THE INFLUENCE OF WINDBREAK BARRIER LOCATION AND PROXIMITY ON THE CROP GROWTH RATE, BIOLOGICAL YIELD, AND ECONOMIC YIELD OF IRRIGATED SNAP BEANS

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CHAPTER I

INTRODUCTION

Oklahoma crop producers are facing a serious economic plight. From 1970 to 1980 farm production expenses rose at a faster rate than gross farm income (35). The traditional agronomic crops (e.g., wheat, peanuts, cotton, soybeans,and sorghum) have experienced yield and price instability in the midst of escalating production costs.

In selected areas of the state, progressive crop producers are exploring the possibility of incorporating horticultural crop production into their farming practices. Horticultural crops offer opportunities for higher crop values and improved cash flow over the traditional agronomic crops.

One such area is in the region of south central Oklahoma encompassed by Caddo, Canadian and Grady counties. There is sufficient acreage suitable for horticultural crop production in close proximity to the Oklahoma City and Dallas markets. The average frost free season ranges from 200 to 220 days. Annual precipitation is 63.5 cm to 88.9 cm (25 to 35 inches). Supplemental irrigation is available in scattered sites throughout the area.

One potentially serious limiting factor is wind.

Interpolated wind data for Caddo County indicates that wind velocity averages about 20.1 km per hour (12.5 miles per hour) and ranges from 17.7 km per hour (11 miles per hour) in August to 24.1 km per hour (15 miles per hour) in March and April. Gusts up to 128.7 km per hour (80 miles per hour) have been reported along squall lines (57).

Wind can influence plant growth at all stages of crop development. Cultivated soil is subject to erosion and small seeded crops can be blown from the seedbed. Windblown soil particles can cause sandblast damage on seedlings and be the source of inoculant for plant diseases (11, 24, 36, 51, 55). Exposed plants may exhibit mechanical damage (18, 36, 51), delayed maturity (18, 49), and reductions in yield and crop quality.

Windbreaks and shelterbelts have been used in a variety of ways to reduce surface wind speed. The American Meteorological Society distinguishes these terms as follows:

Shelterbelt: A belt of trees and/or shrubs arranged as a protection against strong winds; a type of windbreak. The trees may be specially planted or left standing when the original forest is cut.

Windbreak: Any device designed to obstruct wind flow and intended for protection against the ill effects of wind (18).

A reduction in wind speed and the subsequent microclimatic effects resulting from the presence of a windbreak are referred to as the shelter effect or shelter influence. Bates (7) observed that two distinct effects comprise a shelter influence. They are:

Competitive effects: Those effects near barriers arising directly from interference of the barrier with the radiation, climate and rainfall distribution as well as from the presence of the roots of the trees and shrubs comprising the barrier.

Windbreak effects: The reduction in wind speed beyond barriers and the consequent changes in other micrometeorological factors.

Prospective horticultural crop producers have concerns regarding crop adaptability to windy locations. Crop protection with annual or temporary windbreaks may facilitate production in exposed areas. The purpose of this experiment was to examine crop responses to varying degrees of windbreak protection. Specifically, this study examined the influence of wind barrier location and/or proximity on irrigated snap bean:

1) Crop growth rate, net assimilation rate, and leaf area index;

2) Final economic and biological yield.

CHAPTER II

REVIEW OF LITERATURE

Barrier Characteristics Influencing Windbreak Effects

There are certain fundamental barrier characteristics that influence the quality and extent of the windbreak effect. Air flow in shelter is related to the barrier orientation, height, porosity and length (37). The turbulence of the approaching wind, the angle of the wind and the roughness of the soil surface also have influences on the windbreak effect (54).

The effects of barriers are greatest where the wind blows perpendicular to them. As the angle of incidence between wind direction and barrier orientation decreases, there is a reduction in the area afforded protection. Van Eimern, Karschon, Razumova and Robertson (18) summarize from the Russian literature that a deflection of the wind direction by 30 to 45 degrees causes no important decrease in windbreak effect.

Practitioners typically position windbreaks perpendicular to the prevailing, or most frequent, wind. However, Marshall (37) points out that this may not necessarily be the most undesirable wind from which protection is required. Frequency, strength, dryness, structure of the wind and frequency of direction are all important in determining the degree of windbreak effects.

The extent of the windbreak effect is proportional to the barrier height. The convention adopted within the windbreak research literature is to report the distance of the windbreak effect in multiples of the barrier height (H). Marshall (37) contends that the widespread adoption of this convention implies that certain extenuating factors such as speed of the undisturbed wind, stability of the atmosphere and roughness of ground or crop surface, are unimportant.

Wind reduction behind shelterbelts occurs over a wide range of reported distances. Caborn (14) reports that effects have been identified at 100H or more but suggests that effects beyond 40H are unlikely to be of practical consequences. Van Eimern et al. (18) establish the windbreak sheltered zone to be approximately 30H on the leeward and 5H on the windward side of the barrier based on the observations of West European, North American and Russian researchers. Using a twenty percent wind reduction as the criterion for useful shelter, the shelter effect should extend 15H to 20H on the leeward side of the barrier (14).

Another barrier characteristic effecting the windbreak shelter influence is the density or permeability of the windbreak. The degree of permeability is determined by the percentage ratio of the perforated area of the belt, taken perpendicular to its line, to the total vertical area of the belt (18).

A dense barrier provides a greater degree of shelter immediately to the leeward side, but the extent of shelter is restricted due to the turbulence created behind the barrier. The air stream rises over the dense barrier, encounters a high velocity air stream above the barrier and is forced to the ground to mix turbulently with underlying air. Dense barriers also allow wind speed to be more quickly restored on the leeward side, thus reducing the zone of windbreak shelter effect.

At higher barrier permeabilities the turbulence is reduced but so is the degree of shelter. The compromise becomes one in which one must minimize turbulence and maximize the area of reduced wind speed through the selection of barrier porosity. Hogg (1964), in a field study reported by Grace (25), reported that hole area rather than geometry was important in determining the extent of wind-break shelter effect. The range of optimum permeability appears to be forty to fifty percent with gaps evenly distributed (37,54).

Barrier length has an influence on the quality and the extent of the windbreak shelter effect. Wind velocity at the ends of windbreaks will increase relative to the wind speed in the open (14). This phenomenon is an important consideration for field researchers performing small scale plot work as well as for crop producers who may be inadvertently exposing crops to increased wind speeds.

In those field settings where winds frequently veer from a direction normal to the barrier, barrier length is critical in maintaining a degree of shelter on the leeward side. Van Eimern et al. (18) cite a study by Naegeli (1953) who observed the ratio of the length to the height of the barrier must be at least 11.5 if the wind conditions of an infinitely long belt are to be achieved for a line perpendicular to its center. Marshall (37) notes that a barrier 11.5H in length will accomodate directional veers up to thirty degrees from normal incidence while a barrier 20H in length is necessary for veers up to forty five degrees.

In a crop producer's field situation a single shelter-belt offers only limited protection. A network of belts must be established to afford protection over a larger surface area. Field and wind tunnel experiments have examined systems of parallel windbreaks. Although Van Eimern et al. (18) and Caborn (14) cite occasional studies to the contrary, the general consensus appears to be that there is no cumulative effect on wind velocity with a system of parallel windbreaks. In fact, wind tunnel studies have observed an increase in turbulence behind the first windward belt (18).

A number of factors influence the selection of an appropriate distance between parallel windbreaks in order to maintain the windbreak shelter effect. The barrier height, permeability, length, prevailing wind direction and prevailing wind speed should influence the choice. The extent of protection afforded by a single barrier with a perpendicular wind should be considered the greatest possible distance allowed. In this instance the leeward protected zone of the first barrier would overlap the windward protected zone of the second. Caborn (14) suggests that if the two barriers are not more than 30H apart, unobstructed wind speed will not be attained between barriers.

Windbreak Shelter Influence on Microclimate

The reduction in mean wind speed caused by a windbreak is only one aspect of the windbreak shelter effect. Shelter influences effect a range of microclimatic factors (14, 37, 47). This discussion is concerned with the shelter effect on evaporation, transpiration, soil moisture, air temperature, humidity and soil temperature.

Caborn (14) contends that the loss of moisture by evaporation is the critical feature of the effect of wind on crops. Evaporation influences soil moisture content as well as the internal water status of plants through transpiration. The zone of reduced evaporation behind a barrier coincides with the zone of wind reduction. The greatest zone of reduced evaporation is observed up to 10-15H on the leeward side of the barrier (18). In wind tunnel studies cited by Van Eimern et al. (18), barrier permeability of fifty percent reduced evaporation the most. Where barriers are impermeable, the zone of increased turbulence can cause greater evaporation than in the open.

Higher levels of soil moisture can occur behind shelter for two reasons. Where the barrier is permanent in the field, the windbreak has the capacity to modify the distribution of snow. Snow accumulates on the leeward side of the barrier and can provide supplemental soil moisture in those climates where winter precipitation is normally inadequate to restore soil moisture content to field capacity (37). Shelter also retards direct evaporation from the soil surface, thus conserving soil moisture . Caborn (14) cites laboratory and field tests that report increased moisture content of soils in the sheltered zone. Aase and Siddoway (1) observe that tall wheatgrass barriers influenced the soil drying rate of protected locations. This characteristic of windbreak shelter influence may provide an important advantage in maintaining better conditions for seed germination (50).

However, the soil moisture situation can become more complex once a crop has become established and developed a canopy. Soil moisture loss can occur from the soil surface as a result of direct evaporation and from rooting depths in the soil as a result of transpiration from the leaves. In this situation, a shelter may actually result in reduction in soil moisture as compared to no shelter because of a larger leaf surface and a more extensive root system (25, 47).

Windbreak shelter influences on air temperature vary with different times of the day, the season, prevailing weather conditions and type of shelter (18). The most common observation is an increase in air temperature by day and a slight reduction at night. Van Eimern et al. (18) attribute this increase in diurnal amplitude of air temperatures to the reduction of the vertical diffusion and mixing of the air behind the shelter.

The increased risk of frost in a windbreak shelter is a debatable issue. Caborn (14) points out that the reduced wind velocity in a sheltered area makes the risk of night frost greater in sheltered areas as compared to unsheltered regions. With less air movement, thermal stratification may result within the sheltered zone.

However, Van Eimern et al. (18) cite references that contend the greater soil moisture in the sheltered zone may protect the area better than an unsheltered area where soil is dry. Also, in barriers of evenly distributed porosity, the sheltered zone has the capacity of collecting warm air during the day and gradually dissipating the heat energy during the evening. This can afford additional frost protection.

The windbreak shelter effect on soil temperature is dependent upon the time of day, weather conditions, degree of wind reduction, type of crop cover and amount of soil moisture (18). Caborn (14), Marshall (37) and Van Eimern et al. (18) cite research from an international body of literature that documents daytime soil temperature increases in shelter. Van Eimern et al. (18) contend that soil temperature differences between sheltered and exposed locations are due to the relationship between wind movement and evaporation. The reduction in evaporation within the sheltered zone provides moderate amounts of soil moisture that are able to conduct warmth to lower soil strata. This facilitates warmer daytime soil temperatures in sheltered locations as compared to exposed.

The shelter influence on air humidity is dependent on air temperature, wind, transpiration, soil moisture content, evaporation from vegetation, time of day, season and weather conditions (14). Van Eimern et al. (18) supplements this array of influences with the degree of crop coverage, the amount of turbulence and the air mixing behind the barrier.

In research cited by Van Eimern et al. (18) and Caborn (14) absolute humidity in the sheltered locations was generally higher than in the exposed locations. Where relative humidity has been recorded, the higher day time temperatures within shelter offset the effects of additional moisture in the atmosphere. The result is a slight variation in relative humidity, either positively or negatively, between the sheltered and exposed locations (37).

Relative humidity at night, early morning and late afternoon can be expected to be higher in shelter because of the difference in heat balance as compared to midday. Bagley and Gowen (6) observed the greatest differences between shelter and exposed locations occurring early in the morning and late in the evening, with shelter exhibiting the higher relative humidity.

Selected Crop Responses to Windbreak Shelter

The reduction in mean wind speed associated with a windbreak can produce warmer soil temperatures and a slower evaporation rate from soils within the sheltered area (14, 37,47). Such microclimatic influences could have a beneficial effect on seed germination and seedling emergence. Adequate soil moisture and warmer temperatures will influence the rate of seed germination. More rapid hypocotyl elongation at higher temperatures can result in earlier emergence (46). An extended period of soil surface wetness in the lee of shelter during seedling emergence will retard soil crusting and the possible mechanical damage associated with such crusting (8).

Field observations of shelter influence on seedling emergence and stand establishment are scarce. Bagley and Gowen (6) observed that direct seeded tomatoes and snap beans sown in shelter exhibited a greater number of emerged seedlings two weeks after planting. However, Rosenberg, Lecher and Neild (49) observed that the emergence of two snap bean varieties was not greatly affected by the presence of shelter in the field.

A much larger body of literature has been devoted to seedling response and stand maintenance in the wake of wind blown sand. At the seedling growth stage, the lack of canopy cover makes the soil surface vulnerable to evaporative losses and susceptible to erosion. Seedlings can be damaged or destroyed by such exposure. In laboratory wind tunnel studies rangeland grass seedlings were killed or exhibited severely retarded growth as a result of exposure to wind blown sand (23). Peppers, carrots and cotton were easily damaged by wind erosion while sunflower, onion and southern peas exhibited fair resistance with moderate wind erosion conditions (24). Low rates of sand movement for short durations damaged tomato seedlings and caused a reduction in stand (2). Severe plant seedling damage, reductions in growth and reductions in yield have been reported for snapbeans (13, 51), peas (13), cotton (22), winter wheat (4), and sorghum (2).

