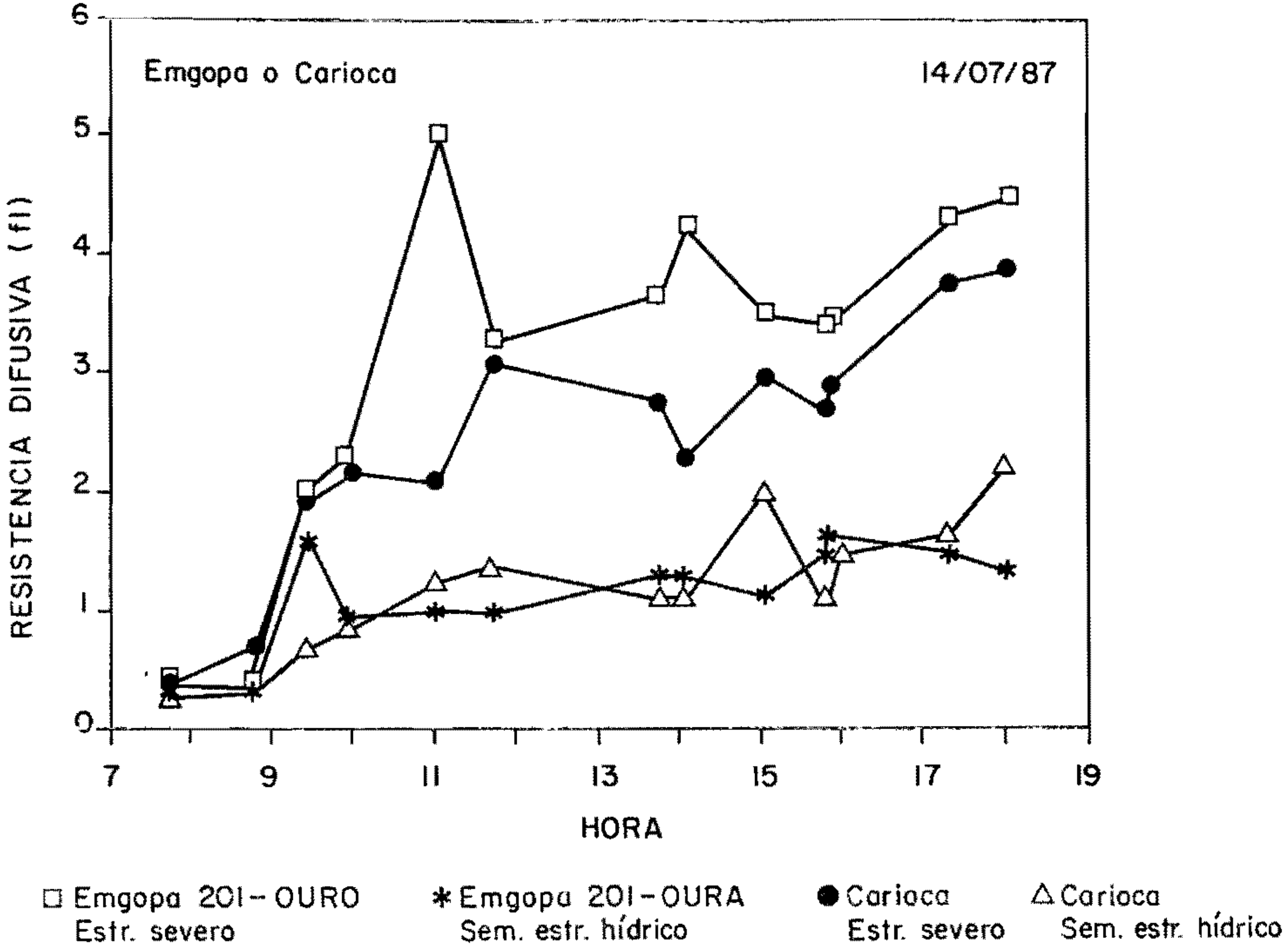

Figura 16. Variação diurna da resistência difusiva estomatal da face inferior, das cultivares EMGOPA 201-Ouro e Carioca, em condições de estresse hídrico severo e sem estresse.

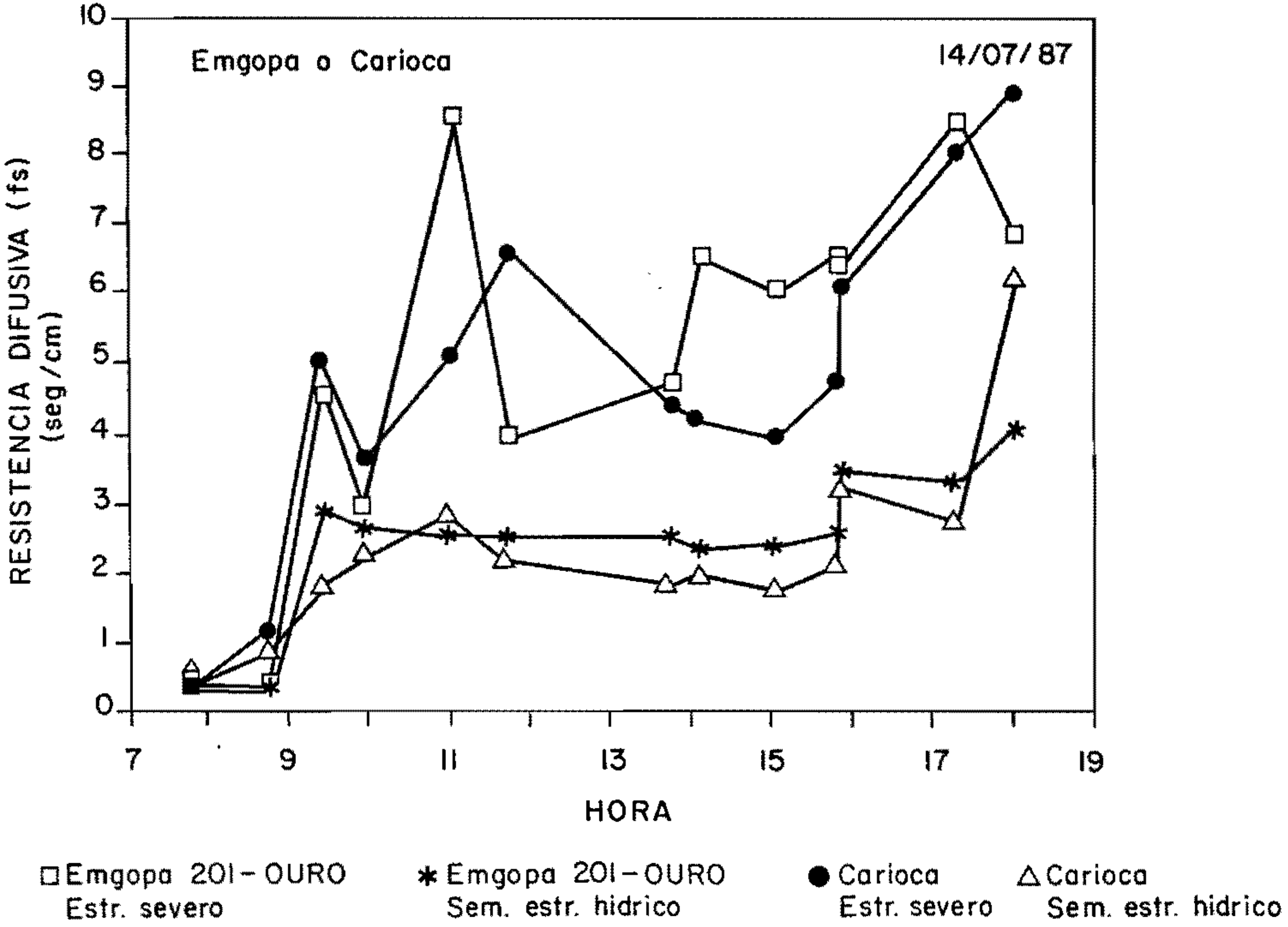

Figura 17. Variação diurna da resistência estomatal da face superior, das cultivares EMGOPA 201-Ouro e Carioca, em condicoes de estresse hídrico severo e sem estresse.

COMPORTAMIENTO DE 30 VARIEDADES DE FRIJOL (*Phaseolus vulgaris* L.) EN SIEMBRAS SIN RIEGO

Evelio García, Miguel González y Benito Faure*

Se realizó un experimento donde se compararon 30 variedades de fríjol de diferentes colores de testa y de las más promisorias, procedentes de la Academia de Ciencias de Cuba, introducidas del CIAT y criollas, con el fin de recomendar a los agricultores las de mejor comportamiento en condiciones de siembras sin riego y de obtener elementos para futuros trabajos de mejoramiento genético en dichas condiciones.

Para el estudio se dividieron en dos grupos: variedades negras (15) y de varios colores (15), en diseños respectivos de bloques al azar con 4 réplicas y parcelas de 11.2 m^2. Se utilizaron testigos locales conocidos, como el Bolita 42 y Criollo para negros y Velasco Largo para el de varios colores. Las siembras se efectuaron en septiembre de 1985 y 1986 y enero de 1986 y 1987.

Las variedades negras de mejor comportamiento fueron el Tazumal (BAT 58), Holguín 518 (BAT 518), Guira 89 e ICTA-Quetzal. En las de varios colores el Chévere (BAT 482), Jíquima 61, Engañador (BAT 93) y el Jíquima 70 fueron mejores. En cuanto a colores, el negro fue el de mayor rendimiento promedio. Las variedades de períodos cortos y largos alcanzaron los menores rendimientos respectivamente y las de mejor rendimiento fueron las de ciclos medios.

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PRELIMINARY RESULTS OF THE BEAN INTERNATIONAL DROUGHT YIELD TRIAL (BIDYT)

J.W. White*

Introduction

The Bean International Drought Yield Trial (BIDYT) was initiated in 1984, consisting of a replicated yield trials with 25 entries (including local checks) distributed to bean researchers interested in drought tolerance. The stated purposes of the BIDYT were:

1. Make germplasm identified at CIAT as drought tolerant available to researchers elsewhere.

2. Determine whether selection at CIAT had been effective in identifying superior genotypes for other sites.

3. Characterize sites and genotypes by their yield responses.

To date, 29 sets of data have been received, and the results are being organized for a publication similar to those prepared for IBYAN's (International Bean Yield and Adaptation Nurseries). This paper discusses preliminary results from the BIDYT, and considers whether such international drought trials should be continued.

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Materials and Methods

The BIDYT was distributed as a yield trial with four replicates in a randomized complete block design. The trial included 23 bean genotypes identified as drought tolerant at CIAT, with space allowed for investigators to include 2 local checks. The 23 genotypes were predominantly small seeded indeterminate materials, but three medium to large seeded type I's were included to assure some variation in plant types (Table 1).

Enough seed was supplied to permit four row plots 4 m long, it being recommended that only the center rows be harvested. However, trials varied greatly in the actual plot layouts used. An option of having a parallel set of materials for irrigated controls (labeled "BIDYT+C") was also made available.

Data for 29 trials have been received. As would be expected, mean yields varied from nearly 0 under drought to over 2500 kg ha^{-1} in irrigated treatments (Table 2).

Results

Rather than present tabulations of individual trial results, emphasis was given to using the data to evaluate the goals of the trial, and to provide a basis for considering alternatives for future trials. Since the first goal of the trial was satisfied by distributing trials, the points which were thought to require attention were:

1. Did materials identified as drought tolerant at CIAT appear to show drought tolerance in locations outside of CIAT?

2. Did the results suggest that certain sites tend to show the same drought response?

3. Did certain genotypes consistently show similar results, thus suggesting common mechanisms of drought tolerance?

Performance of materials

Analysing results of multilocation yield trials is always a perilous endeavor, and having the alternative of excluding data from the irrigated trials provided another dimension of complexity.

Mean yields across trials are one possible index of overall performance, but sites with high yields will bias the results. Nevertheless, such means were generated, including separate means of drought and irrigated trials (Table 3). Based on this index of performance, most test materials were inferior to the local checks.

Bias introduced by variation in yields can be eliminated by standardizing data to a constant mean and standard error. This was done by subtracting out site mean yield, and dividing this value by the standard error, resulting in all trials having a mean yield of 0, with standard error of 1. When overall means are calculated in this manner, the best local check was clearly superior, while V 8025 and BAT 477 were the second and third best entries (Table 3).

Yet another strategy is to base evaluations on ranks of yields. Using this criterion, V 8025 and the best local check interchanged positions, while BAT 477 dropped to sixth place (Table 3).

Although the exact order of the evaluations varied considerably, the overall trend was that the genotypes of the BIDYT performed poorly compared to the local checks (see also Table 4). The few lines which might be considered outstanding were V 8025, BAT 1289, BAT 1298, and BAT 477.

One possible explanation is that the screening strategy at CIAT is inappropriate. Perhaps the soil or climatic conditions are so unusual that mechanisms which give tolerance at CIAT are of little use elsewhere. This possibility is difficult to test, and will require a better understanding of tolerance mechanisms both at CIAT and elsewhere.

A second possibility is that factors affecting non-drought components of adaptation masked effective drought tolerance. The number of genotypes in the BIDYT is too low to permit a decisive evaluation of this point, but the parallel drought adaptation nursery (Bean International Drought Adaptation Nursery, BIDAN), which contained 72 entries, suggested that photoperiod-temperature adaptation was a confounding factor. When genotypes were classed by drought yield and photoperiod response at two contrasting sites, it was seen that the optimal photoperiod response was completely different. In California, a day neutral response was advantageous, while on the coast of Peru, photoperiod sensitive materials yielded better (Table 5).

Characterization of sites

The probable effects of adaptation suggested a need to classify drought sites so that breeding efforts can be directed toward site specific problems. The yield data provided a convenient tool for characterizing sites on exactly the parameter one is most interested in, yield response to environments.

Using a centroid clustering technique (Williams, 1976), sites were classified using absolute yields, and also using ranks of yields. For the classification using absolute yields, the biggest separation was one separating experiments with high and low yields, this being associated primarily irrigated vs drought conditions (Fig. 1A). A more instructive classification appeared to result from classification on ranks of yields (Fig. 1B). Using ranks, the predominant feature was that experiments from the same location tended to form groups irrespective of the water regime.

For example, trials from Chiclayo, Peru and from CIAT Palmira formed one cluster including three irrigated and four drought trials.

These results again suggested that local adaptation was such a dominant force in determining genotype response that their possible drought tolerance was severely affected by local adaptation.

Characterization of genotypes

Just as sites may be classified by yield response, genotypes may be grouped by similarity in response to different drought environments. Again using a centroid clustering algorithm, the genotypes were grouped based on absolute yields and ranks of yields, also including a classification based on absolute yields only of drought experiments. The validity of all three classifications was supported by the result that materials known to be similar were grouped together (Fig. 2). Thus the three medium to large seeded genotypes of growth habit type I, A 195, BAT 1393, and G 4523 were grouped in a single group, using three different criteria, as were the sister lines BAT 85 and BAT 477 (see also Table 1).

Ideally, groupings from the classification based on drought experiments should indicate similarity of tolerance mechanisms. However, given the relatively poor performance of the BIDYT genotypes as compared to local checks, it seems likely that the classification would reflect similarities of general adaptation rather than of specific tolerance mechanism.

The phenology data also permitted consideration of possible mechanisms since relations between yield and time to flower and maturity provide indication of the importance of drought escape through earliness. Table 6 presents correlations between these parameters for individual trials of the BIDYT. Correlations were generally small and not statistically significant. Seven of the ten correlations between days to maturity with drought yield were negative, as compared to three of nine for irrigated trials, but a Chi^2 test (2.5 with 1 d.f.) failed significance. These results could again be attributed to differences in sites having effects on the utility of a specific tolerance mechanism.

The Need for Future International Drought Trials

Given the apparent disappointing performance of the genotypes of the BIDYT, the advisability of continuing international drought trials requires careful consideration. It would certainly be unjustifiable to continue the BIDYT in its present form.

One alternative would be to organize a truly international nursery based upon elite material from different countries, relying upon results of screening from the individual countries. Drawbacks to such an effort would include that adaptation would continue to limit the utility of the materials, and that phytosanitary problems would increase over those encountered in trying to supply seed for the BIDYT. To partially alleviate these problems, a smaller trial might be used, requiring fewer replicates, and excluding the alternative of irrigated controls. To suggest what results might occur with such an interchange, Tables 7 and 8 present drought yields of promising materials sent to CIAT from Brazil (CNPAF) and Mexico (INIFAP) for evaluation.

Another strategy would be to subdivide the nurseries by grain types and or expected adaptation. One also might continue the BIDYT with the same or similar entries, making it available to researchers who want an initial set of materials essentially for diagnostic purposes. Further needs of drought regions could be handled on the basis of specific requests from individual programs. Disadvantages of this approach would include that unless communication among regions is improved, different regions probably would not know what genotypes to request from other programs.

A utopian strategy would be to wait until more information on specific tolerance mechanisms is available, and then rely on distribution of specific parents or progenies from crosses including sources of desired traits. In a sense, such a strategy is already being investigated in a collaborative project between INIFAP and CIAT where outstanding lines from CIAT have been crossed with outstanding Mexican materials, and resulting progenies are being evaluated both in Mexico and Colombia. Perhaps similar trials should be developed at other sites.

Conclusion

With respect to the three points raised previously, these preliminary analyses of the BIDYT suggest the following:

1. Only V 8025, BAT 1289, and BAT 1298 stood out for possible drought tolerance in a wide range of environments.

2. Cluster analyses suggested that factors besides drought predominated in determining similarity of results.

3. Genotypes did tend to form logical clusters based on yield performance. However, given the apparent importance of local adaptation, these groupings probably reflected characteristics of general adaptation, not specific drought tolerance mechanisms.

While this first attempt at evaluation of promising genotypes has been instructive, the effect of local adaptation is so strong that it seems unadvisable to continue the BIDYT unless major modifications are made in its structure.

References

Williams, W.T. 1976. Pattern analysis in agricultural science. 331 pp. Elsevier Scientific Publishing Company; Amsterdam.

Table 1. Description of materials of the BIDYT.

No.	Identification	Seed color	100 seed weight	Growth habit	Pedigree or name	Origin
1	A 54	Cream	19	2	TTS x 77B-ICA 10303	CIAT
2	A 195	Cream	52	1	Red Kloud x ICA 10009	CIAT
3	A 59	Coffee	27	2	A 5 x G 2618	CIAT
4	A 97	Cream	23	2	Aeté 1/37 x (A 23 x G 4000)	CIAT
5	A 170	Cream	20	2	TTS x ICA 10303	CIAT
6	BAT 85	Cream	22	2	(51052 x ICA Bunsi) x (51052 x Cornell 49-242)	CIAT
7	BAT 125	Cream	23	2	(G 4495 x G 5481) x (Jamapa x G 5481)	CIAT
8	BAT 336	Cream	21	2	51052 x Cacahuate	CIAT
9	BAT 477	Cream	24	3	(51051 x ICA Bunsi) x (51052 x Cornell 49-242)	CIAT
10	BAT 1393	Cream	36	1	(G 14013 x (G 4494 x (G 76 x G 1540))	CIAT
11	BAT 798	Black	23	3	(G 4495 x Jamapa) x (G 4495 x G 5479)	CIAT
12	BAT 868	Coffee	25	2	51052 x Ecuador 299	CIAT
13	BAT 1289	Red	21	3	(Honduras 46 x Venezuela 54) x (Desarrural x Cornell 49-242)	CIAT
14	BAT 1298	Pink	21	3	Pompadour Checa x Turrialba 1	CIAT
15	EMP 105	Red	20	2	BAT 1155 x BAT 964	CIAT
16	G 4830	Black	19	2	Rio Tibagí	BRZL
17	G 4523	M. Red	40	1	ICA Línea 17	COLB
18	G 4454	Black	21	2	ICA Tui	COLB
19	G 4446	Coffee	28	3	Puebla 152	MEX
20	G 5059	Cream	23	2	H 6 Mulatinho	BRZL
21	G 5201	Black	18	2	Bxl 1074	MEX
22	G 17722	Pink	26	3	San Cristóbal'83	RDOM
23	V 8025	Black	21	4	Jamapa x Compuesto Chimaltenango 2	CIAT
24	Local Check 1					
25	Local Check 2					

Table 2. Trials reporting data in the BIDYT.

No.	Location	Institution	Drought Yield	Drought S.E.	Irrigated Yield	Irrigated S.E.
			kg ha^{-1}			
1	Chiclayo, Peru	INIA	330	270	350	220
3	Chincha, Peru	INIA	630	134	1420	270
5	Palmira, Colo	CIAT	1640	260	2660	350
7	Quilichao, Colo	CIAT	1400	260	-	-
9	Popayan, Colo	CIAT	520	260	-	-
11	F. Madero, Mex	INIFAP	90	20	-	-
16	Davis, Calif	CIAT	600	-	-	-
21	Goiania, Brazil	CNPAF	850	-	1900	-
23	Chincha, Peru	INIA	280	70	670	190
25	Chillan, Chile	U.C.	1300	80	2470	290
26	Palmiar, Colo	CIAT	1080	200	2550	280
28	Palmira, Colo	CIAT	730	180	2630	220
29	Palmira, Colo	CIAT	1590	220	2080	80
30	Quilichao, Colo	CIAT	820	110	-	-
39	Popayan, Colo	CIAT	-	-	2020	-
41	F. Madero, Mex	INIFAP	588	130		
43	Aguascalientes, Mex	INIFAP	-	-	-	-
45	Chiclayo, Peru	INIA	800	210	1330	290
49	Jutiapa, Guat	ICTA	620	120	1120	150
51	Palmira, Colo	CIAT	600	140	1340	200
53	Quilichao, Colo	CIAT	-	-	2210	200
54	Popayan, Colo	CIAT	-	-	2720	240
55	Riverside, Calif	UCD	80	50	-	-
56	Palmira, Colo	CIAT	1230	250	-	-
58	Zamorano, Hond	EAP	350	110	2560	340
62	Chiclayo, Peru	INIA	370	100		
63	Chiclayo, Peru	CIAT	840	230	1300	250

Table 3. Performance of entries of the BIDYT evaluated as mean yield across sites, yield standardized to eliminate effect of site mean yield, and mean of ranks in individual trials, D = drought, I = irrigated, and 0 = overall mean.

Genotype	Mean Yield			Mean of standarized yield			Mean of yield ranks		
	D	I	0	D	I	0	D	I	0
	------kg ha^{-1}------								
A 54	651	1615	1004	0.12	-0.39	-0.07	12	24	19
A 195	713	1697	1091	0.07	-0.08	0.01	18	17	18
A 59	576	1722	996	-0.55	0.02	-0.34	22	20	23
A 97	637	1685	1021	-0.11	-0.22	-0.15	14	16	17
A 170	633	1867	1086	-0.15	0.41	0.05	16	2	10
BAT 85	702	1598	1031	0.19	-0.45	-0.05	8	11	7
BAT 125	604	1670	995	-0.69	0.00	-0.43	20	18	20
BAT 336	672	1614	1021	0.11	-0.54	-0.13	13	14	13
BAT 477	747	1720	1103	0.55	-0.04	0.33	6	6	4
BAT 1393	685	1654	1040	0.18	-0.28	0.02	10	21	15
BAT 798	593	1705	990	-0.15	0.46	0.07	19	7	16
BAT 868	478	1607	912	-1.02	-0.30	-0.75	24	12	22
BAT 1289	751	1665	1086	0.13	-0.29	-0.03	3	22	8
BAT 1298	723	1801	1118	0.38	0.28	0.34	4	13	6
EMP 105	551	1674	963	-0.82	-0.22	-0.60	25	23	24
G 4830	705	1667	1058	0.06	-0.30	-0.07	9	15	11
G 4523	562	1504	907	-1.15	-0.97	-1.08	23	25	25
G 4454	625	1659	1004	-0.45	-0.25	-0.38	21	19	21
G 4446	628	1839	1072	0.09	0.33	0.18	15	8	14
G 5059	631	1833	1072	-0.36	0.32	-0.11	17	3	12
G 5201	687	1758	1080	-0.08	0.05	-0.03	11	10	9
G 17722	747	1844	1153	0.34	0.49	0.40	7	4	5
V 8025	808	2099	1281	0.77	1.42	1.01	1	1	1
CHECK-1	854	1743	1183	2.29	0.19	1.51	2	9	2
CHECK-2	751	1853	1175	0.44	0.43	0.44	5	5	3

Table 4. Yield ranks of individual genotypes of the BIDYT, including local checks. Trials are arranged according to cluster analysis of Figure 1B. D = drought trail; I = irrigated.

	Trial														
	Chin	Chil	Quil	Quil	Davi	Zamo	Chic	CNP2	CNP3	CNP1	Popa	Chil	Rive	Zamo	Chic
Genotype	I	D	D	D	D	I	I	D	I	D	D	I	D	D	D
A 54	24	12	4	16	15	13	10	19	19	23	19	21	7	5	8
A 195	4	1	19	13	11	2	18	13	12	13	4	6	13	3	20
A 59	16	20	25	21	25	23	13	15	16	20	17	17	14	20	16
A 97	8	5	10	1	6	7	19	22	21	5	16	5	10	7	12
A 170	14	17	15	9	3	3	2	21	24	18	25	10	12	8	24
BAT 85	9	6	12	11	7	8	25	20	18	24	11	9	19	15	4
BAT 125	1	8	13	4	24	18	15	17	23	6	18	15	15	18	25
BAT 336	23	23	8	7	17	11	6	9	10	11	13	7	9	9	10
BAT 477	5	16	16	10	10	6	3	6	5	15	3	25	24	17	1
BAT 1393	20	2	7	12	4	12	1	5	14	7	7	2	3	2	18
BAT 798	2	10	21	2	13	16	17	23	25	16	24	23	21	14	9
BAT 868	11	18	11	25	23	5	14	8	7	22	15	13	25	23	21
BAT 1289	19	22	3	8	9	22	12	14	20	8	5	24	5	11	15
BAT 1298	15	15	17	17	20	25	7	1	2	1	12	4	6	13	7
EMP 105	18	21	24	20	21	20	20	24	22	25	21	19	22	19	6
G 4830	10	13	2	5	8	4	8	3	15	19	9	20	20	6	11
G 4523	25	25	20	19	19	19	22	25	17	17	2	18	8	12	23
G 4454	3	19	23	22	14	14	16	18	13	4	10	11	18	10	22
G 4446	17	24	18	18	22	15	23	16	6	3	20	12	23	24	14
G 5059	6	3	1	6	18	1	5	2	3	2	23	14	17	21	19
G 5201	13	4	9	3	2	17	9	7	4	14	6	16	16	25	13
G 17722	21	11	22	15	16	21	4	11	11	12	22	3	11	1	3
V 8025	7	14	6	14	12	10	24	4	1	21	1	1	4	16	17
CHECK-1	12	9	5	24	1	24	11	10	8	10	8	22	1	22	2
CHECK-2	22	7	14	23	5	9	21	12	9	9	14	8	2	4	5

(Cont.)

Table 4. Cont.

	Palm D	Palm I	Palm I	Palm D	Chic D	Chic I	Made D	Made D	Juti D	Juti I	Chic D	Chin D	Chin D	Chin I	Popa I
A 54	22	24	16	23	1	11	9	5	17	16	21	3	8	12	18
A 195	16	20	24	25	21	23	16	6	15	20	24	18	11	10	13
A 59	12	17	22	15	8	4	15	23	24	23	19	8	1	2	7
A 97	24	11	20	22	12	25	11	21	14	6	12	25	18	19	11
A 170	2	1	1	9	13	17	14	15	22	19	22	7	4	9	12
BAT 85	4	6	6	10	11	10	8	7	3	2	4	20	17	18	25
BAT 125	20	22	25	13	14	21	25	24	10	4	9	9	5	4	10
BAT 336	5	7	8	3	6	7	3	22	25	22	17	19	23	23	23
BAT 477	6	4	4	8	4	20	4	12	7	1	6	17	24	22	24
BAT 1393	18	25	19	19	19	24	21	19	23	24	25	12	6	3	17
BAT 798	13	14	10	14	16	6	23	17	16	8	15	2	2	1	5
BAT 868	23	10	7	16	22	8	10	4	19	14	10	21	25	25	22
BAT 1289	3	9	11	4	9	18	17	16	8	7	3	10	22	20	4
BAT 1298	11	12	18	5	7	15	7	8	21	17	14	4	10	7	15
EMP 105	15	15	21	21	18	14	20	20	20	21	16	5	7	8	2
G 4830	9	18	9	18	15	13	13	10	2	13	20	23	19	17	20
G 4523	19	21	23	24	23	22	24	13	13	25	23	15	14	14	16
G 4454	10	23	17	6	3	12	18	18	18	15	18	16	15	15	19
G 4446	7	3	3	20	10	19	2	1	4	11	7	13	13	13	8
G 5059	25	19	14	12	20	1	12	11	11	9	13	24	21	24	21
G 5201	21	16	15	7	17	9	19	14	6	10	11	22	16	16	9
G 17722	1	5	12	2	5	3	22	25	9	18	5	6	9	6	14
V 8025	8	13	2	17	2	5	6	3	1	3	8	1	12	5	1
CHECK-1	17	8	5	11	24	16	1	2	5	12	1	11	3	11	3
CHECK-2	14	2	13	1	25	2	5	9	12	5	2	14	20	21	6

Table 5. Comparison of photoperiod response of flowering and yield of lines of BIDAN at Davis, California and Chincha, Peru.

Photoperiod Response	No. of lines yielding		
	< 100 kg/ha	100-400	> 400 kg/ha
Davis			
Sensitive	8	4	0
Intermediate	13	10	1
Day neutral	1	13	17
		$Chi^2 = 40$ $p < .001$	
Chincha			
Sensitive	1	7	7
Intermediate	3	14	7
Day neutral	14	13	5
		$Chi^2 = 13$ $p < .025$	

Table 6. Correlations between yield and days to maturity for selected BIDYT experiments (some trials include additional bean genotypes).

		Correlation with yield			
		Drought		Irrigation	
No.	Site	Flowering	Maturity	Flowering	Maturity
5	Palmira	-0.21	-0.39**	0.12	0.23*
23	Chincha, Peru	0.55**	-0.34	0.42*	-0.30
26	Palmira, Colo	-0.04	-0.18	0.14	-0.01
30	Quilichao, Colo	0.22	-0.16	-	-
41	F. Madero, Mex	-0.07	0.53**	-	-
45	Chiclayo, Peru	0.38	-0.26	-0.29	-0.51**
49	Jutiapa, Guat	0.20	-	0.22	-
51	Palmira, Colo	0.17	0.30**	0.15	0.18
53	Quilichao, Colo	-	-	0.40**	0.08
55	Popayan, Colo	-	-	0.03	0.06
55	Riverside, CA	-0.27	-	-	-
56	Palmira, Colo	0.28	0.19	-	-
58	Zamorano, Hond	-0.38	-0.28	0.27	0.37
62	Chiclayo, Peru	-0.02	-0.12	-	-
63	Chiclayo, Peru	0.11	0.35	0.29	0.07

*, ** Significant at the p = 0.05 and p = 0.01 levels, respectively.

Table 7. Yields of selected genotypes from stage I drought screening at CIAT Palmira and Quilichao (1986A), including 14 genotypes sent for screening from CNPAF, Brazil.

Identification	Origin	Drought/Yield Palmira	Drought/Yield Quilichao
		kg ha^{-1}	
BAT 477	CIAT	980	380
FEB 4	CIAT	960	280
Pirata	Brazil	950	360
DOR 350	CIAT	860	250
RAO 30	CIAT	810	140
RAB 175	CIAT	760	250
CNF-128	Brazil	700	290
S. Cristobal 83	D. Republic	640	390
BAT 1289	CIAT	510	180
A 170	CIAT	470	260
CNF-115	Brazil	430	310
8030-1-1	Brazil	420	190
CNF-143	Brazil	380	200
BAT 1224[1]	CIAT	340	180
IPA-7419	Brazil	330	160
Bico de Ouro	Brazil	280	500
CNF-151	Brazil	270	70
Jamapa	Brazil	103	160
CNF-154	Brazil	0	160
CNF-156	Brazil	0	110
CNF-155	Brazil	0	180
Sacquven	Brazil	0	270
Turrialba 2N	Brazil	0	70
Mean		440	240
S.E.		230	NA[2]

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[1] Considered susceptible check at CIAT.

[2] NA = Not available. Unreplicated nursery.

Table 8. Yields of selected genotypes from stage I drought screening of 56 genotypes at CIAT Palmira (1986B) including 20 genotypes from INIFAP, Mexico. The genotypes from INIFAP included 8 materials also considered drought tolerant at CIAT, and thus, are identified with both sources.

Identification	Source[1]	Drought yield
		kg ha^{-1}
G 6333	CIAT	1970
G 6221	CIAT	1920
G 17722	CIAT	1770
G 5428	CIAT	1710
G 5430	CIAT	1570
A 170	INIFAP, CIAT	1510
BAT 477	INIFAP, CIAT	1500
Negro Argel	INIFAP, CIAT	1480
N 81017	INIFAP, MSU	1470
V 8025	INIFAP, CIAT	1450
BAT 1393	INIFAP, CIAT	1080
A 59	INIFAP, CIAT	1010
A 161 X various	INIFAP	930
DGO 5	INIFAP	820
A 424	INIFAP, CIAT	750
A 195	INIFAP, CIAT	690
Negro Queretaro-S	INIFAP	680
Bayo Durango	INIFAP	640
DGO 222	INIFAP	600
Tlaxcala 475	INIFAP	520
CHID 7	INIFAP	360
Pinto Nacional 1	INIFAP	200
MICH 89	INIFAP	110
CHIS 86	INIFAP	0
Mean		850
S.E.		310

Figures

Fig. 1 Classification of 30 BIDYT experiments based on absolute yields and ranks of yields. "D" and "I" indicate drought and irrigated plots respectively. Yields of local checks and BAT 868 were excluded.

Fig.2 Classification of genotypes of the BIDYT based on absolute yields and ranks of yields for 30 trials, and on absolute yields under drought (19 trials). Yields of local checks and BAT 868 were excluded.

Figure 1. Classification of 30 BIDYT experiments based on absolute yields and ranks of yields. "D" and "I" indicate drought and irrigated plots respectively. Yields of local checks and BAT 868 were excluded.

