AN ABSTRACT OF THE THESIS OF

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Title: EFFECT OF DIFFERENTIAL AMOUNTS OF IRRIGATION WATER DEFICIT ON THE YIELD AND WATER USE OF TABLE BEETS (Beta vulgaris L.)

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Abstract Approved : ______________________
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The effects of deficit irrigations and nitrogen rates on the yield and size distribution of 'Detroit Dark Red' table beets were investigated during 1985 and 1986. Beets were grown on a Chehalis silty clay loam (fine-silty, mixed , mesic Cumulic Ultic Haploxeroll) (7.5 cm of available water per 30 cm of soil depth) at a row spacing of 60 cm. Six irrigation treatments of 8, 18, 40, 60, 76, and 95 percent of evapotranspiration during 1985 and 6, 16, 41, 63, 86, and 95 percent during 1986 were imposed by a line source overhead sprinkler system. Nitrogen treatments of 125 and 250 Kg N/Ha were randomized over plots on either side of each sprinkler line. Water production functions developed for the root or total yield versus evapotranspiration or applied water (irrigation plus rainfall) conformed to a second degree polynomial equation. There was no statistical

difference between the functions for the two nitrogen rates at the 5 percent level of significance. The 1986 root yield versus evapotranspiration and root yield versus water applied functions for the higher nitrogen level were $Y = -65.154 + .557ET - 6.058*10^{-4}ET^2$ ($R^2 = .74$) and $Y = 20.172 + .156WAT - 9.166*10^{-5}WAT^2$ ($R^2 = .83$), respectively and did not reach maximums. Similar functions for the lower nitrogen level were $Y = 17.76 + .212ET - 2.39*10^{-4}ET^2$ ($R^2 = .81$) and $Y = 15.885 + .255WAT - 3.547*10^{-4}WAT^2$ ($R^2 = .83$), respectively. These did reach maximums of 63 and 62 MT/Ha at evapotranspiration and water applied levels of 460 and 360 mm, respectively. The 1985 root yield versus water applied for the two nitrogen levels were $Y = 26.018 + .202WAT - 2.92*10^{-4}WAT^2$ ($R^2 = .83$) for the higher nitrogen level and $Y = 27.591 + .163WAT - 2.141*10^{-4}WAT^2$ ($R^2 = .82$) for the lower nitrogen level. Neither of these functions reached maximums in the range of applied water. Evapotranspiration data were not available for 1985.

Roots were graded based on their diameter into five sizes. These from the smallest to the largest were: less than 25 mm, between 26 and 44, between 45 and 70, between 71 and 95, and larger than 96 mm. The yields of the two smallest grades did not change appreciably over the ET range. The yield of the third smallest conformed to the same type of function as did the root yield and reached its maximum at about the same ET as did the root yield. The yields of the two largest grades showed an increasing trend over the ET range.

The percent dry matter in roots and leaves decreased over the ET range and reached a minimum at an ET level which was somewhat less than the ET level for maximum root yield and the middle size grade yield.

EFFECT OF DIFFERENTIAL AMOUNTS OF IRRIGATION WATER DEFICIT ON THE YIELD AND WATER USE OF TABLE BEETS

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EFFECT OF DIFFERENTIAL AMOUNTS OF IRRIGATION WATER DEFICIT ON THE YIELD AND WATER USE OF TABLE BEETS (Beta vulgaris L.)

INTRODUCTION

In the Willamette Valley of western Oregon total annual rainfall averages approximately 1000 mm but rainfall for each of the months of July and August averages only 15 mm. Grass cover evapotranspiration requirements as estimated by a corrected Penman method (Doorenbod and Pruit,1977) may reach 10 mm per day during June, July, and August. This requires that irrigation water be provided for most crops during a major portion if not all of these months. With the increasing costs of water and energy, optimizing the amount of irrigation water becomes important. Optimization results in more savings of water and of the energy needed to move it from its source to individual farms. Therefore determination of water input into the production of crops either alone or in association with other production inputs provides information on the potential savings on water and energy.

The magnitude of these potential savings is determined partly from the yield response to total water applied or to total water used which are referred to as

Water Production Functions. These functions are valuable to growers, to the food processing industry, and to government officials who try to optimize the production of crops on a large scale through management of regional resources.