The presence of shelter can also influence plant height. Sheltered plants typically grow taller than exposed plants. Increases in sheltered plant height have been observed with snap beans (47, 49) and soybeans (20). Wind tunnel studies with sunflower have substantiated reductions in internode length (63) and stem height (39) with exposed plants.

Further support for such observations is found in the realm of mechanical stress literature. The kinetic component of wind has a direct effect on plant growth. Daily handling of cotton plants has caused a reduction in internode length, internode number and height of plants (21). Turgeon and Webb (56) observed reductions in petiole and shoot length of Cucurbita melopepo associated with daily handling. Tomato and pea were dwarfed with various forms of mechanical stimulation (42) while brief, daily mechanical disturbances reduced shoot elongation of tomato (41).

A conflicting observation has been made by Bagley (5) in field work with tomato and snap beans. Plants immediately adjacent to a slat fence barrier appeared slightly smaller than those some distance away. The density of the barrier and the influence of the barrier on net radiation were factors which contributed to such a response. Similar observations have been more commonly associated with living barriers where competitive interactions between barrier and crop plants may exist (14, 18, 37).

The microclimate associated with windbreak shelter may also influence crop maturity. Van Eimern et al. (18) cite references from international research where sheltered new potatoes (Van der Linde, 1958) matured more quickly and strawberries (Van Rhee, 1959) produced an earlier but no larger crop than exposed plants. Rosenberg et al. (49) observed that two snap bean varieties exhibited earlier maturity in shelter. However, results from an earlier unpublished thesis suggested sheltered dry beans exhibited a greater pod set but a delayed maturity.

There is a growing body of international literature collected from France, Holland, Denmark, Russia, Germany, Canada, Great Britain and the United States which documents the economic yield increase of sheltered crops (14, 18, 25, 37, 54). Vegetable crops which have exhibited yield increases in the presence of shelter include corn, beets, turnips, potatoes, carrots, cabbage, tomatoes, dry beans and snap beans (25).

However, crop response to shelter does vary across seasons and climate. Species as well as varietal differences are reported. Van Eimern et al. (18) and Marshall (37) note that percentage yield responses tend to be greater in 'dry' years than 'wet' years. Shelter responses also tend to be greater in continental than oceanic climates. Such variations may be attributed to the improved plant moisture status of plants grown within shelter.

Variation between species and location may be explained by the occurrence of damaging winds at critical times in the crop life cycle. When economic yields depend on successful reproductive growth, physiological and/or mechanical stress during flowering and fruit set can be devastating. Grace (25) makes reference to Tsuboi (1961) who observed the greatest damage to rice yields occurred when typhoons struck during heading and flowering. Strong winds subsequent to these stages caused much less damage.

Total biological yield and economic yield may not be influenced by shelter to the same extent. Shelter has resulted in a positive influence on the vegetative growth of wheat (53), dry beans (47), sugarbeets (12), and soybeans (45). Wind tunnel studies with sunflower have demonstrated reductions in dry weight with increasing wind speeds (63). Brief, daily mechanical disturbance has reduced the dry weight gain of tomato (40).

There appears to be few investigations into the dry matter partitioning response of plants grown in shelter. Marshall (38) reported no detectable effect on the partitioning of dry matter within swede turnips or sugar beets. However, Rosenberg (47) reported higher root/top ratios with sheltered sugar beets late in the season.

The presence of a windbreak can influence insect populations within the sheltered zone. Lewis (34) has noted an increase in lettuce root aphid population in shelter of an artificial barrier during spring aphid migration. In later work, Lewis (32,33) observed increases in insect populations as well as increases in beneficial predators and parasites in the lee of shelter. Such observations have led Lewis to conclude that there is insufficient information available to make an assessment of the merits of shelter on insect ecology.

Microclimatic modifications associated with shelter (e.g. warmer daytime air temperatures, higher absolute humidity and reduced air movement) can influence the incidence of disease within shelter. Van Eimern et al. (18) cite a number of international references where mildew on strawberries, corn blight on corn, *Alternaria brassicae* on cabbage and *Phytophthora infestans* on new potatoes were more prevalent in shelter. Sturrock (54) cites additional references where *Botrytis* reduced yields of sheltered lettuce and *Phomopsis thaea* infected sheltered tea clones.

However, exposed plants also have certain disease vulnerabilities. Mechanical damage associated with wind-blown sand has been substantiated (24, 36, 51). Wounds associated with such damage are susceptible to infection (58). Windblown sand particles have been implicated in the dissemination of bacterial blight of lima bean (55) and angular leaf spot of cotton (11). Wind tunnel studies have demonstrated the increased incidence of bacterial leaf spot of alfalfa and common blight of bean as wind speed and exposure time increased. The greatest incidence occurred in rows nearest the wind source (15).

Crop Growth Analysis and Its Application to Windbreak Shelter Research

Growth analysis is the quantitative description of plant growth, where growth is defined as the increase of plant dry weight (31). The theoretical background for growth analysis has evolved from the work of Blackman (9), Briggs, Kidd and West (10), Williams (64), Watson (61), Hughes and Freeman (27), Wilson (65), and Jolliffe, Eaton and Doust (30). Such analysis has gained international acceptance as a standard method of estimating net photosynthetic production of plants and plant stands across a variety of species.

The application of a 'classical' growth analysis requires the destructive harvest of representative plants or plots over designated time intervals. From these plants two types of measurements are needed:

1. The total dry weight of the individual plant or plants within a stand (W). Researchers frequently partition the plant to get separate dry weight values of roots, stems, leaves.

2. The size of the assimilatory surface. Although it is recognized that other plant parts contribute to the overall photosynthetic capacity of a plant, total leaf area (A) is most commonly employed. Leaf weight, leaf protein and chlorophyll content have also been employed.

Observations of the above primary values over designated time intervals allows the researcher to quantify various growth characteristics and indices that describe component plant part and total dry matter accumulation. The relationship between plant growth and the assimilatory surface area of the plant or plant stand can provide the researcher with valuable insight into the dynamics of photosynthetic production.

Relative growth rate (RGR) is a primary growth characteristic which developed directly from Blackman's concept of efficiency index (9). The relative growth rate of a plant at an instant in time (t) is defined as the increase in plant dry weight per unit of dry weight per unit time (44). It is given by the formula:

$$RGR = \frac{1}{W}\frac{dW}{dt} = \frac{d}{dt}(\log_e W) \quad (2.1)$$

Since it is not practical to make continuous observations of total dry weight over time, researchers more characteristically make observations at designated time intervals. The observations are expressed as mean values over the period between observations. The derivation of the formula for mean relative growth rate is:

$$\overline{RGR} = \frac{\ln W_2 - \ln W_1}{t_2 - t_1} \quad (\text{weight weight}^{-1}\ \text{time}^{-1}) \quad (2.2)$$

where W_2 and W_1 are the values of W at times t_2 and t_1, respectively.

The only assumption necessary to carry out the integration is that W varies without discontinuity throughout the period t_1 to t_2 (44). Application of equation 2.2 does not require the assumption of exponential growth although the solution is the same. Fisher (19) demonstrated that if exponential growth does occur, equation 2.2 gives the mean relative growth rate for the period t_1 to t_2 as well as the relative growth rate throughout the interval.

The assessment of mean relative growth rate need not be confined to whole plants. The mean relative growth rate of plant parts (e.g., root, leaves, stems,etc.) may also be estimated. The application of this growth characteristic in this capacity provides an important tool for investigators examining dry matter partitioning within the plant.

A second growth analysis characteristic is net assimilation rate (NAR) or, synonymously, unit leaf rate. The original introduction of this growth characteristic was intended to reduce the observed distortion in relative growth rate estimates as a result of the inevitable changes of plant form and function associated with plant growth. This problem of ontogenetic drift has been addressed by Briggs, Kidd and West (10), Gregory (26) and Coombe (16).

Net assimilation rate of a plant at an instant in time (t) can be defined as the increase in whole plant dry weight per unit of assimilatory surface (A) per unit of time (44). It is given by the formula:

$$NAR = \frac{1}{A} \frac{dW}{dt} \qquad (2.3)$$

This is an important growth characteristic in the assessment of plant performance because it expresses growth in terms of assimilatory surface area.

The calculation of mean net assimilation rate is not so straightforward. A prerequisite for the accurate estimation of mean net assimilation rate is knowledge of the relationship between assimilatory surface area (A) and total plant dry weight (W) or knowledge of the relationship between A versus t and W versus t. Radford (44) lists a series of mean net assimilation rate formulas that have applicability once the above relationships have been ascertained. Where W varies linearly with A, mean net assimilation rate can be estimated by the formula:

$$\overline{NAR} = \frac{W_2 - W_1}{A_2 - A_1} \quad \frac{(\ln A_2 - \ln A_1)}{t_2 - t_1} \qquad (2.4)$$

A third growth parameter found in the literature of growth analysis is the leaf area ratio (LAR). The leaf area ratio of a plant at an instant in time is defined as the ratio of leaf area (A) to whole plant dry weight (W) (44). Kvet, Ondok, Necas and Jarvis (31) point out that this is the product of two simpler ratios. These ratios are the specific leaf area, which is the ratio of leaf area (A) to leaf dry weight (W_L), and the leaf weight ratio, which is the ratio of leaf dry weight (W_L) to total plant dry weight (W). These relationships can be given by the formula:

$$LAR = \frac{A}{W} = \frac{A}{W_L} \cdot \frac{W_L}{W} \qquad (2.5)$$

Radford (44) notes that very little has been published on methods of calculating mean leaf area ratio. A proper application of the concept of mean leaf area ratio requires knowledge of the relationship between A W^{-1} and t or knowledge of the relationship between A and t as well as W and t. Radford further states it may be better to express

LAR values at t_1 and t_2 rather than a mean LAR, thus avoiding the pitfalls of hidden assumptions.

Briggs, et al. (10) mathematically demonstrated that if changes in plant weight (W) and leaf area (A) are on an exponential basis, the relative growth rate is the product of the net assimilation rate and the leaf area ratio. At an instant in time (t) the following relationship holds:

$$\frac{1}{W}\frac{dW}{dt} = \frac{1}{A}\frac{dW}{dt} \cdot \frac{A}{W} \qquad (2.6)$$

$$RGR = NAR \cdot LAR \qquad (2.7)$$

The practitioner working with mean values for relative growth rate, net assimilation rate and leaf area ratio must exercise caution in applying the following relationship as an equality:

$$\overline{RGR} \neq \overline{NAR} \cdot \overline{LAR} \qquad (2.8)$$

Radford (44) notes that this expression holds as an equality only when A and W are exponential with the same exponent.

Analogous growth characteristics are available to crop researchers investigating stands of plant material as units of dry matter production and assimilatory surface area. Watson (62) introduced the concept of crop growth rate. Crop growth rate of a unit of area of ground occupied by the stand at any instant in time (t) is defined as the increase in total plant dry weight (W) per unit time (44). This can be represented by the formula:

$$CGR = \frac{dW}{dt} \qquad (2.9)$$

The mean crop growth rate over a time period from t_1 to t_2 is given by:

$$\overline{CGR} = \frac{W_2 - W_1}{t_2 - t_1} \qquad (2.10)$$

where W and W are the values of W at times t_1 and t_2 respectively. The only assumption necessary for the appropriate application of equation 2.10 is that W varies without discontinuity throughout the period t_1 and t_2 (44).

The growth characteristic associated with the assimilatory surface of a stand of plants is the leaf area index. The leaf area index (LAI) of a stand of plants at an instant in time (t) is defined as the ratio of leaf area (A) to a unit area of ground (P) occupied by the stand. This relationship can be expressed as:

$$LAI = \frac{A}{P} \qquad (2.11)$$

It follows that the crop growth rate of a stand is dependent on the dry matter production of that stand as well as the total assimilatory surface area. At an instant in time (t) the following relationship holds:

$$CGR = NAR \cdot LAI \qquad (2.12)$$

The earlier precautions associated with the application of equation 2.8 as an equality are applicable when using mean crop growth rate, mean net assimilation rate and mean leaf area index. The relationship:

$$\overline{CGR} \neq \overline{NAR} \cdot \overline{LAI} \qquad (2.13)$$

can be used as an equality only during exponential growth where A and W have the same exponent (44).

In field applications of crop growth analysis, Watson (62) has observed that the photosynthetic capacity of crops expressed as leaf area index is much more variable in agricultural environments than the photosynthetic efficiency measured by net assimilation rate. Some improvement in net assimilation rate may be achieved through breeding or selection but the most dramatic gains in dry matter production have been achieved through the manipulation of leaf area.

The application of such growth analysis techniques to wind and shelter research has been primarily confined to laboratory studies using artificial wind. Wadsworth (59) observed an increase in relative growth rates of young rape plants in a wind tunnel at low wind speeds. This observation was consistent with the earlier findings of Deneke (1931) and Heinicke and Hoffman (1933) as cited by Wadsworth (59) where low wind speeds increased carbon dioxide uptake and assimilation rates.

At higher artificial wind speeds Wadsworth (59) observed a decrease in relative growth rate as well as a reduction in leaf area ratio. This too was consistent with the findings of earlier researchers (Hill, 1921; Bernbeck, 1924; Finnell, 1928; Martin and Clements, 1935; Rao, 1938; Whitehead, 1957) as cited by Wadsworth (59). All found that increased wind speed decreased the amount of growth.

As a result of wind tunnel observations Wadsworth (59) estimated an optimum wind speed for rape growth to be 0.3m sec^{-1}. Under laboratory conditions this wind speed reconciles the reductions in relative growth rate associated with higher wind speeds and the supplemental facilitation of carbon dioxide uptake at lower wind speeds.