A) Absolute yields

```
Chincha   I   1  .....
Madero    D  16  ..   )
Chiclayo  D  24  ..)..)
Zamorano  D  27  .....)
Chincha   D   2  ..   )
Chincha   D   9  ..)..)
Davis     D  11  .....)
CNPAF1    D  19  ..   )
Riverside D  29  ..)..).....
Popayan   D   8  ...........)
Chiclayo  D   3  .....      )
Jutiapa   D  22  .....)     )
Madero    D  30  .....)     )
Quilichao D  14  .....)     )
Chiclayo  D  25  .....)..   )
CNPAF2    D  20  ........)..)
Chincha   I  10  ...........)............
Chiclayo  I   4  .....                   )
Chillan   D  17  .....)                  )
Quilichao D   7  .....)..                )
Palmira   D  12  .....   )               )
Chiclayo  I  26  .....)..)               )
Jutiapa   I  23  ........).....          )
Palmira   D   5  ...........   )         )
CNPAF3    I  21  ...........)  )         )
Popayan   I  15  ...........)..).........)........
Palmira   I   6  .....                            )
Palmira   I  13  .....)..                         )
Chillan   I  18  ........)                        )
Zamorano  I  28  ........)........................)....
```

B) Ranks of yield

```
Chincha   I   1  ...........
Chillan   D  17  ...........)..
Quilichao D   7  ...........   )
Quilichao D  14  ...........)..)
Davis     D  11  ...........   )
Zamorano  I  28  ...........)..)..
Chiclayo  I   4  ..............   )
CNPAF2    D  20  ........      )  )
CNPAF3    I  21  ........).....)  )
CNPAF1    D  19  ..............)..)
Popayan   D   8  .................)
Chillan   I  18  ...........      )
Riverside D  29  ...........)..   )
Zamorano  D  27  ..............)..)
Chiclayo  D   3  ..............   )
Palmira   D   5  ........      )  )
Palmira   I   6  ........)..   )  )
Palmira   I  13  ...........)..)  )
Palmira   D  12  ...........   )  )
Chiclayo  D  24  ...........)..)  )
Chiclayo  I  26  ..............)..)
Madero    D  16  ...........      )
Madero    D  30  ...........).....)
Jutiapa   D  22  ...........      )
Jutiapa   I  23  ........   )     )
Chiclayo  D  25  ........)..).....)..
Chincha   D   2  ........            )
Chincha   D   9  ..      )           )
Chincha   I  10  ..).....)..         )
Popayan   I  15  ...........)........).....
```