An experiment on table beets was conducted on a site located on the Oregon State University Research Farm near Corvallis during 1985 and 1986 growing seasons. The experiment involved studying the effects of reduced or deficit irrigation on the yield response of beets and investigating how beet root size distribution as well as dry matter production changed as availability of water changed.

Table beets are produced on approximately 500 to 600 hectares in Oregon with a value to growers of 1.5 to 2.0 million dollars. Most of the production in the Willamette Valley is for canning with an estimated processed value between 4 and 6 million dollars[(1)].

Water need of table beets is not as high as crops like corn, tomatoes, etc. and rooting depth may be 1.5 meters or more. Nevertheless, beets require irrigation water to achieve high yields and quality. Any prolonged shortage of water during the summer months in Oregon may affect beet yield adversely.

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(1) Extension Economic Information Office. Agricultural & Resource Economic Department, O.S.U., Corvallis.

The price paid by canneries to growers varies with the size of beet roots. Currently beet roots are sized according to their diameter into five grades, hereafter called GØ, G1, G2, G3, and G4. GØ is the grade size less than 25 mm, G1 between 25 and 44, G2 between 45 and 7Ø, G3 between 71 and 95, and G4 more than 95 mm. The G1, G2, and G3 grades are preferred by the canning industry although roots of all sizes are used.

The overall objective of this study was to determine the number of units of water resource required to produce any number of units of yield at two rates of nitrogen fertilizer. The functional relationship between yield and water thus developed assists in the maximization of yield, profit, dry matter or other objectives.

LITERATURE REVIEW

I. INTRODUCTION

Many studies have been done on various aspects of production of table beets. These have provided information on the effects of row spacings (Mack,1979), fertilizers (Mack,1965; Shannon,1967; Mack,1970; Hipp,1977; Gupta,1979; Mack,1979; Hemphill et al.,1982; Gupta,1983), liming (Jackson et al.,1974; Hemphill et al., 1982), boron deficiency (Mack,1965; Hemphill et al.,1982), and harvest dates (Hipp,1977; Mack,1979) on the yield, size distribution, and quality of beet roots. Lacking however, is information on the water use of table beets for Western Oregon and the level of irrigation water for optimum yield and size distribution.

II. WATER PRODUCTION FUNCTIONS

Efficient use of any agricultural resource needs accurate information to enable the farmer or economic planner to predict how many units of that resource are required to produce a unit of the agricultural output. Crop-water production functions relating the yield of a crop to the amount of water applied or used to produce that yield have been developed for several crops during the past 50-60 years (Beckett and Huberty,1928; Clyde et al.,1923) to give the farmers and planners an important tool to optimize the use of water resource in crop production.

Water production functions have been reported for crops such as grain sorghum (Hanks et al.,1969; Garrity et al.,1981), barley grain and corn silage (Power et al.,1973), barley grain (Kalssen et al.,1982), corn grain (Stewart and Hagan,1973), chile pepper (Beese et al.,1981). These production functions have been derived from a statistical fit of an equation to a series of data points of known yield and water use. They have generally been based on the theory that total yield, i.e., the biomass, hereafter G, changes linearly with changes in transpiration, T (de Wit,1958; Hanks et al.,1969; Hanks,1974). A plot of G versus T is thought to essentially go through the origin (Hanks et al.,1969; Kalssen et al.,1984). The linearity holds up to the point of Gmax-Tmax. From this point any increase in transpiration will not be accompanied by a corresponding increase in yield. This point is the lowest level of T found to be associated with maximum yield (Stewart and Hagan,1973).

Separate field measurements of T and evaporation from the bare soil, E, are difficult. It is more convenient, and in many cases more practical, to measure and use evapotranspiration, hereafter referred to as ET, instead of T. Garrity et al. (1981) for grain sorghum, Beese et al. (1981) for chile pepper, Sammis (1981) for alfalfa and cotton, Downey (1972) for non-forage crops, Shalhevet et al. (1983) for potatoes, Hang and Miller (1986) for sugar beet, and many others have used ET instead of T in their functions. When ET is substituted for T, the graph of G versus ET does not pass through the origin but will be offset on the ET axis equal to the amount E (Stewart and Hagan,1973).