In later work with rape, barley and pea grown in water culture Wadsworth (60) observed that four different artificial wind speeds had no significant effect on relative growth rate or net assimilation rate. Final leaf area ratios fell significantly in rape and barley but not in pea. Wadsworth speculated that earlier observations of reductions in growth of whole plants associated with higher wind speeds was the result of a water shortage. Plants in water culture had an abundant supply of water availability and hence did not exhibit such responses.

Application of classical crop growth analysis techniques to field shelter studies is scarce. Most of the quantitative analyses of plant growth responses to wind or shelter have been confined to the total amount of growth rather than the rate of growth. Marshall (38) has observed significant differences between crop growth rates of sheltered and unsheltered swede turnips and sugar beets during the course of the growing season. However, no significant differences in total dry matter production were recorded at the end of the crop growing season.

One growth characteristic that has been employed in shelter effect field work is the leaf area ratio or leaf area index. Increases in leaf areas of sheltered field crops have been reported for soybeans (43), dry beans (47), tobacco (37), swede turnip and sugar beet (38).

CHAPTER III

THE INFLUENCE OF WINDBREAK BARRIER LOCATION ON THE CROP GROWTH RATE OF IRRIGATED SNAP BEANS

Introduction

Wind can be a major limiting factor in crop production. Cultivated soil is subject to erosion and small seeded crops can be blown from the seedbed. Wind and sandblast have caused severe plant seedling damage, reduction in growth or reductions in final yield of snapbeans (13, 51), peas, (13), cotton (22), winter wheat (4) and sorghum (2).

Wind tunnel studies with sunflower have demonstrated reductions in plant dry weight with increasing wind speeds (63). Brief, daily mechanical disturbances have reduced the dry weight gain of tomato (40). In studies where shelter has been provided, a positive influence on the vegetative growth of wheat (53), dry beans (47), sugar beets (12), and soybeans (45) has been reported.

A criticism of the shelter research literature is that investigations have concentrated primarily on the total amount of growth and not the rate of growth of whole plants

(60). Such criticism can be overcome by performing growth analysis investigations in shelter research. Growth analysis is a tool used by researchers to gain infor mation on the rate of growth of plants.

Growth analysis is the quantitative description of plant growth, where growth is defined as the increase of plant dry weight (31). The theoretical background for growth analysis has evolved from the work of Blackman (9), Briggs, Kidd and West (10), Williams (64), Watson (61), Hughes and Freeman (27), Wilson (65), and Jolliffe, Eaton and Doust (30).

The purpose of this study was to examine the influence of windbreak barrier location on the growth analysis parameters, mean crop growth rate, mean net assimilation rate and leaf area index of irrigated snap beans. Incidental observations on the number of flowers and immature pods were made as the crop entered the reproductive phase.

Materials and Methods

Field experiments were conducted at the Perkins Horticulture Farm on Teller sandy loam soil and at the Caddo Farm on Cogg fine sandy loam soil in spring, 1983. Land was fitted for planting following standard field practices at each site. 'Eagle' snap beans (<u>Phaseolus vulgaris</u> L. 'Eagle') were seeded in 96 cm east-west rows at 85.0 kg/ha on April 19 (Perkins) and 89.0 kg/ha on April 25 (Caddo). Seeded rows, 61.0 m in length, were numbered consecutively from south to north, one through thirty four. Three additional guard rows were planted on both the north and south sides of the site.

Row 9 and row 18 were not seeded with snap beans. A slat fence windbreak barrier 45.7 m in length, 1.2 m in height with an approximate porosity of 60% was erected on April 24 (Perkins) and April 25 (Caddo) in an east-west orientation at row 9 and row 18.

Supplemental nitrogen was applied according to soil test results. Ammonium nitrate (34.0 N - 0.0 P - 0.0 K) was applied at 33.6 kg/ha on April 24 (Perkins) and April 25 (Caddo).

A premergent application of metolachlor herbicide at 2.24 kg of active ingredient per hectare was applied on April 20 at the Perkins site. A May 1 premergent application of 2.80 kg of active ingredient per hectare was made at the Caddo site.

Bean leaf beetles were observed at the Perkins site on May 11. One application of carbaryl at 1.12 kg active ingredient per hectare provided control.

Supplemental irrigation was supplied throughout the growing season when precipitation did not supply 2.54 cm weekly.

Wind movement was monitored at the Caddo site with two contact cup anemometers (W-264 series, Weathermeasure) and a combination wind speed and direction sensor (W-200 SD, Weathermeasure). All units monitored wind movement at a height of 45 cm (estimated mature crop canopy height) along a line perpendicular to the midpoint of the east-west barriers. The wind speed and direction sensor (Unit 1) was located between row 1 and the adjacent guard row. A cup anemometer (Unit 2) was located between rows 12 and 13 while the other cup anemometer (Unit 3) was located between rows 24 and 25. Equipment was in place on May 18.

Two hygrothermographs monitored temperature and relative humidity at the Caddo site. The hygrothermographs were placed in vented shelter boxes 15 cm above ground level. Hygrothermograph A was placed 10.0 m south of the wind speed and direction sensor (Unit 1). Hygrothermograph B was 4.0 m west of cup anemomenter unit 2. The hygrothermographs were operational on May 28.

Supplemental climatological monitoring equipment was not available for use at the Perkins site.

This study examined the influence of windbreak barrier location on mean crop growth rate and mean net assimilation rate over three sample harvests. A comparison of leaf area index was made at each sample harvest along with incidental observations of stand count, flower number and pod number.

The experimental design was a split plot. Main plots consisted of three sampling site treatments, while subplots were harvest dates. There were five replications. The sampling site treatments consisted of row 7 (located 4 H south of barrier row 9 and 11 H south of barrier row 18, where H equals barrier height), row 23 (located 4 H north of barrier row 18 and 11 H north of barrier row 4) and row 14 (located 4 H north of barrier row 9 and 3 H south of barrier row 18). A treatment main plot was a 3.5 meter section of row. The first replication began 12.1 meters east of a line that ran perpendicular to the west end of the windbreak barrier. The five treatment replications were continous along the treatment row with a 1.0 meter guard between replications.

Each of the treatment main plots was partitioned into seven 0.5 meter segments. Four segments were designated sample harvest sites for classical crop growth analysis while the remaining three segments served as interior guards between harvest sites within a plot.

One of three harvest dates was randomly assigned to three sample harvest sites in a main plot. The fourth harvest site was used as a substitute in the event an assigned harvest site had a total stand of less than three plants. The three harvest dates were June 2, June 10 and June 21 for Perkins and June 7, June 16 and June 27 for Caddo.

A stand count was recorded and all plants were dug from the harvest site on the designated harvest date. Plants were washed free of soil in the field. Plants were partitioned into retrievable roots, stems and leaves for laboratory dry weight determinations. Total leaf area of a subsample of three randomly selected plants from the stand within a harvest site was measured on a Licor leaf area meter. The mean specific leaf area (leaf area/leaf dry weight) of this sub-sample was used to calculate total leaf area of the canopy within a harvest site by multiplying by total leaf dry weight. Dry weight of plant parts as well as total dry weight was recorded on a total plant stand basis. At harvests II and III flower number and pod number were recorded. At harvest III pods were partitioned from stems for dry weight measurements.

Results

Daily precipitation measurements and maximum/minimum temperature observations for the Caddo site are listed in Appendix A, Table VII and VIII.

Temperature and relative humidity observations were recorded every two hours with hygrothermograph A and hygrothermograph B. Mean day (0600 - 1800 hours) and mean night (0200 -0400; 2000 - 2400 hours) observations for the sampling intervals are presented in Appendix A, Table IX. A significantly higher mean day temperature was observed for hygrothermograph B during the second and third sampling intervals. No other significant differences were recorded.

Prevailing winds were southerly during the course of the experiment, however strong fronts from the north and northwest moved through the area on May 12, 20 and 30 as well as June 5, 26, and 27.

A pairwise comparison of daily mean wind speed over the entire duration of wind speed observations is presented in Table I. All three units exhibited significantly

Table I. A pairwise comparison of mean wind speed at three locations on the Caddo site over four sampling intervals.

Sampling Interval		Mean ($m\text{-}sec^{-1}$)	Unit 1[z]	Unit 2	Unit 3
5/19-6/7	Unit 1	1.9	--		
	Unit 2	1.0	*	--	
	Unit 3	1.4	NS	NS	--
6/8-6/16	Unit 1	2.8	--		
	Unit 2	1.3	*	--	
	Unit 3	1.7	*	NS	--
6/17-6/26	Unit 1	2.1	--		
	Unit 2	0.9	NS	--	
	Unit 3	1.4	NS	NS	--
5/19-7/2	Unit 1	2.3	--		
	Unit 2	1.1	*	--	
	Unit 3	1.6	*	*	--

[z]Cup anemometer unit 1 was located 6.8 H south of the wind barriers. Unit 2 was located between the wind barriers. Unit 3 was located 5.2 H north of the barriers. H equals barrier height, 1.2 m.

NS, * Nonsignificant (NS) or significant at 5% (*) level by t test within each sample interval.

different daily mean wind speeds. Unit 1 had a higher daily mean wind speed than Unit 2 and Unit 3. Unit 2 had the lowest daily mean wind speed.

A comparison of the mean crop growth rates, mean net assimilation rates and leaf area indices over the three sequential harvests is presented in Table II.

Mean crop growth rate was estimated using the formula:

$$\overline{CGR} = \frac{W_2 - W_1}{t_2 - t_1} \qquad (3.1)$$

where W_1 and W_2 are the total dry weight of the plant stand within a 0.5 meter row section at times t_1 and t_2, respectively.

Over the first nine day harvest interval row 4 exhibited a greater mean crop growth rate than row 23. Row 14 had an intermediate mean crop growth rate. There was no significant difference in mean crop growth rates during the second harvest interval. The mean crop growth rate over the entire twenty day observation period was larger for row 14 than for row 23. Row 4 exhibited an intermediate mean crop growth rate over the twenty day interval.

A comparison of plant stand leaf area (A) and total dry weight of the plant stand within a 0.5 meter row section indicated that W varied linearly with A. Mean net assimilation rate was therefore estimated with the formula suggested by Radford (44):

$$\overline{NAR} = \frac{W_2 - W_1}{A_2 - A_1} \; \frac{(\ln A_2 - \ln A_1)}{t_2 - t_2} \qquad (3.2)$$

Table II. The influence of barrier location on mean crop growth rate, mean net assimilation rate and leaf area index over three sequential harvests of a 0.5m row section of irrigated 'Eagle' snap beans at two locations in spring, 1983.

		Mean CGR (g day^{-1})			Mean NAR (gm^{-2} day^{-1})			LAI		
Site[z]	Row[y]	I1[x]	I2	I3	I1	I2	I3	T1[w]	T2	T3
Caddo	4	2.47a[v]	2.97a	2.75ab	8.59a	4.65a	6.40a	0.34a	0.96ab	1.84b
	14	1.82ab	5.64a	3.92a	5.47a	6.94a	6.92a	0.40a	1.03a	2.50a
	23	0.70b	3.00a	1.96b	3.04a	9.98a	7.11a	0.16b	0.35b	1.33c
CV(%)		69	60	43	84	65	27	42	42	42
Perkins	4	2.88a	1.29b	1.96b	10.26a	2.99c	7.14a	0.36a	0.95ab	0.97b
	14	2.22a	3.23b	2.81b	7.76a	6.37b	8.20a	0.47a	0.92b	1.21ab
	23	2.74a	8.12a	5.85a	7.63a	10.12a	10.78a	0.51a	1.18a	2.23a
CV(%)		61	35	33	70	34	46	25	25	25

[z]Sowing dates = April 19 (Perkins; April 25 (Caddo).

[y]Row 4 = 4H south of row 9 barrier; row 23 = 4H north of row 18 barrier; row 14 = 4H north of row 9 barrier and 3H south of row 18 barrier, where H = barrier height (1.2m).

[x]Caddo: I1 = June 7-June 16; I2 = June 16-June 27; I3 = June 7-June 27.
Perkins: I1 = June 1-June 10; I2 = June 10-June 21; I3 = June 1-June 21.

[w]Caddo: T1 = June 7; T2 = June 16; T3 = June 27. Perkins: T1=June 1; T2=June 10; T3=June 21.

[v]Mean separation in columns by Duncan's Multiple Range Test, 5% level. Comparisons between sites are not valid.

There was no significant difference in mean net assimilation rates observed among sampled rows for the two harvest intervals or for the entire twenty day observation period.

Leaf area index was estimated at each sequential harvest. Leaf area index was calculated with the relationship:

$$LAI = \frac{A}{P} \qquad (3.3)$$

Where A is the plant stand leaf area of the 0.5 m row section and P is the unit area of ground occupied by this stand.

There were no observed differences among rows in LAI at the first sample harvest. At the second harvest row 14 had a greater LAI than row 23. At the third sample harvest all LAI values were significantly different with row 14 > 4 > 23.

Comparisons of the sample 0.5 meter plant stand, flower number and pod number are presented in Appendix B, Table XII. Row 14 had a consistently greater total plant stand than row 23 over the three sequential harvests. No difference was observed between row 4 and row 14.

Total numbers of flowers and pods observed in the sample 0.5 meter row section were recorded at the second and third harvest. Row 4 and 14 had more flowers than row 23 but there was no difference in the number of pods observed at the second sample harvest. At the final harvest, row 14 exhibited more flowers than either row 4 or row 23. All rows had significantly different numbers of total pods. Row 14 had the greatest number of pods set while row 23 had the least.

Significant row x harvest interactions were observed for root dry weight, stem dry weight and total number of pods at the Caddo site.

Daily precipitation measurements and maximum/minimum temperature observations for the Perkins site are listed in Appendix A, Tables X and XI. Observations on the influence of barrier location on temperature, relative humidity and wind speed were not made at this site.

The comparisons of mean crop growth rate, mean net assimilation rate and leaf area index over the three sequential harvests are presented in Table II.