Figure 2. Classification of genotypes of the BIDYT based on absolute yields and ranks of yields for 30 trials, and on absolute yields under drought (19 trials). Yields of local checks and BAT 868 were excluded.

```
           Absolute yield                  Ranks of yield          Absolute yield -  drought

A 170     ........          A 170     ...........       A 170     ..
A 54      .....   )         BAT 1298  ........   )      BAT 798   ..)
A 59      ..   )  )         G 17722   ........)..)..    BAT 125   ..)..
EMP 105   ..)..)  )         A 195     .....         )   A 59      ..   )
BAT 125   ..   )  )         BAT 1393  .....)..      )   EMP 105   ..)..)..
BAT 798   ..)..)..)         G 4523    ........)..   )   G 17722   ........)..
BAT 1298  ..      )         G 4454    ...........)  )   A 54      .....      )
G 17722   ..).....)..       A 54      ...........)..)   V 8025    .....)..   )
A 195     .....      )      A 59      ..            )   A 97      ..      )  )
BAT 1393  .....)..   )      BAT 868   ..).....      )   G 4523    ..)     )  )
G 4523    ........)..)      BAT 125   ........)     )   G 5201    ..)..   )  )
A 97      .....      )      BAT 798   ........).....)   BAT 1289  ..   )  )  )
BAT 1289  ..   )     )      A 97      ...........   )   BAT 477   ..)  )  )  )
G 4523    ..)  )     )      G 4830    .....      )  )   BAT 85    ..)..)..)  )
G 5201    ..)..)     )      G 5201    .....)..   )  )   BAT 1298  ..      )  )
BAT 477   ..   )     )      G 5059    ........)..)  )   G 4454    ..)..   )  )
BAT 85    ..)..)     )      BAT 1289  ........   )  )   BAT 336   .....)..)..)
BAT 336   .....)     )      BAT 336   ........)..)  )   A 195     .....      )
G 4454    .....)..   )      BAT 477   .....      )  )   G 4523    .....)..   )
G 5059    ........)..)      BAT 85    .....).....)..)   BAT 1393  ........)..)
G 4446    ...........)      G 4446    ...........   )   G 5059    ...........)
V 8025    ...........)....  V 8025    ...........)..).  G 4446    ...........)....
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STUDIES AT CIAT ON MECHANISMS OF DROUGHT TOLERANCE IN BEANS

J.W. White and J.A. Castillo*

Introduction

Investigation at CIAT on drought tolerance in beans (Phaseolus vulgaris L.) has focused on three classes of mechanisms, in all cases defining drought tolerance as the ability to yield well under drought stress. Drought escape would be indicated through positive associations between yield and earliness or acceleration of maturity. Genotypes which yield well due to reduced water loss or increased water uptake show drought avoidance. And "true" drought tolerance or desiccation tolerance would be indicated by cultivars displaying an ability to yield better than other genotypes eventhough they reach an equal or greater level of water loss.

Drought Escape

Two mechanisms of drought escape have been considered at CIAT. The conventional one is simply that a genotype grows when soil moisture is still adequate, and matures before stress becomes severe. The second alternative is that although a genotype shows normal maturity under irrigated conditions, its maturity date shows plasticity such that drought causes greater acceleration of maturity than occurs in other genotypes.

Evidence for drought escape through earliness was easily found in drought nurseries. Comparing drought yield with days to maturity, yield frequently showed a negative correlation with maturity (Table 1).

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Occasional positive correlations were consistent with the expectation that differences in temporal patterns of water stress would affect the importance of earliness. A severe late season stress would favour early maturing lines, while rains after flowering would benefit late materials.

A particularly interesting case concerning drought escape was found in a trial including three genotypes of P. *acutifolius*, a cultivated species frequently cited as drought tolerant. As shown in Figure 1, it appeared that a large component of their very superior yields was attributable to earliness.

An aspect of drought avoidance which preliminary work has suggested may also be of importance at CIAT is that some cultivars may accelerate pod filling and maturation when subjected to stress. Thus in one trial where drought yields were compared to the reduction in time to maturity under drought vs. irrigated conditions, highest yields were associated with genotypes showing the greatest reduction in maturation time (Fig. 2).

Drought avoidance

The possibility that some bean genotypes are able to avoid water stress either by conserving water or extracting a greater amount of soil water has also been investigated. In evaluations of drought nurseries started in the mid-1970's, a strong relation was detected between reduced canopy temperature, as measured by infrared thermometry, and drought yield (Laing et al., 1984). Lower canopy temperature was presumed due to greater evaporative cooling, in turn reflecting greater transpiration, and greater extraction of soil moisture. Thus, emphasis was placed on evaluating differences in root growth under drought.

To study root growth, core samples of genotypes previously characterized as drought tolerant or drought sensitive (Table 2) were analysed using the method of Newman (1966) and Marsh (1971). Root growth of tolerant genotypes was found to extend to over 1.2 m deep under drought while drought sensitive materials did not reach over 0.8 m deep (Sponchiado, 1985; Fig. 3). As expected, these differences were also associated with marked differences in overall growth (Table 3).

These results were thought conclusive for drought avoidance in the relatively fertile soils of CIAT Palmira, but the question remained whether a similar response would exist in soils posing more severe limitations to root growth. Taking advantage of the very acid soil (pH = 5) at CIAT Quilichao, root growth of the same cultivars were evaluated under conditions where growth was expected to be limited to the approximately 0.3 m deep zone of incorporation of agricultural lime ($CaCO_3$). For all cultivars, no root growth was detected beyond a depth of 0.8 m (Fig. 4), and BAT 1224, a drought sensitive genotype, gave the same drought yields as the two presumed drought tolerant materials (Table 3).

Assuming that greater root growth will be a useful tolerance mechanism under certain drought conditions, and that genotypes might exist which do produce deeper roots in acid soils, root growth was evaluated for 10 genotypes at the two sites. Since the previous study had indicated that important cultivar differences occurred at lower soil depths, analyses were restricted to 0.4 m to 1.2 m deep at Palmira and 0.15 m to 0.6 m at Quilichao. At Palmira, large and significant differences in root length density were found (Table 4) and root growth was highly correlated with yield (Fig. 5). In contrast, no genotype differences in root growth were found at Quilichao, and the correlation between root length density and yield was nonsignificant. However, root growth of the genotypes was highly correlated between the two sites (Fig. 6).

These results demonstrated that greater root growth was associated with greater yields in soils permitting such growth, but the results did not differentiate between direct effects of the root genotype, or of some other plant characteristic which would indirectly permit increased root growth.

To determine the relative importance of root and shoot characteristics, roots and shoots of tolerant and sensitive cultivars were interchanged via grafting at the seedling stage, and plants were then grown under drought stress in the field. Results at both sites were consistent with the hypothesis that the root genotype is directly responsible for greater root growth (Table 5).

Two future needs are seen from the studies on root growth. One is to identify efficient ways to screen for differences in root growth associated with increased drought tolerance. The second is to develop an alternative strategy for soils not permitting extensive development of roots or which have low available soil moisture.

Moisture conservation. Genotypes able to conserve moisture through leaf movements, effects of leaf size or reflectivity on leaf temperature, or stomatal behaviour which conserved water without reducing photosynthesis also might show higher yields under stress.

Recent work using carbon isotope discrimination to evaluate water use efficiency indicated large genotypic differences in the latter parameter (White et al., 1988), and this may have reflected differences in leaf characteristics.

Attempts to quantify leaf movements in relation to solar movements were able to detect genotypic differences (Table 6), but no relation with yield was noted. Indeed, we suspect such a relation will be very difficult to detect. Most bean cultivars show marked ability for solar tracking, and subtle quantitative differences will undoubtedly be confounded by differences in levels of overall water stress.

Desiccation tolerance

In the first studies on root growth, leaf water potentials were monitored to determine whether there was any evidence that tolerant cultivars were better able to function at low water potentials. Unfortunately, at Palmira, the overwhelming effect of root growth made this comparison impossible. The results of the grafting experiments (Table 5) also suggest that the effect of root genotype is so strong that other differences in tolerance are difficult to detect.

Integration of mechanisms with other factors

From the above results, it seems that even such simple mechanisms as drought escape and drought avoidance through greater root growth are not panaceas which should be blindly incorporated in all germplasm for drought regions. Rather it seems that the correct suite of mechanisms will have to be developed for each site, and that such planning should account for season to season variation in stress, and if possible, effects of different cultural practices. A strictly empirical solution would consist of relying on repeated observations of different genotypes over time and in different environments. However, this approach will be very time consuming. As an alternative, research is also being conducted on the use of growth simulation models, such as BEANGRO (Hoogenboom, et al., 1988), to predict integrated effects of different mechanisms in the context of variable climatic conditions and agronomic practices. Similar work with a soybean simulation model has already shown that the relative importance of root growth, osmotic adjustment, and stomatal resistance should vary with soil texture (Jones and Zur, 1984).

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Table 1. Effectiveness of earliness as a source of drought tolerance, judged by correlations between yield and days to flower or maturity.

Trial	Site	Mean yield	No. of entries	Correl. with yield	
				Flower	Maturity
8427	Palmira	1650	72	-.21	-.39**
8450	Palmira	1320	144	-.20*	-.22*
8446	Palmira	1080	72	-.04	-.18
8447	Quilichao	820	72	.22	-.17
8520	Palmira	600	72	.17	.30**
8521	Quilichao	2200	72	.40**	.08
8535	Palmira	2160	240	.14	-.24*
8536	Quilichao	2440	240	.21*	.29**
8618	Palmira	440	156	-.38**	-.51**
8619	Quilichao	240	156	-.38**	-.53**
8620	Palmira	510	72	-.03	-.11
8621	Quilichao	320	72	-.42**	-.34**

*, ** Significant at the p = 0.05 and p = 0.01 levels, respectively.

Table 2. Yields of bean lines BAT 85, BAT 477, BAT 1224 and A 70 in various drought trials including irrigated controls at Palmira, Colombia, and results of ANOVA over all trials.

Trial	No. of entries	Water regime	Line				Mean of all entries
			BAT 85	BAT 477	BAT 1224	A 70	
			-----------	-----------	$kg\ ha^{-1}$	-----------	-----------
1982B	72	D+	710	590	40	50	260
		I	2090	2010	1970	2090	1710
1983A	72	D	250	60	NP+	10	46
		I	1930	1950	NP	1530	1490
1984A	72	D	1960	1870	NP	1670	1640
		I	2920	3200	NP	3360	2660
1984A	6	D	1020	970	420	650	735
		I	2520	2660	2640	2760	2560
1984B	72	D	1210	1260	NP	1160	1080
		I	2870	2930	NP	2490	2550
1986A	10	D	NP	980	130	240	520
		I	NP	1940	2230	2450	2070
Mean		D	810	770	190	450	
		I	2230	2280	2270	2320	
Standard error of differences of means							
Regime			57**				
Line			67**				
Regime x line			103**				

\+ D = drought treatments; I = Irrigated control.

++ NP = variety not present in trial.

** Significant at the p = 0.01 level.

Table 3. Basic crop growth parameters of drought tolerant lines BAT 85 and BAT 477 and susceptible lines BAT 1224 and A 70 at Palmira and Quilichao.

Line	Seed yield	Harvest index	Crop growth rate		Leaf area duration
			40 days	50 days	
	kg ha^{-1}	%	----g m^{-2} day^{-1}----		day
		Palmira, drought			
BAT 85	1460a+	55a	8.6a	6.0a	92a
BAT 477	1460a	58a	9.2a	6.4a	83ab
BAT 1224	550 b	28 b	6.5 b	4.3 b	74 b
A 70	570 b	29 b	4.9 b	2.9 c	80ab
		Palmira, irrigated			
BAT 85	2520a	48a	15.5a	13.6a	170 b
BAT 477	2540ab	84a	17.0a	14.4a	161 b
BAT 1224	2340a	41a	13.8a	13.2a	186a
A 70	2770 b	51a	14.5a	13.6a	170 b
		Quilichao, drought			
BAT 85	590a	21a			86a
BAT 477	720a	24a			81a
BAT 1224	720a	35a			69ab
A 70	190 b	10 b			49 b
		Quilichao, irrigated			
BAT 85	2900a	54a			133a
BAT 477	2950a	53a			121a
BAT 1224	2660 b	53a			134a
A 70	2124 c	58a			91 b

+ Means followed by different letters within treatments are statistically different ($p = 0.05$) based on Duncan's multiple range test.

Table 4. Root length density and seed yields under drought of 10 genotypes grown at CIAT Palmira and Quilichao. Root length densities are means soil layers 0.4 to 1.2 m deep at Palmira, and 0.15 to 0.6 m deep at Quilichao.

Genotype	Palmira		Quilichao	
	Root length dens.	Yield	Root length dens.	Yield
	m^{-2}	kg ha^{-1}	m^{-2}	kg ha^{-1}
BAT 477	3000	980	4110	342
A 170	2230	790	3640	156
San Cristobal 83	2180	760	4680	211
V 8025	1890	620	3700	341
BAT 1289	700	580	2700	339
G 5059	1340	560	3460	281
Carioca	1440	320	2890	355
A 70	650	240	2120	105
Porrillo Sintetico	620	230	3370	138
BAT 1224	1080	130	2470	184
Mean	1510	520	3310	245
S.E.	510	130	970	53

Table 5. Seed yields (kg/ha) of reciprocally grafted plants under field drought conditions at CIAT-Palmira in two semesters, and CIAT-Quilichao in one semester.

Palmira, Semester A:	Shoots of:	Grafted		Control	
		BAT 85	BAT 1224	BAT 85	BAT 1224
Roots of:	BAT 85	1344	1390	1457	-
	BAT 1224	639	461	-	765

Significance of effect of:	F	Probability
Root	7.018	0.01
Shoot	0.031	NS
Graft	0.751	NS

Palmira, Semester B:	Shoots of:	Grafted		Control	
		BAT 477	BAT 1224	BAT 477	BAT 1224
Roots of:	BAT 477	596	839	703	-
	BAT 1224	164	30	-	39

Significance of effect of:	F	Probability
Root	18.592	0.01
Shoot	0.090	NS
Graft	0.108	NS

Quilichao:	Shoots of:	Grafted		Control	
		BAT 477	BAT 1224	BAT 477	BAT 1224
Roots of:	BAT 477	500	1000	650	-
	BAT 1224	810	610	-	1120

Significance of effect of:	F	Probability
Root	7.15	0.05
Shoot	56.13	0.01
Graft	7.42	0.05

Table 6. Comparison of leaf orientation and yields for six lines grown at CIAT-Palmira. Data for orientation are means of angle of incidence of sunlight (o° = rays parallel to leaf surface), measured over 12 hours 58 days after planting.

Line	Angle of orientation		Yield (kg/ha)	
	Drought	Control	Drought	Control
BAT 85	29	38	1020	1520
BAT 477	33	36	970	2660
G 5059	30	39	680	2110
G 4830	34	41	680	2670
A 70	33	41	650	2760
BAT 1224	31	36	420	2640
Mean	32	39	740	2560
S.E.	2.1		126	

Figures

Fig. 1. Relation between yield and days to maturity under drought stress for 156 genotypes, including three genotypes of *P. acutifolius* at CIAT Palmira.

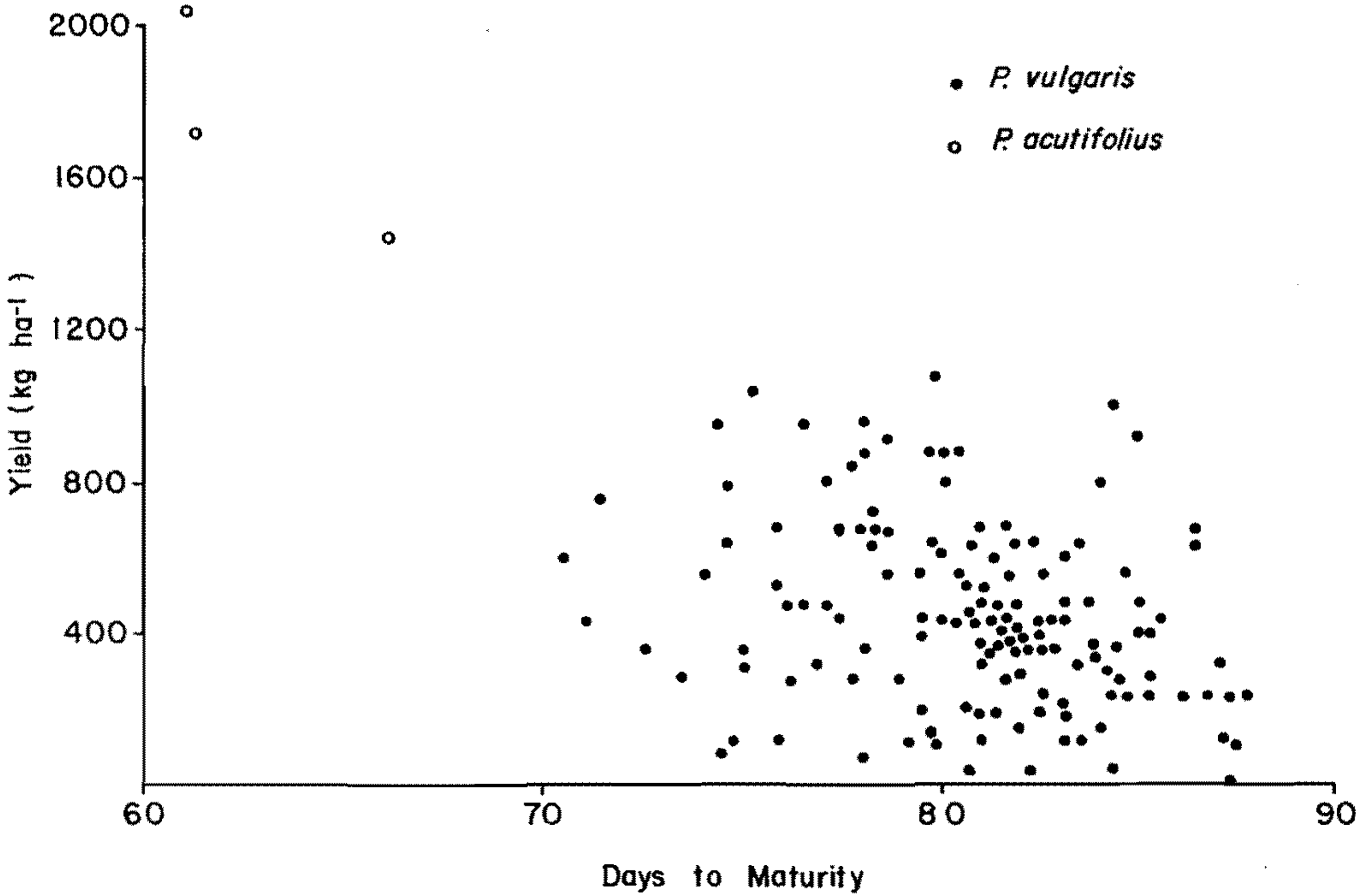
Fig. 2. Relation between yield under drought stress and the reduction in time to maturity under drought vs. irrigated conditions for 72 bean genotypes. CIAT, Palmira, 1985.

Fig. 3. Distribution of roots within the soil profile for four bean lines grown under drought and irrigated regimes at Palmira. Root samples were taken at 56 days after planting.

Fig. 4. Distribution of roots within the soil profile for four bean lines grown under two drought and irrigated regimes at Quilichao. Root samples were taken at 56 days after planting.

Fig. 5. Comparison of root length density and seed yield of 10 genotypes grown under drought stress at CIAT Palmira.

Fig. 6. Comparison of root length density of 10 genotypes grown under drought stress at CIAT Palmira and CIAT Quilichao.



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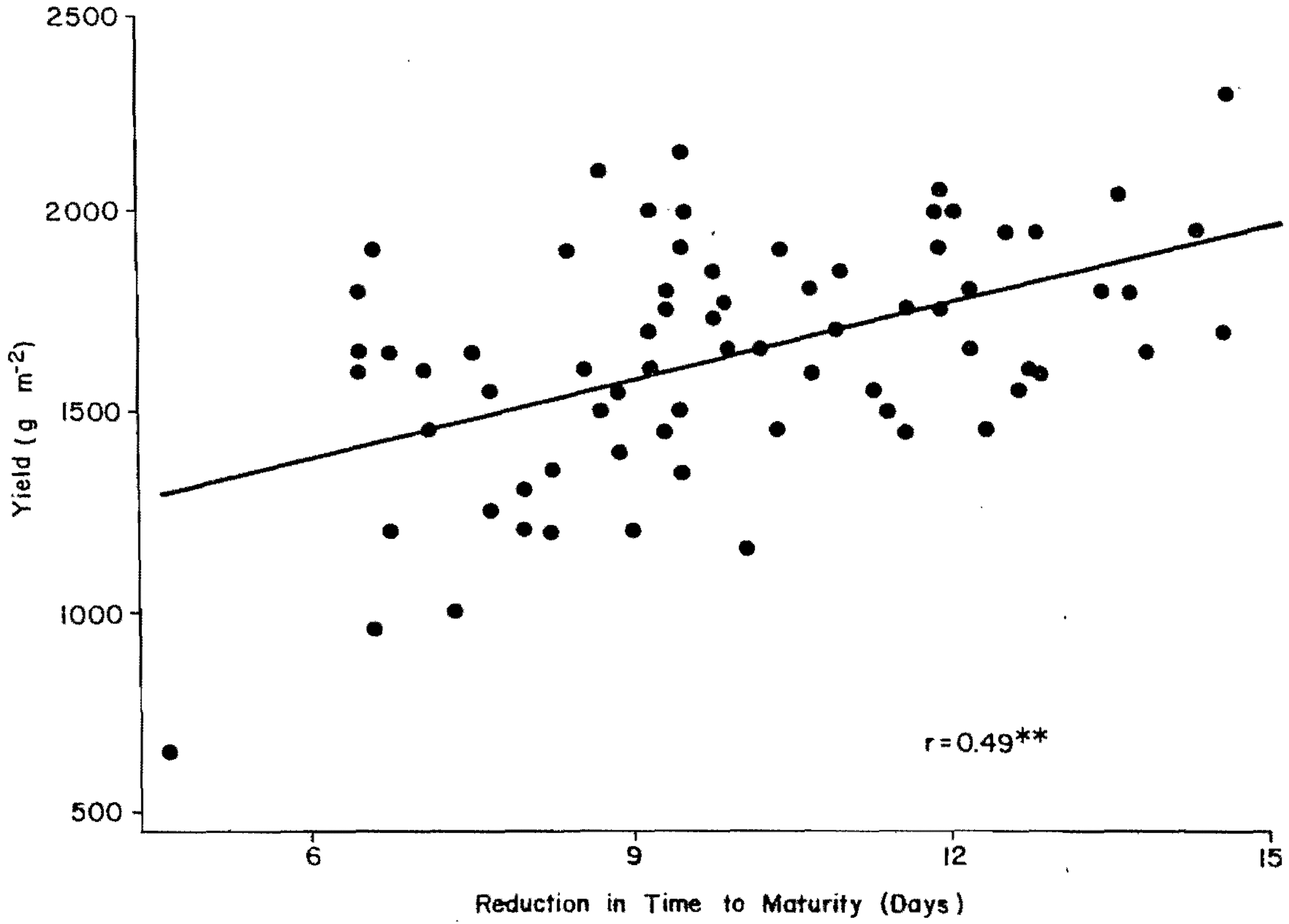

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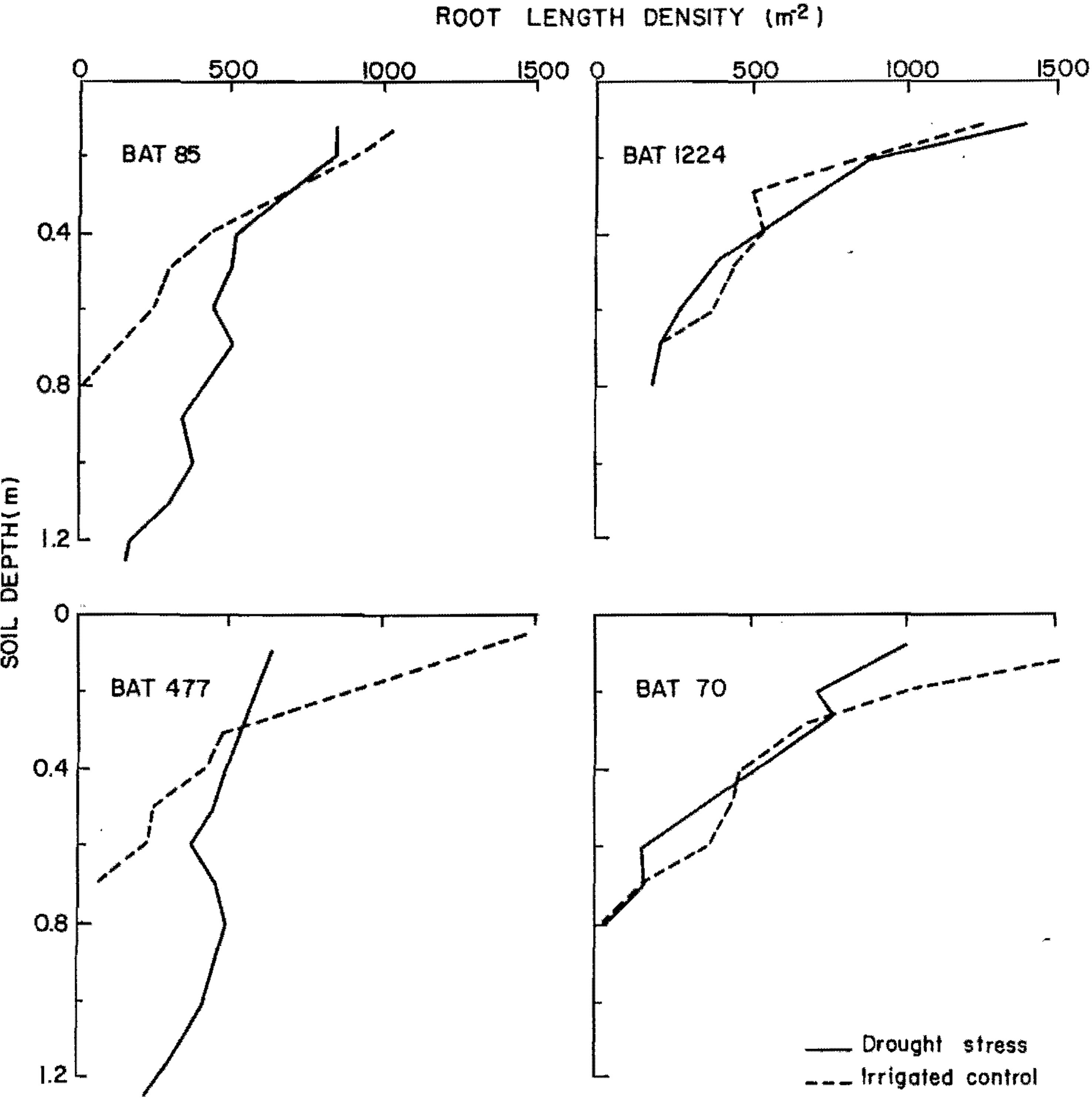


Figure 3. Distribution of roots within the soil profile for four bean lines grown under drought and irrigated regimes at Palmira. Root samples were taken at 56 days after planting.

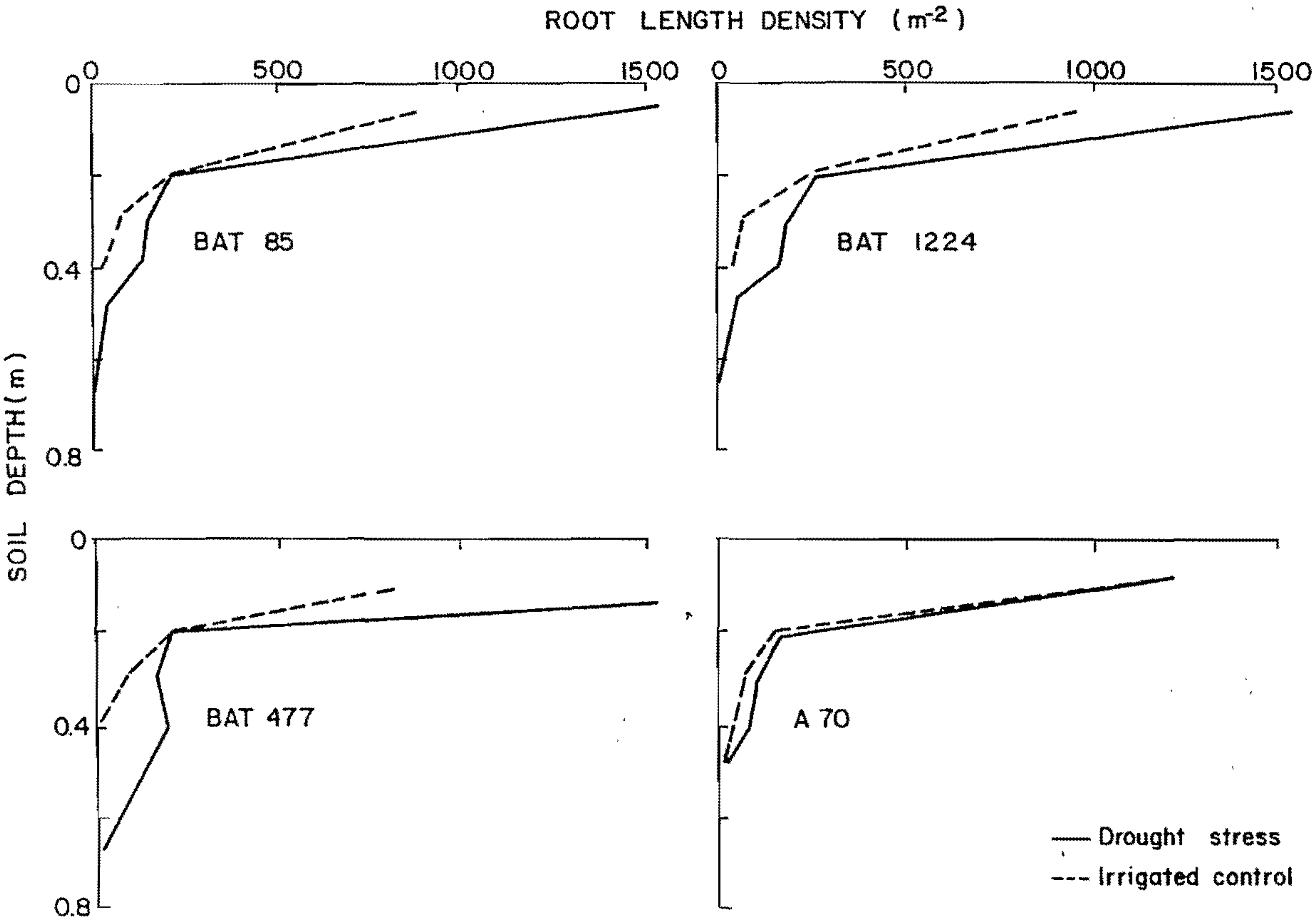
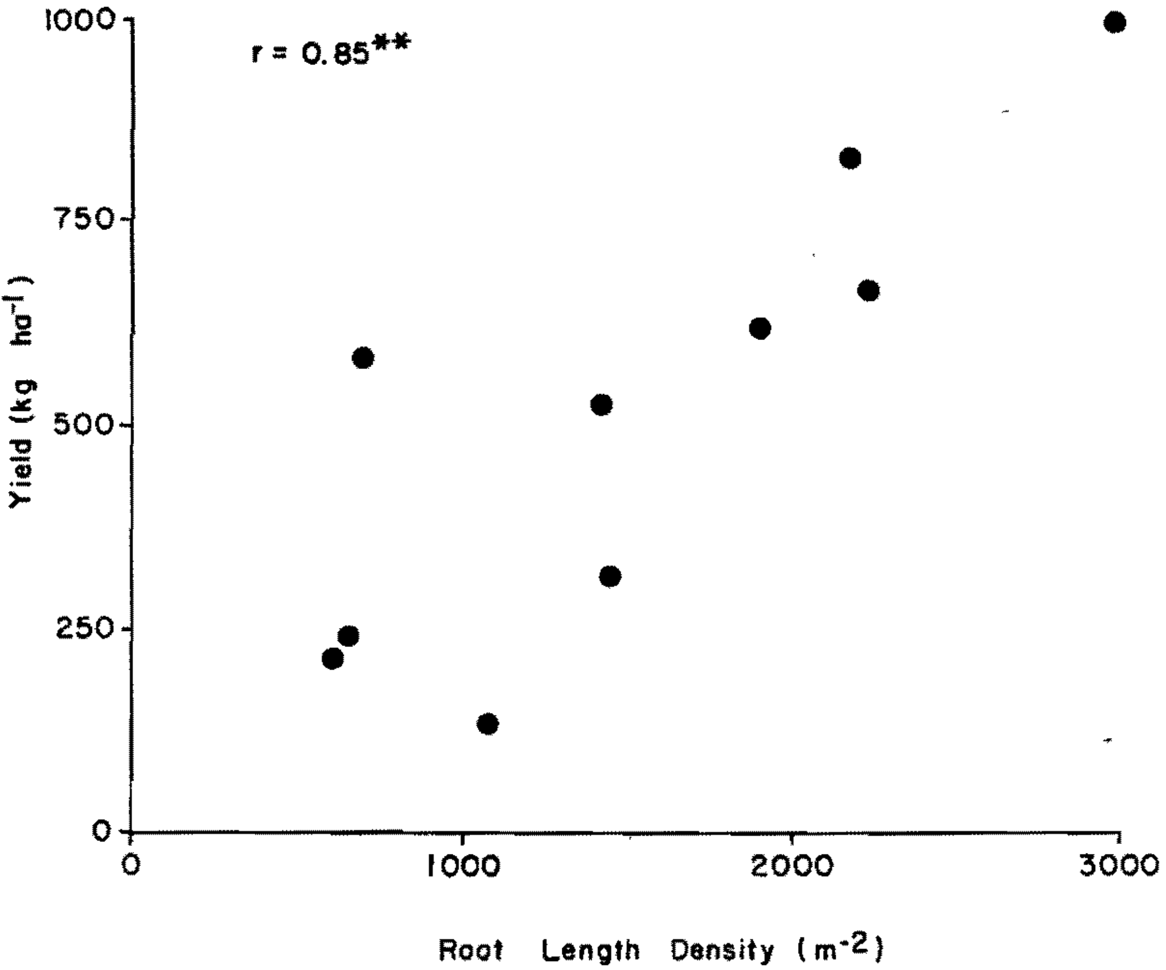


Figure 4. Distribution of roots within the soil profile for four bean lines grown under two drought and irrigated regimes at Quilichao. Root samples were taken at 56 days after planting.



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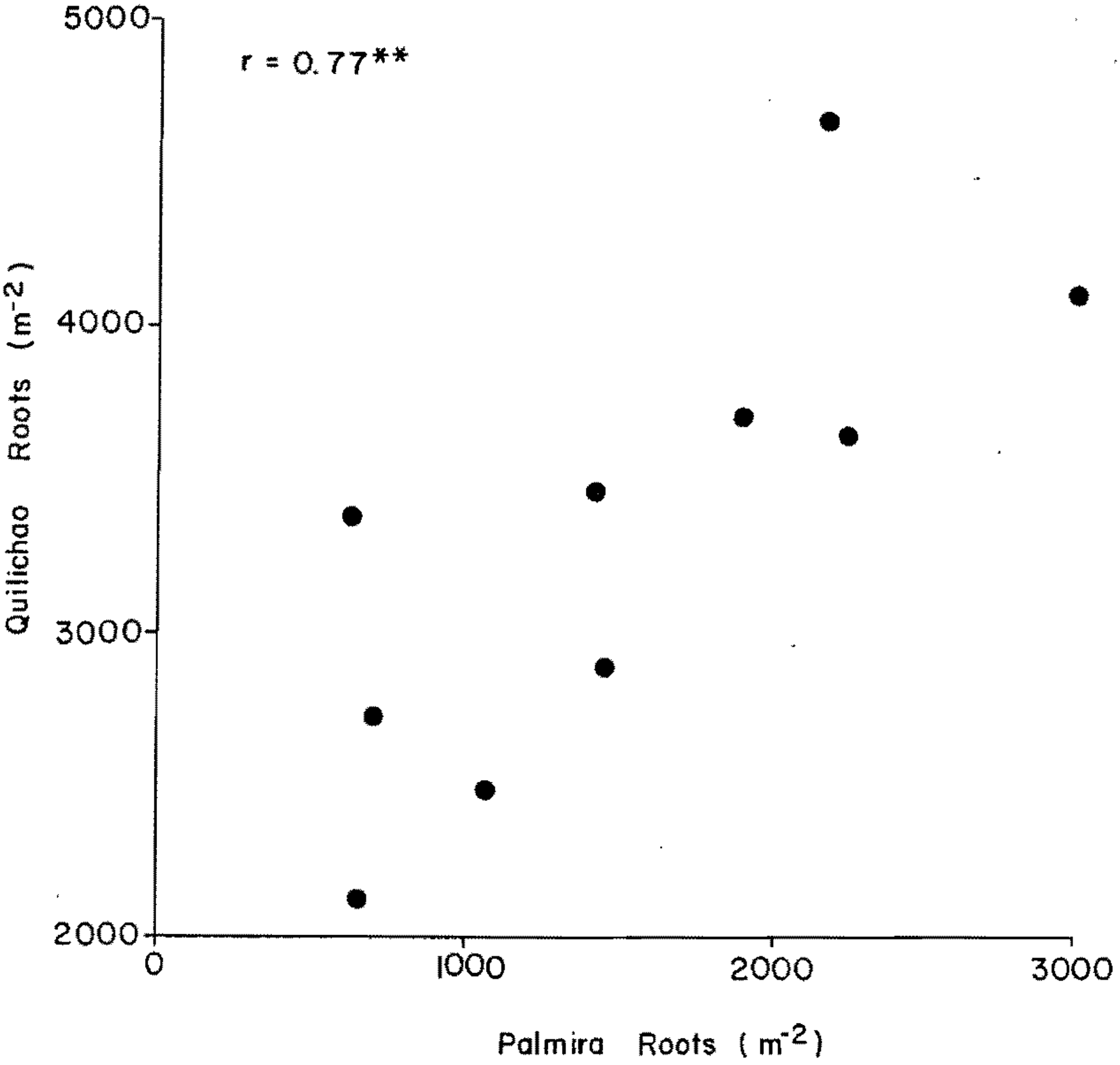

Figure 6. Comparison of root length density of 10 genotypes grown under drought stress at CIAT Palmira and CIAT Quilichao.

CORRELATIONS BETWEEN CARBON ISOTOPE RATIO, WATER-USE EFFICIENCY AND YIELD

J.R. Ehleringer*

Abstract

Recent theoretical studies have indicated that isotopic discrimination against $^{13}CO_2$ during photosynthesis in C_3 reflects water-use efficiency. Empirical data for a number of crop and native species support theoretical predictions and indicate that there is substantial variation in water-use efficiency both within and between species. These relationship between carbon isotope ratio and water-use efficiency are observed in both short-term gas exchange observations as well as long-term seasonal crop observations. Carbon isotope ratio and genotype ranking patterns persist between years and when plants are grown in different habitats. More recent studies also indicate that there can be a significant correlation between primary productivity (yield) and carbon isotope ratio. To test whether carbon isotope ratios could be extended to screening in common beans (Phaseolus vulgaris L.), leaf carbon isotope ratios and crop growth parameters were determined for ten bean cultivars grown under drought stress at two CIAT sites in Colombia. Leaf carbon isotope ratio showed considerable promise for determining the relative importance of water-use efficiency in different environments, offering physiologists and plant breeders a powerful new tool.

Key words: $^{13}C/^{12}C$, carbon isotope ratio, drought tolerance, leaf conductance, Phaseolus vulgaris, stable isotopes, stomata, water-use efficiency, yield.

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Introduction

About a third of the land area of the earth is classified as arid. An additional third is semi-arid or exposed to periodic drought conditions. In these regions, if not all agronomic situations, primary productivity is often limited by soil water availability (Fisher and Turner, 1978; Boyer, 1982). Both yield and evapotranspiration of a crop are linearly dependent on soil water availability. When both parameters are simultaneously measured, they are consistantly tightly correlated (Hanks, 1983), indicating the inevitable tradeoff between transpirational and photosynthetic fluxes as stomata regulate the diffusion rates of water vapor out of and carbon dioxide into the leaf.

From both a basic standpoint as well as for potential agricultural applications, it is important to know how the rates with which water is lost by a crop relate to rates of primary productivity. The pioneering studies on this topic were by Briggs and Shantz (1913, 1914) on the water requirements for growth of plants in the Great Plains region. Their studies on plants in containers focused on the amount of water which was consumed per unit dry matter production. One striking feature of their results was the observation of a "... marked difference in efficiency exhibited by different plants in the use of water". They further noted that there were measurable differences in this character between varieties of the same crop.

As an index of the two processes, we can measure the water-use efficiency (WUE), which is defined as the molar ratio of photosynthetic carbon gain to transpirational water loss (Tanner and Sinclair, 1983). WUE can be measured either on an instantaneous, gas-exchange basis or on a long-term scale as the yield to water consumption ratio. One agricultural goal in semiarid and arid agriculture is to achieve high yield without the expense of a low WUE, and breeding for increased WUE is frequently suggested as a desirable characteristic for drought tolerance (Blum, 1980;

Zobel, 1983), although Tanner and Sinclair (1983) and Sinclair, Tanner and Bennett (1984) questioned the extent to which exploitable variation might exist in this parameter.

Gas Exchange and Water-Use Efficiency

Since limited water availability is of major concern for the cultivation of crop plants and as well appears to limit the productivity of most if not all native plants, it is not too surprising that for many years there has been an intense interest in trying to understand how leaves simultaneously regulate carbon dioxide uptake and transpirational water loss (Farquhar and Sharkey, 1982; Taylor et al., 1983). Photosynthetic rates (A) tend to decline in response to a decreased leaf conductance (g), because carbon dioxide diffusion rates into the leaf and hence intercellular carbon dioxide concentrations (c_i, the carbon dioxide concentration inside the leaf after diffusion from the outside air through the stomata) are progressively reduced with a reduction in leaf conductance. However, if leaf temperatures do not change substantially as the stomata close, there may be an increase in the water-use efficiency (molar ratio of photosynthesis to transpiration).

This follows because the rate of net photosynthesis as influenced by stomatal activity can be described as:

$$A = (c_a - c_i) \cdot g/1.6 \qquad (1)$$

and the transpiration rate (E) as

$$E = \Delta w \cdot g \qquad (2)$$

where c_a is the atmospheric carbon dioxide concentration, Δw is the water vapor gradient, and 1.6 is the ratio of the diffusivities of water to carbon dioxide in air and is used to convert the conductance to water vapor through the stomata to the conductance to carbon dioxide through the stomata.

Combining these two equations we see that the water-use efficiency (A/E) becomes

$$A/E = (c_a - c_i) / (1.6 \cdot \Delta w) \qquad (3)$$

Thus, under natural field conditions the leaf water-use efficiency depends on both the intercellular carbon dioxide concentration and the leaf to air water vapor gradient. High water-use efficiency can be achieved by decreasing c_i or by decreasing Δw (e.g. photosynthesizing during cooler seasons or cooler times of the day, both of which have the effect of reducing leaf temperature during photosynthetically active periods).

For a given decrease in stomatal or leaf conductance, the water-use efficiency of a leaf is typically increased (assuming leaf temperature remains constant). This is because a unit decrease in leaf conductance has a smaller impact on photosynthetic rate than it does on transpiration rate. In Figure 1, the relationship between A and E is plotted. Note that the relationship is curvilinear and that the slope of this relationship, which is water-use efficiency, decreases as the flux rates increase.

Carbon Isotope Ratio

Measuring leaf water-use efficiency using gas exchange equipment over long time periods has been difficult because of the necessity to simultaneously measure biomass production and water consumption in a nondestructive manner. This is labor-intensive and because of equipment cost, sample sizes are usually quite small. Canopy-level aerodynamic methods also have limitations for many of the same reasons. As an alternative approach to the problem, Farquhar, O'Leary and Berry (1982b) first proposed that leaf water-use efficiencies could be measured using carbon isotope ratios at natural abundance levels.

The carbon isotope ratio ($\delta^{13}C$) is the ratio of the $^{13}C/^{12}C$ composition of a sample (R_{sample}) relative to the $^{13}C/^{12}C$ composition of a standard (R_{std}),

$$\delta^{13}C = (R_{sample}/R_{std} - 1) \cdot 1000 \quad (4)$$

where $\delta^{13}C$ has units of parts per mil (o/oo) and represents the deviation in composition of the sample from the standard, which happens to be a fossil belemnite from the Pee Dee Formation in South Carolina (PDB).

Farquhar et al. (1982b) proposed that there should be a relationship between the average c_i during the photosynthetically active period and $\delta^{13}C$. Their idea is based upon two observations: first $^{13}CO_2$ in air diffuses more slowly than $^{12}CO_2$, and second, that RuBP carboxylase, the initial carboxylating enzymatic reaction of photosynthesis in C_3 plants will discriminate against $^{13}CO_2$. While RuBP carboxylase can discriminate against $^{13}CO_2$, it does so only as a function of CO_2 levels actually at the sites where carboxylation is occurring (i.e., c_i level). Thus, it is predicted that

$$\delta^{13}C_{leaf} = \delta^{13}C_{air} - a - (b - a) \cdot c_i/c_a \quad (5)$$

where a is the discrimination due to diffusion differences (4.4 o/oo) and b is the net discrimination due to RuBP carboxylase (27 o/oo).

The advantage of using stable isotopes is that since carbon is continually being fixed by a leaf, measuring the carbon isotope ratio of a leaf provides a long-term indication of c_i. Therefore, carbon isotope ratio could be useful as a long-term indicator of leaf-water use efficiency (assuming leaf temperatures are equivalent). Since various environmental factors (such as drought, temperature, or salinity) influence gas exchange and thus c_i, carbon isotope ratios can be used to estimate how water-use efficiency changes in response to a diversity of environmental conditions.

Observations of $\delta^{13}C$ and Water-Use Efficiency

A number of data sets from different laboratories exist which verify the expected relationships between $\delta^{13}C$ and intercellular CO_2 (Farquhar et al., 1982a; Bradford et al., 1983; Downton et al., 1985; Ehleringer et al., 1985; Seeman and Critchley, 1985). In the original set of observations using instantaneous gas exchange measurements, Farquhar et al. (1982a) found a best-fit agreement to a RuBP carboxylase discrimination value of b = 27 (Fig. 2). More recent observations of RuBP carboxylase kinetics *in vitro* suggest that the value is closer to b = 29 (Roeske and O'Leary, 1984). However, not all of the organic carbon pool of C_3 plants is derived from this enzymatic reaction alone. There are also PEP carboxylations occurring in C_3 plants, and since these reactions do not discriminate against $^{13}CO_2$, the effect is to make the total carbon pool slightly heavier in ^{13}C. Thus, the overall net result is to create an effective value for RuBP carboxylase discrimination of b = 27 (Farquhar, Hubick, Condon, and Richards, 1987).

The extension of carbon isotope ratio to long-term growth studies was made by Farquhar and Richards (1984), who established that there was a strong correlation between carbon isotope ratio and the ratio of above ground productivity to the amount of water consumed by the crop (Fig. 3). Their results indicated a two-fold range in absolute water-use efficiencies among genotypes grown under common growth chamber conditions. Moreover, their study clearly established that there was substantial genetically-based variation in water-use efficiency among different wheat cultivars and that carbon isotope ratios were a reliable tool for detecting water-use efficiency differences.