The total biomass produced is usually not the economical yield. Crops like table beets have only a portion of their total biomass as marketable yield, hereafter referred to as Y. If the ratio of marketable over total yield; Y/G, or the change in this ratio over the corresponding change in ET - $\Delta(Y/G)/\Delta ET$, i.e., the slope of Y/G versus ET line- remains constant over the ET range under consideration, we can expect the plot of Y-ET to also be linear (Stewart and Hagan,1973). However the slope of this line will probably be different from the slope of G-ET line. A constant Y/G ratio presumably means that the plant does not change its water allocation strategy under different moisture deficit levels.

Implicit in the Y-ET linear model is the assumption that cumulative E through the growing season does not change appreciabley from one ET level to the next. This could be erroneous for most of the row crops like table beets. These crops have a period of cover developement before the crop canopy can effectively shade the ground and minimize evaporation from the soil surface. This causes a degree of curvilinearity in the Y-ET function. Kalssen et. al. (1984) in a study on the water use of spring barley found that when the effect of E was removed from a curvilinear Y-ET relationship and Y was plotted against T the graph became linear. This shows a change in total evaporation from the soil surface as total seasonal ET changes.

If the slope of Y/G versus ET line is not a constant (Stewart and Hagan,1973) or if the coefficient of variation of the Y/G ratio around a statistical average is high, a linear Y-ET relationship can not be assumed even when G-ET function is linear. In fact a generalization of a linear model to all crops would not be valid. A "specific study of different crop types and in many cases, varieties" (Stewart and Hagan,1973) is necessary. Stewart and Hagan (1969) also mention factors like inhomogenity among the members of a given plant population, fertility status of the field, weather changes from year to year, plant population, row spacing, and the high-ET-need growth stages as factors which cause deviation from an ideal linear model. Curvilinear functions have been reported by Hang and Miller (1986) for sugar beet dry matter yield, Miller and Hang (1982) for wheat, Grimes et al. (1969) for cotton lint yield, Turk et al. (1980) for cowpea, and Hanks et al. (1969) for wheat.

The relationship between yield and total applied water, i.e., irrigation + rainfall,,hereafter referred to as WAT, for sunflower and safflower (Hang and Evans,1985), sugar beet (Hang and Miller,1986), potatoes (Hang and Miller,1986), cotton lint (Grimes et al.,1969), sweet corn (Petersen et al.,1985), sorghum (Yaron,1975) and other crops follow a quadratic equation of the form,

$$Y = a + b\,WAT - c\,WAT^2 .$$

where a, b, and c are the regression parameters and WAT is as previously defined.

Stewart and Hagan (1973) give the reason for the convex shape of the relationship as being the effect of the non-ET uses of water. These are the deep percolation losses of water and the portion of applied water which remains in soil after maturity and harvest. Other losses could be evaporation from water droplets and surface runoff.

III. EFFECT OF BORON AND NITROGEN ON THE WATER PRODUCTION FUNCTION OF TABLE BEETS

The production function parameters may be influenced by soil fertility status. Both the crop ET and yield change as the fertility level changes. Boron deficiency affects the quality of beet roots but usually does not have an appreciable effect on yield and size distribution (Hemphill et al.,1982). Mack (1970) also found no effect of boron on yield. However, relative to other nutrients it is needed in small quantities -about 0.5-1.0 ppm B in soil- (Mack,1985). The effect of boron on the production function parameters therefore would seem to be negligible.

Boron can affect the yield-ET function in another way. Measurements of ET use soil water content determinations which are obtained through various methods including neutron scattering technique. In this method (Van Bavel,1963) fast emitted neutrons are slowed by collisions with certain atoms. The primary element which slows down the neutrons is the hydrogen atom in water. A count of neutrons which have been slowed by collisions with hydrogen atoms is an estimation of the amount of water molocules in soil. However other elements like chlorine, boron and iron can absorb the neutrons (Hauser,1984) and change the count rate. This causes underestimation of the water content in soil and leads to overestimation of soil water depletion and an overestimation of ET. These chemical elements do not occur in high quantities in most soils of temperate regions unless they have been added as fertilizers. It has been estimated that boron concentrations of more than 10 ppm could affect the neutron probe calibration curve to a significant degree (Hillel,1980).