There were no observed differences among rows in mean crop growth rate for the first harvest interval. For the second harvest interval and for the entire twenty day observation period the row with barrier protection on the south (row 23) exhibited a greater mean crop growth rate than either of the other two sample rows.

There was an observed difference in mean net assimilation rate for all sample rows for the second harvest interval. Row 23 exhibited a greater mean net assimilation rate than either row 14 or row 4. Row 4 had a significantly lower net assimilation rate than row 14. No differences in mean net assimilation rates were observed during the first harvest interval or for the entire twenty day observation period.

There were no observed differences among rows in LAI for the first sample harvest. At the second harvest, row 23 had a significantly greater LAI than row 14. Row 4 exhibited an intermediate value. At the third sample harvest row 23 exhibited a greater LAI than row 4 while row 14 had an intermediate value.

Comparisons of the sample 0.5 m plant stand, flower number and pod number are presented in Appendix B, Table XII. There were no observed differences in plant stand except for the final sample harvest. At the third sample harvest row 23 had a greater stand than either row 14 or row 4.

There were no observed differences in total flower number at either the second or third sample harvest. There was an observed difference in the number of pods at the final harvest with row 23 exhibiting a greater number of pods than either row 14 or row 4.

Significant row x harvest interactions were observed for leaf area index, stem, leaf and total dry weight, and total number of pods at the Perkins site.

Symptoms of common bacterial blight of beans were observed in the field at the time of the final sample harvest. It appeared that the disease became established in the rows south of the barriers and progressed in a northerly direction. Laboratory analysis confirmed the pathogen as <u>Xanthomonas phaseoli</u> (E.F. Sm. Dowson). More detailed observations on pod disease and foliar disease were made during the economic yield phase of the study.

Discussion

Barrier location influenced the mean wind speed at the Caddo site. The anemometer with barrier protection on the north side exhibited the highest mean wind speed. The anemometer with protection on both the north and south sides had the lowest mean wind speed. This observation might have been anticipated considering the prevailing winds were from the south.

The prevailing winds at the Caddo site may not have been the most destructive. The anemometer sheltered by barriers to the south side was fully exposed to the winds associated with the seasonal fronts from the north and west moving through the area in the early part of the season. This northern exposure was also subject to turbulence created by the presence of the barrier as a result of the prevailing winds from the south. The exposure to the abrupt fronts and turbulence created by the prevailing winds may well have made the north side of the barriers the most vulnerable relative to the destructive capacity of the wind.

The reduction in mean wind speed associated with barrier location is only one effect of shelter. Shelter influences a range of microclimatic factors including evaporation, soil moisture, air temperature, humidity and soil temperature (14, 37, 47). A significantly higher mean day temperature was observed for hygrothermograph B (barriers on both north and south) during the second and third sequential harvest intervals. An increase in daytime air temperature in shelter is an observation in agreement with other shelter studies (18).

Reduction in night time shelter temperature (18), higher night time relative humidity (6) and slight daytime relative humidity variations, either positively or negatively, between sheltered and exposed locations have been reported (37). The sensitivity of available equipment monitoring the Caddo microclimate may account for the lack of more definitive differences between observation sites.

Barrier location appeared to have some influence on total plant stand. Row 14 (barriers to the north and south) had a consistently larger stand count than row 23 (barriers only to the south) over the three sequential harvests. No difference in stand count was observed between row 4 (barriers to the north) and row 14. Rosenberg, et al. (49) observed that the emergence of two snap bean varieties was not greatly affected by the presence of shelter in the field. Observations on seedling emergence and monitoring of microclimatic modifications were beyond the scope of this investigation. However, observations of other researchers demonstrate that the microclimate created by barriers can produce warmer soil temperatures and a slower evaporation rate from soils within shelter (14, 37, 47). An extended period of soil surface wetness in the lee of shelter during seedling emergence can retard soil crusting and the possible mechanical damage associated with such crusting (8). Such microclimatic modifications may account for the greater stand count for row 14 with barrier protection on both the north and south side.

Barrier location appears to have influenced the leaf area index at the Caddo site. Row 14 (barriers to the north and south) exhibited the largest LAI at the final sample harvest. Row 23 (barriers only to the south) had the smallest LAI. Part of this difference may be attributed to the observed difference in total plant stand at the second and third harvests. Stands with higher plant densities exhibit greater canopy overlap, more mutual shading and plants compensate with greater individual leaf area.

Another contributing factor to the greater LAI of row 14 is the microclimatic modifications caused by the presence of barriers on both the north and south side of the row. The shelter created by the barriers reduced mean wind speed and caused an increase in mean day temperature. Other researchers have observed increased absolute humidity (14,18), increased daytime soil temperatures (14, 18, 37), and reduced soil drying (1). Those conditions may contribute to a more rapid development of new leaf canopy and a delayed senescence of older leaves. Such a response would be reflected in greater LAI.

A larger LAI for the sheltered row is consistent with the observations of other researchers. Increases in leaf areas of sheltered crops have been reported for soybeans (43), dry beans (47), tobacco (37), swede turnip and sugar beet (38).

Barrier location had no effect on mean net assimilation rates of sampled rows at the Caddo site. Although the magnitude of relative differences appears substantial for the first two intervals, large coefficients of variation prevented significance from being declared. Watson (62) has observed that the photosynthetic efficiency measured by net assimilation rate is much less variable in agricultural environments than the photosynthetic capacity of crops as expressed by leaf area index.

The mean crop growth rate of row 4 was greater than that of row 23 over the first harvest interval. This observation suggests that the competitive advantage of one row over another may have been established in the early phases of vegetative growth. It may also indicate that the turbulence from the prevailing winds and exposure to seasonal fronts was more detrimental to crop growth than exposure to prevailing winds over the early phases of vegetative growth.

The mean crop growth rate of row 14 (barriers to the north and south) was greater than that of row 23 (barriers to the south) over the course of the twenty day observation period. This outcome might have been predicted after reviewing the previous remarks about NAR and LAI. Consider the instantaneous relationship:

$$CGR = NAR \cdot LAI \tag{3.4}$$

where the rate of dry matter production per unit land area (crop growth rate) is the product of the rate of increase of dry matter per unit land area (net assimilation rate) and the ratio of leaf area to land area (leaf area index) When NAR remains constant, CGR will vary directly with LAI. At the Caddo site, row 14 exhibited the largest LAI at the third sample harvest and a larger mean CGR than row 23 which had the smallest LAI.

Incidental observations of the number of flowers and pod set indicate that barrier location at the Caddo site did influence these parameters. The row with barriers to the north and south had a greater number of flowers and pods than either of the other two sampled rows. This observation suggests that the row with protection on both north and south sides has a greater potential for economic yield than the row with protection to the north or the row with protection to the south.

Observations of earlier maturity associated with shelter microclimate exist in the literature. Work with new potatoes and strawberries (18) as well as snap beans (49) has demonstrated earlier maturity in shelter.

Significant row x harvest interactions imply the patterns of differences among rows for root dry weight, stem dry weight and total number of pods were not the same for all harvests. Wind direction and speed were changing throughout the harvest intervals. The subsequent barrier influence on these parameters was also changing and may account for the observed patterns of differences.

Under the conditions of the investigation at the Caddo site it appears that barrier location did influence mean crop growth rate and its constituent component leaf area index. No effect on mean net assimilation rate was observed. In a crop producing situation barrier placement should take into consideration prevailing winds as well as the direction of the most destructive winds.

The Perkins site has prevailing winds from the south and southwest during the growing season. The mean daily wind speeds for this area of the state are considerably lower than those reported for Caddo County. The frequency and destructiveness of seasonal fronts from the north and west are also not as great at the Perkins site as at the Caddo site.

The absence of micrometeorological monitoring equipment at the Perkins site makes it impossible to substantiate the microenvironmental influence of barrier location on sampled rows. Speculation based on Caddo observations is difficult because of the macroenvironmental differences between sites.

There were no differences among sampled rows during the first harvest interval relative to mean crop growth rate,mean net assimilation rate, stand, and flower number.

There was also no observed difference in LAI after the first harvest. The failure of barrier location to influence these parameters at the first harvest interval for the Perkins site might have been hypothesized because the climate is not as severe as at the Caddo site.

Differences were observed during the subsequent harvest interval. Row 23 (barriers located on the south) exhibited a greater mean crop growth rate and a greater mean net assimilation rate than either of the other two rows. Row 23 had a larger stand and a greater number of pods than the other two sample rows at the third harvest.

It would be fallacious to attribute these differences solely to an influence of barrier location. A larger, unaccountable plant stand in row 23 could have biased the mean crop growth rate and mean net assimilation rate over the second harvest interval.

The outbreak of common bean blight in the southern half of the experimental site also had an influence. Foliar disease can suppress net assimilation rate, crop growth rate and leaf area index. Symptoms were observed late in the experiment and could account for the differences observed over the second harvest interval and at the third sample harvest. The presence of disease symptoms may also account for the significant row x harvest interactions observed for leaf area index, total number of pods, stem, leaf and total plant dry weight.

To summarize the results at the Perkins site, the influence of barrier location was not substantiated. Any barrier influence on the observed parameter was obscured by the development and spread of pathogens over the site.

CHAPTER IV

THE INFLUENCE OF WINDBREAK BARRIER LOCATION AND PROXIMITY ON THE FINAL STAND, ECONOMIC YIELD AND BIOLOGICAL YIELD OF IRRIGATED SNAP BEANS

Introduction

There is a growing body of international research which documents the increase in economic yield of wind sheltered crops (14, 18, 37, 54). Vegetable crops which have exhibited yield increases in the presence of shelter include corn, beets, turnips, potatoes, carrots, cabbage, tomatoes and dry beans (25).

Shelter has also influenced the biological yield of crop plants. Shelter has demonstrated a positive influence on the vegetative growth of wheat (53), dry beans (47), sugar beets (12), and soybeans (45). Wind tunnel studies with sunflower have demonstrated reductions in dry weight with increasing wind speeds (63).

However, there do exist some crop response inconsistencies within the shelter literature. Marshall (37) notes that economic and biological yield are rarely the same and may be influenced by shelter in different ways.

Response to shelter appears to vary with species and cultivar (18). Seasonal and climatic differences in crop response have been observed with greater yield responses in "dry" growing seasons and the more continental climates (18, 37).

Economic yield of sheltered snap beans grown in the northern Great Plains does appear to vary with cultivars. Some sheltered cultivars have exhibited increased yields while others are unaffected (49). The purpose of this investigation was to examine the influence of windbreak barrier location and proximity on the economic and biological yield of irrigated snap beans grown in two Oklahoma locations. Final stand counts and pod counts were performed at both locations.

Materials and Methods

This investigation was conducted on the same research plots described in the previous discussion. The study was completely randomized with eight treatment rows (rows 2, 6, 12, 16, 21, 25, 29 and 33) and four replications within each treatment row. Samples were harvested on June 22 (Perkins) and July 5 (Caddo) when plants were commercially mature.

Each replication was partitioned into ten 0.5 meter segments. A stand count was performed in each segment. A randomly selected plant from each 0.5 meter stand was cut off at ground level and partitioned into stem, leaves, mature pods (sieve size 4 or larger) and immature pods. Total number and fresh weight was recorded for mature and immature pods. Dry weight measurements were made on above ground plant parts. Economic yield was defined as mature pod fresh weight. Biological yield was defined as above ground plant dry weight.

Row estimates of 0.5 m stand totals were obtained by computing the product of a sample plant observation and its sample stand count for each 0.5 m segment.

Results

The influence of windbreak barrier location and proximity on the final stand at the Caddo site is presented in Table III. Row 16 (one of two sample rows with barriers to the north and south) exhibited a significantly greater final stand than either row 21 (2.4 H north of barriers) or row 25 (5.6 H north of barriers). There was no difference among all rows sampled north of the barriers. There was no difference among all rows between and to the south of the barriers.

Mature pod fresh weights for sampled rows are presented in Table IV and Appendix C, Figure 1. The two rows between barriers (rows 12 and 16) and the first row sampled directly south of the barriers (row 6) had a significantly greater pod fresh weight than the two most distant sample rows north of the barrier (rows 29 and 33).

The number of mature and immature pods is presented in

Table III. The influence of barrier location on final stand and above ground mean dry weight values of 0.5M row section of irrigated 'Eagle' snap beans at Caddo site, spring, 1983.

				Dry Weight (g)				
Site	Row	Barrier Distance[z]	Stand[y]	Leaf	Stem	Mature Pod	Immature	Above Ground Total
Caddo	33	12.0H	7.4abc[x]	24.08c	18.25c	7.25cd	4.78bc	54.36c
	29	8.8H	7.1abc	42.46ab	30.81ab	5.15d	6.29abc	84.71abc
	25	5.6H	6.4bc	37.73abc	27.66bc	11.42bcd	4.03c	80.83bc
	21	2.4H	6.2c	40.01abc	31.61ab	11.75bcd	4.29c	87.66abc
	16		8.9a	47.72a	40.09a	25.73a	7.75a	121.30a
	12		7.5abc	35.47abc	35.51ab	18.84ab	8.00a	97.82ab
	6	2.4H	7.8abc	30.39bc	27.95abc	20.21ab	7.78a	86.33abc
	2	5.6H	8.1ab	28.01bc	24.97bc	16.14abc	7.35ab	76.46bc

[z]Values for rows 21-33 represent distance north of the barriers; for rows 2 and 6, distance south of barriers; rows 12 and 16 were between barriers. H equals barrier height, 1.2 m.

[y]Stand represents the mean number of plants in a 0.5 meter row section.

[x]Mean separation in columns by Duncan's Multiple Range Test, 5% level.

Table IV. The influence of barrier location and proximity on mature pod mean fresh weight of 'Eagle' snap beans at two locations.