Cultivar-based variation in leaf carbon isotope ratios under common growth conditions has now been detected in a variety of additional crop species including barley (Farquhar, Hubick, Condon and Richards, 1987), beans (White et al., 1988), crested wheatgrass (Johnson, Asay, Tieszen and Ehleringer, unpublished observations), peanut (Hubick, Farquhar, and Shorter, 1986), and tomato (Martin and Thortenson, 1987). Many more additional examples are expected as stable isotope analysis is extended to other crops. We have found similar intraspecific variation in carbon isotopic composition among native plants, although most of these results have not yet been published.

Patterns of Water-Use Efficiency and Productivity

Increased c_i levels (more negative $\delta^{13}C$ values) could result in an enhanced photosynthetic rate and perhaps also in an enhanced biological yield, but only if the soil moisture levels are not depleted before the crop is able to complete its life cycle. It is likely that because of differences in life expectancies and phenological patterns among plants, that there many not be a unique relationship between yield and water-use efficiency. Figure 4 demonstrates three possible relationships between biomass or seed yield and water-use efficiency for plants growing on a soil with a fixed amount of soil water available. Pattern A is that expected for an ephemeral, drought-escaping crop, where the maximum yield is associated with a low water-use efficiency. Conservative water-use efficiency by plants of pattern A could result in a decreased biological yield because of the reduced photosynthetic rates associated with a higher WUE. Pattern B is the expected pattern for longer-lived annual and for perennial plants where the selective pressures favor survival by drought avoidance. In such plants, we would expect mechanisms to conserve water use by the plant such as a high stomatal sensitivity to Δw. Pattern C represents the pattern expected for a drought-escaping plant in which phenological or developmental restrictions could result in a yield reduction if the soil water is consumed at a rate rapid enough to deplete the available moisture before the crop has matured. In this case, the greatest yield is not associated with extremes in WUE, but instead with an intermediate WUE value.

Three data sets are available to evaluate yield and carbon isotope ratio relationships. Condon et al. (1987) measured grain yield and dry matter production in field-grown wheat cultivars and found that both of these parameters were negatively correlated with carbon isotope ratio (they actually present their data as discrimination against $^{13}CO_2$, so their reported values have a positive sign). Thus, wheat would appear to fit Pattern A from Fig. 4. In contrast, Hubick et al. (1986) observed that in peanuts WUE (as measured by carbon isotope ratio) was positively correlated with dry matter production at low WUE values, but leveled off at higher WUE values. From those data, peanuts would appear to be similar to Pattern C of Fig. 4. The third example is common bean and is discussed in greater detail next.

$\delta^{13}C$ and Productivity in Beans

In a preliminary study of leaf carbon isotope ratios in common beans, White et al. (1988) investigated the relationships between biomass productivity and $\delta^{13}C$ for ten different lines under irrigated and nonirrigated conditions at Palmira, Columbia (deep, neutral soil) and under non-irrigated conditions at Quilichao, Columbia (shallow, acid soil).

The effectiveness of the irrigation treatment at Palmira was indicated by nonirrigation (151 mm) mean yields of only 520 kg ha^{-1}, but a mean yield of 2010 kg ha^{-1} with normal irrigation (501 mm). Significant differences among genotypes were found for all carbon isotope ratio measurements under nonirrigated conditions, but under the irrigated treatment, biomass did not show significant differences (Table 1). Irrigation treatment by bean line interactions were significant for all parameters, indicating strong genotypic differences in response to water regimes. The comparison of BAT

477 and A 170 yields are particularly illustrative. BAT 477 had the highest yield under nonirrigated conditions, but the fourth lowest yield under irrigation, while A 170 was highest under the irrigated treatment, but third under nonirrigated conditions.

Under nonirrigated conditions at Palmira, $\delta^{13}C$ was negatively and linearly correlated with all growth parameters. When all ten lines were included in the analysis, the biomass correlation was sgnificant at the $p<0.05$ level. However, if BAT 1224 was excluded from the analyses, seed yield and biomass had strong linear correlations ($p<0.01$) with $\delta^{13}C$.

Although within a water treatment at Palmira $\delta^{13}C$ was only significantly correlated with growth parameters under nonirrigated conditions, there was nonetheless a strong, significant correlation between biomass, seed yield and LAI with $\delta^{13}C$ when all data were combined. Fig. 5 indicates that across all bean lines in the two water treatments, the $\delta^{13}C$ correlation with biomass was $r=0.91$ and with seed yield $r=0.89$.

At Quilichao, all linear correlations of $\delta^{13}C$ with growth parameters were nonsignificant. However, when these data were fitted with parabolic curves, all growth parameters showed significant relationships with $\delta^{13}C$ such that intermediate $\delta^{13}C$ levels were associated with maximum values (Fig. 6).

Of interest in breeding studies is knowing the extent to which genotypic patterns exhibited at one site are indicative of the pattern observed at other sites. The comparison of $\delta^{13}C$ values from bean lines under nonirrigated conditions at Palmira and Quilichao showed a strong, significant correlation ($r=0.84$, $P<0.01$, Fig. 7). Similar data demonstrating similar genotype rankings between sites under similar growth conditions have been obtained fro Agropyron cristatum, a common range grass of the intermountain region of the United States (Johnson, Asay, Tieszen and Ehleringer, unpublished observations).

Although data on the year to year consistency of genotype rankings are not yet available for beans, such data are available for grasses. Fig. 8 illustrates that between successive years the genotype carbon rankings with respect to carbon isotope ratio remained very constant for *Agropyron cristatum*, even though there was a large difference in the rainfall that fell during the two years. Thus, the preliminary data appear to suggest a strong site-to-site and year to year consistency for carbon isotope ratio and genotype ranking.

$\delta^{13}C$ and Leaf Conductance: A Possible Mechanism for Increased Productivity

While there exists a theoretical basis for expecting $\delta^{13}C$ and water-use efficiency to be correlated, the basis for why $\delta^{13}C$ and primary productivity should be correlated is less well established. However, it follows directly from the same arguements since the gas exchange flux rate and water-use efficiency are always negatively correlated. Consider how stomatal activity affects both flux rate and the point at which the leaf is operating on the A/E curve (Fig. 1).

The effect of a decrease in leaf conductance on photosynthetic rate is best visualized by examining the dependence of net photosynthesis on intercellular CO_2 and the role that leaf conductance plays in regulating c_i values (Fig. 9). While a unit decrease in leaf conductance results in a unit decrease in transpiration rate, its impact is less on photosynthesis because of the positive x-axis intercept (the CO_2 compensation point) and, thus, the slope of the A/E curve increases as flux decreases. In our analyses of beans which follows, we have assumed that the A vs c_i response curves of different bean lines were similar (we have preliminary evidence to suggest that this may be the case).

From Fig. 9, it follows that since A and c_i are positively related, any increase in leaf conductance (g) would increase productivity if leaves maintained the same A vs c_i response curve. That is, an increased rate of primary productivity comes at the expense of a reduced water-use efficiency. Although there are clearly means by which increased productivity need not reduce water-use efficiency, water-use efficiency and primary productivity must be negatively correlated if leaves of different bean lines are maintaining the same A vs. c_i response curve. Based on this, we would predict that leaf conductance and carbon isotope ratio should be negatively correlated.

While White et al. (1988) did not measure leaf conductances, Ehleringer (unpublished observations) has correlated maximum leaf conductances and carbon isotope ratio for dry beans grown in Utah under well-watered, field conditions. Fig. 10 illustrates that for dry beans, there appears to be a strong negative correlation between carbon isotope ratio and leaf conductance, implying that leaves with higher conductances are operating at proportionally higher c_i levels. A mechanism as simple as maintaining higher leaf conductances could be responsible for the observed higher rates of primary productivity in bean lines with more negative carbon isotope ratios.

Leaf conductance has been reported to be positively correlated with stomatal density in some crop species (Nerkar, Wilson and Lawes, 1981; El-Sharkawy, Cock and Hernandez, 1985), but not in others (Jones, 1977). Preliminary observations of stomatal densities on both the upper or lower surfaces of the leaves on these dry bean lines indicated that there was no significant correlation between stomatal density and leaf conductance. It is however possible that the differences in leaf conductances among bean lines arises because of differences in stomatal sensitivity to humidity.

Conclusion

Carbon isotope ratio analysis at natural abundance levels seems to hold promise as a useful tool for evaluating long-term water-use efficiency in crops. This technique has the advantage of averaging a plant's activity over time and can be used to screen large numbers of genotypes in a rapid manner. A number of recent studies are suggestive that for some crop species carbon isotope ratios may also be tightly correlated with yield.

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Table 1. Leaf carbon isotope ratio, seed yield, and biomass for 10 bean lines grown under irrigated and nonirrigated field conditions at Palmira, Colombia (from White, Castillo, and Ehleringer, 1987).

Line	Carbon isotope ratio (o/oo)	Seed yield (kg ha $^{-1}$)	Biomass (kg ha $^{-1}$)
Nonirrigated treatment			
BAT 477	-26.59	980	2390
A 170	-26.39	790	2070
S. Cristobal 83	-26.91	760	3070
V 8025	-26.27	620	2070
BAT 1289	-25.49	580	2300
Mulatinho H8	-26.22	560	1990
Carioca	-25.31	320	1060
A 70	-25.61	240	1570
Porillo S.	-25.26	230	1130
BAT 1224	-26.51	130	1330
Irrigated treatment			
BAT 477	-27.75	1940	4940
A 170	-27.02	2330	4820
S. Cristobal 83	-27.77	1990	4390
V 8025	-27.87	2090	4340
BAT 1289	-27.41	1830	4380
Mulatinho H8	-26.98	1840	3530
Cariaoca	-27.84	2120	4440
A 70	-27.10	2450	4630
Porrillo S.	-27.43	1930	4160
BAT 1224	-28.18	2230	4460

Figures

Fig. 1. The relationship between the photosynthetic rate (A) and transpiration rate (E) of a leaf.

Fig. 2. The dependence of carbon isotope ratio on intercellular carbon dioxide concentrations using gas exchange techniques (from Farquhar et al., 1982a).

Fig. 3. The correlation between leaf carbon isotope ratio as whole plant water-use efficiency (measured as biomass production divided by total soil water consumed). From Farquhar and Richards (1984).

Fig. 4. Possible relationships between biomass or seed yield and water-use efficiency in plants. Pattern A is that expected for short-lived, drought-escaping annuals on deep soils. Pattern B is that expected for long-lived plants where there is strong selection for survival through drought periods. Pattern C is that expected for short-lived, drought-escaping annuals on shallow soils. See text for further details.

Fig. 5. Linear correlations between aboveground biomass (kg ha^{-1}) (left) and seed yield (kg ha^{-1}) (right) and leaf carbon isotope ratio (o/ooo) for irrigated (closed symbols) and nonirrigated (open symbols) bean lines at Palmira, Colombia. From White et al. (1988).

Fig. 6. Nonlinear second order correlation between above ground biomass (kg ha^{-1}) (left) and seed yield (kg ha^{-1}) (right) and leaf carbon isotope ratio (o/ooo) for nonirrigated bean lines at Quilichao, Colombia. From White et al. (1988).

Fig. 7. Linear correlation between leaf carbon isotope ratios of bean lines grown under nonirrigated conditions at Palmira and Quilichao, Colombia. From White et al. (1988).

Fig. 8. Correlation between seed carbon isotope ratios of different Agropyron cristatum genotypes harvested on successive years. From Johnson, Asay, Tieszen, and Ehleringer (unpublished observations).

Fig. 9. The dependence of photosynthesis (A) on intercellular carbon dioxide concentration (c_i), often referred to as the demand function of photosynthesis. The intersecting linear lines represent different leaf conductance (g) values and this line is often referred to as the supply function of photosynthesis. The intersection of demand and supply function is the operational point of the leaf for those conditions.

Fig. 10. The correlation between adaxial and abaxial leaf conductance values and leaf carbon isotope ratio for dry beans in Utah. From Ehleringer (unpublished observations).

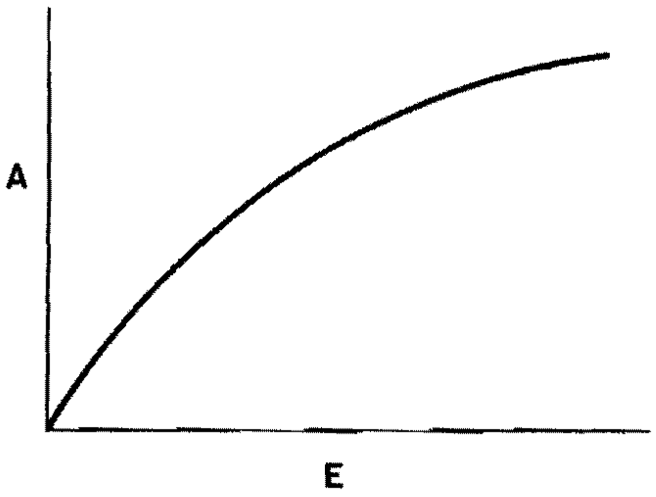

Figure 1. The relationship between the photosynthetic rate (A) and transpiration rate (E) of a leaf.

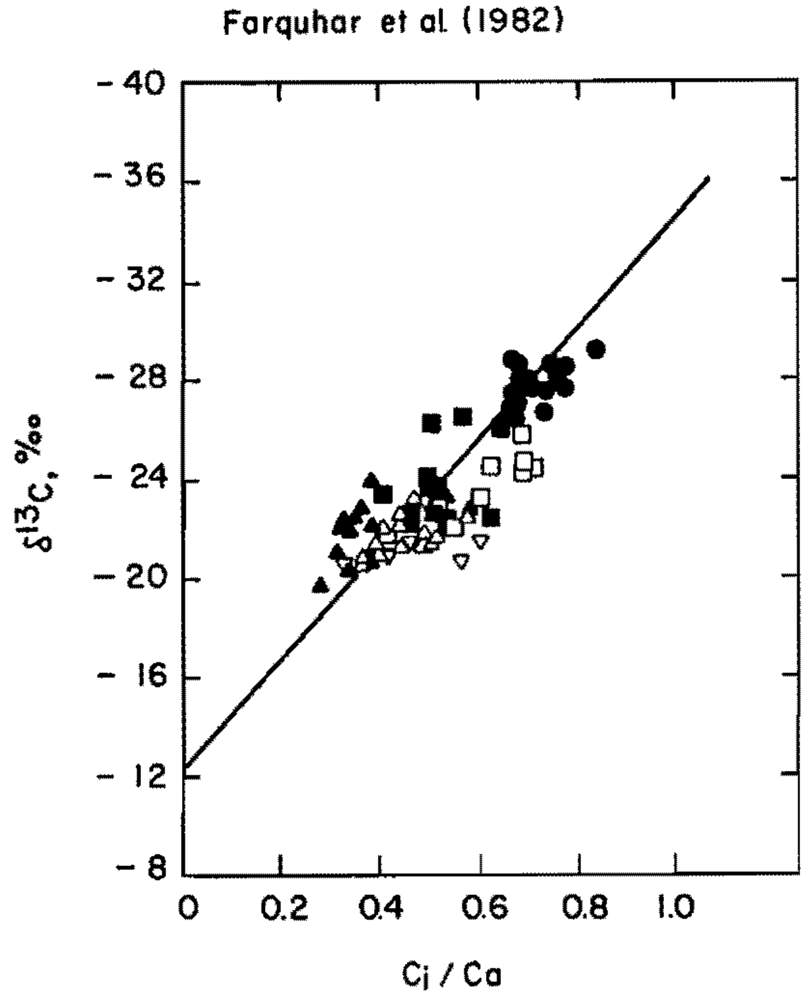

Figure 2. The dependence of carbon isotope ratio on intercellular carbon dioxide concentrations using gas exchange techniques (from Farquhar et al., 1982a).

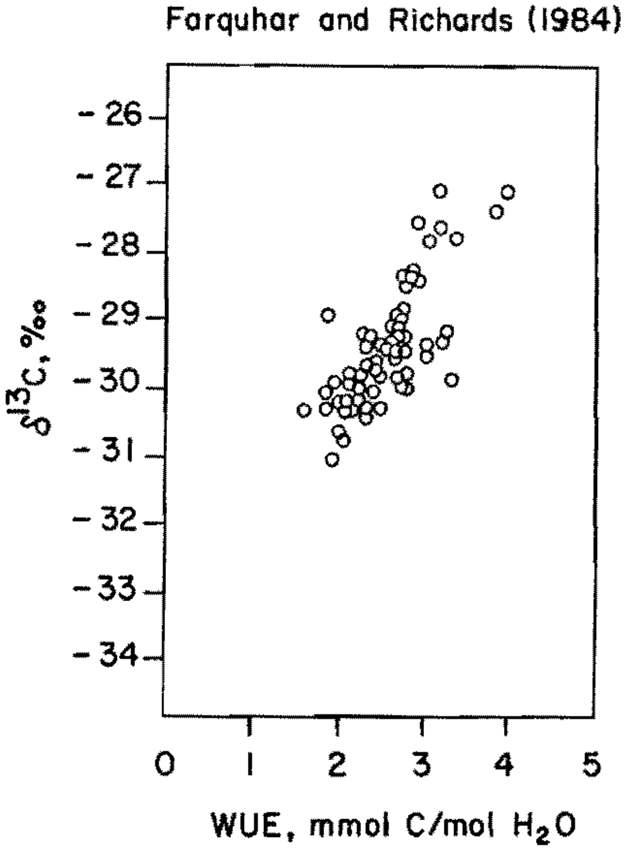

Figure 3. The correlation between leaf carbon isotope ratio as whole plant water-use efficiency (measured as biomass production divided by total soil water consumed). From Farquhar and Richards (1984).

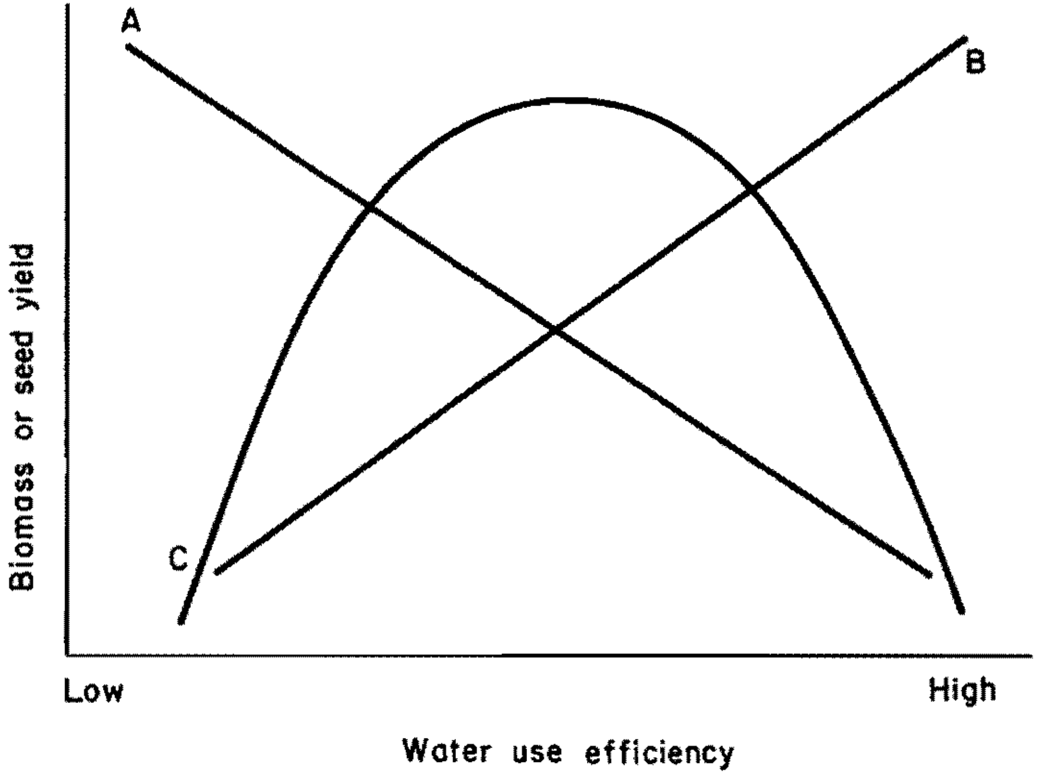

Figure 4. Possible relationships between biomass or seed yield and water-use efficiency in plants. Pattern A is that expected for short-lived, drought-escaping annuals on deep soils. Pattern B is that expected for long-lived plants where there is strong selection for survival through drought periods. Pattern C is that expected for short-lived, drought-escaping annuals on shallow soils. See text for further details.

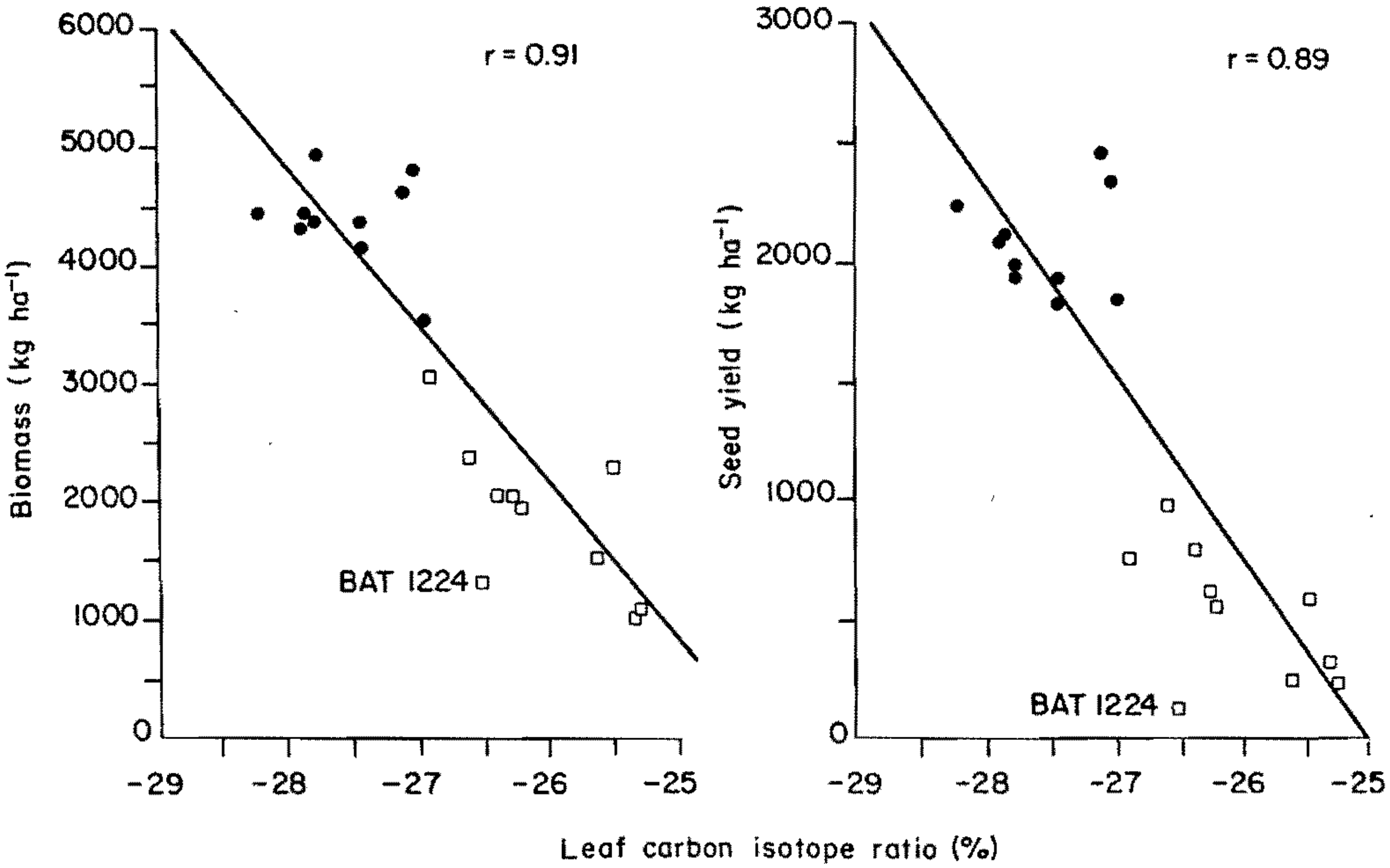

Figure 5. Linear correlations between aboveground biomass (kg ha) (left) and seed yield (kg ha) (right) and leaf carbon isotope ratio (o/ooo) for irrigated (closed symbols) and nonirrigated (open symbols) bean lines at Palmira, Colombia. From White et al. (1988).

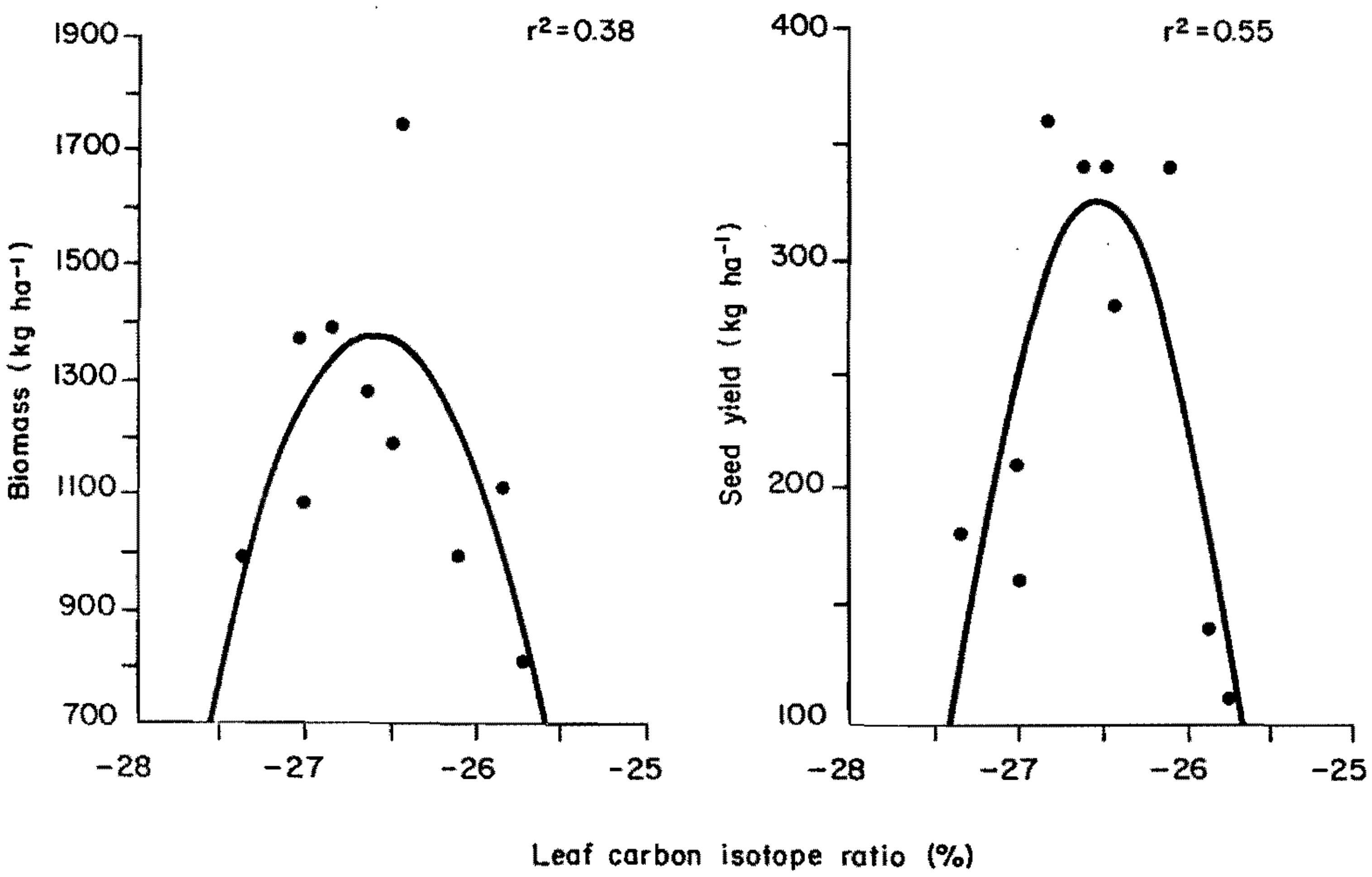

Figure 6. Nonlinear second order correlation between above ground biomass (kg ha) (left) and seed yield (kg ha) (right) and leaf carbon isotope ratio (o/ooo) for nonirrigated bean lines at Quilichao, Colombia. From White et al. (1988).

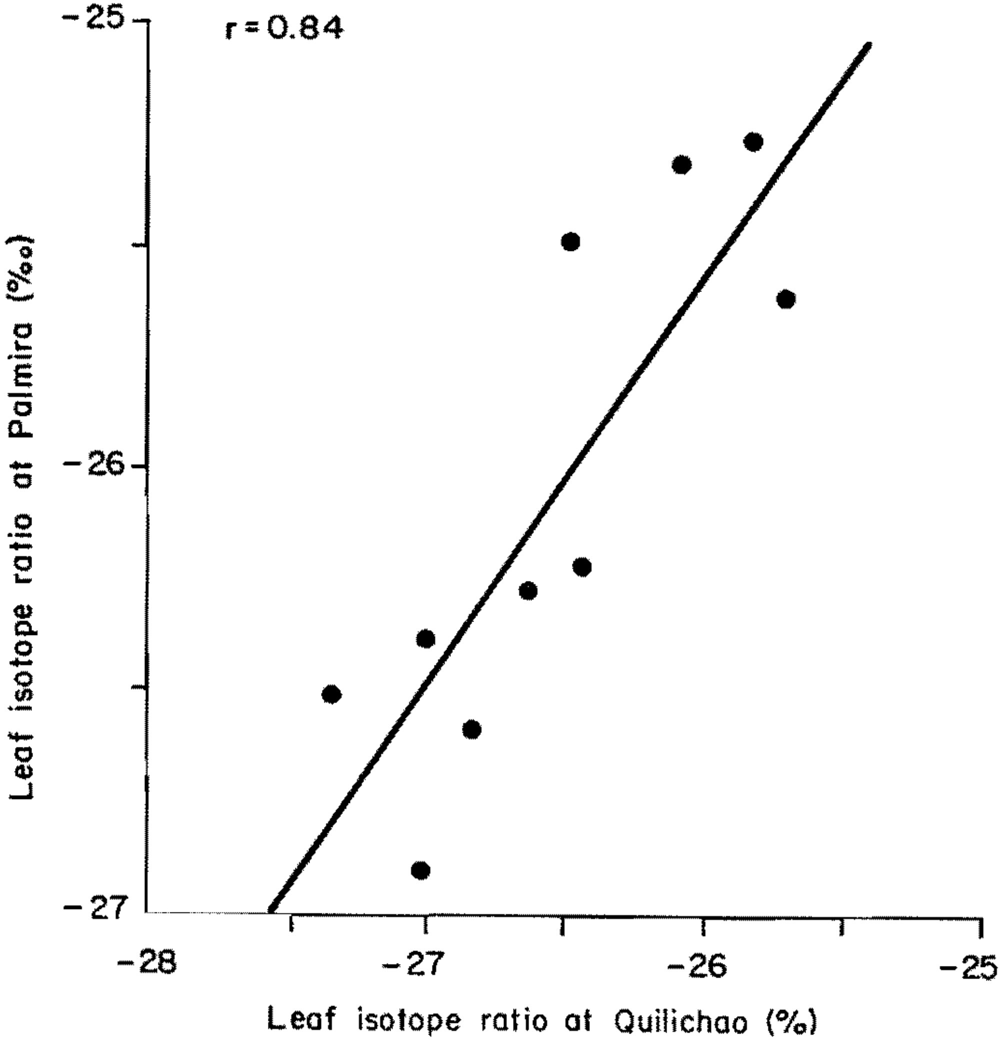

Figure 7. Linear correlation between leaf carbon isotope ratios of bean lines grown under nonirrigated conditions at Palmira and Quilichao, Colombia. From White et al. (1988).

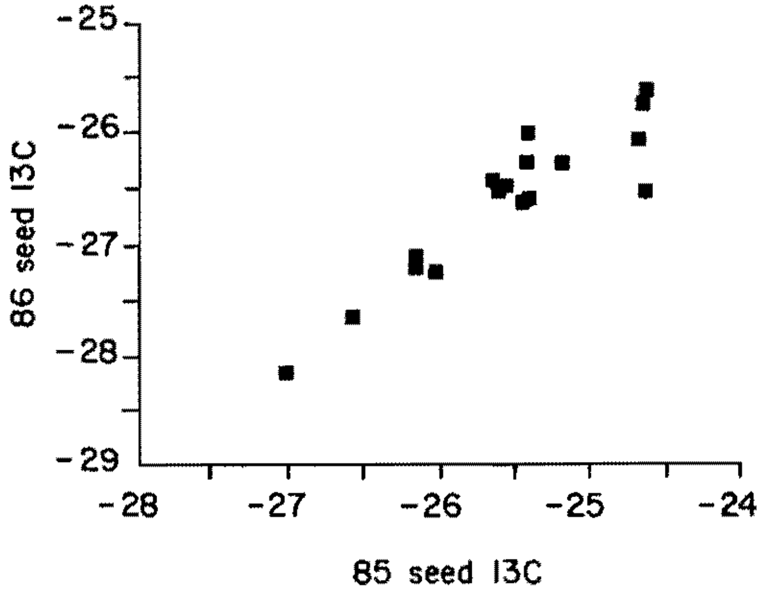

Figure 8. Correlation between seed carbon isotope ratios of different *Agropyron cristatum* genotypes harvested on successive years. From Johnson, Asay, Tieszen, and Ehleringer (unpublished observations).

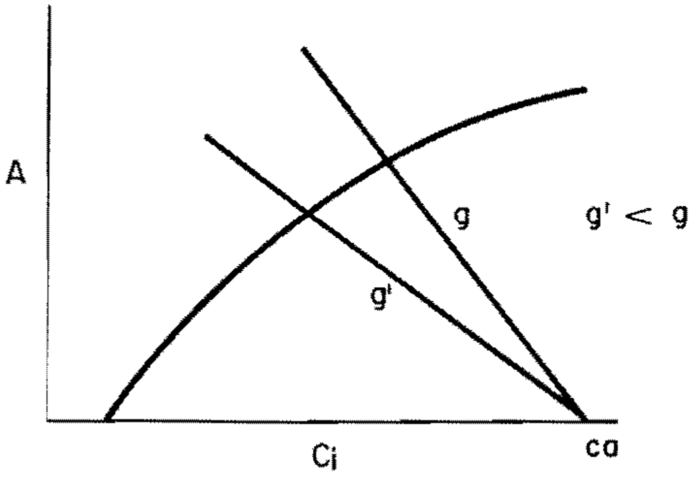

Figure 9. The dependence of photosynthesis (A) on intercellular carbon dioxide concentration (c), often referred to as the demand function of photosynthesis. The intersecting linear lines represent different leaf conductance (g) values and this line is often referred to as the supply function of photosynthesis. The intersection of demand and supply function is the operational point of the leaf for those conditions.

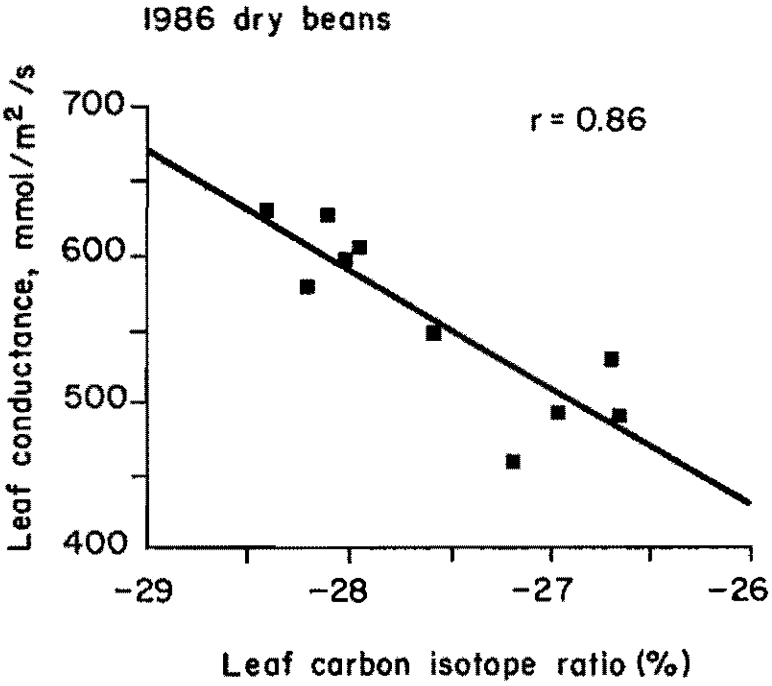

Figure 10. The correlation between adaxial and abaxial leaf conductance values and leaf carbon isotope ratio for dry beans in Utah. From Ehleringer (unpublished observations).

USE OF MODELS IN STUDIES OF DROUGHT TOLERANCE[1]

Gerrit Hoogenboom, J. W. Jones, and J. W. White*

Introduction

Most agricultural research has traditionally been conducted under either field conditions or in controlled environmental such as greenhouses. Data collected during experiments were analyzed by hand or with hand calculators. After computers were introduced, some of the analysis procedures were replaced with computer programs. Currently statistical analysis techniques are widely used by most agricultural researchers to calculate the significance of their experimental results and to evaluate the original hypotheses. However, only a few researchers have gone further and tried to apply their models, developed on computers, under practical agricultural conditions or in farmer's fields. Unfortunately many agronomists trained in the traditional schools are still apathetic toward the use of computers in agriculture, mainly because they are unfamiliar with the capabilities of computer and the potential of computer applications. This has prevented a mutual cooperation between computer and systems analysts on one had and agronomists on the other.

During the last 15 years, a new research discipline has slowly emerged in agriculture. Computer simulation or modeling integrates the knowledge of such fields as soil physics, soil chemistry, plant nutrition, crop and plant physiology, biochemistry, agrometeorology, and agronomy with systems

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analysis, mathematics, and computer science. In computer simulations, the functioning of physical and physiological systems is represented through relational (Gold, 1977) and Forrester diagrams (Forrester, 1971). These diagrams are then translated into mathematical models and implemented on computers (France and Thornley, 1984; Jones et al., 1987). If accurate plant models have been developed, the models will correctly predict what occurs under real field conditions.

Models can be very simple and have only one or two equations, or they can be extremely complex and consist of hundreds of equations. Some models can be implemented on simple hand calculators or hand computers, while others need the latest and fastest super-computers. A simple model in agriculture might predict yield as a function of total seasonal radiation, temperature, and rainfall. A complex model also might predict final yield, but would require hourly inputs of radiation, air and soil temperature, rainfall, relative humidity, and wind run. From this data, it would calculate the detailed physiological processes of water uptake, transpiration, photosynthesis, organogenesis, biomass partitioning, and other processes at time intervals as small as one minute. Although both models have been developed to predict final yield, the complex model should be more accurate than the simple model. It is fairly easy to develop and test simple models, but complex ones require many resources in the form of time, equipment, and manpower both for development and calibration, and for validation of the model before it can actually be used by other researchers or extensionists (Dent and Blackie, 1979).

Crop Simulation Models

Many of the computer models developed in agronomy and soil science are dynamic and mechanistic simulation models. These models are called dynamic because for each calculation and update of the internal model variables, information is needed from the previous time step. For example, to model leaf growth, we need to know total leaf area from the previous days in order to predict photosynthesis correctly for today. After we have calculated today's growth and death rates, we can update the leaf area with the net increase in area and predict what the total leaf area will be at the end of today. The same process will be repeated for subsequent days. These models are mechanistic because among their main objectives are to describe the actual processes which occur in the plant and to summarize the internal mechanisms of plant growth. As mentioned earlier, we can find relatively simple and relatively complex dynamic and mechanistic computer models.

A distinction can also be made between the objectives and goals behind the various crop modeling efforts. Some models have been developed to study only specific aspects of plant growth and development, such as reproductive development, seed growth, stomatal resistance, and root water uptake. These models contain many details which relate to the processes they simulate, but other processes which occur in the same or other organs of the plant are ignored. The main purpose of these models is to study hypotheses which relate to the processes the models describe and simulate. They are called research models because they are mainly used for research purposes. On the other hand there are management models, which in most cases include a more complete, but simplified, description of plant growth and development. Such models will respond to differences in irrigation or fertilization regimes, planting dates, cultivar choice, etc., and will predict yield as a function of management inputs and cultural practices. They are called management models because their main purpose is to study the effect of management decisions on final yield and yield components. Of course, many models have been developed which contain components of both types of models.

Legume Models

At the University of Florida, a crop modeling effort was initiated primarily to study the effect of irrigation on growth, development, and yield of soybeans (Glycine max (L.) Merr.). As a result of this research project, a simulation model was developed which contains both management and research components. The computer model, called SOYGRO, simulates the different growth processes in the soybean plant from planting until harvest maturity, and predicts total growth and development at the different vegetative and reproductive growth stages of the soybean plant. Although the main goal of the model SOYGRO is to predict yield, it also simulates other physiological processes as a function of environmental conditions. The design, development, and construction of a simulation model is a continuous process which improvements are continuously being incorporated to the model. In the case of the model SOYGRO a series of versions thus have been published (Wilkerson et al., 1983, 1985; Jones et al., 1988a).

Since 1985, a model called BEANGRO has also been under development. The model simulate vegetative growth, reproductive development, and final yield of common bean (Phaseolus vulgaris L.). Only a few models which simulate growth of dry bean have been reported in the literature (White, 1981). For BEANGRO, the code of the soybean model SOYGRO was used as a standard, and modifications were made to the different submodules and input files of the model to describe the specific growth and development characteristics of dry bean (Hoogenboom et al., 1986a and b). A third legume model which has been developed by the cropping systems analysis group at the University of Florida is the peanut (Arachis hypogaea L.) model, PNUTGRO (Boote et al., 1988). All three models are part of a U.S. Agency of International Development project called IBSNAT (International Benchmark Sites Network for Agrotechnology). The IBSNAT project is designing a new methodology for planning agricultural development and controlling farming outcomes in the developing countries. Included in the techniques used to accomplish these objectives are computer models and data bases (Jones, 1986a).

Model Applications

Although computer modeling is a fairly new discipline, potential applications have been widely published. Jones et al. (1985), Jones (1986b), and Ritchie (1986) showed the use of computer models to improve management decisions. Elwell et al. (1987) determined the potential yield limiting factors of soybean through crop modeling. Programs are also being developed to apply models on a farm scale level, integrating both crop models and farming systems research models (Thornton and Dent, 1987; Jagtap and Jones, 1987).

Computer models have shown particular promise in studies of the impact of drought on crop production and yield. Pisani (1987) used the CERES-MAIZE model, a dynamic simulation model which predicts growth and yield of corn (Zea mays L.) (Jones and Kiniry, 1986) to assess the impact of drought on maize during early stages of the growing season. Boote and Jones (1986) presented the potential and limitations of crop growth simulation models for the evaluation of crop varieties and cropping systems in arid and semi-arid regions. They used the peanut model PNUTGRO (Boote et al., 1988) to create potential cultivar characteristics and crop management conditions, and predict used there to growth, development, and yield of the new cultivars for environmental conditions in Gainesville, Florida and Niamey, Niger.

In this paper, we will demonstrate the use of the dry bean model BEANGRO in studies of drought tolerance. We will especially concentrate on bean plant characteristics which are thought related to drought resistance and avoidance (White and Castillo, 1988) and will predict the yield of hypothetical cultivars incorporating these characteristics under drought conditions at CIAT, Colombia. The advantage of using simulation models for such applications is that many theoretical experiments can be conducted with the aid of crop models and computers without actually investing in resources for field experiments. The results of these simulations will show if modifications to the plant have a potential for an economical increase in yield (Wallace, 1985). A physiologist can validate the model predictions, and if necessary perform further experiments to clarify the mechanisms involved. A breeder can then concentrate breeding efforts around the most promising traits (White and Singh, 1988).

Dry Bean Model Description

The first version of the dry bean model BEANGRO during the conversion process from the soybean model SOYGRO was described by Hoogenboom et al. (1986A, B), and a more detailed description of the model was presented during the Bean International Trials Workshop (Hoogenboom et al., 1988A). Currently a first version of the bean model is being finalized and prepared for public release. A user's guide, which explains the procedure of running the model on a micro-computer (Hoogenboom et al., 1988B), and technical documentation will also be published.

The dry bean model predicts vegetative growth and reproductive development. A description and explanation of the module which simulates reproductive development for all three legume models was given by Jones et al. (1988b). The model has separate routines which calculate photosynthesis, respiration, biomass partitioning, growth of leaves, stems, roots, and after flowers have been initiated and pods are set, pod and seed growth. The model also accounts for infiltration of rainfall and irrigation into the soil profile, saturated and unsaturated flow for the different soil layers, water uptake, soil evaporation, and transpiration. The soil water balance section is based on generic soil water and root growth modules, developed by Ritchie (1985) and used in the CERES and SOYGRO models. The potential daily evapotranspiration rate is calculated from temperature and radiation based on the equilibrium evapotranspiration defined by Priestly and Taylor (1972).