Unlike boron, nitrogen does have an appreciable effect on the production function parameters since it affects the overall growth of beets. The study by Hemphill et al. (1982) clearly showed the response of table beets to nitrogen fertilizer and positive responses of table beet yields to nitrogen have also been demonstrated by Shannon et al. (1967) and Mack (1970). The data of Kallsen et. al. (1984) show a high dependence of production function parameters on nitrogen levels for spring barley. Bennett et al. (1986) found that when corn was subjected to simultaneous nitrogen and water stresses, the higher-N plants were able to extract more water from depths below 0.3 meters in the soil profile. Higher-N plants also had higher transpiration rates and a more efficient extraction of water from the soil profile. The data of Bauder et al. (1975) for corn show that at any soil water level yield is different for different levels of nitrogen fertilizer. The functions reported by Grimes et al. (1969) relating cotton lint yield to applied water have different production function parameters for different N levels.

The production functions for different nitrogen levels should therefore be reported separately unless the applied levels of nitrogen do not limit growth. No such separation of functions would appear to be necessary for different boron treatments since they usually have not affected yield appreciably.

MATERIALS AND METHODS

Field experiments were conducted on 'Detroit Dark Red' table beets during 1985 and 1986 at the Oregon State University Vegetable Reasearch Farm near Corvallis. The soil was a well-drained Chehalis silty clay loam (fine-silty, mixed, mesic Cumulic Ultic Haploxeroll) (Soil Survey Manual for Linn County, Oregon, 1969). It has a water holding capacity of about 7.5 cm of available water per 30 cm of depth.

During 1985 beets were planted on May 31. Emergence was observed on June 10 and harvest was started on August 27 and completed on the 28th. During 1986 the planting was on May 28, emergence was observed on June 3 and harvest was on September 2. The period from planting to emergence was shorter by four days during 1986 because of warmer ambient temperatures which prevailed during that period. Length of time from planting to harvest was 89 days for 1985 and 98 days for 1986. In both years beets were planted with a row spacing of 60 cm.

Water was applied to all plots simultaneously using two line source sprinkler systems (Hanks et al.,1976). The two sides of each sprinkler line together created four main plots having similar water application pattern. The four plots were then used as four replications of fertilizer treatments. During 1985 nitrogen levels of approximately 50, 125, and 250 Kg N/Ha (hereafter referred to as N1, N2, and N3, respectively) were randomized in three sub plots in each main plot. Two boron levels of 0.0 and 5.0 Kg B/Ha (hereafter referred to as B0 and B1, respectively) were then randomized in each nitrogen treatment sub plot. The sub plot with the lowest nitrogen treatment was not harvested at the end of the season.

In 1986 two nitrogen levels of 125 and 250 Kg N/Ha (hereafter referred to as N2 and N3, respectively) were applied. Different boron rates were not used in 1986 in order to have a larger area from which a suitable harvest area could be chosen for each irrigation treatment.

Figure 1 gives the line source water application rates in relation to the distance from the sprinkler line. Water application is expressed in percentage of that received at 5.79 meter (the 10th row) from the sprinkler line. Five other treatments with three harvest rows per treatment would be the rows numbered 3 at 1.52 meters, 16 at 9.45 meters, 19 at 11.28 meters, 22 at 13.11 meters, and 25 at 14.84 meters from the line source. The third row was to receive more than 100 percentage of ET and other rows were to receive diminishing amounts of irrigation water down to no water applied at the 25th row.

Figures 2 and 3 give layouts of the experimental design and the dimensions of the plots for the two years. They include the positions of neutron probe access holes and the six irrigation treatment rows. Irrigation water was measured by catch cans placed slightly above the canopy level and beside the neutron probe access holes.

Irrigation water was applied, on average, every ten to eleven days. The reference crop ETs were determined from a corrected Penman method with a revised wind function term (Doorenbos and Pruitt,1977). Crop coefficient curves (figure 4) were developed by comparing the local conditions to the FAO guidelines (Doorenbos and Pruitt,1977). Daily ET needs of table beets (ETmax) were then determined by multiplying the daily reference ETs by the corresponding crop coefficients (Kc). Weather data for the corrected Penman model were collected by an automated weather station which had been set up on a grass covered field adjacent to the experimental site.

Seasonal crop water use (ETact) was determined by hydrologic balance at each neutron access tube by adding the seasonal irrigation and rainfall depths to the seasonal depletions. Soil water depletion was computed from neutron probe measurements of soil water content.