		Mature pod fresh weight (g)	
Row	Distance[z]	Caddo	Perkins
33	12.0H	71.0 c[y]	279.1a
29	8.8H	57.6 c	248.3a
25	5.6H	119.2 bc	178.2 abc
21	2.4H	122.7 bc	209.6 ab
16		274.7 a	176.1 abc
12		194.4 ab	199.9 ab
6	2.4H	218.7 ab	105.2 bc
2	5.6H	162.0 abc	88.5 c
CV (%)		111.8	97.5

[z]Values for rows 21-33 represent distance north of the wind barriers; for rows 2 and 6, distance south of the barriers. Rows 12 and 16 were located between wind barriers. H equals barrier height, 1.2 m.

[y]Mean separation in columns by Duncan's Multiple Range Test, 5% level.

Appendix C, Table XV. The two rows with shelter on both sides (row 12 and 16) had a greater number of mature pods than row 19 (8.8 H north of barriers). Row 6 and 16 also had a greater number of mature pods than the most distant row from shelter, row 33 (12.0 H north of barriers).

The number of immature pods (less than sieve size 4) was significantly greater for the two rows between the barriers (row 12 and 16) than the row most distant from the barriers on the north side (row 33). There was no statistical difference among any of the rows sampled either north or south of the barriers relative to immature pod number.

Above ground total dry weight observations are presented in Table III and Appendix C, Figure 3. Row 16 exhibited a greater total dry weight than row 2 (5.6 H south of barriers) and row 25 (5.6 H north of barriers). Sheltered rows 12 and 16 each had a greater total dry weight than row 33 (12.0 H north of barriers).

At the Perkins site there was no observed differences in final plant stand.

Observations on mature pod fresh weight are presented in Table IV and Appendix C, Figure 2. The two most northern rows (29 and 33) had a significantly greater number of mature pods than either row 2 or row 6. There was no observed difference between the sheltered rows (12 and 16) and any of the rows sampled to the north or to the south of the windbreak barriers.

There was no difference among rows relative to the number of immature pods.

Above ground total dry weight observations are presented in Table V and Appendix C, Figure 4. Rows 29 (8.8 H north), 33(12.0 H north) and one sheltered row (row 12) exhibited a significantly greater dry weight than either of the two rows sampled south of the barriers (row 2 and 6).

Symptoms of common bacterial blight of beans were observed during the final sample harvest of the previously discussed experiment. The pathogen, Xanthomomas phaseoli (E.F. Sm. Dowson), was confirmed by laboratory analysis at harvest time during this experiment. A subjective evaluation of percent pod disease and percent foliar disease was performed using the assessment keys described by James (28).

The results of the subjective evaluation of disease symptoms is presented in Table VI. The two most southern rows (row 2 and 6) and one of the sheltered rows (row 12) exhibited a significantly greater percentage of foliar disease symptoms.

The same three rows also had a significantly greater incidence of pod disease symptoms than the three most northern rows (rows 25, 29 and 33).

Discussion

The observations on final plant stand at the Caddo

Table V. The influence of barrier location on final stand and above ground mean dry weight values of 0.5M row section of irrigated 'Eagle' snap beans at Perkins site, spring, 1983.

Site	Row	Distance[z]	Stand[y]	Dry Weight (g) Leaf	Stem	Mature Pod	Immature Pod	Above Ground Total
Perkins	33	12.0H	5.0a[x]	31.87a	24.73a	22.99a	5.61ab	85.21a
	29	8.8H	5.3a	26.32abc	21.61ab	21.42a	5.09ab	74.44a
	25	5.6H	6.8a	22.25bc	17.18abc	16.40ab	3.56b	59.39ab
	21	2.4H	5.4a	23.82abc	20.27abc	18.50ab	5.50ab	68.09ab
	16		5.2a	21.23bc	17.91abc	15.92abc	5.22ab	60.27ab
	12		5.8a	26.80ab	23.88a	16.68ab	6.98a	74.34a
	6	2.4H	17.82c	13.72bc	9.00bc	4.95ab	45.49b	6.3a
	2	5.6H	17.83c	12.51c	7.03c	5.88ab	43.25b	6.0a

[z] Values for rows 21-33 represent distance north of the barriers; for rows 2 and 6, distance south of barriers; rows 12 and 16 were between barriers. H equals barrier height, 1.2 m.

[y] Stand represents the mean number of plants in a 0.5 meter row section.

[x] Mean separation in columns by Duncan's Multiple Range Test, 5% level.

Table VI. A subjective evaluation of the incidence of common blight at Perkins, spring, 1983.

Row	%Foliar Disease[z]	%Pod Disease
33	0.0b[y]	0.0c
29	0.3b	0.3c
25	0.1b	0.0c
21	1.1b	2.4b
16	0.5b	0.1c
12	19.6a	3.6ab
6	19.8a	4.1a
2	22.4a	3.4ab

[z]An estimate of the % of sample plant leaf area exhibiting disease symptoms.

[y]Mean separation in columns by Duncan's Multiple Range Test, 5% level.

site made during this study were consistent with those made during the former experiment. The reduction in final stand associated with rows 2.4 H to 5.6 H north of the barriers compared to the sheltered row may be attributed to the turbulence caused by prevailing winds on the lee side of the windbreak barriers. In early shelter research work, Bates (7) documented a reduction in wind velocity on the windward side of a barrier up to 2 H in distance. On the leeward side of the same barrier, turbulence actually increased wind velocity within the 1 H to 2 H range.

The location and proximity of windbreak barriers appears to have influenced the economic yield of snap beans, reported as mature pod fresh weight. Rows with barrier protection on both north and south sides had a greater yield than those 8 H to 12 H north of the barriers. The northern rows were afforded nominal protection from prevailing winds and were subject to the full destructiveness of seasonal fronts moving through from the north and northwest.

The reduction in mean wind speed associated with shelter minimizes the kinetic component of wind and eases mechanical stress from wind loading. When economic yields depend on successful reproductive growth, physiological and mechanical stress during flowering and fruit set can be devastating. Observations of Tsuboi (1961) as cited by Grace (25) documented the greatest damage to rice occurred when typhoons struck during heading and flowering.

Yield observations were made from a once over harvest. Doust and Eaton (17) observed that peak productivity of annual bean plants was obtained from the middle phase of flowering. There is the possibility that rows exhibiting the greatest mature pod fresh weight were demonstrating earlier maturity rather than greater overall economic yield potential. Shelter literature has examples of earlier crop maturity occurring within shelter (18, 49).

The examination of mature and immature pod numbers was an attempt to establish whether some rows were more productive in terms of total pod number or whether they were merely exhibiting an earlier cohort of pods set. It appears that under the conditions of the Caddo study, barrier location and proximity not only influenced mature pod number and total fresh weight but immature pod number as well. The most distant row from the barriers (12.0 H north) not only had one of the lower mature pod numbers and total fresh weight observations, but it also exhibited one of the lower immature pod number observations. Economic yield differences were not just an artifact of maturity variations.

At the Caddo site there is some consistency between the observations of economic and biological yield. The two sheltered rows exhibited a greater dry weight than the most distant rows 12.0 H north of the barriers (row 33). One of the sheltered rows (row 16) had a greater final dry weight than the most distant row sampled 5.6 H south of the barriers (row 2).

Rosenberg, et al. (49) observed more rapid and luxurious vegetative growth of snap bean plants grown in shelter. Higher daytime air temperatures, higher soil temperatures, reduced mechanical stress and reduced moisture stress of sheltered plants were cited as contributing shelter effects.

Rosenberg et al. (49) also observed greater stomatal apertures and increased transpiration rates among the sheltered plants. The authors suggest that the increased stomatal aperture of the sheltered plants permitted more active photosynthesis, contributing to the more vigorous and luxurious growth of bean plants in shelter.

The shelter protection from the mechanical stress of wind loading is a significant factor in final dry weight observations. Mitchell et al. (40) have observed reductions in the dry weight gain of tomatoes subjected to brief, daily mechanical disturbances.

The eariler discussion noted that the Perkins site was more moderate than the Caddo site relative to the frequency and destructiveness of seasonal fronts. Prevailing winds during the growing season are from the south and southwest but the mean daily wind speed is not as great as at the Caddo site. Under such conditions one would speculate that the influence of barriers would not be as great. There was no observed difference relative to final plant stand. This is consistent with the preliminary hypothesis. However, there were differences observed across the field relative to mature pod fresh weight, number of mature pods and above ground mean dry weight. Attributing these observed differences to barrier location and proximity would be faulty.

There were no on site meteorological observations made to substantiate an influence caused by barrier location or proximity. Observations and interpretation are further confounded by the outbreak of common bacterial blight of beans. The differences among rows relative to mature pod fresh weight, number of mature pods and above ground mean dry weight may be more closely associated with the presence of a pathogen rather than barrier location or proximity. Appendix C, Table XVI illustrates significant partial correlations exist between percent foliar disease and number of mature pods, mature pod fresh weight, and the dry weight of all partitioned above ground plant parts (i.e., stem, leaf, mature pod and immature pod). There were also significant partial correlation between the percent pod disease and all parameters listed.

Barrier location may have had an influence on the spread of the pathogen across the field. Examining Table VI, the two rows south of the barriers and the southern row between barriers had a significantly higher percentage of foliar disease than all remaining rows to the north. The same three rows (2, 6 and 12) had a significantly greter percent of pod diseased than the three northern more rows (25, 29 and 33). It seems quite plausible the disease first appeared south of the barriers and was advancing north across the field.

Windblown sand particles have been implicated in the dissemination of bacterial blight of lima beans (55) and angular leaf spot of cotton (11). Wind tunnel studies have demonstrated the increased incidence of bacterial leaf spot of alfalfa and common blight of bean as wind speed and exposure time increased. The greatest incidence occurred in rows nearest the wind source (15).

Snap beans on the south side of the barriers may have been innoculated by wind blown soil particles carried by prevailing winds. The extent of the intial innoculation and subsequent progression of the pathogen across the field appears to have been influenced by the presence of the barriers perpendicular to the prevailing winds.

CHAPTER V

SUMMARY AND CONCLUSIONS

Under the conditions of the Caddo site in spring, 1983, it appears that barrier location did influence mean wind speed. The south side of the barrier was exposed to prevailing winds and consequently exhibited the highest mean wind speed over the course of the study.

However, the prevailing winds at the Caddo site may not have been the most destructive. Seasonal fronts moving across the site from north and west have the potential of causing damage to a crop. The direction of both the prevailing winds as well as the most destructive winds must be considered for effective windbreak barrier placement.

Barrier location appears to have influenced mean crop growth rate and leaf area index at the Caddo site. The sample row on the north side of the barrier had the smallest leaf area index after the final harvest and a lower overall crop growth rate than the row with shelter on both sides. The sample row on the north side of the barrier was subjected to seasonal fronts as well as the turbulence created by prevailing winds passing over the barrier.

Barrier location and proximity also influenced final plant stand, economic yield (mature pod fresh weight), and biological yield (above ground dry weight) at the Caddo site. Selected sample rows north of the barriers exhibited a lower final plant stand, a smaller economic yield and a smaller biological yield when compared with selected sample rows between barriers.

Differences in growth analysis parameters, final stand and yield were also observed at the Perkins site in spring, 1983. However, the influence of barrier location and/or proximity on these parameters could not be substantiated. The site lacked meteorological monitoring equipment and observations were further confounded by an outbreak of common bean blight. Observations on the incidence of disease symptoms across the site suggest barrier location and proximity may have influenced the extent of initial innoculation and subsequent progression of the pathogen across the field.

Growth analysis has application in the shelter research context. The growth analysis observations of this study were limited in scope. Observations were made over two ten day intervals during the late vegetative and early reproductive phase of snap bean growth. A closer examination of barrier influence on seedling emergence, initial stand establishment and early vegetative growth may allow the researcher to identify the point where sheltered plants achieve their competitive advantage.

A liability of growth analysis in the field is the typically high coefficients of variation. Researchers have attempted to deal with this problem by pairing sample plants or harvesting exceptionally large samples. A more appropriate alternative would be to estimate growth characteristics from fitted growth curves of total plant dry weight and assimilatory surface area (31, 44). This would eliminate the need for an arbitrary pairing of sample plants and it would allow for more manageable sample sizes.

The microclimatic modifications provided by shelter and their influence on plant productivity are well documented (14, 37, 47). However, plant productivity is not soley determined by external conditions. Neales and Incoll (42) cite at least four internal factors which can influence photosynthesis including the varying geometry of the diffusive CO_2 pathway, the chlorophyll content of the assimilatory surface area and the biochemical mechanisms of CO_2 assimilation. The fourth internal factor, which may have relevance to the shelter research context, is the influence of assimilate flow from the leaf on the rate of photosynthesis of the leaf surface. A strong sink demand, as a result of developing flowers and pods, may influence assimilate translocation rates from the leaves and alter the rate of leaf photosynthesis.

A greenhouse study examining sink-source relationships of the bean plant should complement future field investigations in this area. A field study monitoring the influence of shelter on reproductive growth and subsequent leaf photosynthetic rates may provide additional insight into the competitive advantage achieved by sheltered plants.

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APPENDIX A

METEOROLOGICAL OBSERVATIONS AT THE

CADDO AND PERKINS SITES

Table VII. Daily rainfall record for the Caddo Research Station, 1983.