The vegetative and reproductive development sections use predicted hourly temperatures and night length to calculate several thermal and photothermal indexes, and are reevaluated at hourly intervals. All other plant processes defined in the model are calculated and updated after each 24 hour time step. BEANGRO requires daily weather data in the form of total radiation, minimum and maximum temperature, and total rainfall as inputs. Also needed are crop management practices such as row and plant spacing, planting date, cultivar, and irrigation and fertilization regimes (IBSNAT Project, 1988). Finally information about the soil profile and soil water conditions are required. This is especially important when the model is used to study the effect of drought on crop production and yield. For each soil layer, a saturated soil water content, a drained upper limit (which is similar to field capacity) and a lower limit (permanent wilting point) are defined. Other parameters which define soil albedo, saturated conductivity, and root distribution can be estimated based upon the soil texture of each layer. More information about the input requirements of the simulation models is given in IBSNAT Technical Report 5 (IBSNAT Project, 1986).

For initial development of the model, experiments were conducted at the Irrigation Research and Education Park of the University of Florida during the 1985 Fall season (Hoogenboom et al., 1986) and the 1986 Spring season (Mahamadou et al., 1987). Although several different irrigation regimes were applied during the growing seasons, only data from the non-stressed and fully irrigated plots were used to calibrate the model. At the same time, the model was tested with data sets collected at CIAT-Palmira, Colombia, during the 1985 and 1986 growing season (White, personal communication). The model predicted growth of the different plant components accurately for both locations (Hoogenboom et al., 1988a), although modifications in the model are still needed to be able to predict yield correctly under a wider range of environmental conditions.

Simulation Conditions

For special applications under different drought and irrigation conditions, the dry bean model was validated with experimental data collected during the 1986 growing season (Mahamadou et al., 1987). Beans in this experiment were grown under five different irrigation levels, from daily irrigation to rainfed only. All the legume models show a very strong response as a function of the total amount of accumulated water received during the season, whether from rainfall or irrigation, (reflecting the fact that the first version of SOYGRO was developed to study irrigation management). The dry bean model predicted growth and yield of the rainfed and daily irrigated treatments accurately, while some of the predictions for the other irrigation treatments could still be improved. Overall, the predictions of the model were within the error range of the field observations. Therefore the model could be used to demonstrate the potential of crop models for drought studies in dry beans. The main objective of this study was to look at the qualitative responses of the model, not detailed quantitative responses. Thus, the actual precision of the simulated results is less important than general trends.

The CIAT-Palmira station is geographically closer to bean growing areas than the University of Florida, experimental conditions at CIAT were used to define the parameters which describe the soil profile characteristics and crop management data files of the model. Although conditions for extreme drought are not very common at CIAT, the institute is located in an area which has relatively wet and dry seasons, and therefore the model has a potential to show differences in response to CIAT's weather conditions. CIAT was also the only tropical location which had enough weather and soils data available to be able to initiate and run the model. Possible future applications will be in the Jutiapa region of Guatemala, and in Durango, Mexico.

CIAT is located close to the equator (latitude 3.3°N), so the effect of varying daylength on development is not very important because of the fairly stable daylength during the entire year. Also daily total radiation and temperature only show minor variations over the entire growing season. Overall, most responses to environmental conditions will vary as a function of seasonal rainfall. The soil at CIAT is a silty clay (loamy clayey, Aquic Hapludoll) with a rather large water holding capacity. Soil data collected at CIAT (White and Castillo, personal communication) were used to define the soil water characteristics of each layer of the profile. For these studies, the genetic characteristics of the bean line BAT 477 were selected to define the cultivar characteristics. BAT 477, a line developed at CIAT, has shown a potential for higher yields under relatively dry conditions. BAT 477 was also studied in the experiments both in Gainesville and at CIAT and was used for initial development of the model. Unfortunately only 8 complete years of historical weather data were available from CIAT (1979 through 1986). In the new Decision Support System for Agrotechnology Transfer (DSSAT), options are available to analyze long term effects through programs which "generate" weather records and which use grafical and statistical analysis to assess simulation results (Jagtap and Jones, 1987). However, in the study presented in this paper real weather data were used. Measured daily minimum and maximum air temperature, rainfall, and radiation were stored in data files, read at daily time intervals by the computer model, and used in calculating all the processes simulated by the model.

Planting Date

To study the effect of planting date as a function of seasonal and yearly weather variation, the first simulation was run assuming a planting date of January 1. In subsequent runs, planting was initiated at intervals of 15 days until October 15, for a total of 20 planting dates. The simulations were then repeated for each of the eight years, which resulted in a total of 160 simulations. In Fig. 1 total accumulated rainfall received by the bean crop during the growing season is shown as a function of planting date. For each planting date, a total of 8 points is shown, these representing the 8 years for which the simulation was run. There was strong variation in total rainfall. Planting dates around the end of June and the beginning of July (calendar day 150 to 170) showed less than 150 mm, while early plantings in March (calendar day 60 to 90) or late plantings in September (calendar day 245 to 275) showed rainfall as high as 350 to 400 mm. The rainfall pattern was clearly bi-modal, with the highest amounts corresponding to the rainy season and the lowest amounts to the dry season. Especially during the wet seasons, a very strong year to year variation was predicted. The March 1 (calendar day 60) planting date showed a minimum of 150 mm and a maximum of 450 mm during the 8 years simulated period.

A similar bi-modal distribution was found when simulated total biomass at the end of the season was plotted as a function of planting date (Fig. 2). The maximum biomass predicted by the model varied between 6000 and 7000 kg/ha for all planting dates except during May, June, and July, which were the dry months. The lowest biomass varied between 0 and 1000 kg/ha, which was mainly predicted during the dry months, but was also found for some of the January and March planting dates. From Figures 1 and 2, it can be concluded that there was a linear relationship ($R^2 = 0.63$) between total rainfall during the season and biomass harvested at the end of the season (Fig. 3). For total amounts of rainfall greater than 300 mm, total biomass reached a maximum around 6000 kg/ha and did not increase as a function of rainfall at higher amounts.

Yield followed a very similar pattern as a function of planting date, as was found for observation for rainfall and biomass (Fig. 4). The highest predicted yields varied between 3500 and 4000 kg/ha, while the lowest yields were of zero yields (0 kg/ha). Although most of the zero-yield planting dates were found in May and June, they were sometimes predicted for other planting dates where more total rainfall had been received during the season. Apparently the rainfall during some of those years was not evenly distributed over the entire growing season, and therefore not enough soil moisture was present during seed filling to permit a high yield. For the conditions of the simulations, only the planting dates from August 15 through October 1 predicted a minimum expected yield of 1000 kg/ha, with no yield lower than this amount. Although yield was strongly dependent on rainfall, this relationship only held for intermediate amounts of rainfall received during the season (Fig. 5). For rainfall between 150 and 200 mm, there was a linear relationship ($R^2 = 0.59$) with yield, which increased from 0 to 3000 kg/ha. For total rainfall below 100 mm, zero yield was predicted.

These results show that computer simulations of plant growth can be used to determine the possibilities of sustainable agriculture in certain regions. When several years of historical weather data are available, similar computer simulations can be made to determine yield as a function of planting date. When all results show a low yield, independent of the year or the planting date, there is a high chance that the region will be unable to produce enough agricultural products either to satisfy their own need for food or to trade or sell beans in exchange for other products. The risks involved are then too high for the farmers to invest in seed or other inputs, and no net positive return can be expected. On the other hand, if the model shows that certain planting dates have a higher potential yield than others, it might be worthwhile for breeders to select for drought resistant traits which will increase the productivity of beans under those conditions.

Yield and Probability

In the previous section, we demonstrated the response of the dry bean model BEANGRO to periods of drought. During dry periods, a yield decrease, with a minimum of zero yield, was predicted when compared with periods which receive higher amounts of rainfall. Rainfall at CIAT-Palmira varied strongly as a function of time (Fig. 1), and therefore planting dates needed to be selected for further simulations. In these simulations, one or more plant traits thought important under drought stress were modified, and predicted yield and yield components were analyzed under both dry and wet conditions. Cumulative probability functions (Fig. 6) were used to select the months which had both low and high yields. Although these probability functions are normally used to determine efficient crop management strategies (Thornton and Dent, 1987), we used these functions to examine the distribution of yields over the range of potential planting dates (Fig. 4).

The probability function shown in Figure 6 is the accumulated yield for all combinations of 8 years and 20 planting dates. The function indicated that there was a 10 % probability under these environmental conditions that there was no yield (0 kg/ha). There was a 50 % probability that yield was less than 2000 kg/ha (shown by the large arrows). One can also consider the inverse of the cumulative density function : there was a 65 % (100 % - 35 %) probability (small arrows) that yield was higher than 1000 kg/ha. In general, the yields predicted for CIAT's environmental conditions were high compared with drought areas like the highlands of Mexico, where yields seldom reach 1000 kg/ha. However, the predicted yields still served to show the possibilities of applications of the model for drought conditions.

Separate cumulative probability curves were calculated for all planting dates in each month. During the month of June, there was a 50% probability of 0 kg/ha yield, and the maximum yield predicted was 1000 kg/ha. During March, the probability was 80 % that yield was higher than 2000 kg/ha. The results of June and March were extremes for respectively severely dry and wet conditions for the 8 years of weather data used in this study. February and August planting dates showed a diagonal cumulative probability distribution with an equal probability for all yield levels within the predicted range. Therefore, these two months were used for further simulations in which parameters representing certain traits related to drought avoidance were modified.

Cultivar Characteristics

Until now we have only discussed the use of BEANGRO for analysis of the variability of yield as a function of the uncertainty of weather conditions, especially rainfall. The model, however, can also be used to modify specific cultivar traits and characteristics and study the effect of these modifications on yield and yield components. Boote and Jones (1986) demonstrated this application with the peanut simulation model. However, in this paper, we have taken a slightly different approach. Specific parameters which affect a given trait related to drought response were selected and modified at + 10 % or - 10 % intervals. The model was then run for both the February and August planting dates using the 8 years of weather data from CIAT-Palmira. Finally, yield and other model predictions were plotted as a function of a given cultivar trait.

Specific leaf area

The assumption was made that thick leaves and a smaller total leaf area per plant will reduce the total amount of water lost through transpiration, and consequently, that the crop will be more efficient with available soil water. On the other hand, a bigger canopy, consisting of relatively thin leaves, has a potential for higher total canopy photosynthetic rates and consequently, biomass production and final yield. The standard value (value used to calibrate the model) for Specific Leaf Area (SLA) is 300 cm^2/g, and SLA was varied at ± 15 cm^2/g intervals between a minimum SLA of 195 cm^2/g and a maximum SLA of 405 cm^2/g. Total mean, maximum, and minimum predicted biomass at the end of the season are shown in Fig. 7. The minimum biomass was independent of SLA, but maximum biomass increased as a function of SLA from 4000 kg/ha to 7000 kg/ha. The mean predicted value for all planting dates and simulation years increased from 2000 kg/ha to 4000 kg/ha when SLA increased from 195 cm^2/g to 405 cm^2/g.

Yield showed no response to SLA for values higher than 300 cm^2/g, the value used in the standard version of the model (Fig. 8). However, when SLA decreased from 300 cm^2/g to 195 cm^2/g and leaves became thicker, yield dropped from 1750 kg/ha to 1000 kg/ha. Thus, for these simulations the model predicted the lowest yield for canopies with low SLA's, thick leaves, and small amounts of total leaf area, while the highest yields were predicted for canopies with the highest SLA's and the thinnest leaves.

Water use efficiency (WUE), calculated as yield per unit of transpiration (yield efficiency, Tanner and Sinclair, 1983), showed a maximum at a SLA of 265 cm^2/g, close to the SLA of 300 cm^2/g used in the model (Fig. 9). For both lower and higher values of SLA, the WUE decreased. This was caused by a slowly increasing total accumulated transpiration rate as a function of SLA, while yield reached a maximum at a SLA of 300 cm^2/g. Thus the hypothesis that the water use efficiency is highest for plants with the smallest SLA and the thickest leaves was rejected. However, the model did predict that decreasing the SLA slightly from the current value of 300 cm^2/g (Fig. 9, broken line) to 265 cm^2/g will increase the overall yield or water use efficiency.

Biomass partitioning to roots

The second hypothesis was that if a larger fraction of total carbohydrates is distributed into the root system, the plant will have more soil volume to explore, will extract more soil water, and therefore will be able to avoid drought stress for a longer period. The standard value defined in the model was used as a check, and this parameter was increased or decreased at steps of ± 2 %. This resulted in a minimum of 88 % and a maximum of 116 % of the original biomass fraction distributed to the root system. The model predicted that the highest yield will be occur when the largest fraction of carbohydrates will be partitioned into the roots, while the lowest yield will be found when the smallest fraction of carbohydrates is distributed to the roots (Fig. 10). There was no significant effect of root partitioning factor on total above ground biomass production. Biomass was fairly constant over the entire range of partitioning and averaged around 4000 kg/ha (Fig. 11).

The model illustrates that modifying plant characteristics which affect or relate to biomass partitioning into the root system has a potential to improve yield. As part of the experimental study used to calibrate the model, it was found that the root density of all five irrigation treatments was very similar for all depths, while there was a significant difference in total above ground biomass (Hoogenboom et al., 1988). Unfortunately, roots are the most difficult components of the plant to study, and many aspects of the rhizosphere have often been ignored in previous investigations because of labor intensive measurements. The model, however, can be used in preliminary studies to investigate traits which may affect drought tolerance or resistance, and permit selection of traits which merit further study under field or greenhouse conditions.

Maximum rooting depth

For the third hypothesis, it was assumed that a deeper penetrating root system has the potential to increase the plant's capability to extract water from deeper soil layers, which previously have been unexplored by the root system. Because the plants will still have the same total root biomass and root length, actual root length density will decrease with a lower maximum rooting depth and will increase with a shallower maximum rooting depth. It is assumed in the model that roots will not grow deeper than the maximum rooting depth. This can either be caused by genetic constraints of the cultivar or physical factors in the soil profile. For this study, the rooting characteristics of the cultivar determine the maximum rooting depth and no other physical soil conditions, except soil water, limit root growth.

Under standard conditions, the maximum rooting depth of the model for the soil conditions at CIAT-Palmira is 1.25 m. The maximum rooting depth was varied at increments of ± 0.05 m. A very shallow soil of 0.6 m was selected for the minimum depth, while the maximum depth was 1.5 m (Fig. 12). The average biomass gradually increased from 3000 kg/ha to 4000 kg/ha when maximum rooting depth increased from 0.6 m to 1.2 m. For maximum rooting depths below 1.25 m, there was no significant difference in the mean total biomass predicted at the end of the season. Yield increased from 1300 kg/ha to 2100 kg/ha, with most of the increase occurring when rooting depth was lowered from 0.6 m to 1.25 m (Fig. 13). Except for the shallow rooting depth, WUE increased significantly when maximum rooting depth increased and roots were allowed to penetrate deeper into the soil profile (Fig. 14). These model predictions show that yield, biomass, and WUE will be higher for plants with deeper roots, than for plants with shallower roots. Therefore opportunities exist for plant breeders to select for plants which show root systems with deep penetrating roots early during the growing season.

Root length weight ratio

The last rooting characteristic to be studied with the simulation model was the root length weight ratio. This factor is an indication of the thickness of the root system, similar to the specific leaf area of the canopy. Thin roots have a rather high root length weight ratio, while thick roots have a low root length weight ratio. In the model, it is assumed that all roots have the same thickness, and that there is no difference between tap roots, primary roots, and secondary roots. Growth in the model is based on carbohydrate balance, and therefore a certain amount of carbohydrate is allocated to the root system. Given a certain amount of root biomass, the root length weight ratio will determine the total length of new root growth. This in turn determines the total root length which is potentially available for water uptake. In general, the longer the total root length of a plant, the larger the amount of water which can be extracted by the entire root system. In the current version of the model, it is assumed that the root length weight ratio is 5000 cm/g, which is rather low compared with field observations. For this study we are mainly interested in the relative effects of the parameter modifications, and therefore absolute values are not very important.

The root length weight ratio was changed with increments of ± 10 %, with a minimum value of 3000 cm/g and a maximum value of 10000 cm/g. The root system with a ratio of 10000 cm/g is three times as long as the root system with a ratio of 3000 cm/g. Yield increased from 1350 kg/ha to 2300 kg/ha, with most of the increase occurring when the root length weight ratio changed from 3000 to 6000 cm/g (Fig. 15). Total predicted biomass showed a similar response to the increase in root length weight ratio. It is interesting to note that, while the total root system was confined to the same total soil volume, accumulated transpiration and therefore total water uptake by the root system at the end of the growing season increased significantly when the root length weight ratio increased. A total accumulated transpiration of 135 mm was predicted for plants with a root length weight ratio of 3000 cm/g, and a total of 185 mm was predicted for plants with a root length weight ratio of 10000 cm/g (Fig. 16). In all cases the standard deviation was very small, independent of either planting date or weather year.

Conclusions

In this paper, we have shown the potential application of a computer simulation model in studies of crop response to drought. Depending on the type and amount of data available, the model can be used to study the potential yield under drought conditions and determine if breeding for higher yield is feasible, or if, due to environmental conditions, yield will never be higher than a certain amount. The model can also be used to suggest which characteristics of plants will make them more susceptible or resistant to drought stress. Breeders can then use the results of these theoretical studies to orient their breeding program. However, one needs to keep in mind that a model is never "perfect", and will never be able to simulate a system completely, as in this example, a bean crop. To develop a model, a modeler has to make assumptions, and the results of the model are only valid within the realm of these assumptions. The results shown in this paper, however, clearly show a potential use of models in the field of drought stress studies.

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Figure Legends

Figure 1.	Total accumulated rainfall for the entire growing season at CIAT Palmira as a function of planting date. There are eight (1979-1986) simulations for each planting date.
Figure 2.	Biomass predicted at the end of the growing season as a function of planting date.
Figure 3.	Biomass predicted at the end of the growing season as a function of total seasonal rainfall.
Figure 4.	Final seed yield as a function of planting date.
Figure 5.	Final seed yield as a function of total seasonal rainfall.
Figure 6.	Cumulative probability as a function of final yield.
Figure 7.	Mean, maximum, and minimum predicted biomass (Δ, X, ± 1 sd.) at the end of the growing season as a function of specific leaf area (vertical line represents value for SLA used in the standard version of the model).
Figure 8.	Mean, maximum, and minimum predicted seed yield (Δ, X, ± 1 sd.) as a function of specific leaf area (vertical line represents value for SLA used in the standard version of the model).
Figure 9.	Water use efficiency (yield efficiency) as a function of specific leaf area (vertical line represents value for SLA used in the standard version of the model).
Figure 10.	Predicted seed yield (Δ, X, ± 1 sd.) as a function of biomass partitioning to the root system (vertical line represents value used for partitioning in the standard version of the model).
Figure 11.	Mean, maximum, and minimum predicted biomass (Δ, X, ± 1 sd.) at the end of the growing season as a function of biomass partitioning to the root system (vertical line represents value used for partitioning in the standard version of the model).

Figure 12. Mean, maximum, and minimum predicted biomass (Δ, X, ± 1 sd.) at the end of the growing season as a function of maximum rooting depth (vertical line represents value used for maximum rooting depth in the standard version of the model).

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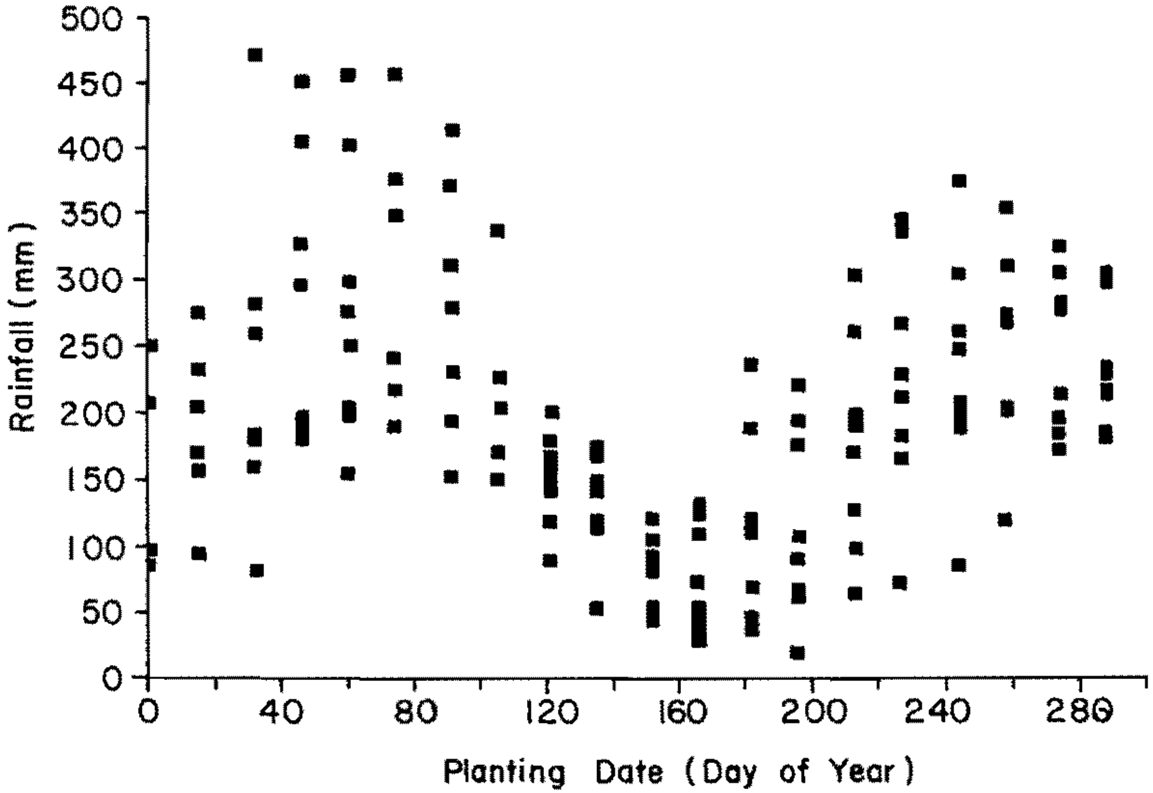
Figure 14. Water use efficiency (yield efficiency) as a function of maximum rooting depth (vertical line represents value used for maximum rooting depth in the standard version of the model).

Figure 15. Predicted seed yield (Δ, X, ± 1 sd.) as a function of root length weight ratio (vertical line represents value used for maximum rooting depth in the standard version of the model).

Figure 16. Total accumulated transpiration (Δ, X, ± 1 sd.) for the entire growing season as a function of root length weight ratio (vertical line represents value used for maximum rooting depth in the standard version of the model).



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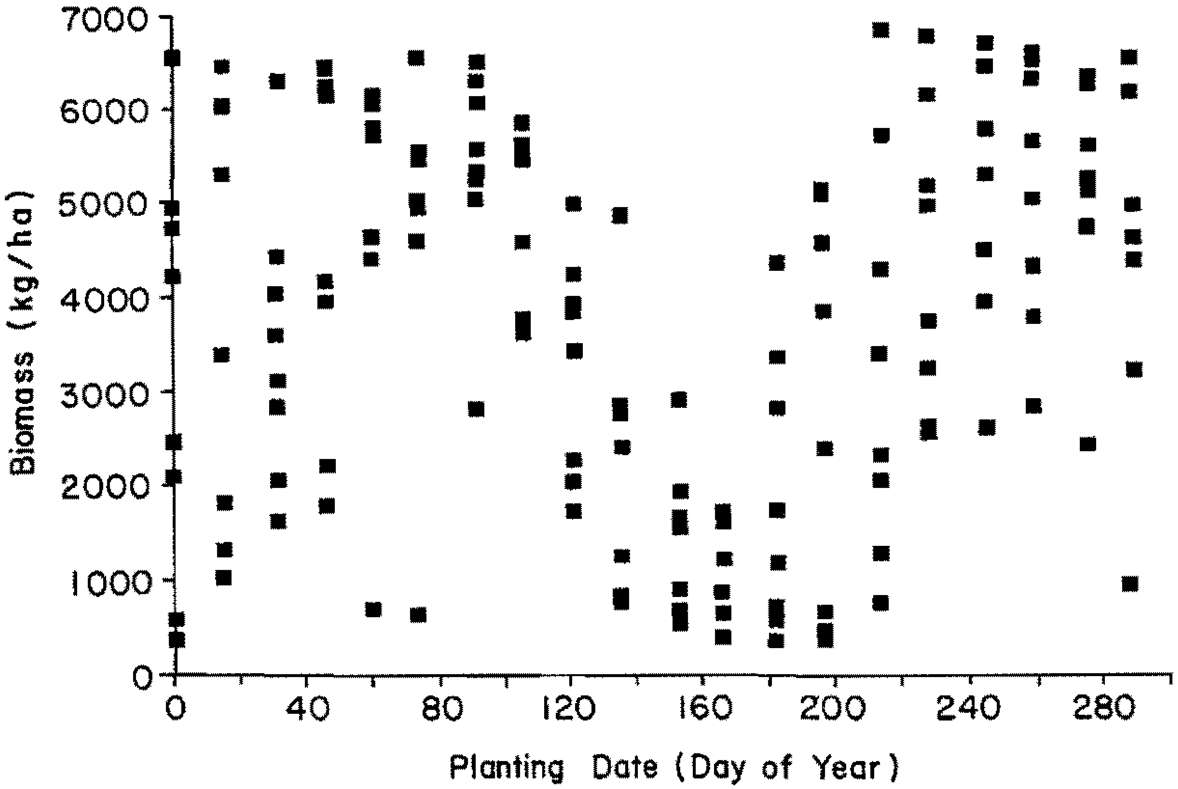


Figure 2. Biomass predicted at the end of the growing season as a function of planting date.

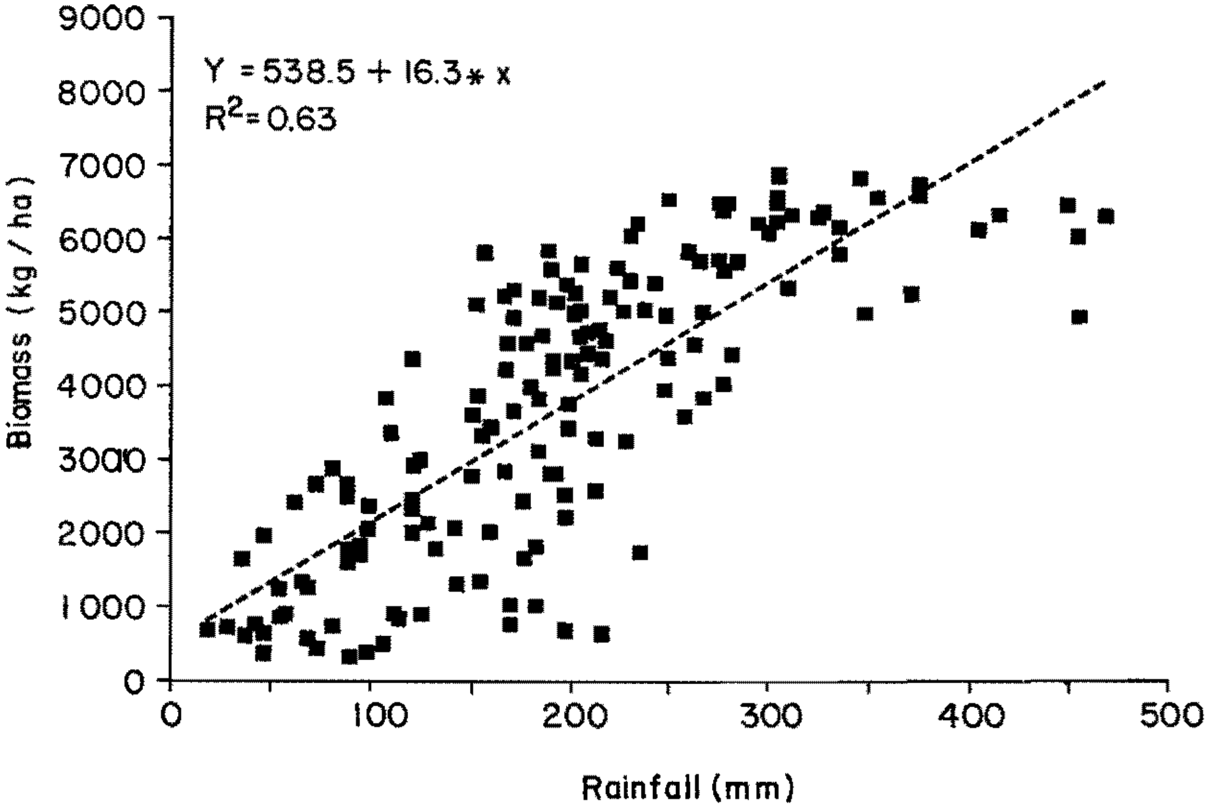


Figure 3. Biomass predicted at the end of the growing season as a function of total seasonal rainfall.

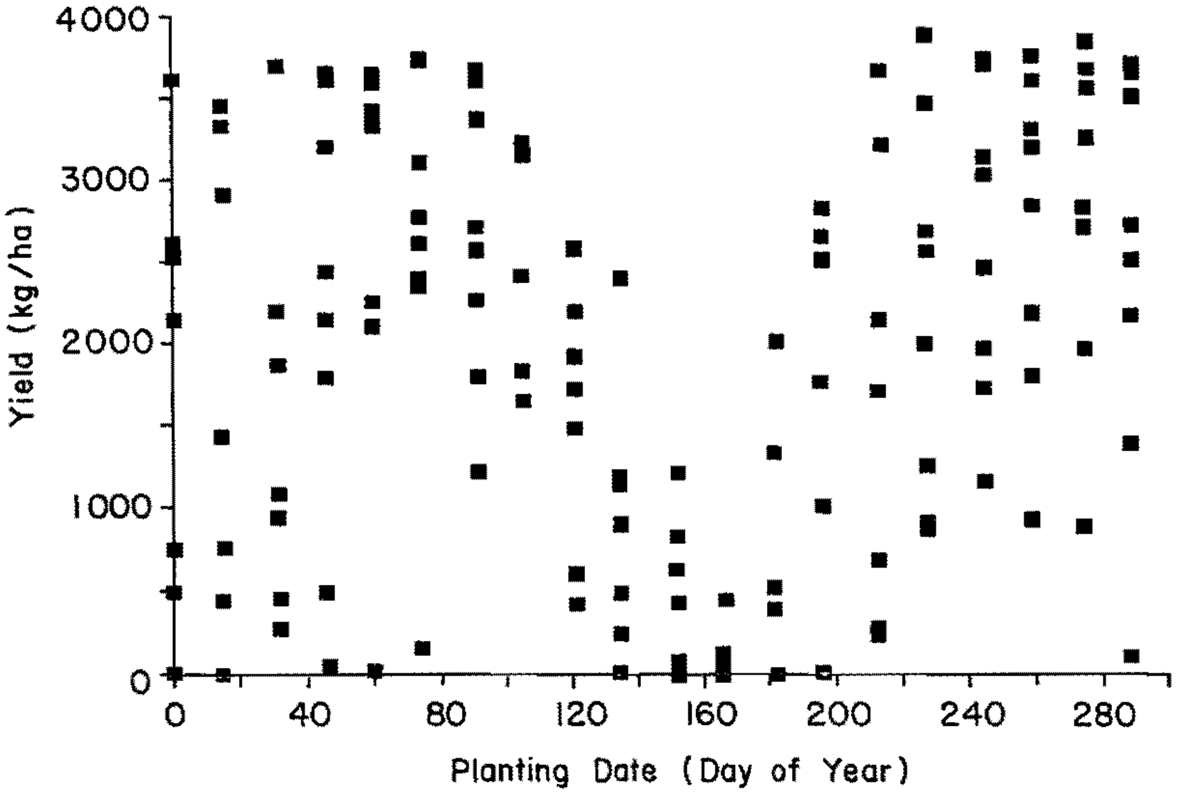


Figure 4. Final seed yield as a function of planting date.

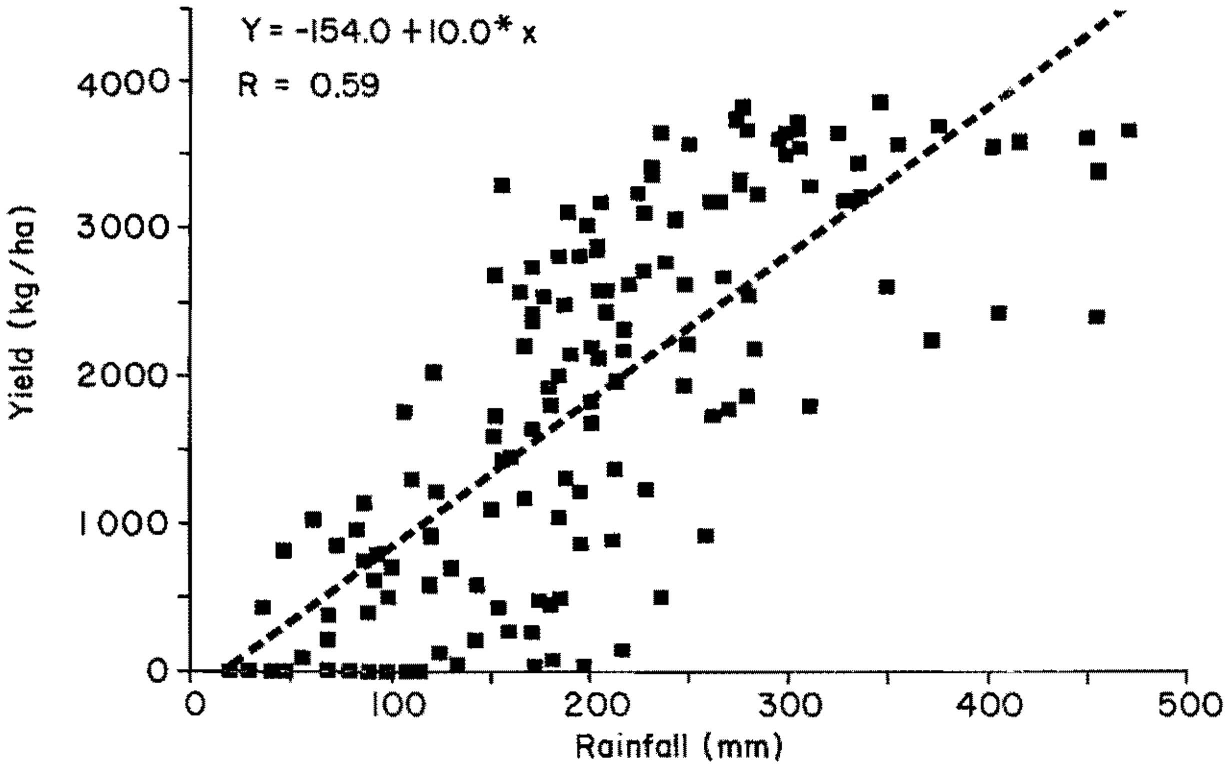


Figure 5. Final seed yield as a function of total seasonal rainfall.

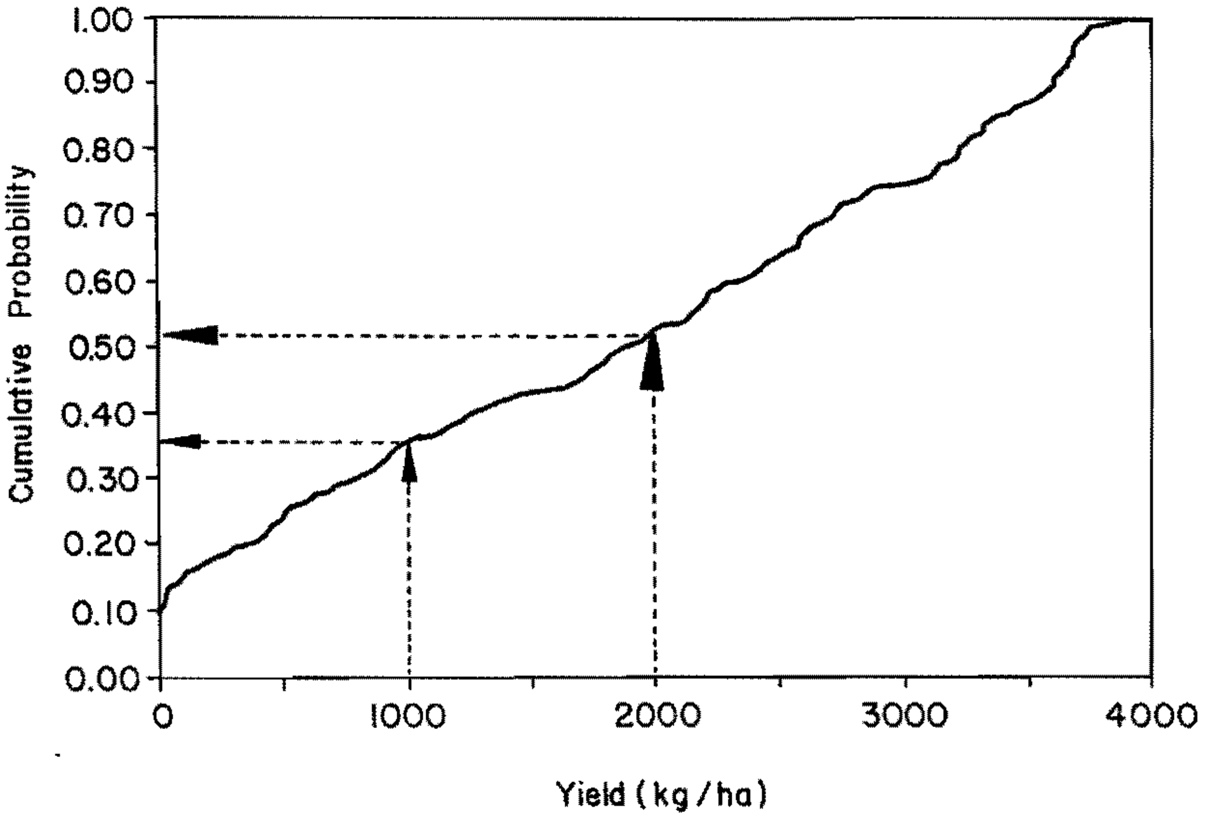


Figure 6. Cumulative probability as a function of final yield.

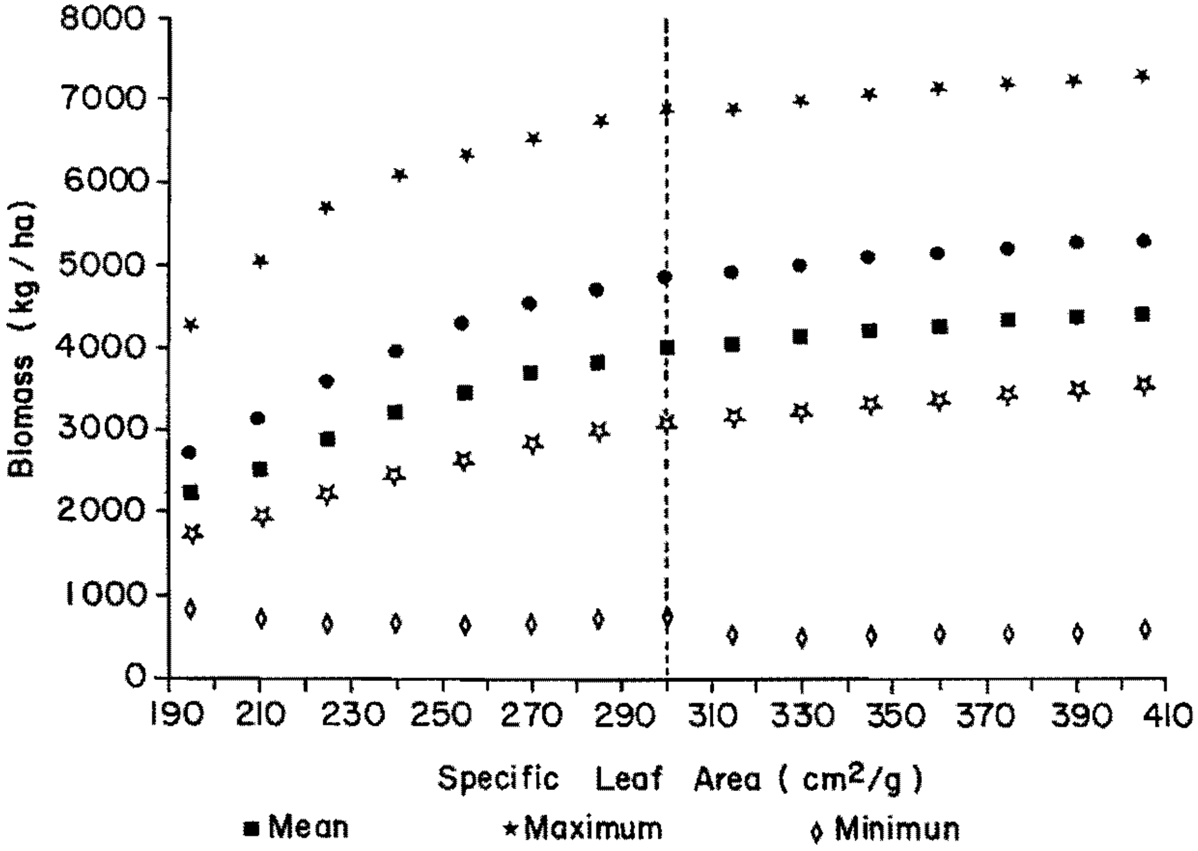


Figure 7. Mean, maximum, and minimum predicted biomass (Δ, X, ± 1 sd.) at the end of the growing season as a function of specific leaf area (vertical line represents value for SLA used in the standard version of the model).

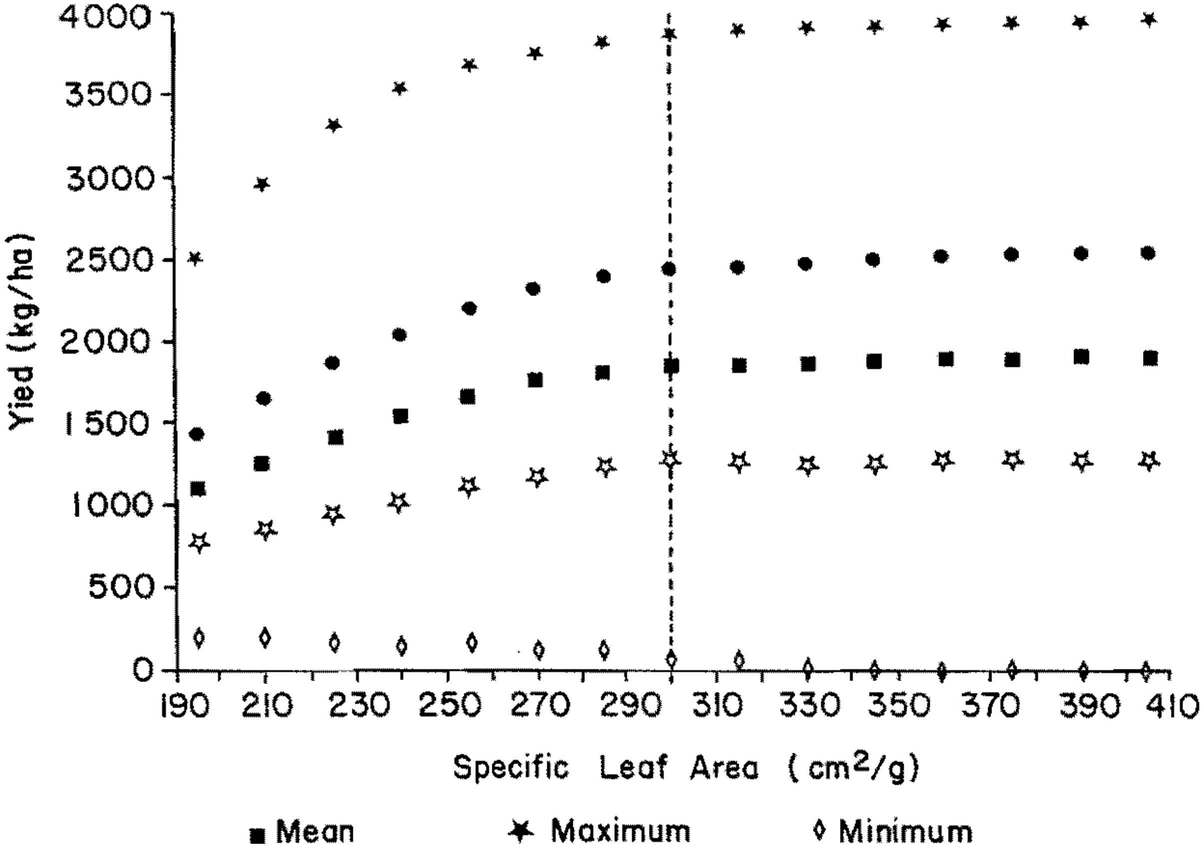


Figure 8. Mean, maximum, and minimum predicted seed yield (Δ, X, ± 1 sd.) as a function of specific leaf area (vertical line represents value for SLA used in the standard version of the model).

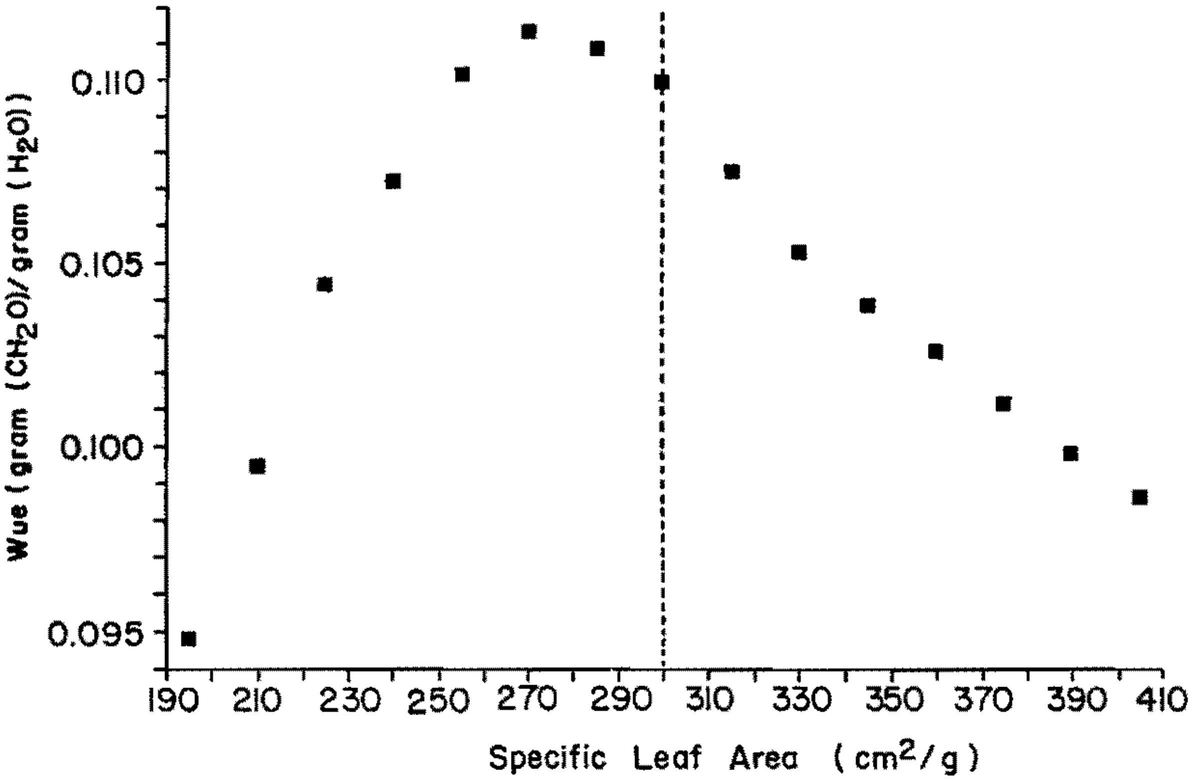


Figure 9. Water use efficiency (yield efficiency) as a function of specific leaf area (vertical line represents value for SLA used in the standard version of the model).

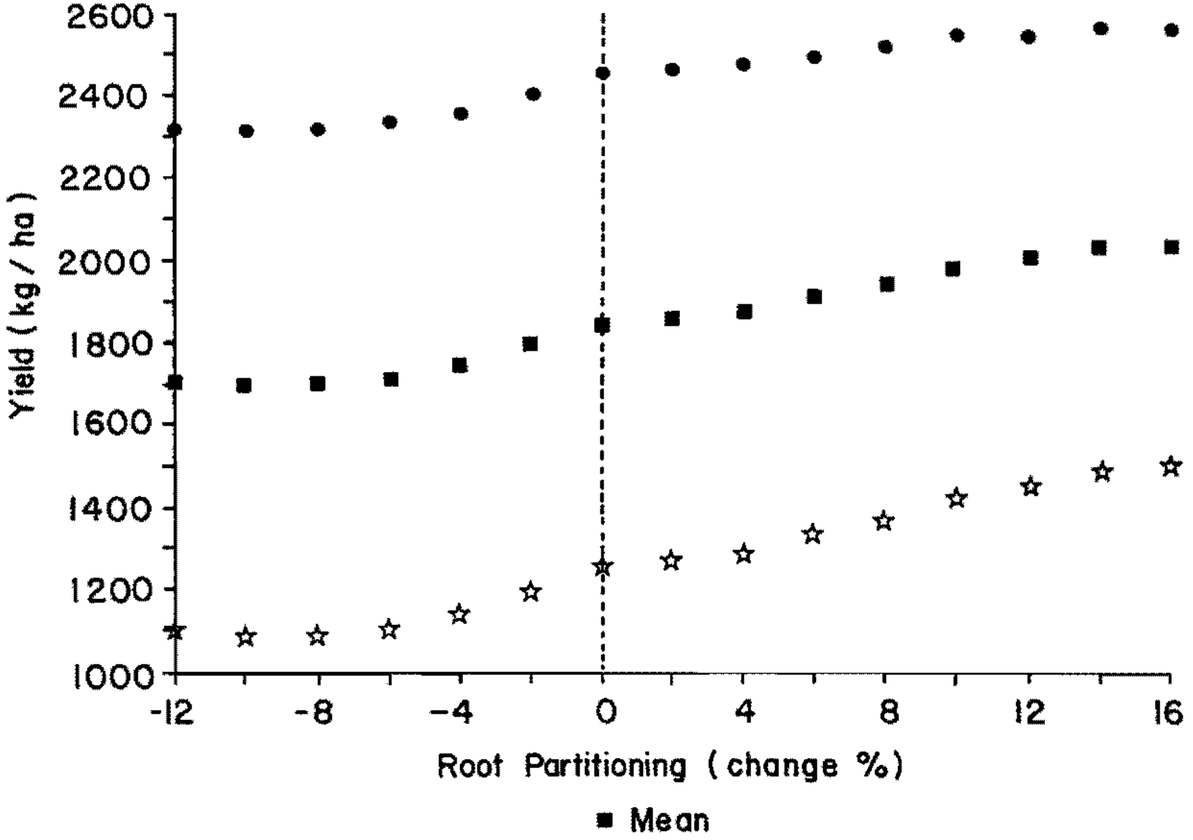
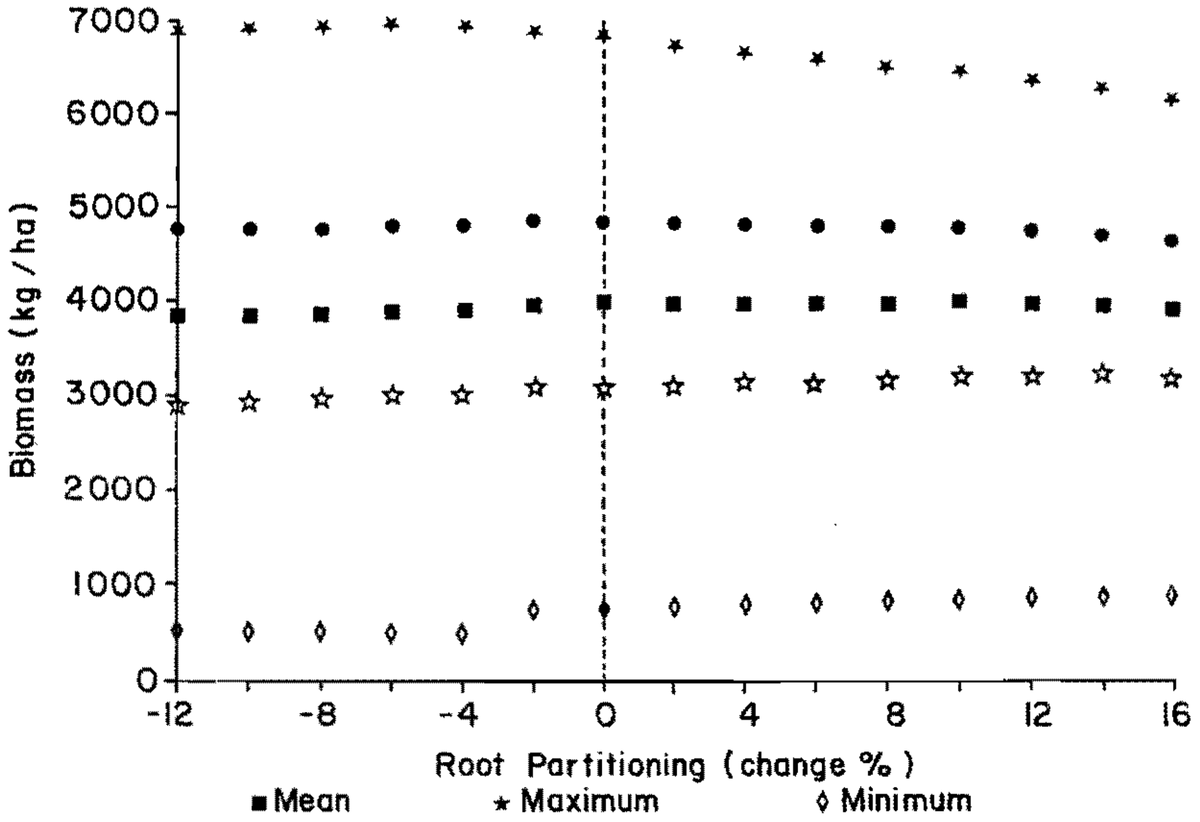


Figure 10. Predicted seed yield (Δ, X, $\pm$ 1 sd.) as a function of biomass partitioning to the root system (vertical line represents value used for partitioning in the standard version of the model).



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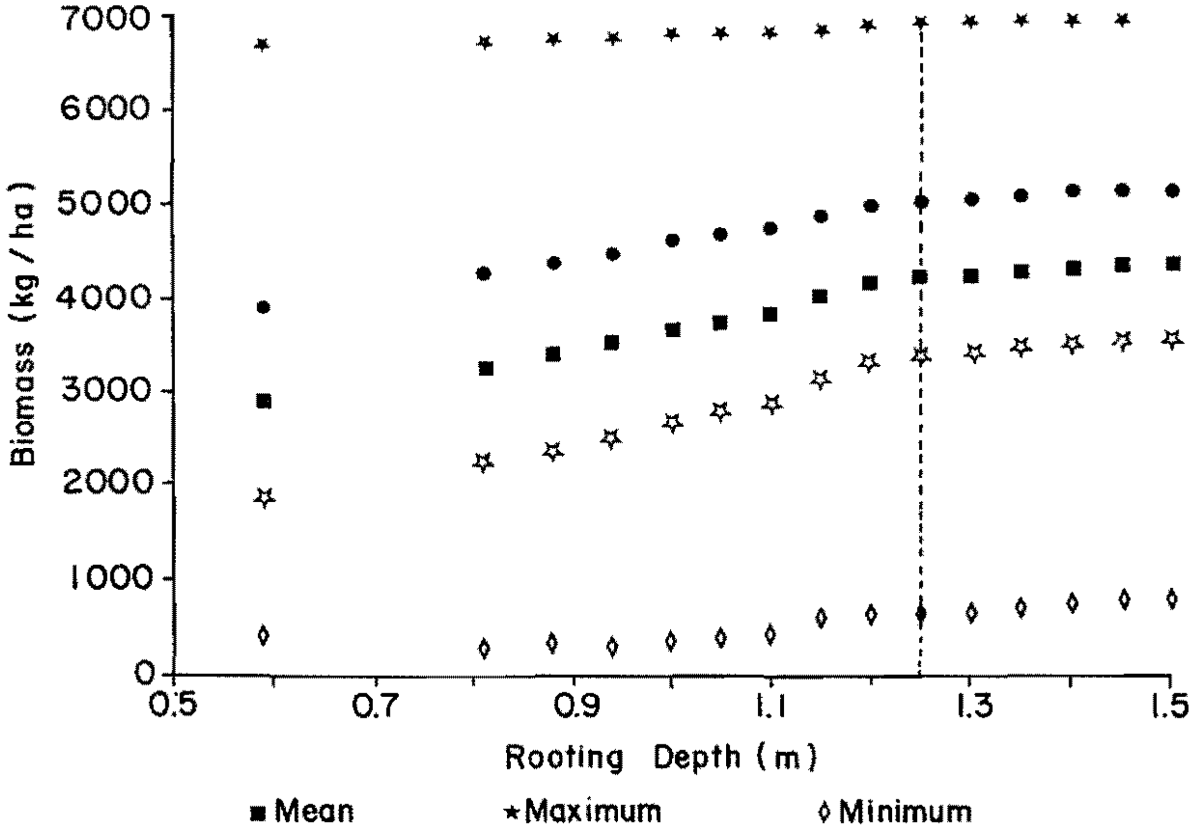
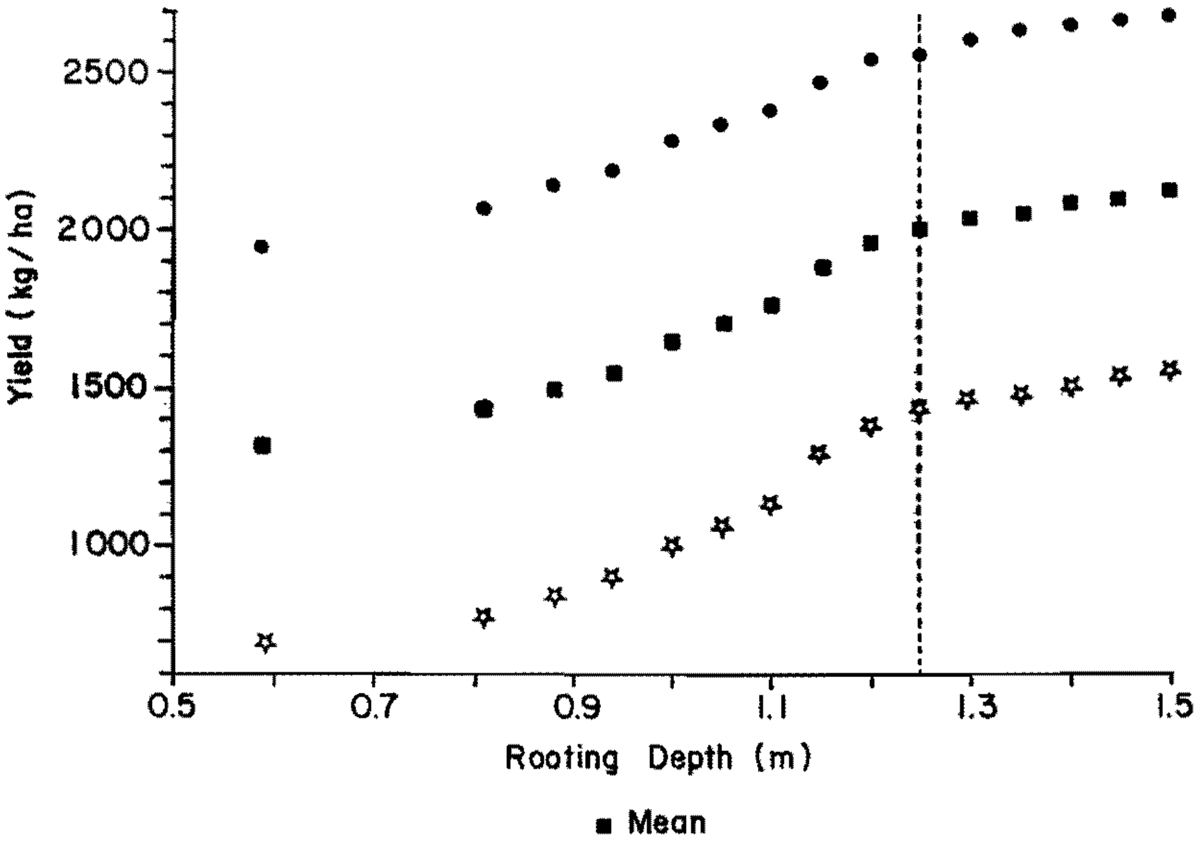


Figure 12. Mean, maximum, and minimum predicted biomass (Δ, X, ± 1 sd.) at the end of the growing season as a function of maximum rooting depth (vertical line represents value used for maximum rooting depth in the standard version of the model).



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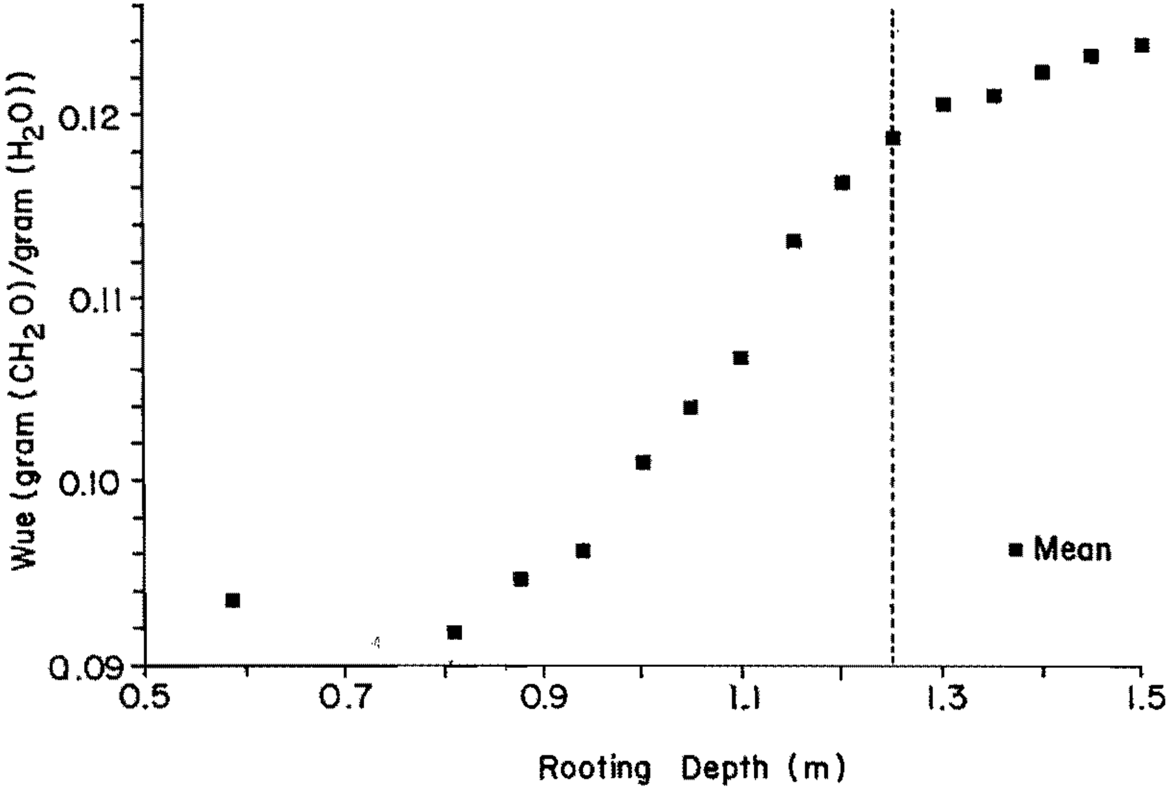

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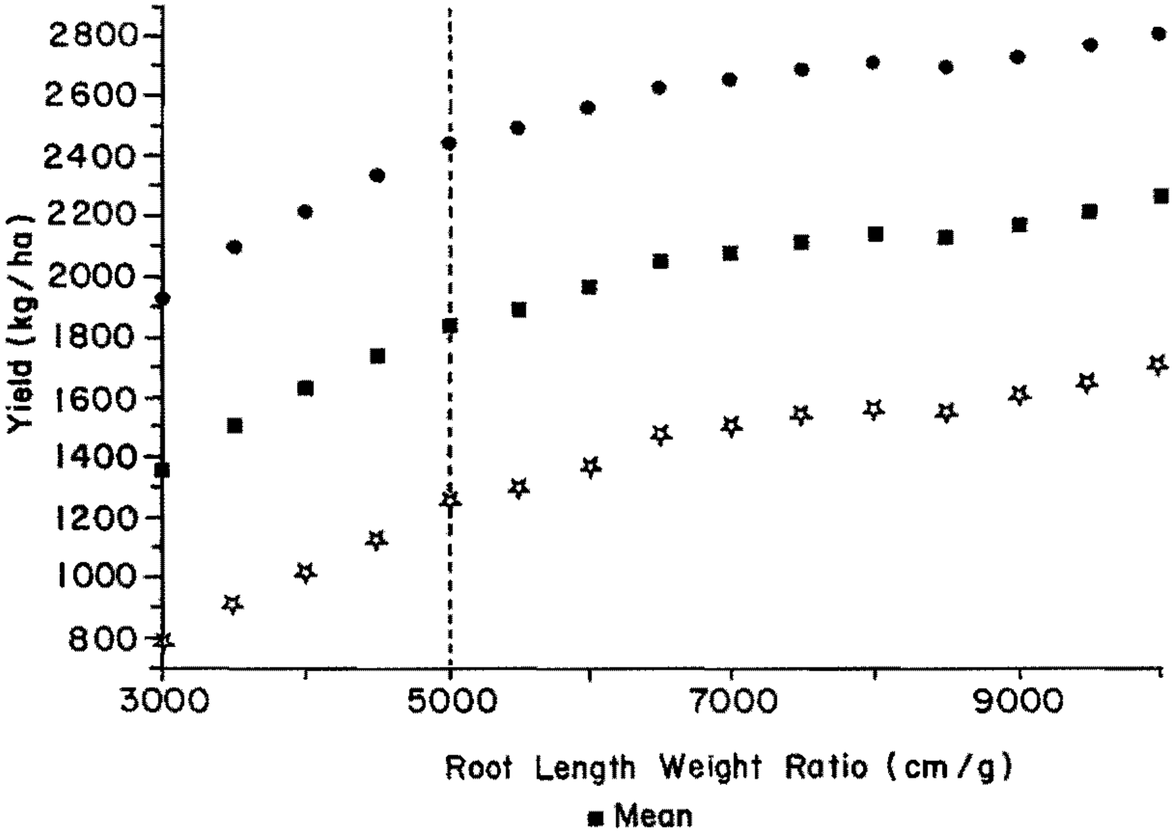

Figure 15. Predicted seed yield (Δ, X, ± 1 sd.) as a function of root length weight ratio (vertical line represents value used for maximum rooting depth in the standard version of the model).

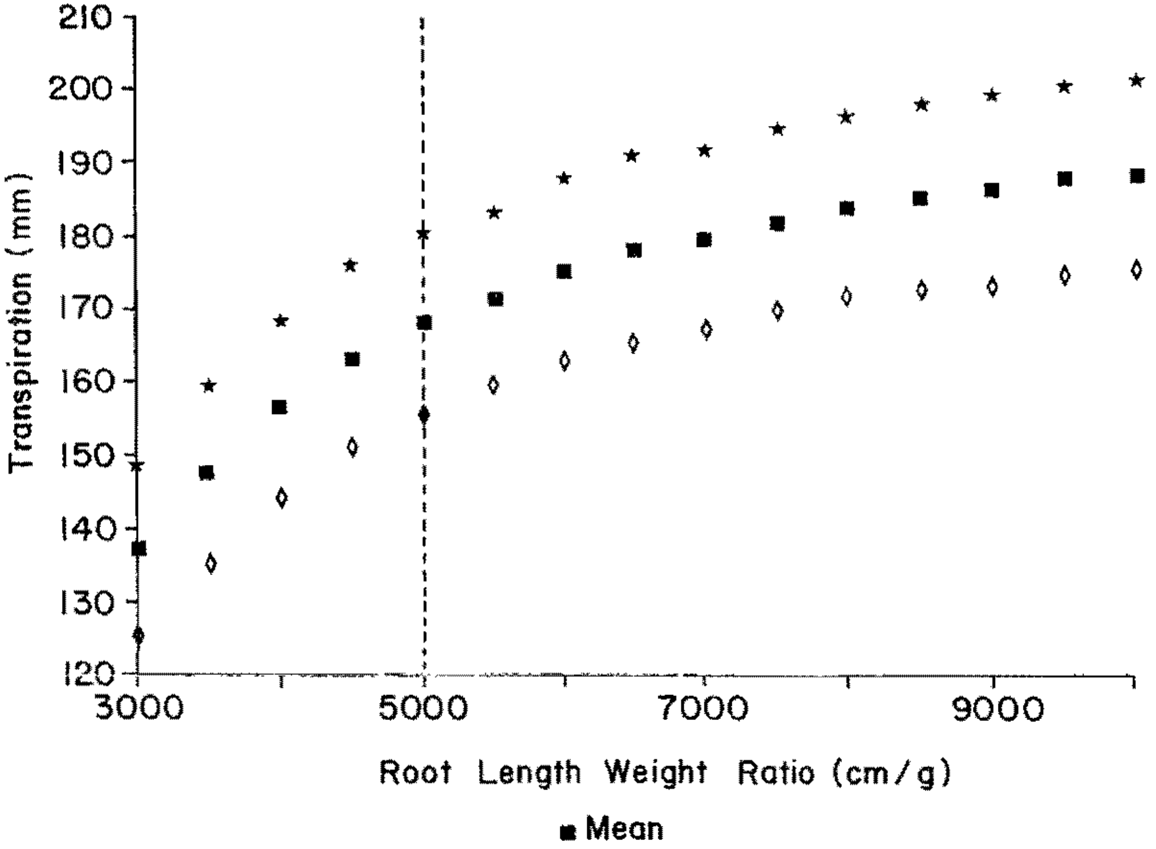

Figure 16. Total accumulated transpiration (Δ, X, ± 1 sd.) for the entire growing season as a function of root length weight ratio (vertical line represents value used for maximum rooting depth in the standard version of the model).

CARACTERIZACION DE LAS SEQUIAS EN CONDICIONES DE RIEGO Y SECANO EN TERMINOS DE LOS REQUERIMIENTOS DE AGUA DE LOS CULTIVOS

Manuel Paulet*

Introducción

Se presentan algunas reflexiones desde el punto de vista de las relaciones de productividad agua-suelo-planta considerando lo que el autor ha podido apreciar de las discusiones realizadas en el Taller de IBYAN y, en parte, del taller de Sequías. La observación principal es que, en general, con excepciones, las investigaciones realizadas no introducen la cantidad de agua utilizada como elemento de variación, quedando una preocupación cuando se descartan resultados aparentemente sin éxito sin haber analizado cuál fue la situación agua-suelo durante la ejecución del trabajo. En relación con las sequías, parecería aún más relevante que las investigaciones incluyan observaciones sobre la condición suelo-agua-planta. Los conceptos utilizados en estas reflexiones se presentaron en el Taller de IBYAN.

Discusión

1. Un indicador de la condición de las plantas en términos de su resistencia a períodos de déficit de agua (en relación con su demanda) es la cantidad de producto deseable (Y) por unidad de cantidad de agua utilizada (ET). Este indicador se podría expresar de diversas maneras según el interés del investigador: a) por etapas de crecimiento; b)

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considerando varias medidas del producto deseable según la etapa de crecimiento.

2. Para una misma cantidad de agua utilizada, las plantas que manifiestan una mayor relación (Y/ET) tendrían mayor resistencia al déficit de agua. Comparativamente las de mayor Y/ET tienen menor demanda de agua por unidad de producto.

3. Esto podría implicar:
   a) Que la demanda ET es menor porque el ciclo vegetativo es más corto.
   b) Que la demanda es menor porque la evapotranspiración del suelo (E), es menor.
   c) Que unas plantas producen más que otras con la misma cantidad de agua, o sea, que son más eficientes en la utilización del agua (menor Kc).
   d) Que unas plantas pueden satisfacer sus necesidades de agua con más altas tensiones de humedad en el suelo que otras.

4. Dependiendo de las condiciones el objetivo de la resistencia a las sequías estaría orientado hacia las dos últimas condiciones.

5. En la práctica la (ET) se estima mediante ecuaciones en función de las condiciones del clima (RAD, TE, HREL) y de las características de las plantas (Kc). En el trabajo presentado en el Taller sobre Mejoramiento de Fríjol se dan ejemplos de cálculo y referencias sobre la metodología. La medición de ET real se realiza mediante el cálculo del balance hídrico del cual resulta difícil medir las pérdidas por percolación y cambio en el almacenamiento del suelo. Experimentalmente la medición se realiza con lisímetros. (ET = R - (PE + AS)).

6. El estimado de ET por etapas del cultivo para todo el ciclo vegetativo debe realizarse para conocer las demandas locales y la condición de déficit que deberá satisfacerse ya sea mediante lluvia o riego.

7. Como el riego o la lluvia son generalmente ineficientes en proveer la cantidad de agua requerida por ET, (por exceso o deficit), su cálculo permite conocer las cantidades de agua que se requerirán dependiendo del método de riego y/o la distribución y oportunidad de las lluvias.

8. Para condiciones de secano, los valores de ET (Figura 18, Paulet, M, Taller de IBYAN), permiten conocer el riesgo de éxito si se comparan con las lluvias probables.

9. El control de la humedad del suelo será siempre beneficioso para conocer la situación de energía del agua en el suelo - asociada a las lluvias o al riego y a la tasa de ET - y por tanto, apreciar las condiciones de "stress" que pueden presentarse (o ausencia de éste, caso existe agua en el subsuelo por nivel freatico alto, o exceso de lluvia o riego).

10. El control de la humedad del suelo es necesario para investigar las condiciones de sequía (3c y 3d) aunque fuera para poder correlacionar con otros indicadores medidos en la planta.

11. Para la agricultura en condiciones de secano, la variabilidad de las lluvias en el espacio y en el tiempo será siempre un factor de riesgo para la producción de cosechas.

12. A continuación presentamos un resumen del procedimiento utilizado en el análisis de un número de resultados experimentales de varios años en una localidad del Perú[1]. En este procedimiento se puede:

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[1] Paulet, M. 1973. Apreciación del significado del riego suplementario para la producción agrícola en la Sierra del Perú. UNA/DKA/USAID. 61p.

a) Apreciar el efecto de la cantidad de lluvia sobre la variación de rendimientos en interacción con varios niveles de fertilización.
b) Apreciar el riesgo de la agricultura de secano para tomar decisiones.
c) Ajustar la oportunidad de siembra a las mejores probabilidades de éxito.

Relación entre la cantidad de agua de lluvia y la productividad en interacción con varios niveles de NPK.

13. Se relacionan los rendimientos obtenidos con las cantidades de NPK aplicados, más las cantidades de lluvia caídas, ya sean en períodos críticos (PC) y/o durante el ciclo vegetativo del cultivo (PT). Posteriormente se analizan las frecuencias de dichas cantidades de agua, provenientes de los registros de lluvia existentes, para conocer la probabilidad de ocurrencia de las cantidades de lluvia consideradas y, por ende, la probabilidad de obtener los rendimientos asociados a esas cantidades con el nivel de fertilización incluido. Para obtener variación en los resultados, los trabajos deben replicarse en lugares diferentes (aunque habría otros factores si la variación de suelos es importante) o en un número de años. Veinte o más resultados de rendimientos serían deseables.

14. El análisis estadístico es regresión múltiple buscando la ecuación de mejor ajuste - stepwise regression - mediante cambios en las variables y sus interacciones, conociendo las probables tendencias de estas relaciones (Cuadro 1). El análisis de frecuencias consiste en el ordenamiento de los datos mensuales de lluvias de mayor a menor, para uno, dos, tres, cuatro, meses consecutivos según la duración del período crítico (PC) o ciclo vegetativo (PT) -- en relación con el abastecimiento de agua a la planta -- que se desee examinar. las cantidades obtenidas se presentan en tablas como el Cuadro 2. La

última columna del Cuadro 2 indica la probabilidad $(P (X = x) = m/(N+1))$, de que una lluvia (X) en un año cualquiera sea igual o mayor que (x) - aquella a que está asociado en la tabla-.

15. Por ejemplo, en el Cuadro 2, si la siembra fuera el primero de septiembre, la probabilidad de que caigan 13 cm (asociado a bajos rendimientos en la Figura 2), durante el período de 60 a 120 días después de la siembra -- columna de noviembre -- es de 70% (ver nota[1]). Para esta fecha de siembra, mayores cantidades de agua que 13 cm están asociadas a menores probabilidades. Si cambiamos la fecha de siembra a primero de noviembre -- la columna de enero representa el período de 60 a 120 días después de la siembra --, se observa que existe un 75% de probabilidades de obtener por lo menos 20 cm de lluvia en ese período, lo que está asociado con rendimientos óptimos (Figura 2).

16. La información del Cuadro 2 se transfiere a un gráfico como la Figura 1 (Log x probabilidades) para linearizar el comportamiento de los datos de lluvia en función de sus frecuencias. Para el caso de eventos hidrológicos como las lluvias, la distribución de sus frecuencias se puede linearizar bastante bien cuando se utilizan los logaritmos de sus magnitudes, queriendo indicar que los eventos menos frecuentes tienen magnitudes extremas o muy distintas de la media. La relación probabilidades con cantidad de agua de lluvia que aparece en la Figura 2 provienen de la Figura 1.

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[1] m, número de orden de 13 cm = 38, N, número total de registros = 53, entonces, $P = 38/(53 + 1) = 0.7037$

Cuadro 1. Función de producción del cultivo de papa en el Mantaro.

Nombre	Código variable	Coeficiente	F/var	Valor máximo	Promedio	Valor mínimo	Desv. standard	Unidades
Constante		-122153.						
N	NITRO	129.25	5.67	280	114	0	74.4	kg/ha
N^2	TRFB	0.1074	0.82					
P	FOSFO	173.59	8.22	240	86	0	63	kg/ha
P^2	TRFC	0.2418	2.23					
K	POTAS	62.15	0.88	240	101	0	66	kg/ha
K^2	TRFD	0.1474	0.86					
PT	AGPT	300.46	5.12	89.8	58.4	41.3	9.9	cm
PC	AGPC	9259.12	38.19	30.7	23.9	15.4	4.4	cm
PC^2	TRFF	-173.07	29.78					
NxK	MULTA	-0.2185	2.65					
NxPC	MULTC	-4.3899	3.38					
PxPT	SALTC	-3.3543	10.34					
PxPC	SUBEA	-3.5154	1.43					
Y	RENDI			37,774	16,011	1,238	8,234	kg/ha
Observaciones		157						
R^2		0.36						
F		6.15**						

PC Precipitación crítica en el cultivo de papa (cantidad de lluvia desde 60 a 120 días después de la siembra).

** Aquí y en los siguientes cuadros, indica significación al 99% de probabilidades.

Cuadro 2. Cantidad de lluvia en mm
Suma de 2 meses consecutivos - ordenándolas descendentemente y cálculo de la probabilidad respectiva.

SET	OCT	NOV	DIC	ENE	FEB	MAR	ABR	MAY	JUN	JUL	AGO	PROB
212.30	218.10	249.20	312.40	364.60	361.40	297.90	179.60	104.70	44.70	88.60	0.00	0.0185
196.00	206.50	247.70	296.90	339.00	350.80	283.70	174.10	79.00	37.10	85.20	0.00	0.0370
173.30	205.80	241.90	293.20	331.70	350.20	273.50	169.40	71.90	36.30	59.90	0.00	0.0556
151.60	190.50	235.00	289.10	323.60	330.70	240.00	135.40	62.80	34.70	56.40	0.00	0.0741
150.30	188.80	224.80	286.70	312.70	327.60	236.50	131.10	60.50	33.40	52.40	0.00	0.0926
148.40	180.80	213.90	284.80	308.30	327.60	234.50	126.40	53.60	32.00	52.00	0.00	0.1111
146.40	177.60	210.80	284.40	306.50	324.60	234.00	124.40	51.10	29.40	46.40	0.00	0.1296
143.00	173.50	205.50	283.00	300.50	313.70	224.60	113.30	50.10	28.50	45.20	0.00	0.1481
142.20	169.90	203.70	264.40	299.70	290.80	222.20	110.30	50.10	28.20	36.10	0.00	0.1667
142.00	164.90	202.50	263.60	299.40	289.60	213.90	104.10	48.80	27.50	33.20	0.00	0.1852
141.50	164.30	193.10	252.50	298.00	280.90	213.10	102.30	48.50	26.50	32.70	0.00	0.2037
138.20	163.30	191.30	251.90	297.80	274.90	206.70	101.10	47.00	25.60	30.90	0.00	0.2222
137.30	155.00	198.80	251.40	293.30	269.90	204.00	99.30	46.70	24.90	30.70	0.00	0.2407
133.90	147.60	186.10	250.60	293.10	266.10	199.10	96.30	46.20	24.50	30.20	0.00	0.2593
127.90	146.30	185.60	249.90	279.20	262.60	195.60	91.70	45.30	23.20	28.20	0.00	0.2778
127.90	146.10	185.10	244.90	278.80	259.60	195.00	89.50	44.00	21.90	28.20	0.00	0.2963
126.00	146.00	184.30	242.80	276.60	259.30	186.50	88.70	43.10	21.40	27.50	0.00	0.3148
124.40	145.50	177.10	239.00	274.00	259.10	177.60	85.00	43.00	18.60	27.40	0.00	0.3333
123.00	144.10	170.20	236.40	269.60	258.00	176.80	83.00	42.70	17.80	27.10	0.00	0.3519
120.20	143.00	166.80	234.70	266.50	251.30	175.20	82.90	39.30	17.60	26.50	0.00	0.3704
119.20	141.40	166.10	224.80	264.70	249.20	172.50	81.40	39.10	17.30	26.50	0.00	0.3889
118.30	139.40	163.60	222.30	261.10	248.90	170.70	80.30	38.50	16.30	25.60	0.00	0.4074
117.30	139.30	160.80	219.80	254.30	248.80	169.90	77.00	36.30	15.70	24.40	0.00	0.4259
116.60	135.60	158.70	219.80	251.20	244.70	167.80	76.00	36.10	15.00	24.10	0.00	0.4444
113.80	135.10	158.60	217.70	250.40	244.60	164.70	71.40	34.60	13.70	21.90	0.00	0.4630

Cont.

Cuadro 2. Cont.

SET	OCT	NOV	DIC	ENE	FEB	MAR	ABR	MAY	JUN	JUL	AGO	PROB
111.60	133.90	156.00	215.40	246.00	242.10	163.90	70.70	30.80	13.50	20.40	0.00	0.4815
110.10	132.70	155.90	214.90	245.50	241.80	162.30	70.20	29.20	13.50	19.80	0.00	0.5000
106.40	130.00	154.50	212.30	241.60	232.60	159.20	69.30	28.20	12.90	19.70	0.00	0.5185
102.90	124.70	152.70	210.90	239.10	221.80	157.20	67.30	27.10	12.70	19.10	0.00	0.5370
101.40	124.00	150.70	209.00	236.10	220.80	155.40	66.60	26.90	11.50	18.80	0.00	0.5556
101.40	123.60	150.10	208.60	232.70	212.10	155.20	66.20	26.50	11.20	18.80	0.00	0.5741
98.80	123.50	148.80	202.40	231.40	202.20	152.70	64.00	25.90	10.40	18.30	0.00	0.5926
98.60	122.80	148.60	198.70	230.10	202.20	146.80	61.80	25.30	9.70	15.80	0.00	0.6111
97.30	122.40	148.50	197.50	218.40	200.60	144.10	61.70	23.90	9.60	15.70	0.00	0.6296
97.30	121.50	148.10	195.80	216.20	200.20	144.00	61.50	19.60	9.50	15.30	0.00	0.6481
91.90	120.20	142.80	195.60	212.60	196.10	143.30	58.70	19.30	8.90	14.70	0.00	0.6667
91.70	118.10	141.10	193.20	205.50	192.80	136.20	57.20	18.90	8.60	12.20	0.00	0.6852
88.90	117.50	130.50	192.50	203.20	190.50	132.80	57.10	18.70	6.90	11.70	0.00	0.7037
85.60	116.40	129.60	191.70	202.60	188.70	129.80	56.30	16.50	6.90	7.90	0.00	0.7222
84.90	114.40	127.70	191.40	200.90	187.90	127.70	56.10	15.60	6.80	7.20	0.00	0.7407
84.60	114.30	125.20	182.50	198.10	179.30	124.50	55.40	15.30	6.40	6.90	0.00	0.7593
81.70	109.30	122.90	176.70	190.50	169.10	124.30	54.90	14.50	6.30	6.10	0.00	0.7778
81.20	108.80	120.60	165.80	177.00	166.90	123.70	54.80	13.70	6.10	5.60	0.00	0.7963
79.30	107.10	120.40	159.00	175.70	160.30	114.10	52.10	13.50	6.10	5.00	0.00	0.8148
76.10	103.70	119.80	154.90	173.80	156.30	110.40	49.50	11.70	4.80	4.30	0.00	0.8333
74.40	102.20	119.10	152.90	173.50	154.10	110.00	49.00	11.20	2.70	3.10	0.00	0.8519
73.50	99.50	117.10	150.80	169.70	151.60	110.00	48.80	9.10	2.30	3.00	0.00	0.8704
72.40	98.30	116.40	148.80	164.40	139.70	105.70	47.10	8.00	1.80	2.30	0.00	0.8889
71.60	98.30	112.30	144.30	152.70	138.20	104.30	43.00	5.40	1.50	1.50	0.00	0.9074
65.80	90.50	109.10	139.20	152.10	137.10	97.50	42.40	5.10	1.30	0.90	0.00	0.9259
65.80	83.00	107.80	137.20	151.10	131.00	96.50	42.40	4.10	1.00	0.80	0.00	0.0444
56.90	81.30	107.20	129.30	144.70	128.80	92.70	42.10	3.80	0.00	0.00	0.00	0.9630
52.00	77.00	85.10	116.90	130.00	110.30	88.70	26.90	2.30	0.00	0.00	0.00	0.9815

Figuras

Fig.1. Distribución, probabilística de magnitudes de lluvia para precipitación total (PT) y precipitación crítica (PC) en Mantaro y Cajamarca, por cultivo y fecha de siembra.

Fig.2. Efecto del uso de fertilizantes y cantidad de lluvia en los rendimientos de papa en el Mantaro.

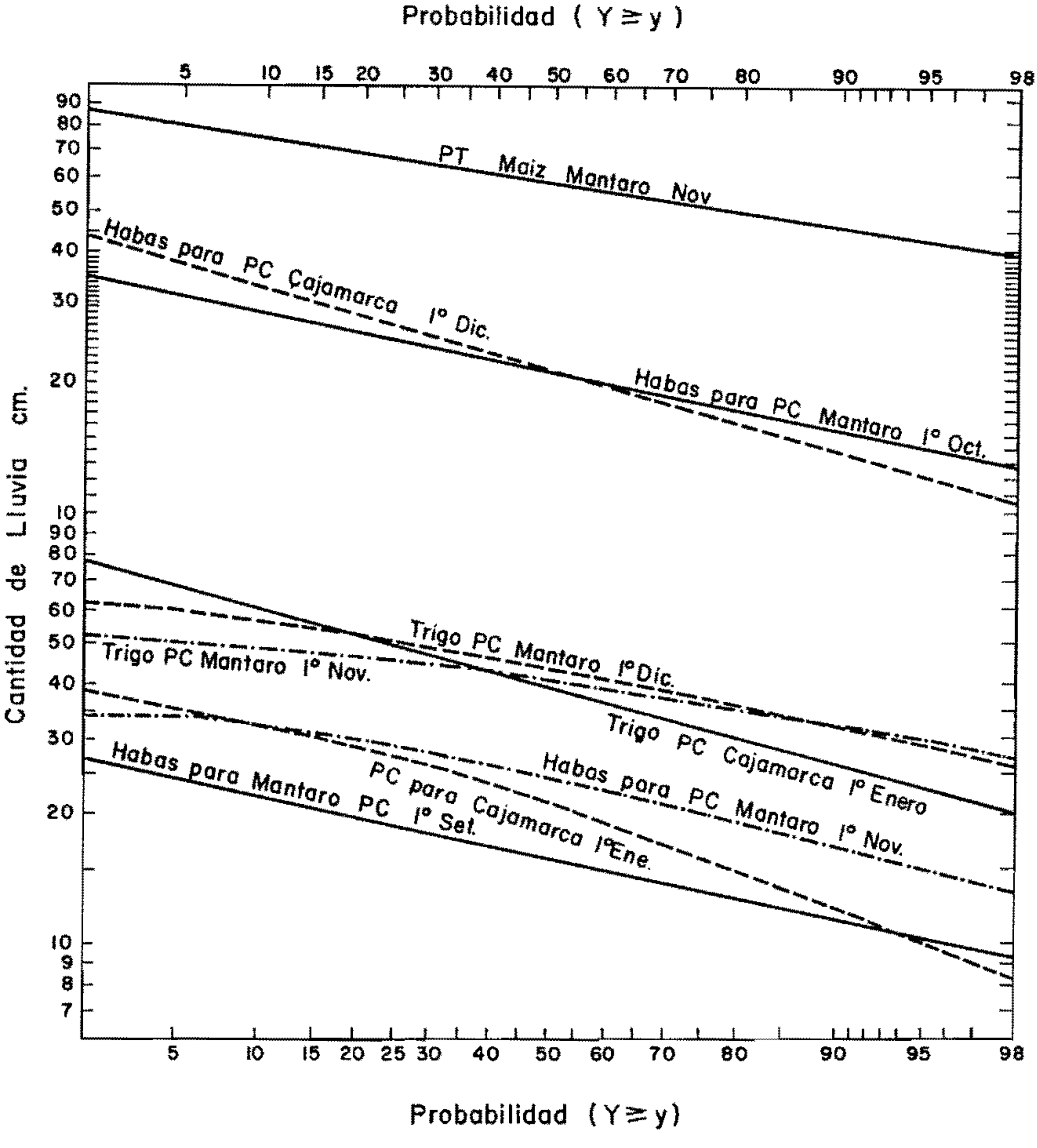

Figura 1. Distribución, probabilística de magnitudes de lluvia para precipitación total (PT) y precipitación crítica (PC) en Mantaro y Cajamarca, por cultivo y fecha de siembra.

Siembra	Probabilidad de que ocurra un PC igual o mayor que aquel que se elija																	
1° Septiembre	75	68	57	47	38	30	24	18	13	10	7	5	4	3	2				Mantaro
1° Octubre	97	95	92	87	80	75	65	58	50	44	35	30	25	20	15	12	10	8	
1° Noviembre	98	97	95	92	89	85	80	76	70	65	59	52	46	40	34	28	23	19	
1° Diciembre	92	89	85	80	75	70	61	58	51	47	42	37	33	28	25	22	19	16	Cajamarca
1° Enero	87	83	79	75	70	65	60	56	51	47	42	38	34	30	26	22	19	16	

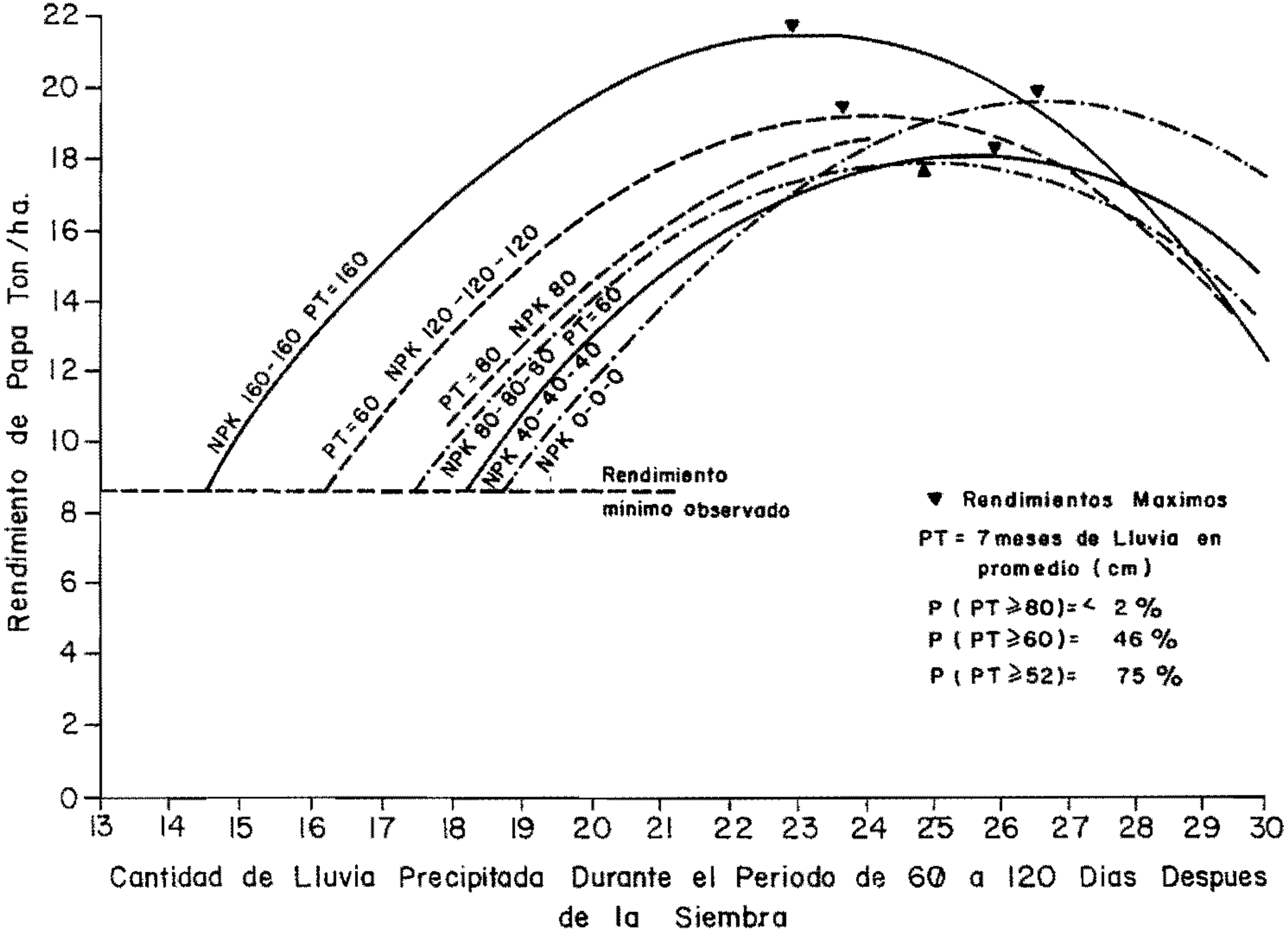

Figura 2. Efecto del uso de fertilizantes y cantidad de lluvia en los rendimientos de papa en el Mantaro.

MANAGEMENT OF DROUGHT TRIALS

J. Castillo and J.W. White*

Introduction

Progress in drought research depends on obtaining data which reflect effects of appropriate levels of moisture deficit, and which contain acceptably low levels of unexplainable variation, usually referred to as "experimental error". Experience at CIAT has been that effective strategies for managing nurseries cannot be pulled out of textbooks or transferred blindly from one site to another. Each nursery location presents particular problems depending on soil types, climatic conditions, and infrastructure.

The discussion of management in this chapter is drawn primarily from experiences at CIAT. Where relevant, research from other institutes working with beans has been included. Observations tend to be anecdotal since most researchers polish their nursery management without resorting to designed experiments producing publishable data. Emphasis is given to yield trials because they are the backbone of a sound drought program, and also since the principles for management of yield trials apply directly to other drought research.

For convenience, trial management is discussed in three sections: basic agronomic management necessary to minimize experimental error; management of drought stress; and minimum data requirements.

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Basic Management

Although all trials should be managed to reduce experimental error, limitations of resources place many constraints on this goal. Plot sizes and number of replications are reduced; seed of dubious quality is used; weeds, diseased and pests are not always controlled as well as one might with access to more labour, machinery, or agrochemicals. However, in drought research, the amount of error which can be tolerated is reduced. The low yields sought in drought nurseries mean that genotype or treatment differences are reduced. One consequence is that greater precision (lower experimental error) is needed in order to detect significant differences. Furthermore, with suboptimal crop growth, variation in field conditions, whether soil moisture, soil fertility or other factors, has a more pronounced effect on crop growth.

Fortunately, many practical solutions exist for reducing experimental error. Drought experiments should be located preferentially on sites with relatively uniform soil conditions. Additional attention may be given to multiplication and selection of seed to assure a good stand, and plots may be "over sown" and later thinned to the desired stand. Extra attention may be given to routine practices for control of weeds, diseases, and pests. Since most of these solutions fall under the realm of basic agronomy, or have been discussed in relation to drought elsewhere (Loomis, 1983), there is no need to pursue them in detail. However, we will examine one point which has proven particularly important at CIAT.

As mentioned earlier, effects of heterogeneity of field conditions are more pronounced under drought conditions. This problem becomes particularly severe in yield trials with large numbers of genotypes. Experience at CIAT has been that an appropriate experimental design can do much to alleviate the problem. In using lattice design, where sub-blocks within replicates permit partial correction for heterogeneity, reductions in experimental error as compared to randomized complete block designs have been as high as 50% (Table 1).

A still unresolved problem for experimental designs is presented by nurseries which are too large to permit full replication. When presented with the task of evaluating 500 genotypes of which only a small fraction are expected to possess desirable characteristics, the option of using a complete replication seems of dubious value, and indeed is often impossible without a seed multiplication. Many alternatives for correcting data from such trials have been suggested. These include:

1. Intensive use of checks, and correction of yields using yield of nearest checks.
2. To fit a response surface across a field, thus removing effects of strong gradients.
3. Use of a correction factor based on means of adjacent plots (Yates, 1936; Knotl, 1972).
4. Use of augmented designs where control lines are repeated several times in a standard design, and test lines are assigned to plots adjacent to controls (Federer, 1956; Lin and Poushinsky, 1983).

Careful evaluation of these possibilities would be of great use for improving drought screening.

Managing Levels of Drought

Experience at CIAT has been that achieving the desired level of stress is one of the most important yet difficult facets of managing drought trials. Extreme drought can so reduce yields that genotype differences disappear, while insufficient stress will result in selection of non-tolerant genotypes. Very few regions with major drought problems are dependent on irrigation, so most strategies have to focus on alternatives under rainfed conditions, with the possibility of supplemental irrigations.

Selection of an appropriate planting date is often the first problem encountered. A study of probability of drought stress based on 50 years rainfall data proved useful at CIAT Palmira. It clearly identified the two periods with greatest probability of obtaining drought (Fig. 1). The possibility of resorting to two planting dates in a single season was also considered. Even a shift in planting dates as short as 14 day can result in totally different patterns of rainfall distribution relative to the planting date (Fig. 2), thus generating two patterns of cultivar response in one season (Fig. 3).

The main problem with manipulating planting dates to obtain greater stress is that this may result in severe departures from practices of farmers. For example, researchers in Honduras are faced with the possibility of using two drought periods, one colder than the normal season, and one warmer (S. Zuluaga, personal communication). Only experience in a specific location can determine the best solution.

Many other strategies have been suggested for managing stress within a site. Crop rotation involving a crop with high water consumption can be used to deplete soil moisture prior to planting. The main drought plot at CIAT Palmira was recently equipped with underground drains and was subsoiled to reduce effects of a soil layer with a very low soil permeability.

Portable shelters have a role for experiments with small plot sizes, but seem of limited use for evaluations of large numbers of genotypes. Experience in Durango, Mexico has been that a low cost metal frame covered with polyethylene sheeting kept the rain out, but exacerbated disease problems due to the microclimate of the shelter (F. Ibarra and A. Pajarito, personal communication).

Researchers initiating drought research often ask for guidance on the exact level of stress needed for an effective trial, usually referring to the quantity of water which should be administered. Our experience has been that there is no way of predetermining the amount of water a drought trial should receive. The preference at CIAT has been to manage stress empirically based on the level of stress developing in the crop. Generally, trials are established with the minimum amount of water needed to assure a uniform, vigorous stand of seedlings, and then irrigations are withheld until stress becomes so severe that there is danger of losing the trial. Where possible, initial screening nurseries are given more water than advanced trials since they contain fewer tolerant genotypes.

One problem we have not resolved to our satisfaction is whether there is an advantage in establishing a very vigorous vegetative crop by being more generous with water in the first 4 weeks of crop growth. Presumably, once water was withdrawn, the crop would develop more severe symptoms than those obtained when the crop develops under drought from the earliest stages.

A specialized system for producing a range of levels of stress in a small plot is that offered by line source sprinkler systems. By closely spacing sprinklers along a single line, and planting genotypes in strips perpendicular to the line, water is applied in a gradient. The obvious advantage of such a system lies in the economies provided by obtaining a large variation in stress levels within a small area. A possible drawback to line source systems, besides those of costs of the installation, lays in the question of whether the patterns of stress are representative of as wide a range drought stress as might be obtained with other approaches such as multiple planting dates.

To evaluate this problem under CIAT conditions, 23 cultivars were classified using cluster analysis (Williams, 1976) based on yields from conventional drought trials and from a line source where six levels of stress were obtained. The results suggested that yields from the line source tended to produce a less reasonable classification of genotypes than did the other systems since closely related cultivars such as BAT 85 and BAT477 were not grouped together, nor were materials such as the large seeded type I's, BAT 1393 and A 195 (Table 2). These results are not seen as a conclusive argument against use of line source sprinklers, but do suggest that their use should be evaluated carefully.

A final issue which has caused considerable discussion in drought research is whether there is value in grouping materials by flowering or maturity characteristics to allow stress to be applied at a specific developmental stage. Thus, at CIAT the first drought trials were planted with genotypes blocked by expected time to flower. In Mexico, a similar approach was attempted, but based on installation of rain shelters at appropriate stages (F. Ibarra and A. Pajarito, personal communication). This approach would be valid if there was a demonstrated need to screen for a particular response during onset of flowering.

As an alternative, for regions with very diverse grain types, it might be more efficient to manage separate trials for different groups of materials. Thus at CIAT, we have considered the possibility of grouping materials by grain size and growth habit, so that large seeded type I's are managed separately from small seeded indeterminate materials.

Data Analysis

Irrespective of the breeding strategy adopted, one eventually confronts the problem of analysing data from drought yield trials. Although this sounds like a simple task, our experience has been that much useful information is often lost, and what is worse, materials are misclassified, thus reducing the efficiency and effectivity of the selection process.

A very common error is to equate low yields with drought susceptibility. Considering data for 15 lines from a screening trial at CIAT using both stress and irrigated control plots, this problem is readily illustrated (Table 3). V 7918 and San Cristobal 83 presented clear examples of tolerant lines combining the highest yields under drought conditions with excellent yields in control plots. BAT 51 and A 170 also seemed to merit distinction. At the other extreme, BAT 1554 appeared truly susceptible, having a very low yield under drought conditions, but high yield in the control. BAT 1282 would probably also qualify as susceptible. However, materials such as G 12865 and BAT 1198 did not show drought susceptibility, but poor overall performance, presumably due to lack of climatic adaptation or susceptibility to diseases or pests.

As discussed below, evaluations of tolerance are easily made if irrigated control plots are used, but where controls are not possible, the investigator has to accept the possibility of confounding adaptation or other problems with lack of drought tolerance. Data from additional trials or information on flowering and maturity dates or disease incidence may be of use. Fortunately, lines which yield poorly are usually of little interest except in studies of tolerance mechanisms where confusing drought susceptible materials with other poor yielding lines may result in misleading results.

Where data from control and stress plots or two or more sites are available, some criterion is usually sought for ordering overall performance of different materials. This may range from arithmetic means to more complex "stress indices". Ideally such indices should provide a single value for each material, be statistically tractable, and permit comparisons across trials. Ease of calculation is not a serious limitation. An index would be particularly useful if it can be extended to sets of trials lacking non-stress plots.

Five indices which are frequently referred to are presented in Table 4. Data illustrating their use for 15 lines from a drought trial at CIAT-Palmira are given in Table 3. The geometric means are similar to the arithmetic means, except that varieties having high arithmetic means through a combination of very high control yields, but moderate drought yields, have lower geometric means. Thus, if a 2500 kg/ha limit for mean yield was used as a selection criterion, A 70 and BAT 477 would be accepted using the arithmetic mean, but rejected using the geometric mean. Percent yield reduction and the Fisher-Mauer Stress Index (Fisher and Mauer, 1978), place 4 lines as superior to V 7916, but of these BAT 1198 and G 4830 are poor materials as judged by mean yields for below V 7916. This is an inherent defect of parameters based on yield reduction. The only remedy is to use this parameter in conjunction with yield data, but this violate the original goal of obtaining a statistic which permits selection based on a single variate. The same arguments apply for the response index except that the situation is more extreme. Preference at CIAT has been to use the geometric mean. It is easily extended to additional trials (the geometric mean of 3 variables is calculated as the cube-root of their product; higher numbers of trials simply require higher order roots), penalizes materials with large differences between control and stress yield, and may be standardized for comparison among trials by dividing through the overall mean of the geometric means. Similar conclusions were reached by Samper and Adams (1985).