Station Name Caddo Research Station (Ft. Cobb) **Date** 1983

Day of Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1	1.60											
2											.03	
3										.10		.31
4			.16	.06								
5			.19	.82								
6						.27				.25	.17	
7								.28		.30		
8				.04				1.54				
9												
10					.13	.18						
11						.60			.42			
12									.35			
13					.35				.15			
14					1.47	1.94						
15												
16			.50									
17										.85		
18					.18					.50		
19	.15							.14		3.70		
20		.38			T			.02	.05	5.55		
21		.12		.36	.57				.02	.03		
22		.15		.06	.47							
23											.45	
24												
25						.82						
26			1.32								.18	
27						1.34						.25
28					.53	.49						
29			.06	.02	.08							
30					.05							
31	1.64				.50							
Monthly Totals	3.39	.65	2.23	1.36	4.33	5.64	0	1.98	.99	11.28	.83	.56
Long Term. Ave.	0.72	1.20	1.74	2.39	4.31	3.15	3.13	2.51	2.71	2.35	1.54	1.31
Deviat	2.67	-0.55	.49	-1.03	.02	2.49	-3.13	-0.53	-1.72	8.93	-0.71	-0.75

Quarter	Total	Total for Year
1	6.27	
2	11.33	17.6
3	2.97	20.57
4	12.67	33.24

Table VIII. Daily temperature record for the Caddo Research Station, 1983.

Station Caddo Research Station (Ft. Cobb) **Date** 1983

Day of Month	Jan Min	Jan Max	Feb Min	Feb Max	Mar Min	Mar Max	Apr Min	Apr Max	May Min	May Max	June Min	June Max	July Min	July Max	Aug Min	Aug Max	Sept Min	Sept Max	Oct Min	Oct Max	Nov Min	Nov Max	Dec Min	Dec Max
1	23	35	26	29	38	75	45	49	61	85	49	73	67	97	73	102	70	93	58	89	55	73	25	52
2	27	40	26	36	41	83	38	58	50	77	59	93	74	97	74	101	65	95	65	90	61	77	30	52
3	20	30	24	38	57	67	31	71	44	74	68	83	76	98	77	98	63	95	69	86	61	77	35	51
4	25	35	24	28	57	64	41	43	42	83	61	85	70	77	72	94	70	98	65	81	59	69	35	50
5	29	36	24	34	45	66	36	48	55	87	64	81	67	89	81	100	76	97	49	88	59	67	32	36
6	26	54	27	29	47	60	36	46	62	94	55	80	65	88	74	103	74	100	55	68	53	62	24	46
7	32	53	10	37	42	64	36	45	50	80	49	79	65	90	72	90	76	99	59	67	57	67	24	62
8	36	57	23		39	66	40	45	48	73	53	84	61	93	67	91	72	95	61	68	54	69	28	54
9	35	59			36	55	30	60	45	77	65	87	63	94	73	91	69	92	60	80	42	49	30	52
10	33	53		50	34	50	32	75	53	66	64	83	62	96	73	98	73	95	55	79	32	52	29	60
11	34	55		38	25	57	45	84	60	84	61	83	60	98	75	103	72	88	59	76	27	69	31	58
12	26	68	30	53	34	70	52	77	64	89	64	83	70	95	77	104	69	95	45	63	45	67	26	54
13	33	70	32	60	43	74	43	50	63	78	72	86	70	94	66	103	66	67	43	74	35	65	28	48
14	38	59	42	63	46	80	33	56	55	56	62	81	71	87	68	105	59	85	52	74	47	60	28	48
15	24	57	45	53	54	69	28	63	45	65	57	85	71	87	69	105	62	92	55	80	40	63	22	34
16	23	53	31	62	42	43	38	69	44	71	61	87	72	85	74	105	65	95	57	85	33	69	20	35
17	28	50	34	57	36	49	49	75	57	78	64	86	73	95	76	103	73	97	61	73	40	68	20	14
18	28	32	35	62	37	50	45	70	47	72	66	92	73	99	72	95	73	97	62	75	39	70	8	10
19	28	30	40	71	38	39	46	53	47	80	67	93	71	97	62	75	72	87	62	68	36	70	4	21
20	29	32	47	63	32	42	36	60	60	75	69	94	72	91	72	90	52	58	55	58	39	67	-3	4
21	30	34	41		28	47	44	60	56		67	93	71	100	72	100	39	71	53	55	33	77	-2	-2
22	26	38			26	44	43	77	50	83	68	90	70	102	71	103	42	82	47	52	60	72	-2	9
23	15	46		64	36	41	53	68	56	79	70	90	71	104	83	101	47	82	43	70	34	75	-1	6
24	30	48	42	53	36	50	42	70	43	85	69	87	73	104	74	100	53	86	47	73	29	67	3	6
25	28	47	35	51	42	52	44	79	60	85	69	85	73	106	73	99	63	87	49	67	33	66	1	5
26	33	34	34	50	46	52	46	83	55	88	70	91	75	106	71	100	59	93	38	72	29	59	3	6
27	24	38	36	58	36	50	58	90	64	90	64	91	73	105	70	100	63	90	45	77	25	38	3	27
28	26	48	33	67	29	58	57	73	62	92	64	85	71	106	71	101	63	89	51	78	24	42	7	19
29	25	56			40	59	56	82	65	83	62	91	73	106	72	105	65	87	54	75	27	58	0	29
30	35	56			44	62	58	83	56	56	67	95	73	105	73	104	59	87	54	78	33	37	3	24
31	38	40			42	72			47	69			74	106	76	103			52	78			1	34
Monthly Totals	29	47	32	50	40	58	43	65	54	78	63	87	70	96	73	99	64	89	54	74	41	64	16	32
Monthly HI		70		71		83		90		94		95		106		105		100		90		77		62
Monthly LO	15		10		25		28		42		49		60		62		39		38		24		-3	
LTA																								
Dev																								

Yearly HI 106 LO -3

Table IX. The influence of barrier location on day and night mean air temperature and relative humidity at two point locations on the Caddo site.

Sampling Interval	Temperature (C°)				Relative Humidity (%)			
	Day		Night		Day		Night	
	A[y]	B	A	B	A	B	A	B
5/28-6/7	17.3	18.0 (NS)	15.5	14.8 (NS)	67.9	68.8 (NS)	74.7	76.9 (NS)
6/8-6/16	18.5	21.0 (*)	18.8	17.6 (NS)	69.1	66.6 (NS)	68.0	74.3 (NS)
6/17-6/26	21.7	23.6 (*)	19.0	18.8 (NS)	72.0	68.1 (NS)	77.1	79.9 (NS)

[z]Daytime observations were made every two hours, 0600-1800 hours. Night time observations were made every two hours, 0200-0400 hours and 2000-2400 hours.

[y]Hygrothermograph A was located 21.5 m south of the wind barriers. Hygrothermograph B was located 25 m north of hygrothermograph A, between the wind barriers.

NS, * Nonsignificant (NS) or significant at 5% (*) level by t test within each sampling interval.

Table X. Daily rainfall record for the Perkins Horticulture Research Station, 1983.

Station Name Agronomy Research Station (Perkins) **Date** 1983

Day of Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1		1.91							.11		.04	
2		.30		.18								
3												.18
4			.85	.14						.47		
5		.07	.14	1.00		.05						
6			.10									
7										.54	.25	
8				.08						.15		
9											.33	
10		.15										
11					.38	1.46				.09		
12				.04						.23		
13				.13	1.24				.97			
14					.94	.67			.16			
15							.02					
16									.05			
17										.22		
18					.36					.14		
19	.13									.90	.07	
20		.63	.20	.03				.54	.63	3.70		
21		.53			.85			.42		4.20		
22	.22	.30		.15	.07							
23			.15	.32							.75	
24			.09									
25						.47						
26	.30		1.41			.84						
27	.05		.15			.73					.32	.11
28					.94	.44						
29					.51	.76						
30			.30	.07	.17							
31					.65							
Monthly Totals	.7	3.89	3.39	2.14	6.11	5.42	.02	.96	1.92	10.64	1.76	.29
Long Term. Ave.	1.53	1.46	2.20	3.16	5.09	4.58	3.45	3.19	3.81	3.21	1.90	1.42
Deviat	-0.83	2.43	1.19	-1.02	1.02	.84	-3.43	-2.23	-1.89	7.43	-0.14	-1.13

Quarter	Total	Total for Year
1	7.98	
2	13.67	21.65
3	2.9	24.55
4	12.69	37.24

Table XI. Daily temperature record for the Perkins Horticulture Research Station, 1983.

Station Agronomy Research Station (Perkins) Date 1983

Day of Month	Jan		Feb		Mar		Apr		May		June		July		Aug		Sept		Oct		Nov		Dec	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
1	22	42	32	45	39	58	49	73	62	83	48	72	73	94	75	100	63	86	56	89	58	79	18	38
2	26	39	25	35	47	70	42	55	42	84	54	73	70	95	69	102	58	94	64	88	60	71	20	46
3	24	44	19	32	47	73	32	68	42	65	64	80	70	95	79	100	58	94	68	89	60	75	34	52
4	24	34	19	29	56	67	36	64	43	71	60	83	72	95	68	98	66	95	63	87	56	80	23	37
5	28	36	23	33	50	62	36	44	54	83	61	84	62	95	70	95	72	95	44	81	47	64	26	60
6	30	48	24	34	48	68	33	43	62	85	52	80	59	88	71	101	71	95	46	86	46	64	21	37
7	29	62	15	29	42	57	32	48	52	87	47	72	62	88	79	102	72	98	54	64	48	58	22	46
8	31	57	18	40	39	53	37	50	50	75	54	79	60	88	67	93	70	95	54	69	51	61	23	56
9	37	58	33	44	31	53	31	43	46	72	60	83	59	89	67	95	67	91	55	69	40	63	25	58
10	31	57	35	45	26	50	35	59	50	75	64	85	73	91	71	95	68	92	58	80	29	45	25	45
11	33	52	28	50	23	43	47	69	56	69	64	86	66	95	70	99	68	92	58	78	25	47	32	56
12	22	50	32	41	33	54	56	83	63	79	66	79	68	96	72	104	68	94	40	69	33	53	19	39
13	24	56	31	54	44	68	41	78	59	88	69	83	68	93	74	105	58	98	36	59	31	57	23	47
14	32	74	40	58	47	72	33	47	55	78	56	83	67	94	72	99	53	73	48	70	44	64	18	44
15	22	54	43	61	52	78	28	53	43	57	56	81	68	96	73	100	58	83	59	78	36	62	20	40
16	22	43	28	51	44	75	38	65	52	60	64	86	68	88	76	103	60	92	56	77	31	60	16	38
17	23	53	31	63	35	56	44	69	53	69	62	86	72	93	73	104	63	90	58	79	40	68	16	40
18	24	45	39	61	35	46	39	74	50	68	64	89	71	93	70	100	72	95	55	72	44	70	5	35
19	28	33	41	64	36	44	44	61	46	69	65	92	70	97	69	98	78	95	55	67	50	78	0	11
20	27	30	50	67	30	41	38	49	55	74	73	93	76	98	69	90	48	84	57	70	31	62	0	7
21	29	39	46	58	26	36			55	78	63	92	68	98	68	86	36	55	48	68	38	65	0	16
22	24	36	43	53	23	44	49	56	50	68	68	92	68	98	68	95	39	67	46	58	49	65	-6	6
23	20	31	43	57	31	46	51	61	56	82	68	91	76	101	70	100	40	74	46	57	30	75	-4	10
24	21	43	43	58	33	43	42	68	55	79	68	91	73	101	68	98	49	78	41	65	24	42	-3	10
25	31	45	30	50	39	50	43	67	60	83	61	89	72	104	70	97	62	82	40	68	27	54	-5	5
26	30	45	43	50	42	52	47	78	60	83	66	84	72	101	70	98	58	79	35	64	35	66	2	13
27	24	34	37	53	37	55	57	82	63	85	62	85	71	103	69	99	60	91	37	73	27	55	11	27
28	24	40	33	53	28	45	56	80	59	90	63	85	72	103	69	98	60	90	43	77	22	35	16	28
29	31	51			39	53	57	73	58	90	62	86	70	102	69	100	61	89	50	79	20	35	12	20
30	29	50			41	48	59	83	50	81	68	88	75	102	70	100	56	86	51	74	26	52	4	20
31	37	49			41	54			45	57			67	100	73	104			52	69			20	31
Monthly Totals	27	46	33	49	38	55	42	64	53	76	62	84	69	96	71	99	60	87	51	73	39	61	14	33
Monthly HI		74		67		78		83		90		93		104		105		98		89		80		60
Monthly LO	20		15		23		28		42		47		59		67		36		35		20		-6	
LTA																								
Dev																								

Yearly HI 105 LO -6

APPENDIX B

CROP GROWTH RATE STUDY

Table XII. The influence of barrier location on stand, flower number and pod number over three sequential harvests of a 0.5m row section of irrigated 'Eagle' snap beans at two locations in spring, 1983.

Site[z]	Row[y]	Stand T1[x]	Stand T2	Stand T3	Number of Flowers T2	Number of Flowers T3	Number of Pods T2	Number of Pods T3
Caddo	4	9.2ab[w]	11.6a	11.6a	67.3a	31.0b	11.9a	117.2b
	14	10.0a	10.4a	12.4a	48.0a	77.9a	1.1a	183.1a
	23	7.2b	7.2b	7.4b	12.0b	30.5b	0.0a	27.1c
Perkins	4	5.6a	7.4a	6.2b	66.9a	39.3a	26.3a	92.3b
	14	7.4a	6.6a	6.2b	79.7a	17.3a	30.8a	112.2b
	23	7.8a	7.2a	9.4a	78.9a	9.3a	33.9a	209.6a

[z] Sowing dates = April 19 (Perkins); April 25 (Caddo).

[y] Row 4 = 4H south of row 9 barrier; row 23 = 4H north of row 18 barrier; row 14 = 4H north of row 9 barrier and 3H south of row 18 barrier, where H = barrier height (1.2m).

[x] Caddo: T1 = June 7; T2 = June 16; T3 = June 27 (sowing date = April 25).
Perkins: T1 = June 1; T2 = June 10; T3 = June 21 (sowing date = April 19).