Where data from more than 3 or 4 trials with the same entries are available, various alternatives for data analysis may be considered. Simple means are of little use since much information is lost. One alternative is to use various types of stability analysis (Lin et al., 1986). For diverse environments and materials, clustering techniques such as used to compare the data from line source and conventional trials are particularly helpful in detecting patterns, although selection of techniques contains a large subjective element. For a discussion of basic techniques and application to agricultural problems see Williams (1976).

In almost all trials, additional data is recorded besides yields. For drought trials, recording days to flower and maturity is useful both for interpreting the specific response of individual genotypes, and as a way of evaluating the relative importance of escape as tolerance mechanism.

A particularly neglected area of data taking is that of the climatic and soil moisture conditions of the trial. However, in the past this negligence has perhaps been justified by the difficulty in using such data to characterize levels of stress obtained. With the availability of models for estimating water regimes, such as WATBAL (Reddy, 1979) and BEANGRO (Hoogenboom et al., 1988), it is possible to characterize drought stress developed in a crop based on estimates of potential and actual evapotranspiration. However, such models require more data than total water applied. WATBAL is a simple model which estimates water balance assuming complete canopy cover of a generic crop. Minimum inputs are potential evapotranspiration, rainfall, and initial and maximum soil moisture storage. BEANGRO is a process oriented crop simulation model which predicts parameters of crop water balance along with a great many other parameters. Data requirements for BEANGRO are more extensive. The reader is referred to the paper by Hoogenboom et al. (this book) for further information on application of the model to drought research.

Conclusion

As with any agronomic research, management of drought trials requires a great deal of on location judgments. Experience at CIAT has been that each site will require a specific strategy, and thus we would argue against attempts to prescribe uniform practices for managing drought. Researchers should keep an open mind concerning possible strategies to assure success in their drought nurseries (Table 5). If we were to cite the factors which have most contributed to progress at CIAT, they would be use of the lattice design to reduce error due to variation in field conditions, and the emphasis placed on achieving a uniform stand of seedlings.

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Table 1. Comparison of the efficiency of randomized complete block (RCB) and lattice designs in drought nurseries. Data are presented for drought and control treatments plus their geometric means, all analysed independently. The relative efficiency is indicated by the reduction in Error Mean Square. For Trial Palmira,8449, a line source sprinkler was used to apply the water in amounts from 104 mm to 261 mm during the crop cycle.

Trial	No. of entries	Treatment	Yield (kg/ha)	Error mean square RCB	Error mean square Lattice	Reduction in EMS
Palmira, 8223	72	Drought	259	35194	28977	18%
		Control	1711	72068	67417	6%
		Geom. Mean	532	99715	77053	23%
Palmira, 8427	72	Drought	1645	97107	69935	28%
		Control	2656	128759	119534	7%
		Geom. Mean	2067	76291	60156	21%
Palmira, 8446	72	Drought	1079	97071	39217	60%
		Control	2550	91032	78125	14%
		Geom. Mean	1624	97395	40374	56%
Quilichao, 8447	72	Drought	815	36591	253779	31%
Palmira, 8448	25	Drought	1591	72458	64240	11%
Palmira, 8449	25	261 mm	2632	67247	57251	15%
		233 mm	2340	82357	73185	11%
		193 mm	2160	73870	62536	15%
		153 mm	1544	95554	70290	26%
		105 mm	941	89582	58574	35%
		104 mm	730	69941	38082	54%

Table 2. Comparisons of classifications of 25 lines according to cluster analyses using sets of data from conventional drought trials and a line source trial with 6 moisture levels and 2 planting dates. The conventional trials were conducted in Palmira, Quilichao and Popayan, and the line source in Palmira.

11 Dry and humid trials				7 Dry trials	Line source Mean of 2 dates	Line source 2 dates = 12 values	
Line	Yield (kg/ha)	Growth habit	Seed size	Line	Line	Line	Yield (kg/ha)
A 54	1415	2	S	A 54	A 54	A 54	1887
A 59	1394	2	S	A 97	BAT 477	A 195	1726
A 97	1462	2	S	BAT 868	G 4830	BAT 477	1881
A 195	1361	1	L	G 4454	G 5059	BAT 1298	1940
BAT 125	1387	2	S		G 5201	G 4523	1730
BAT 1298	1621	3	S	A 195		G 4830	1904
BAT 1393	1411	1	L	BAT 1393	A 97	G 5059	1987
EMP 105	1386	2	S	G 4494	A 195	G 5201	1959
G 4454	1403	2	S	G 4523	BAT 85		
G 4494	1403	1	L		BAT 125	A 97	1537
G 4495	1779	2	S	BAT 85	BAT 336	BAT 125	1682
G 4523	1399	1	L	BAT 336	BAT 798	BAT 336	1682
				BAT 477	BAT 868	BAT 798	1662
BAT 85	1554	2	S	BAT 1289	BAT 1289	BAT 868	1541
BAT 336	1588	2	S	G 4830	BAT 1298	BAT 1289	1718
BAT 477	1641	3	S	G 5201	BAT 1393	BAT 1393	1648
BAT 1289	1773	3	S	V 8025	G 4454	EMP 105	1649
V 8025	1814	4	S		G 4523	G 4454	1545
				A 170	V 8025	G 4495	1526
A 170	1693	2	S	BAT 125		V 8025	1568
BAT 798	1577	3	S	BAT 798	G 4446		
G 4446	1487	3	S	BAT 1298	G 4494	A 59	1333
G 17722	1671	3	S	EMP 105	G 4495		
				G 4446	EMP 105	A 170	2158
G 4830	1714	2	S	G 4454			
G 5059	1486	2	S	G 17722	A 59	BAT 85	1836
G 5201	1587	2	S				
				G 5059	A 170	G 4454	1544
BAT 868	1488	3	S				
				A 59	G 17722	G 4494	1383
						G 17722	2263

Table 3. Comparison of different indices of drought tolerance defined in Table 4. Base data are from a nursery of 72 lines grown at CIAT-Palmira with stress and irrigated control plots.

Line	Yield of treatments		Mean yield of treatments		Res- ponse (kg/ha)	Yield reduc. (%)	Yield index
	Drought (kg/ha)	Control (kg/ha)	Arth.[1] (kg/ha)	Geom. (kg/ha)			
V 7918	2300	3361	2831	2780	1061	31.6	0.73
S. Crist. 83	2149	2934	2542	2511	785	26.8	0.62
A 170	2002	3386	2694	2604	1384	40.9	0.94
BAT 51	1904	3555	2730	2602	1651	46.4	1.07
BAT 477	1871	3197	2534	2446	1326	41.5	0.96
G 5070	1807	2423	2115	2092	616	25.4	0.59
G 4830	1775	2404	2090	2066	629	26.2	0.60
G 4977	1687	3041	2364	2265	1354	44.5	1.03
A 70	1674	3356	2515	2370	1682	50.1	1.16
G 5435	1596	2942	2269	2167	1346	45.8	1.06
BAT 1282	1459	3090	2275	2123	1631	52.8	1.22
BAT 1198	1406	1886	1646	1628	480	25.5	0.59
G 5059	1185	2368	1777	1675	1183	50.0	1.15
G 12865	936	1703	1320	1263	767	45.0	1.04
BAT 1554	641	3373	2007	1470	2732	81.0	1.87

[1] Arith = Arithmetic mean. Geom = Geometric mean.

Table 4. Stress indices C and D are control and drought yields of individual lines respectively, C_m and D_m are means across all lines, and W is the difference in water applied to control and stress plots.

Index	Formula	Extendable to multiple trials?
Arithmetic Mean	$I = (D + C)/2$	Yes
Geometric Mean	$I = V D * C$	Yes
Response	$I = (C - D)/W$	Yes
Percent Reduction	$I = 100*(1-(D/C))$	No
Fisher & Mauer[a] Stress Index	$I = (1-(D/C)) / (1-(D_m/C_m))$	Yes

[a] Fisher and Mauer (1978).

Table 5. Summary of factors which might be considered in the planning of drought nurseries.

I. Location

  A. Soil characteristics
  B. Reliability of stress

II. Experimental design

  A. Replicated trials
  B. Unreplicated nurseries

III. Planting Date

  A. In relation to periods of maximum stress and practices of farmers
  B. Multiple dates

IV. Physical distribution of trial

V. Management of levels of stress

  A. Agronomic practices
    1. Pattern and density of planting
    2. Previous crops to mine the soil water profile
    3. Deep plowing or extra cultivation to dry the soil

  B. Management of water
    1. Sprinkler *vs* gravity irrigation
    2. Irrigation pattern
      a) Dates
      b) Line source
    3. Drainage systems and rain shelters

VI. Data to record

  A. For entire trial
  B. For individual plots

VII. Data analysis

Figures

Fig. 1. Probability of encountering a 20 day drought stress for a period starting 30 days following a given date. ICA Palmira, 1930-1980.

Fig. 2. Rainfall distribution for two trials planted with a 13 day difference. Palmira, 1985 A.

Fig. 3. Yields of 25 lines in two drought trials planted in contiguous lots, but with 13 days difference in planting dates. Palmira, 1985 A.

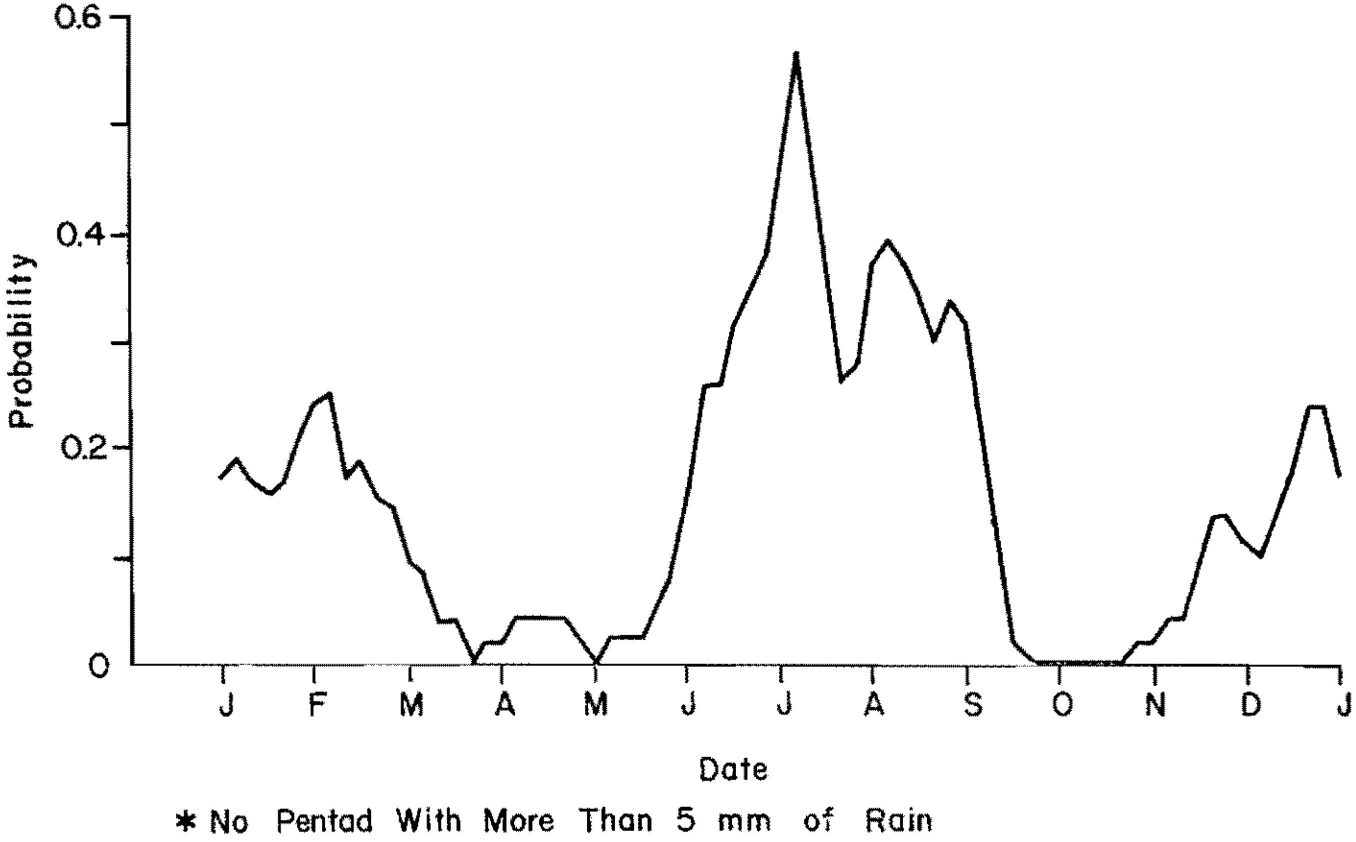

Figure 1. Probability of encountering a 20 day drought stress for a period starting 30 days following a given date. ICA Palmira, 1930-1980.

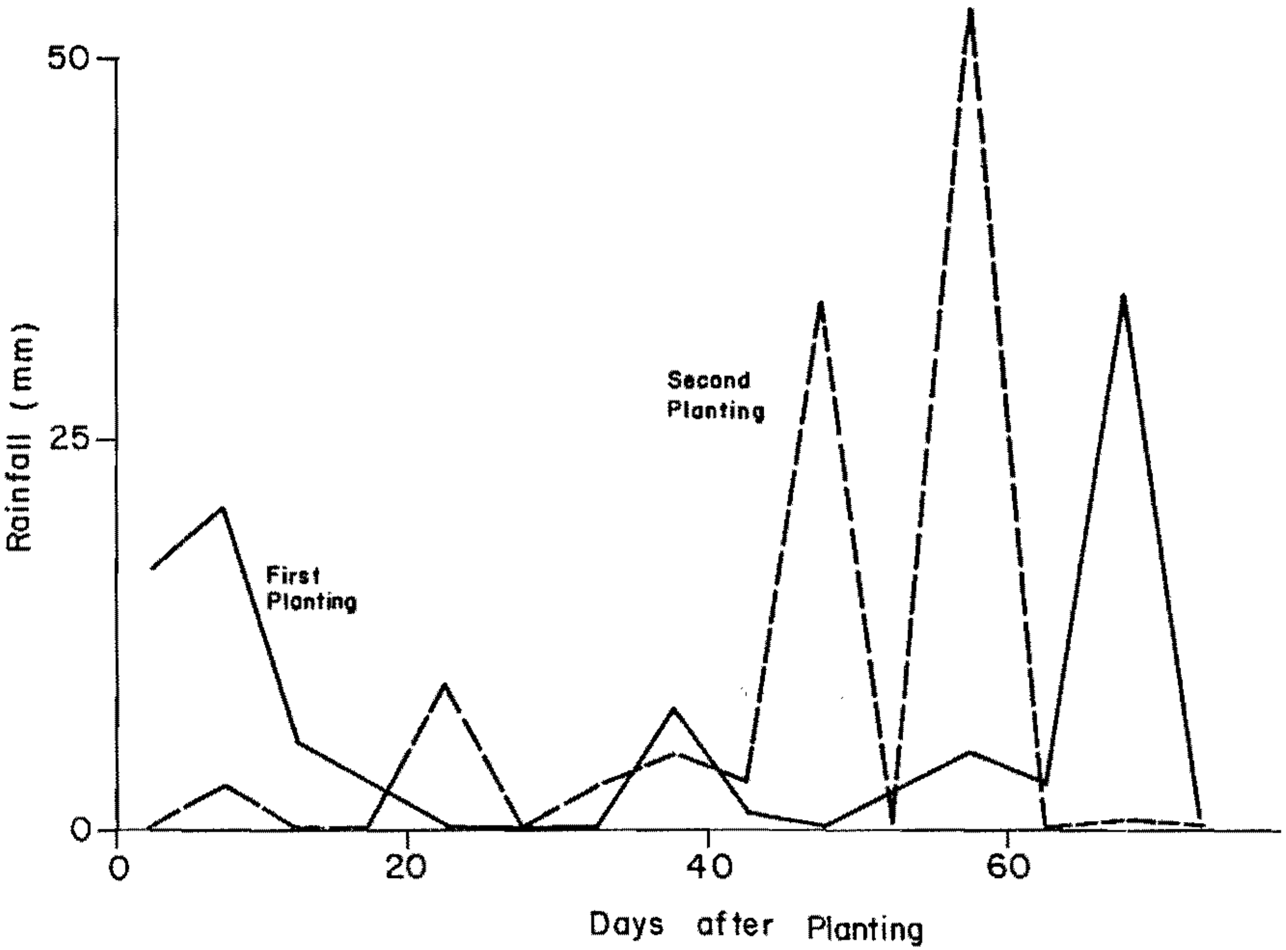

Figure 2. Rainfall distribution for two trials planted with a 13 day difference. Palmira, 1985 A.

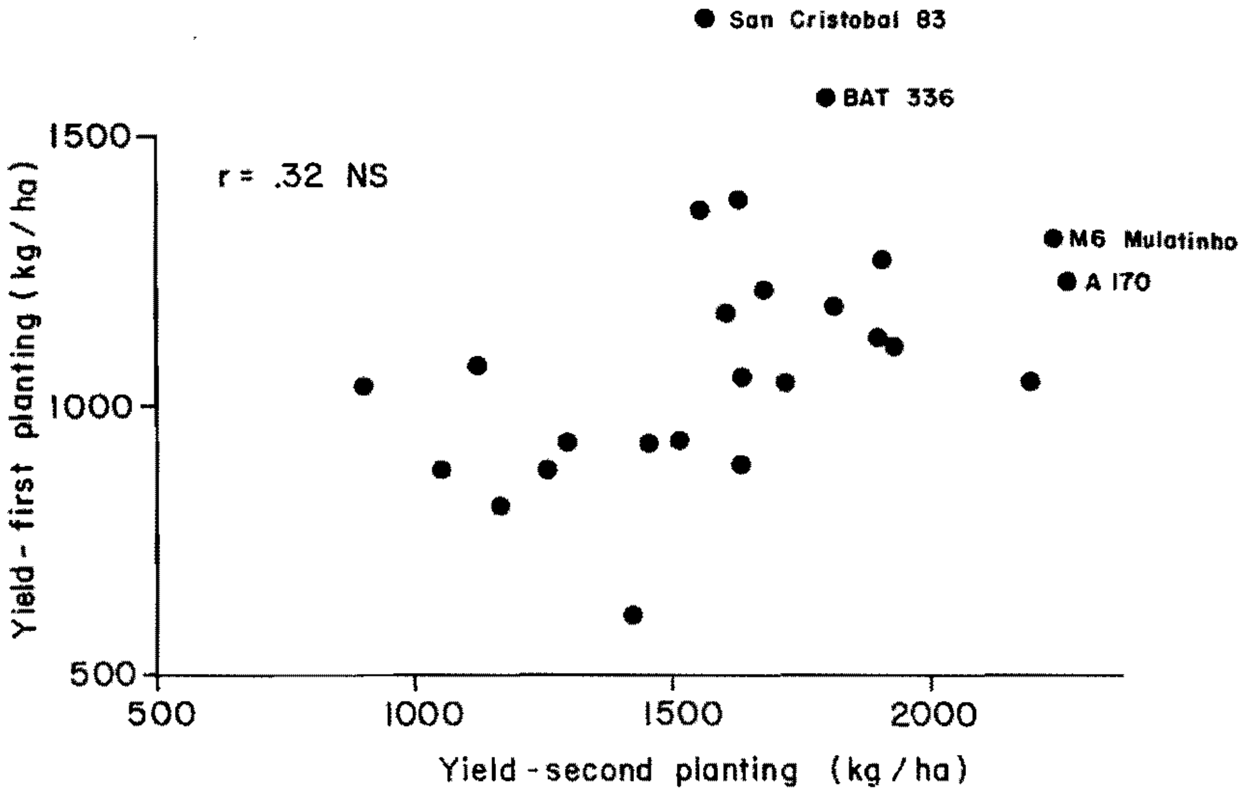

Figure 2. Yields of 25 lines in two drought trials planted in contiguous lots, but with 13 days difference in planting dates. Palmira, 1985 A.

BREEDING COMMON BEANS FOR ADAPTATION TO DROUGHT CONDITIONS

S. Singh and J. White*

Introduction

Soil fertility and drought are the most important physiological problems limiting bean (Phaseolus vulgaris L.) production. Approximately 60% of bean production regions suffer serious drought stress. With irrigation conditions, drought may be predictable both in timing and intensity, but under rainfed conditions unpredictability is the rule. In areas such as Central America, where beans are often planted toward the end of the rainy season, initial soil moisture is usually adequate, and the stress period depends on when, and how abruptly, rains cease. Bean crops in north-central Mexico and north-east Brazil are planted at the onset of short, unreliable rainy seasons. In southern Brazil, total rainfall usually is adequate, but a two week dry period often occurs during pod-fill, causing marked yield reductions.

Given the variability in drought situations, breeders must plan strategies more carefully than for better defined problems such as disease or insect resistance. Drought conditions at experimental sites must resemble those encountered by farmers. High levels of drought tolerance must be combined with other desirable characteristics.

"Drought tolerance" is used herein in a broad sense, encompassing all mechanisms which permit greater yields under soil moisture deficits. "Tolerance mechanisms" thus include characteristics such as earliness and

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deep roots which, under a broader ecological classification, would be considered "escape" or "avoidance" mechanisms.

Emphasis is given to management of drought problems through development of tolerant cultivars, but the importance of agronomic management in reducing stress should not be underestimated. Pests and diseases, particularly nematodes and pathogenic root fungi, may increase water loss or reduce the efficiency of the root system in extracting soil moisture, thus exacerbating stress. In addition to breeding for drought tolerance, the researcher should consider alternative strategies for alleviating drought stress or otherwise increasing yields.

The results of the Bean International Drought Yield Trials (BIDYT) presented elsewhere in these proceedings suggest that either different tolerance mechanisms are needed for different environments, or that adaptations to non-drought factors (photoperiod, temperature, diseases or others) have an overriding effect on yield, thus masking potentially superior drought tolerance of the BIDYT entries.

The most important questions then are what level of tolerance can be achieved in a given environment, and how to reach this level efficiently. Identifying appropriate parental materials is one step. Utilizing selection criteria besides yield will help if such criteria truly reflect drought tolerance. And finally, yield testing should be done in such a way that truly tolerant materials are selected. The rest of this paper discusses these subjects in further detail, starting with selection criteria based on tolerance mechanisms, then considering genetics of tolerance and drought breeding strategies.

Tolerance Mechanisms and Selection Criteria

One of the most frustrating aspects of drought breeding is the lack of practical selection criteria besides yield. Studies of mechanism of drought tolerance have suggested a wide range of selection criteria, but the sad reality is that none of these have unequivocably been demonstrated to have practical application to beans.

Before testing a proposed selection criterion, two questions should be asked:

1. Was the technique developed using a representative set of cultivars?
2. Were the drought conditions used relevant to the production region?

All too often, one finds tolerance studies based on 2 or 3 varieties apparently selected at random, with results coming from potted plants grown in a greenhouse.

Problems in interpreting mechanism studies are also encountered when cause and effect are confused. When it was found that drought stress causes accumulation of the amino acid proline in plant tissues, considerable enthusiasm was caused by the prospect of assaying tolerance simply by measuring tissue proline levels (Stewart, 1972; Singh et al., 1972). However, several years later it became clear that while proline accumulation is a result of drought stress, it is neither a cause nor a correlated measure of tolerance (Stewart and Hanson, 1980). A more complicated situation is that of root growth. While there is good evidence that deep roots are related to drought tolerance, it is not clear whether deep rooting is a result of specific genes for deep roots (perhaps acting in a way similar to those controlling growth habit), or whether deep roots are simply a result of greater overall plant vigor. Such vigor presumably would result from more subtle tolerance mechanisms such as osmotic adjustment or cell desiccation tolerance. If the former case is true, then there is hope for simple screening techniques using container grown plants. If the latter holds, then screening would be more efficient if performed on the underlying mechanisms which ultimately permit greater root growth.

Another caution that breeders should consider is whether a mechanism is sensitive to effects of adaptation to non-drought factors. Simple morphological characteristics such as leaf size and amount of leaf pubescence might be expressed in a broad range of environments, but characteristics involving more complex processes may prove so sensitive to local conditions that it may be difficult to transfer them from parental materials adapted to other regions.

Finally, there should be no expectation of finding a single tolerance mechanism, and thus a single selection criterion which will assure identification of the best materials. Most contemporary drought research assumes that tolerance results from interactions of a series of mechanisms, some of which may operate in opposition to one another. This implies the need to rely either on multiple selection criteria, or on criteria such as canopy temperature or carbon-isotope discrimination ratio which integrate effects of multiple mechanisms.

Tolerance mechanisms are discussed elsewhere in these proceedings, so this subject will not be discussed further other than to present a summary of possible mechanisms in Table 1. While we remain optimistic that physiological studies will some day identify improved selection criteria for drought tolerance, we conclude that seed yield is the only character of unequivocable use for drought tolerance breeding at the present time. Investigators are encouraged to seek improved criteria, but their efforts should be balanced with needs for immediate results which will most likely come through judicious use of yield as the primary criterion.

Genetics of Drought Tolerance

Literature on inheritance of drought tolerance in beans is very scant. This probably reflects the lack of reliable screening criteria and sources of drought tolerance, and/or lack of interest on the part of researchers. As discussed previously, various morphological, physiological, and chemical traits have been reported to be associated with drought tolerance. However, the range of available variation for these characteristics, their inheritance, and the practical benefits from use of them as selection criteria are only beginning to be researched.

Menosso _et al._ (1978) studied the inheritance of free proline accumulation in both turgid and dehydrated leaves of common bean utilizing parental, F_1, F_2, and backcross progenies. Low content of free proline both in turgid and dehydrated leaves was partially dominant and approximately 4 genes were involved in its inheritance. Broad and narrow sense heritability estimates in turgid leaves were 65.9% and 51.7%, respectively. Broad sense heritability value for dehydrated leaves was 84.5%. However, Hanson _et al._, (1979), concluded that proline accumulation was only a symptom of severe internal water stress, and apparently had no survival value during drought. Therefore proline accumulation is now considered of no practical value for breeding for drought tolerance (Stewart and Hanson, 1980).

In snap bean (_Phaseolus vulgaris_ L.), Bouwkamp and Summers (1982) identified two accessions, PI 297079 and PI 151062 which possessed heat-drought tolerance as measured by number of pods formed on plants in controlled environment. This combined resistance to heat and drought was a controlled by a single dominant gene in PI 297079 and by two epistatic genes in PI 151062.

Difference in seed yield is utilized as the eventual measure of level of tolerance of bean cultivars to drought. Inheritance of yield under drought stress in beans has not been reported yet. Under irrigation conditions, heritability was low (less than 0.40) for seed yield and pods/m^2, intermediate (0.57) for seeds/pod and high (0.88)for 100-seed weight (Nienhuis and Singh, 1988). It is likely that under moisture deficient conditions genetic variance and heritability values for yield will be different.

Breeding for Drought Tolerance

Results from directed breeding experiments for drought tolerance *per se* in beans have not been reported to the best of our knowledge. Even research programs located in endemic bean production areas have only recently undertaken such activities. This probably reflects the lack of dependable screening techniques, especially for hybrid segregating populations. Most evaluation and selection has been indirect, and has been limited to advanced homozygous lines or cultivars grown under drought in yield trials. Since 1981, a modest effort for breeding for drought tolerance in dry beans has been underway at CIAT. In brief, breeding for any character involves: 1) determining objectives and priorities, 2) collection of sources of desirable germplasm, 3) choice of breeding methods and strategies (i.e. hybridization, inbreeding, evaluation and selection in hybrid generations, 4) evaluation of advanced lines, and 5) identification, seed increase and release of new cultivars. The first cycle of selection has not been completed, so the following discussion of relevant points is based on only very limited experience.

Determining priorities:

While breeding beans for water stress environments, the primary interest often lies not so much in maximizing yield, but assuring a minimum yield which covers the cost of production and provides some additional returns to the growers. Farmers would obviously desire this year after year, but complete crop losses are a common occurrence. Parsons (1979), sharing this opinion, noted that harvestable yield and its reliability from year to year, rather than mere plant survival, were important to growers. The minimum yield level would vary from region to region depending upon the drought pressure, cropping system, returns from other alternative crops, and bean prices. Under these circumstances minimizing losses from other production constraints are essential objectives of a breeding program.

Heichel (1983) suggested that before initiating a selection program for drought tolerance, the climatic and soil characteristics of the production region need to be well understood since the seasonal progression of temperature, the amount and distribution of rainfall, and the availability of soil moisture will determine which plant characteristics should be modified to improve water use efficiency. Specht and Williams (1984) described four prerequisites for breeding soybean for drought and heat tolerance: 1) characterization of stress, 2) development of appropriate selection criteria, 3) development of suitable screening technique, and 4) assemblage of appropriate germplasm.

A breeding strategy for unpredictable drought areas can differ from that of predictable drought regions. In an unpredictable drought region, such as the highlands of Mexico or north-east Brazil, the stages of crop growth at which drought stress occur, the rate of stress development, frequency of stress, and stress severity vary greatly from year to year, and in some years no drought conditions occur, allowing good crop harvest. Under such conditions improved cultivars should combine characters permitting acceptable yields both under drought and mesic conditions.

Rosielle and Hamblin (1981) provided theoretical arguments suggesting that selection for tolerance to stress conditions alone will increase stability of performance, but it will result in reduced mean yield in a non-stress environment and a decrease in mean productivity. This is because genetic variances in stress environments are generally lower than in non-stress environments, and tolerance and mean productivity show negative genetic correlations. Landraces grown in drought endemic areas of the highlands of Mexico already possess a high degree of plasticity or homeostasis such that in dry years a low, but assured yield is obtained. However, when conditions are favorable, high yields are obtained from the same cultivars. Improving such cultivars while maintaining this desirable trait presents a major challenge.

Sources of drought tolerance:

Germplasm found to be drought-tolerant at CIAT-Palmira, and some widely known landraces from drought regions (presumably with drought tolerance, but which could not be evaluated at CIAT-Palmira due to poor adaptation) are given in Table 2. Attempts should be continued to search for new and better sources of resistance to drought both from germplasm bank accessions and improved experimental lines of common beans. The value of wild or non-cultivated accessions of common bean, *P. vulgaris*, from drier regions of central and northern Mexico and south-western United States as sources of drought tolerance has not been explored yet. The use of other species of *Phaseolus* as sources of tolerance is discussed in a subsequent section.

Breeding methods and strategies for germplasm development::

In discussing breeding strategies, it must be acknowledged that little or no breeding has been done for drought tolerance in beans. Sources of tolerance from different drought endemic areas vary in seed size, maturity and growth habit and possess specific adaptation (especially sensitivity to photoperiod), and all these traits are associated with yield potential. In addition to drought, other factors such as diseases and insect pests are prevalent in drought areas, and due to absence of constitutive traits and selection criteria (Specht and Williams, 1984), selection for drought tolerance would largely be based on yield performance.

Three strategies are discussed: 1) improvement *per se* of each parental source of drought tolerance, 2) breeding for drought tolerance *per se*, and 3) breeding drought tolerance in commercial cultivars.

Improvement per se of parental sources of drought tolerance. As a first priority, emphasis should be placed on improvement of each parental source of drought tolerance. This requires a critical and thorough evaluation of parental sources for their response to photoperiod, temperature extremes, and reaction to principal diseases and insect pests. For example, sources of drought tolerance from the highlands of Mexico (e.g. Durango 222, Bayo Criollo del Llano, Bayo Rio Grande and Apetito; Table 3) are all susceptible to BCMV and highly sensitive to photoperiod. At higher latitudes (e.g. Davis, California, U.S.A.), none of these flower within 90 days when planted in mid June. Desirable genes for each of such major constraints should subsequently be sought and incorporated in the drought tolerant parents while maintaining most of their other traits. An inbred-backcross (Wehrhahn and Allard, 1965) program or its modifications could be utilized for rapid incorporation and improvement of individual traits. Around 100 hybrid plants should be used as male parents from the first (F_1RC_1) and subsequent backcrosses. Two backcrosses with recurrent parent followed by two generations of inbreeding are often adequate before beginning single plant selection and progeny test (A. Bliss, personal communication).

Miranda (personal communication) used the backcross method to transfer resistance to bean common mosaic virus controlled by a single dominant gene from a black seeded introduction, cv. Costa Rica, into local landraces of "mulatinho" seed type grown extensively in the north-east of Brazil.

In addition to the backcross method, three-way, top-crosses, and modified double crosses may be used (Singh, 1982) to rapidly increase the frequency of desirable genes. In this system, different but simpatric landraces or cultivars from a given geographical area (e.g. semi-arid highland of Mexico), similar in growth habit, maturity and seed characteristics (size and shape) are used jointly in crosses as an alternative to conventional backcross program.

Breeding for drought tolerance per se. For programs with long range goals of increasing drought tolerance, or a need to develop parents with outstanding levels of drought tolerance, a breeding program dedicated specifically to drought tolerance may be justifiable. This approach calls for intercrosses among different sources of drought tolerance and implies relaxing selection for disease resistance, grain types or other features sought in more integrated approaches such as discussed later.

As a first goal, crosses should assure maximum recombination of different traits, mechanisms, sources, and genes associated with drought tolerance. Parents carrying genes for larger root volume and deeper root growth, early or late maturity, tolerance to heat or low temperature, poor soil fertility, small foliage, low canopy temperature, and other traits associated with drought tolerance should also be intercrossed with the drought tolerant parents. When differences among parents are extremely large for seed size, maturity, growth habit and adaptation strategies such as recurrent selection, backcrosses, three-way crosses, or modified double crosses, should be used to increase frequency of desirable genes. Otherwise a large proportion of such crosses or recombinant plants within populations may lack desirable traits.

Hurd (1969, 1971, 1976), when breeding for drought tolerance in wheat, argued for working with a few carefully planned crosses in wheat, but with very large population size (20.000 to 50.000 plants) for each cross. He recommended "heavy discards", reducing populations to 1000 plants per cross to be advanced for yield testing.

In contrast, at CIAT emphasis has been placed on performing a relatively large number of crosses (with average of about 2000 F_2 plants per cross) among carefully selected parents in the hopes of identifying populations of particular promise. If needed, additional seed of promising crosses can be produced subsequently. In the absence of a quick and reliable selection criterion for segregating materials, hybrid populations are yield tested at commercial cropping densities in replicated trials from the F_2 to F_4 generations (Fig. 1). The distinction should be made here that for breeding for drought tolerance per se, nurseries from F_2 until termination of final selection in F_8 or F_9 are kept free from diseases and insect pests. Optimum growing conditions are provided for the F_2 yield test, in order to identify crosses with the highest yield potential. Drought stress is gradually increased in the F_3, F_4, F_5, and subsequent generations. It is intended that the highest level of moisture stress applied during screening and selection should represent a compromise among drought stress occurring in farmers' fields of the region, the yield level desired, and the tolerance levels available among segregating populations and parents.

The F_2 to F_5 populations are managed through single pod bulks. Individual plant selections commence from F_5 onwards, followed by seed increase (F_6), and yield trials of bulk families or lines in subsequent generations (F_7, F_8 and F_9) in representative drought environments. For yield testing of all advanced lines, materials are grouped according to maturity, seed size and growth habit. Final evaluations are done both under drought and non-stress conditions.

In the future, if any of characters associated with drought tolerance prove highly heritable, and large genetic variation can be detected in F_2, single plant selection could commence immediately, being followed by seed increase and progeny test in replicated trials in subsequent generations. Thus, further single plant selection would be restricted only to promising F_5 or F_6 families.

Incorporation of drought tolerance in commercial cultivars. Breeding for drought tolerance in commercial cultivars differs from breeding for drought tolerance *per se* due to the fact that, in addition to drought tolerance, other production limiting factors, such as diseases and insect resistance, must simultaneously be bred into commercial bean types prevalent in a given production region. Representative production regions and their main bean production problems are given in Table 3.

Using the program at CIAT to illustrate a possible system, separate breeding projects have been initiated for three major dry bean types: medium seeded indeterminate type III for Mexican highlands; small seeded indeterminate bush beans for north eastern Brazil; and medium and large seeded bush beans for Turkish Anatolian highlands and similar areas. Donor parents are selected for other production problems and utilized in crosses. An example of parents to be utilized for improvement of drought tolerant bean cultivars for semi-arid highlands of Mexico is given in Table 4.

Since the desirable traits sought in a new cultivar are often numerous, and each character is controlled by different genes and types of gene actions, the number of crosses and population sizes needed are much larger (over 3000 F_2 seeds per cross) than those for breeding exclusively for drought tolerance. While the mass selections involving early generation yield tests outlined in Figure 1 could be used effectively, nursery management in each generation should be varied to permit exposure to different problems of production region in order to simultaneously select for two or more desirable traits.

Continuing with the example of work at CIAT, the F_2 yield trial is conducted under optimum management at the Palmira station to identify high yielding crosses. The best populations, maintained as single pod bulks, are yield tested in F_3 under moderate pressure of drought, low soil fertility, common bacterial blight and angular leaf spot at the Santander de Quilichao station. Again using single pod bulks, selected F_4 populations are grown in replicated yield trials at the Popayan station under the pressure of anthracnose in earlier growth stages followed by moderate stress for drought during post flowering and pod development. The F_5 bulks are screened in spaced-plantings under drought pressure at Palmira, and single plant selections are made. Thus, by the time the single plant selection commences in F_5, early segregating generations have been exposed to climatic, soil and biotic stresses occurring at three contrasting sites, allowing only survival and identification of genotypes which combine desirable traits in successive generations. When the number of traits desired in cultivars is numerous, extreme pressure for any single trait, especially quantitatively inherited ones in early segregating generations, is avoided.

The bulk families or lines from F_7 onwards are yield tested under drought and non-stress environments, and evaluated in separate complementary nurseries for anthracnose, common bacterial blight, angular leaf spot, halo blight, BCMV, rust, and leafhopper resistance. At this stage other selection criteria such as canopy temperature, root characteristics, ^{13}Carbon discrimination ratio, or leaf thickness, could also be employed.

Transfer of drought tolerance from other Phaseolus species

Many researchers feel that genetic variability for drought tolerance is low in common beans, and they have suggested utilizing genes for tolerance from other species. Tepary bean (*P. acutifolius*) is the most commonly suggested source, although other *Phaseolus* species, e.g. *P. retensis* and *P. coccineus* (possesses a deep and tuberous primary root system) merit consideration.

Freeman (1912) and Currence (1928) found that while Pinto beans (*P. vulgaris*) were drought tolerant, tepary beans possessed higher drought tolerance. Coyne and Serrano (1963) found that tepary beans had higher percentage of soluble solids in the young leaves and a higher respiration rate when grown at either high or low levels of available soil moisture than moderately drought tolerant dry pinto and susceptible snap bean cultivars. They suggested that drought tolerance in tepary was due to its ability to maintain photosynthesis and normal respiration rates.

Interspecific crosses between *P. vulgaris* and *P. acutifolius* are made utilizing embryo rescue techniques. Although, teparies are often cited for their high level of drought tolerance, the only trait of major economic importance that has successfully bean transferred from teparies to common bean cultivars is tolerance to common bacterial blight (Xanthomonas campestris pv phaseoli E.F. Sm. Dows). Hucl and Scoles (1985) noted that resistance to common bacterial blight in Great Northern white bean cultivars from Nebraska e.g. Great Northern Nebraska #1, Jules, Tara, Star, Valley and Emerson, were derived from P. acutifolius crosses reported by Honma (1956). Similarly, lines XAN 159, XAN 160 and XAN 161, highly tolerant to common bacterial blight, were selected at CIAT from segregating populations of P. vulgaris x P. acutifolius made by Thomas and Waines (1982, 1984). Drought tolerant lines of common bean from crosses involving teparies have yet to be developed.

As all accessions of teparies may not carry the same level of drought tolerance and some variation in crossability may exist among accessions of the two species, more objective and thorough evaluation of the species should be made prior to undertaking inter-specific hybridization. Since some sources of drought tolerance in common bean have already been identified (Table 2), these would be promising parents for use in crosses with teparies.

Progress in Breeding for Drought Tolerance

Although bean breeders have studied drought tolerance since at least the 1930's (Babb et al., 1941), no known successful releases of cultivars have involved materials deliberately selected for drought tolerance. However, progress from selection under stress conditions has resulted in improved performance. In a comparison of two sets of experimental bean lines, one set having received a previous selection for yield under drought but the other not, the previously screened lines were vastly superior to the unselected materials (Figure 2). Similarly, evaluations of materials selected visually for yield under drought have resulted in lines of equal or better performance than known tolerant lines (Table 5). In a report on bean breeding in Kenya, Muigai (1983) reported that lines GLP 1004 and GLP-X 92 had tolerance to drought and GLP 806 was tolerant to both heat and drought. Popa and Dinca (1985), discussing problems of dry bean production in Rumania, noted that the two most productive lines, F 77-1765 and F 77-1345, which yielded over 4 t/ha, were relatively early maturing, and possessed good levels of drought tolerance.

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Table 1. Classification of drought screening strategies based on measurement of possible tolerance mechanisms.

I. Measurements of individual mechanisms

- A. Drought escape
  - 1. Earliness
  - 2. Recuperation
- B. Drought tolerance with high plant water potential
  - 1. Maintenance of uptake
    - a) Greater root growth - lateral or vertical
    - b) Increased hydraulic conductance
  - 2. Reduction of water loss
    - a) Reduced area of transpiration
    - b) Greater resistance
    - c) Reduced gradient - lower leaf temperature
- C. Drought tolerance with low water potential
  - 1. Maintenance of turgor
    - a) Osmotic adjustment
    - b) Increased cell elasticity
  - 2. Desiccation tolerance
    - a) Membrane stability under desiccation
    - b) Protein function
- D. Drought tolerance through adaptation to indirect effects of drought
  - 1. Heat tolerance
  - 2. Tolerance to nutrient deficit

II. Measurements which integrate effects of several mechanisms of tolerance

- A. Integration for less than a few minutes
  - 1. Stomatal conductance
  - 2. Leaf photosynthetic rate
  - 3. Canopy temperature
- B. Integration for less than a few hours
  - 1. Leaf water potential
- C. Integration over long periods
  - 1. Water use efficiency
  - 2. Biomass and harvest index
  - 3. Yield

Table 2. Some sources of tolerance to water stress utilized in breeding for drought tolerance in beans, and associated characteristics. For photoperiod response, N = day neutral, I = intermediate, and S = sensitive.

Identification	Origin*	BCMV	Growth habit	Seed size	Seed color	Photoperiod response	Gene pool
A 54	CIAT	R	2	Small	Cream	N	2
A 170	CIAT	R	2	Small	Cream	I	2
A 195	CIAT	R	1	Large	Cream	S	7
BAT 336	CIAT	R	3	Small	Cream	I	3
BAT 477	CIAT	R	3	Small	Cream	N	3
BAT 1289	CIAT	R	3	Small	Pink	I	3
Bayo Criollo del Llano	Mexico	S	3	Medium	Beige	S	5
Bayo Rio Grande	Mexico	S	3	Medium	Beige	S	5
Durango 5	Mexico	S	3	Medium	Cream	-	5
Durango 222	Mexico	S	3	Medium	Cream	-	5
Chiapas 7	Mexico	S	3	Large	Cream	-	5
Apetito	Mexico	S	3	Small	Purple	S	5
G 1502	Italy	S	2	Medium	Cream mottled	N	8
Rio Tibagi (lote 10)	Brazil	R	2	Small	Black	N	2
Gordo	Brazil	S	1	Medium	Beige	S	7
Mulatinho Vagem Roxa	Brazil	S	3	Small	Cream	-	3
Rim de Porco	Brazil	S	3	Small	Cream	-	3
Favinha	Brazil	S	3	Medium	Cream	-	3
San Cristobal 83	Dominican Republic	R	3	Medium	Red mottled	I	5
ICA Linea 17	Colombia	S	1	Large	Red mottled	S	7
V 8025	CIAT	R	3	Small	Black	N	3

* All entries from CIAT are improved experimental lines but none were bred for drought tolerance.

Table 3. Examples of bean production regions with drought problems.

Production region	Cropping system & Bean types grown	Important cultivars	Non-drought production problems
Highlands of Mexico – 1.2 million ha – 350 kg/ha mean yield	Monoculture & intercropping Type 3, Medium beige, cream, pinto, cream stripped, pink speckeled, black	Bayo Rio Grande, Bayo Criollo del Llano, Pinto Nacional, Ojo de Cabra 400, Flor de Mayo Negro Zacatecas	Root rots, poor soil fertility, anthracnose, common bacterial blight, angular leaf spot, halo blight, rust, cold, Mexican bean beetle
North-east of Brazil – 1.6 million ha – 300 kg/ha mean yield	Intercropping Type 3, 1 Small cream Medium cream mottled and beige	Mulatinho Vagem Roxa, Rim de Porco, Favinha, Pituco, Gordo, Bagazzo	Roots rots, anthracnose, angular leaf spot, common bacterial blight, rust, leaf hopper
West Asia & North-Africa & some European countries Drought with limited irrigation – 0.6 million ha – 1100 kg/ha mean yield	Monoculture Type 3, 1 Medium and large white and cream mottled	Dermeson, Barbunya, Oranda, Borlotos, Horos	Cold, bean yellow mosaic virus, bean common mosaic virus, halo blight
Coastal Peru – 25000 ha 750 kg/ha mean yield	Monoculture Type 3, 1 Large beige, yellow and white, small white	Canario, bayo, Blanco comun, Caballeros, Panamito	Salinity, root rots, nematodes, rust, bean common mosaic, cold

Table 4. Plan for single crosses[1] for varietal improvement of bean for semi-arid highlands of Mexico.

Base cultivars (females)	Donor Parents (Males)					
	Drought tolerance	Early maturity	Anthracnose resistance	Angular leaf spot resistance	Common bacterial blight resistance	Rust resistance
Bayo Madero	V 8025	G 2923	G 811	A 339	XAN 159	BAT 76
Bayo Criollo del Llano	BAT 477	BAT 304	AB 136	BAT 67	PI 207262	A 295
Bayo Rio Grande	G 1502	G 2883	A 483	G 5173	A 840	BAT 308
Pinto Nacional	Durango 222	BAB 60	Mexico 222	G 2676	G 17341	EMP 81
Ojo de Cabra 400	Apetito	G 122	A 252	A 74	XAN 112	Redland Pioneer
Flor de Mayo	San Cristobal 83	Bola 60 dias	G 2333	G 5653	A 193	Cuilapa 72

[1] Six base cultivars are crossed to produce 36 single crosses from which in subsequent plantings 18 or more double crosses, backcrosses, three-way crosses, etc., are generated for combining two or more desirable traits from donor parents while maintaining substantial contribution from regional base cultivars.

Table 5. Yield of selected dry bean lines bred for drought tolerance. CIAT-Palmira, 1985A.

Identification	Genealogy	Yield kg/ha	100 seed weight
SX 2232-9	A 176 x (BAT 336 x (A 147 x BAT 798)F_1)F_1	1583	22.2
SX 2232-10	A 176 x (BAT 336 x (A 147 x BAT 798)F_1)F_1	1569	20.7
SX 2232-24	A 176 x (BAT 336 x (A 147 x BAT 798)F_1)F_1	1672	21.7
SX 2232-28	A 176 x (BAT 336 x (A 147 x BAT 798)F_1)F_1	1107	17.2
SX 1984-6	A 54 x (Seaway x BAT 137)F_1	1421	19.3
SX 1984-4	A 54 x (Seaway x BAT 137)F_1	1413	19.0
SX 2069-23	BAT 336 x (A 97 x BAT 240)F_1	1412	20.0
SX 2069-22	BAT 336 x (A 97 x BAT 240)F_1	1227	22.2
SX 1506-8	BAT 477 x Toche 400	1687	20.9
SX 2187-14	A 97 x (BAT 483 x (G 3719 x Apetito)F_1)F_1	1272	17.7
SX 2187-15	A 97 x (BAT 483 x (G 3719 x Apetito)F_1)F_1	1178	21.3
BZ 1428-2	A 97 x XAN 75	1317	18.9
BZ 1428-4	A 97 x XAN 75	1447	18.4
SX 1998-3	A 147 x (A 54 x BAT 271)F_1	1311	20.1
SX 1998-6	A 147 x (A 54 x BAT 271)F_1	1306	19.5
A 170*		1398	17.6
BAT 85*		1396	15.7
BAT 477*		1548	18.0
BAT 477* (irrigated control)		2383	21.1
Mean		1455 ± 63.0	20.0 ± 2.1

* Tolerant checks

Figures

Fig. 1. Mass selection method involving early generation yield test used at CIAT for breeding for drought tolerance in beans.

Figure 1. Mass selection method involving early generation yield test used at CIAT for breeding for drought tolerance in beans.

Month planted	Generation	Activities	Location & selection pressure
December	Parental	Intermate among selected parents.	Palmira None
March	Parental and F	Intermate among selected parents & crosses. Save F_2 seed from selected single crosses.	Palmira None
June	Parental and F_1 Save F seed from selected crosses	Intermate among selected parents and crosses.	Palmira
December	F_2	Grow out & save F_2 seed from selected crosses.	Palmira None
June	F_3	Yield test all crosses in replicated trials. Save F_3 bulk* from selected crosses.	Palmira None
December	F_4	Yield test & save F_4 bulk* from selected crosses.	Quilichao Drought, common blight, angular leaf spot, fertility, root rots
June	F_4	Yield test & save F_5 bulk* from selected crosses.	Popayan Drought, anthracnose root rots
December	F_5	Space-plant and make single plant selection.	Palmira Drought, root rots
June	F_6	Progeny test and seed increase. Save bulk F_7 seed from selected lines.	Quilichao Same as in F_3
December	F_7	Yield test select lines for national programs, VEF, EP, IBYAN and other nurseries and specific physiological studies	Palmira, Quilichao and Popayan Same as in F_3, F_4, F_5

* Single pod bulk

CONCLUSIONS

In the final session of the workshop, the participants prepared a list of subjects which were thought to merit further attention, and these were discussed as far as time permitted. Although the discussions drifted over a wide range of topics, the workshop coordinator has tried to summarize them systematically in the next section.

Defining "Drought Tolerance"

Most participants appeared to use what might be termed an agronomic definition of "drought tolerance" by simply stating that a genotype is drought tolerant if it yields relatively well under drought stress. Possible mechanisms of drought tolerance are:

1) Drought escape
2) Drought avoidance
3) Desiccation tolerance.

However, in the discussions, it became clear that physiological ecologists prefer an alternate terminology. For them, drought tolerance refers to tolerance to drought at the tissue level, this being equivalent to the desiccation tolerance of agronomists. Ability to yield well under drought is simply adaptation to drought. Thus an ecological classification of mechanisms of drought adaptation would be:

1) Drought escape
2) Drought avoidance
3) Drought tolerance.

Also mentioned was the term "drought resistance", used by Levitt (1980) within his extensive classification of adaptations to stress. There was general agreement that this term is confusing in an agronomic context because "resistance" is usually applied only to situations where there is no yield reduction under stress (e.g. in the case of virus resistance). The consensus in discussing these differences in terminology was that while either an agronomic or ecological classification is useable, one should be aware of possible misunderstandings which could arise.

Characterizing Drought Stress

Throughout the workshop, it was apparent that few bean researchers attempt to characterize the drought stress obtained in their trials. M. Paulet suggested that stress can be characterized through simple water balance calculations based either on pan evaporation or an estimate of potential evapotranspiration from the Penman equation or similar approaches. It was also mentioned that the BEANGRO model can provide estimations of various parameters of the crop water balance.

Characterizing Genotype Response to Drought

In analysing data from drought trials with irrigated checks, one frequently wants to classify genotypes by their apparent drought response. This is commonly done through indices such as percent yield reduction, yield response (such as calculated by C. Guimaraes for data from the line source system at CNPAF), and the Fisher drought index. All of these indices were thought problematic since a genotype with a low yield under irrigation will often appear drought tolerant. The geometric mean was mentioned as an alternative, although it was recognized that this parameter is best suited for identifying genotypes which combine drought tolerance with good yield potential. No specific recommendation was made on whether to use a specific index. Examining data using graphs when comparing yields under different environments seemed preferable to trying to condense complex data into a single variable.

Equipment for Drought Research

Several researchers indicated an interest in equipment suitable for drought research in developing countries, and they requested that special consideration be given to low cost, reliable products. The discussions centered around two broad areas: measurement of parameters for estimates of water balance and environmental conditions, and measurement of physiological and plant parameters.

In the discussions of methods for obtaining data on amount of irrigation water applied, soil moisture content, and other parameters related to crop water balance, it was noted that there is a large literature on techniques for measurement of water use. The FAO publications in the series of FAO Irrigation and Drainage Management Papers are of particularle useful. This series includes discussions of estimating evapotranspiration in different crops, including beans (Doorenbos and Kassam, 1979), guidelines for design and management of weather stations (Doorenbos, 1976), and instructions for construction of devices for measuring surface irrigation (Kraatz and Mahajan, 1975).

The discussions on equipment for measuring physiological parameters tended to focus on recommendations with respect to products from specific manufacturers, but in most cases these discussions reduced to basic differences in equipment design.

There was a consensus for pressure chambers, that the two most widely used makes are acceptable, but that models with digital displays of pressure should be avoided both because they are hard to read when the pressure is fluctuating, and because service may prove problematic.

Several examples were cited where equipment could be manufactured for much lower prices than equivalent commercial versions. Leaf temperature may be monitored through homemade thermocouples. A steady state porometer can be built with a humidity sensor, an air pump, a flow meter, and plastic chamber. Pressure chambers have already been built in developing countries, the essential components being a steel cylinder capable of withstanding the pressures required, a manometer, and valves permitting fine adjustments in flow rate. Light sensors can be produced using photodiodes or photocells. Unfortunately, most bean researchers lack the expertise needed to produce such equipment. J. Ehleringer referred interested researchers to a soon to be released book on measurement of ecological parameters (Methods in Plant Physiological Ecology). Also suggested was to seek support to organize an international workshop on techniques and equipment for studying plant water relations.

For research on roots, the basic practice of analysing root samples with a line-intercept technique (Newman method) seems adequate, but improved equipment would help. Better root washers are available (e.g. Marchant et al., 1986), but computer aided length estimation was thought to require further refinement.

Future Drought Nurseries

The results of the Bean International Drought Yield Trials indicated that continuing the nursery in its present form would be of little use to bean researchers. Two needs were identified for future nurseries. One is a small yield trial (e.g. 16 entries by 3 replicates) which would permit people initiating work on drought to evaluate a well characterized set of germplasm in an exploratory yield trial. The second is to provide a nursery where the best drought materials from different programs may be interchanged among programs. Expecting that adaptation problems will limit the usefulness of many of the lines which would be included in such a nursery, it was thought better to distribute a relatively large number of materials (36 to 49), while only providing enough seed for two replicates plots. The option of an irrigated check was not considered necessary for either nursery.

Recognizing that shipment of genotypes susceptible to bean common mosaic virus (BCMV) is hazardous, it was agreed that all entries in nurseries should be resistant to BCMV. The Bean Physiology program at CIAT will receive candidates for such nurseries, will test them for resistance to BCMV, and do the subsequent seed multiplication. Researchers interested in receiving the nurseries may request them through CIAT Bean Program researchers, or write directly to the Bean Physiology program.

Communication of Research Results

To facilitate interchange of information on drought research, the possibility of preparing an informal newsletter was also considered. J. White indicated that he could distribute such a newsletter on a 6 month basis if sufficient material were submitted. It was also noted that workers should publish in Hojas de Frijol or the Bean Improvement Coop Annual Report if they have preliminary results of general interest.

General Conclusions

The discussions of specific points did not leave time for a general summary of conclusions from the Workshop. However, several points emerged repeatedly during the presentations, and these may be considered as general conclusions of the workshop.

Foremost was the consensus that bean genotypes do show strong differences in response to drought. Furthermore, drought escape and drought avoidance appear to be more important tolerance mechanisms than desiccation tolerance. However, further research is needed on *Phaseolus vulgaris* and related species (especially *P. acutifolius*) to determine whether it would be possible to increase levels of osmotic adjustment in beans. Similarly, although available data on water use efficiency (estimated using carbon isotope discrimination ratios) indicates that high water use efficiency is associated with poor growth and low yields under drought, there is a need to obtain information on the genetic variation in water use efficiency in beans, and to determine whether intermediate levels of water use efficiency can be sought as a way of assuring yield stability with an acceptable minimum yield.

Two papers (Zuluaga et al., and White and Castillo) noted that part of the supposed drought tolerance of P. acutifolius is attributable to its very early maturity. It was further suggested that a portion of the tolerance of P. acutifolius may somehow be related to its small seed size.

It was expected that the utility of drought escape and drought avoidance will vary greatly with local climatic and edaphic conditions. Two strategies for dealing with such variation are to rely on very extensive empirical testing (e.g. yield trials conducted over many sites and many seasons within a region) or to use water balance or simulation models to estimate the expected variation.

The importance attributed to root effects in determining drought response highlighted the need for greater emphasis on studies of root growth and function under different soil and moisture conditions. Grafting studies provide a useful first step towards determining the relative importance of root and shoot effects, but much more attention is needed in the area of specific studies on root physiology.

Most of the discussions focused on arriving at a basic understanding of effects of drought on beans, and interpreting these effects in terms of tolerance mechanisms which might be selected for in a breeding program. Thus, specific strategies for breeding for drought per se were not examined closely. Most participants seemed to acknowledge the need to emphasize yield testing in early generations with use of replicated plots. Many participants have initiated breeding projects for drought tolerance in the past two or three years, and it is anticipated that in future workshops, breeders will be able to report on their experiences in this area.

Regrettably, none of the workshop participants discussed possible strategies for agronomic management to alleviate drought problems, particularly for small farmers. In Mexico, research is apparently being done on ways to improve water retention (e.g. through tillage patterns). Practices such as weed control and deep plowing also might be of interest. A future workshop should make a special effort to bring researchers with expertise in these areas.

As a final conclusion it can be said that the workshop was characterized by a sense of optimism and a belief that researchers are progressing in their understanding of drought problems in beans. Assuming adequate support for research, the next few years should see many questions resolved. Hopefully we will also see the release of the first potential cultivars bred specifically for drought tolerance.

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