[w] Mean separation in columns by Duncan's Multiple Range Test, 5% level. Comparisons between sites are not valid.

Table XIII. The influence of barrier location on mean crop root growth rate, crop stem growth rate and crop leaf growth rate over three sequential harvests of a 0.5m row section of irrigated 'Eagle' snap beans at two locations in spring, 1983.

		Root Gr (g. day^{-1})			Stem GR (g. day^{-1})			Leaf GR (g. day^{-1})		
Site[z]	Row[y]	I1[x]	I2	I3	I1	I2	I3	I1	I2	I3
Caddo	4	0.32a[w]	0.03b	0.16a	0.88a	1.16a	1.03a	1.27a	1.00a	1.12a
	14	(0.20)b[v]	0.38a	0.12a	0.85a	2.17a	1.57a	1.17ab	2.03a	1.65a
	23	(0.02)b	0.20ab	0.10a	0.33a	1.03a	0.71b	0.38b	1.67a	1.09a
Perkins	4	0.18a	0.01b	0.09a	1.18a	0.36b	0.71b	1.52a	(0.15)b	0.55b
	14	0.08b	0.06b	0.07a	0.88a	0.93b	0.91b	1.26a	0.39b	0.76b
	23	0.08a	0.30a	0.21a	1.12a	2.25a	1.78a	1.53a	1.78a	1.68a

[z] Sowing dates = April 19 (Perkins); April 25 (Caddo).

[y] Row 4 = 4H south of row 9 barrier; row 23 = 4H north of row 18 barrier; row 14 = 4H north of row 9 barrier and 3H south of row 18 barrier; where H = barrier height (1.2m).

[x] Caddo: I1 = June 7-June 16; I2 = June 16-June 27; I3 = June 7-June 27.
Perkins: I1 = June 1-June 10; I2 = June 10-June 21; I3 = June 1-June 21.

[w] Mean separation in columns by Duncan's Multiple Range Test, 5% level. Comparisons between sites are not valid.

[v] Brackets indicate negative values.

Table XIV. The influence of barrier location on mean total dry weight and leaf, stem, root and pod dry weight ratios over three sequential harvests of a 0.5cm row section of irrigated 'Eagle' snap beans at two locations in spring, 1983.

		Mean total dry weight (g)			Dry Weight Ratios									
					Root %			Stem %			Leaf %			Pod %
Site[z]	Row[y]	T1[x]	T2	T3	T1	T2	T3	T1	T2	T3	T1	T2	T3	T3
Caddo	4	14.0aC[w]	36.2aB	68.9bA	18.9bA	15.5aA	8.8aB	25.4aC	31.2aB	35.0aA	55.7aA	53.4abA	43.9bB	12.3a
	14	20.2aC	36.6aB	98.6aA	30.2aA	12.2aB	9.2aB	22.2bC	32.7aB	36.2aA	47.5bB	55.1aA	43.1bB	11.5a
	23	7.7aB	14.0bB	47.0cA	30.1aA	17.6aB	10.0aC	21.6bC	31.7aB	33.6aA	48.3bA	50.7bA	54.3aA	2.1b
Perkins	4	11.8aB	34.8aA	49.0cA	12.6cA	8.6aB	6.4aC	29.6aC	36.2aA	34.6aB	57.8aA	55.1aB	35.9aC	23.1b
	14	15.6aC	33.4aB	68.9bA	17.1aA	9.7aB	5.7aC	29.2aC	34.4bA	31.6bB	53.7bA	55.9aA	33.8abB	28.9ab
	23	18.6aC	40.5aB	129.8aA	15.0bA	8.9aB	5.2aC	29.2aB	35.7aA	30.1cB	55.8abA	55.4aA	32.4bB	32. 2a

[z] Sowing dates = April 19 (Perkins); April 25 (Caddo).

[y] Row 4 = 4H south of row 9 barrier; row 23 = 4H north of row 18 barrier; row 14 = 4H north of row 9 barrier and 3H south of row 18 barrier, where H = barrier height (1.2m)

[x] Caddo: T1 = June 7; T2 = June 16; T3 = June 27.
Perkins: T1 = June 1; T2 = June 10; T3 = June 21.

[w] Mean separation within columns (small letters) and within rows (capital letters) under headings by Duncan's Multiple Range Test, 5% level. Comparisons between sites are not valid.

APPENDIX C

BIOLOGICAL AND ECONOMIC YIELD STUDY

Table XV. The influence of barrier location on the number of mature and immature pods within a 0. m row section of irrigated 'Eagle' snap beans, at two locations, spring, 1983.

Row	Barrier[z] Distance	Caddo Mature	Caddo Immature	Perkins Mature	Perkins Immature
33	12.0H	15.2cd[y]	34.9b	53.8a	83.7a
29	8.8H	12.9d	56.2ab	48.3ab	73.2a
25	5.6H	25.0bcd	41.0ab	38.2abc	65.6a
21	2.4H	25.4bcd	50.8ab	41.5abc	73.8a
16		53.4a	69.8a	34.2abc	66.4a
12		38.5abc	67.5a	42.1abc	83.9a
6	2.4H	46.6ab	61.2ab	25.6bc	67.0a
2	5.6H	35.4abcd	58.4ab	23.3c	69.9a

[z]Values for rows 21-33 represent distance north of the barriers; for rows 2 and 6, distance south of barriers; rows 12 and 16 were between barriers. H. equals barrier height, 1.2 m.

[y]Mean separation in columns by Duncan's Multiple Range Test, 5% level.

Table XVI. Partial correlation coefficients between percent pod disease and percent foliar disease and selected 'Eagle' snap bean plant parameters at the Perkins site.

Plant parameters	Partial Correlation Coefficients	
	% Pod Disease	% Foliar Disease
Mature pod number	0.545**	0.428**
Mature pod fresh weight	0.554**	0.433**
Maature pod dry weight	0.557**	0.408**
Immature pod number	0.134(NS)	0.408**
Immature pod fresh weight	0.331**	0.459**
Immature pod dry weight	0.314**	0.447**
Leaf dry weight	0.269**	0.462**
Stem dry weight	0.360**	0.444**

NS, *, ** Not significant (NS), significant at the 5% (*) and 1% (**) levels.

Figure 1. Barrier Location and the Mature Pod Mean Fresh Weight Yield Observations of 'Eagle' Snap Beans at the Caddo Site.

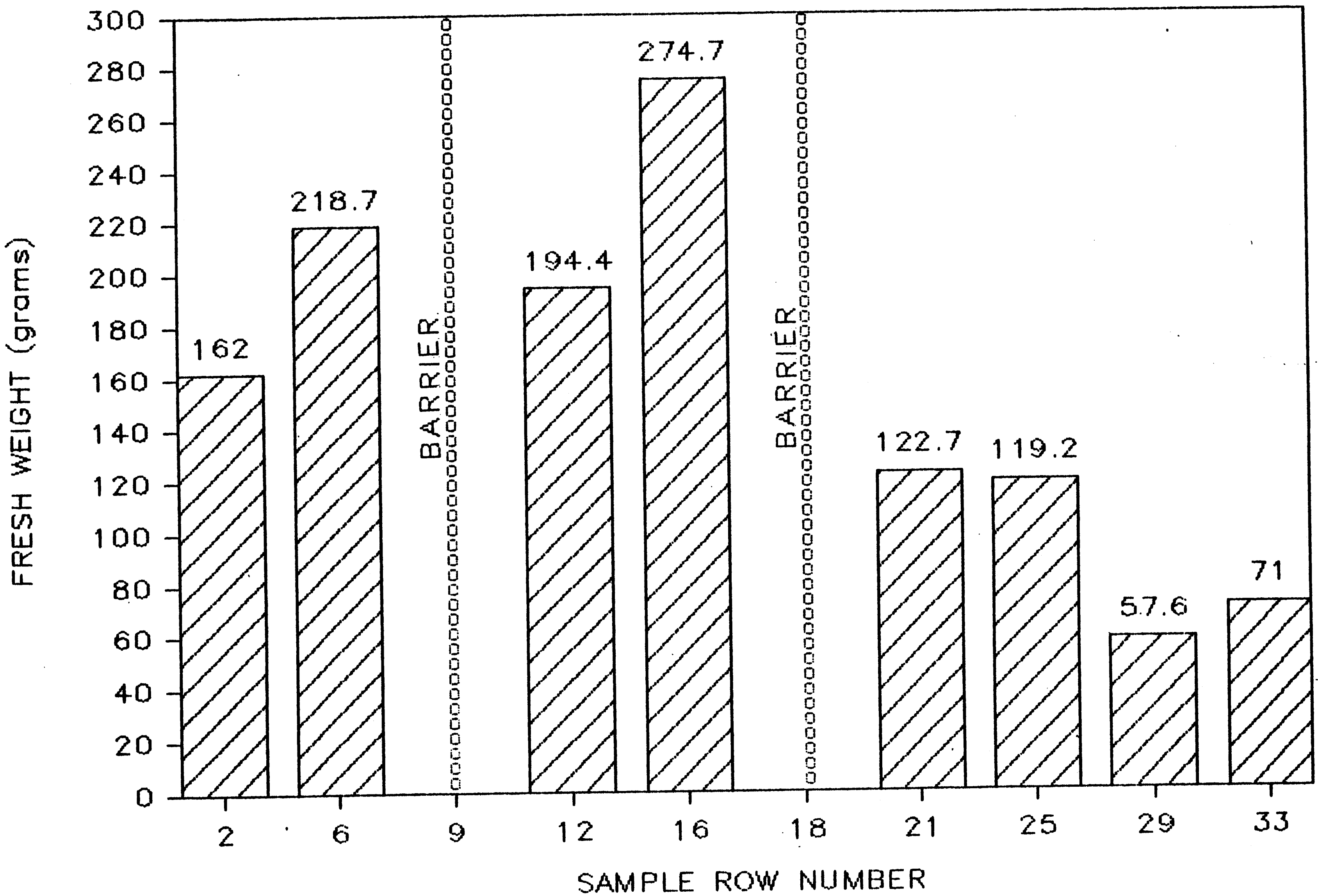
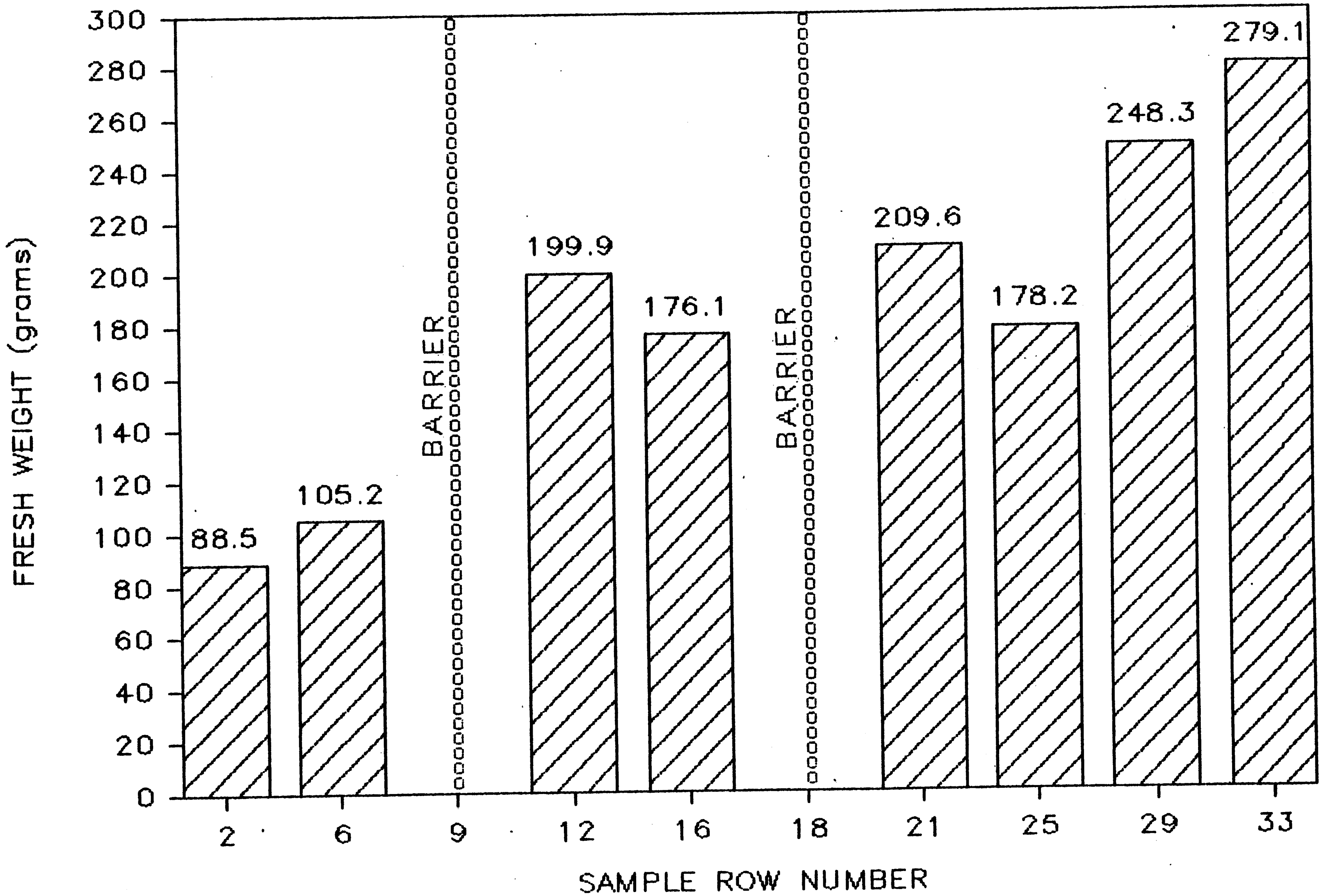

FRESH WEIGHT (grams)
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
162
218.7
BARRIER
194.4
274.7
BARRIER
122.7
119.2
57.6
71
2
6
9
12
16
18
21
25
29
33
SAMPLE ROW NUMBER

Figure 2. Barrier Location and the Mature Pod Mean Fresh Weight Yield Observations of 'Eagle' Snap Beans at the Perkins Site.



FRESH WEIGHT (grams)
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
88.5
105.2
BARRIER
199.9
176.1
BARRIER
209.6
178.2
248.3
279.1
2
6
9
12
16
18
21
25
29
33
SAMPLE ROW NUMBER

Figure 3. Barrier Location and the Above Ground Mean Dry Weight Observations of 'Eagle' Snap Beans at the Caddo Site.

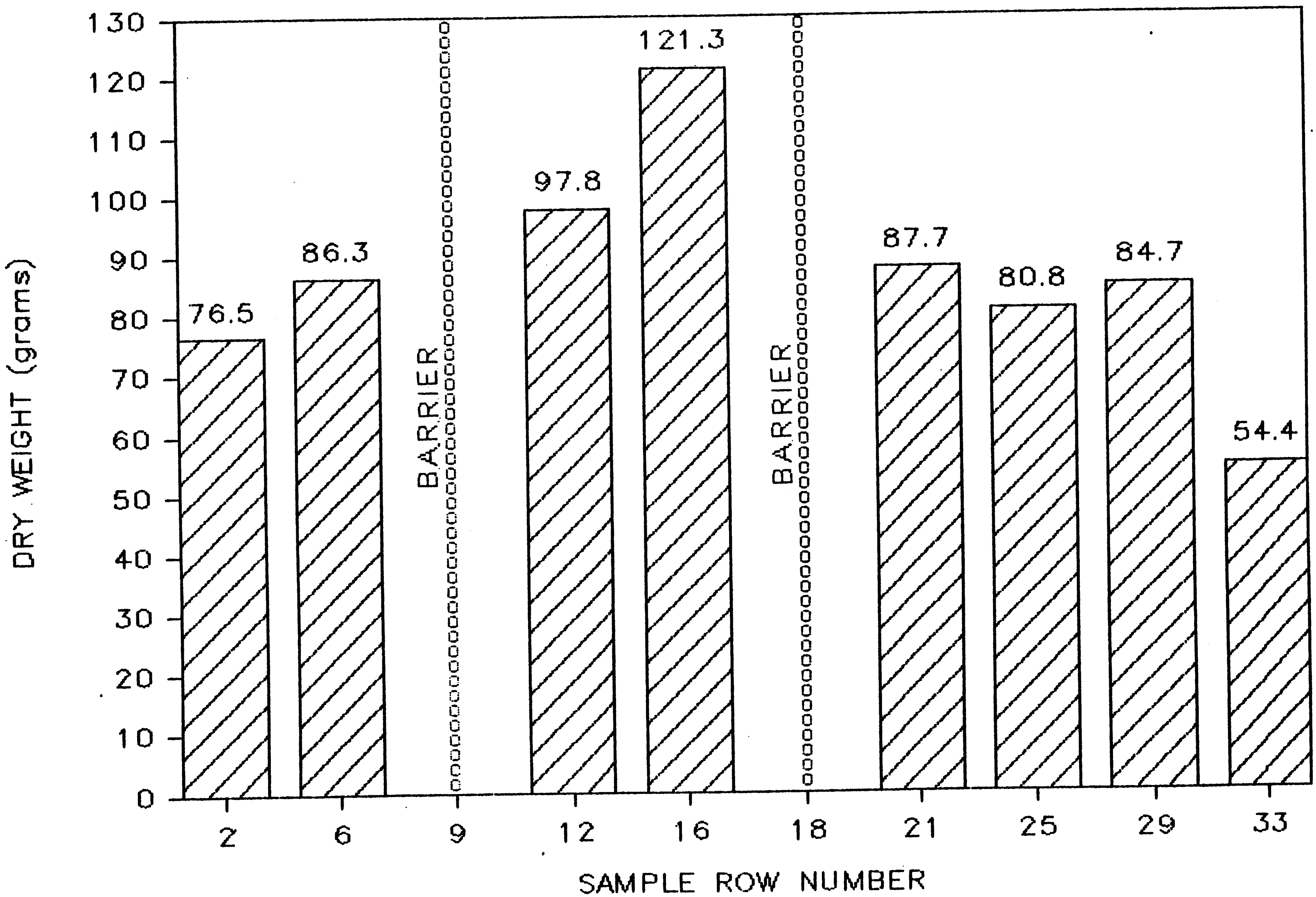

DRY WEIGHT (grams)
130
120
110
100
90
80
70
60
50
40
30
20
10
0
76.5
86.3
BARRIER
97.8
121.3
BARRIER
87.7
80.8
84.7
54.4
2
6
9
12
16
18
21
25
29
33
SAMPLE ROW NUMBER

Figure 4. Barrier Location and the Above Ground Mean Dry Weight Observations of 'Eagle' Snap Beans at the Perkins Site.

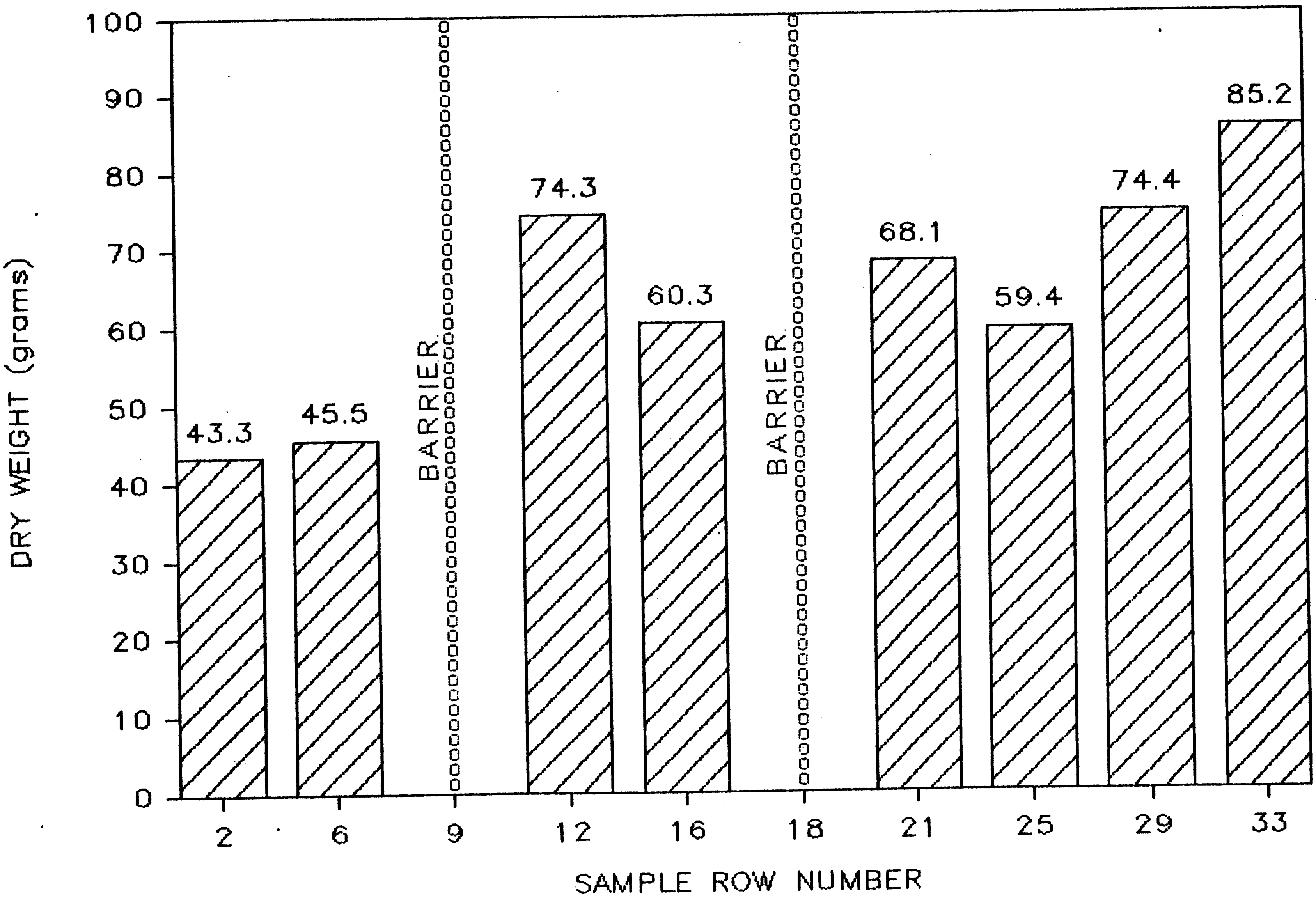
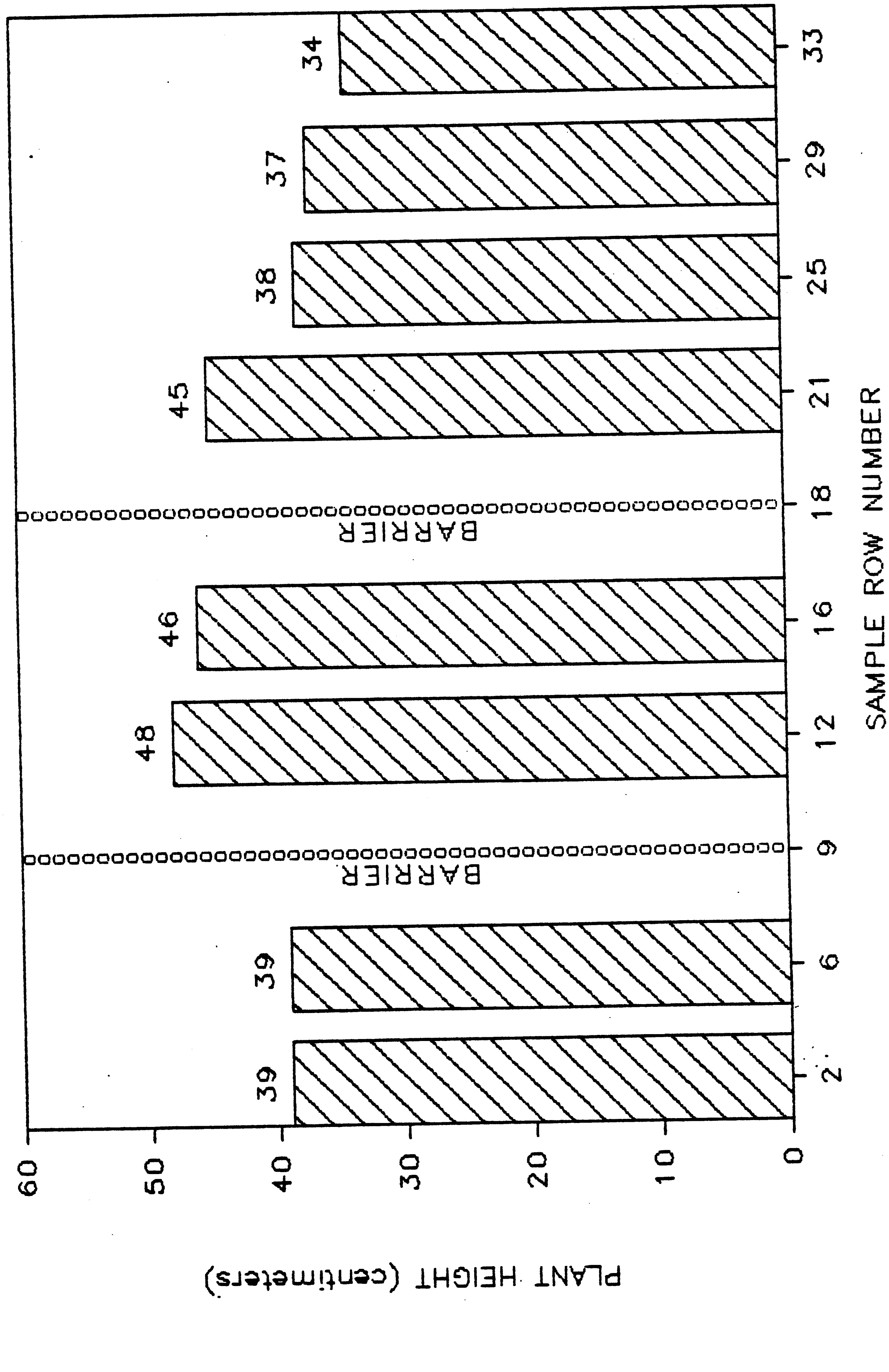

DRY WEIGHT (grams)
100
90
80
70
60
50
40
30
20
10
0
43.3
45.5
74.3
60.3
68.1
59.4
74.4
85.2
BARRIER
BARRIER
2
6
9
12
16
18
21
25
29
33
SAMPLE ROW NUMBER

Figure 5. Barrier Location and the Plant Height of 'Eagle' Snap Beans at the Caddo Site.



PLANT HEIGHT (centimeters)
60
50
40
30
20
10
0
SAMPLE ROW NUMBER
2
6
9
12
16
18
21
25
29
33
39
39
48
46
45
38
37
34
BARRIER
BARRIER

VITA

Kevin Edward Holley

Candidate for the Degree of

Master of Science

Thesis: THE INFLUENCE OF WINDBREAK BARRIER LOCATION AND PROXIMITY ON THE CROP GROWTH RATE, BIOLOGICAL YIELD AND ECONOMIC YIELD OF IRRIGATED SNAP BEANS (PHASEOLUS VULGARIS L.)

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Biographical:

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