These measurements were taken three times between irrigations. Neutron probe access tubes were placed in the six rows which represented the six irrigation treatments. During 1985 access holes were in the higher boron treatments of the two higher nitrogen treatments and during 1986 in all of the plots. These gave a total of 48 points in the field at which water contents were measured in the 30, 60, 90, 120, and 150 cm depths during 1985 and in the 10, 20, 30, 60, 90, 120, and 150 cm depths during 1986. Calibration curves were developed for the neutron probe for both years (figure A.1 for 1986). A separate curve was developed for the neutron probe surface 0-15 cm measurements for 1986 (figure 5).

The harvest area in each plot was 5.57 meter^2 and consisted of one 3.1-meter-section in each irrigation treatment row and one section in each of two rows immediately adjacent to the treatment row on both sides. It was thought that in this way a more representative average yield for each irrigation treatment could be obtained.

Beet roots were graded into five sizes: G0 less than 25 mm, G1 between 25 and 44, G2 between 45 and 70, G3 between 71 and 95, and G4 greater than 96 mm, in diameter. During 1985 the harvest data recorded were the beet root yield and weights of each size grade. The yield data from the two boron treatments were added together and used as the yield per 11.15 $meter^2$ for that nitrogen treatment. In 1986 total yields of roots and tops (leaves) were measured and sub-samples were taken of each treatment for dry matter yield analysis. These samples were weighed, dried at 60 degrees centigrade until there was no more appreciable change in weight, and subsequently reweighed.

The least squares method was used to fit linear, second, and third order polynomial models to the yield-water data in an effort to find the equation which most completely described the relationship between G or Y yields and ET or WAT. In these equations ET or WAT were the independent variables and G or Y were the dependent variables. The goodness of fit of the three models were compared using their coefficients of determination, R^2, and an analysis of the probability of being zero of each regression coefficient. The best equation was thought to be the one with the highest R^2 and with the least probability of any of its coefficients to be zero.

The third degree models fitted to the yield versus water use data did not improve upon the second degree ones which in turn were always better than the linear models. In none of the cases the second degree models improved the fit over the linear models by more than 5 percent increase in R^2. The second degree polynomial models were subsequently chosen for further analysis.

RESULTS AND DISCUSSION

I. YIELD

A. Total And Root Yield Production Functions

a. 1986 Experiment

The Y-ET function for the N2 level (figure 6) reaches a maximum of 63 MT/Ha for an ETact of 460 mm[2]. The N3 level function however does not reach a maximum in the range of ET under study. The highest yield achieved is 71.5 MT/Ha at the highest ET level of 454 mm. If the N2 and N3 Y-ET functions are extrapolated to zero yield, then 138 mm and 112 mm, respectively, are the minimum of ETs needed before a measureable Y is obtained. The functions for the two nitrogen levels are statistically the same (α= 5%) but since the function for the N3 level is not complete they are reported as separate functions in table A.1.

The reason a maximum yield for N3 level was not reached is thought to be mainly the result of general underirrigation of all plots. The underirrigation had the greatest impact on the N3 level yields since the

(2) dY/dET=.557-2(6.058E-4)*ET=0, then ETmax=460 mm and Ymax=63 MT/Ha.

higher nitrogen level causes a greater growth response and a higher evaporative demand (Bennett et al.,1986). After analysing the water application data it was found that the six irrigation treatments had actually received on the average 95, 86, 63, 41, 16, and 6 percent of Penman estimated ET as measured by neutron probe. Therefore the depth of applied water was not sufficient to supply the required high-ET data points. If more water had been applied it would have likely caused the function to level off. In addition to this the corrected Penman method can have a possible error of plus or minus 10 percent in summer (Doorenbos and Pruitt,1977). This could have aggrevated the problem of adding the exact required amount of water to maintain the desired treatments.

The Y-WAT functions (figure 7 and table A.2) show the same trends as were observed in Y-ET functions. The function for the N2 level reaches a maximum yield of 62 MT/Ha for a maximum applied water of 361 mm. The maximum yield computed by this function is essentially the same as what was computed using the Y-ET function. The remaining ET need of 99 mm of water (=460-361=99 mm) which is not supplied by applied water is obtained from the soil storage. The function for the N3 level does not reach a maximum and the highest yield computed is 70 MT/Ha at an applied water of 428 mm. The percent increase in yield at 361 mm of WAT is about 4 percent of N2 yield. The extrapolation of the function for the N2 and N3 levels to the WAT=0 mm line indicates that if no water is applied, approximately 16 and 20 MT/Ha, respectively, of yield is obtained. These minimum yields are however dependant upon the soil water holding capacity since the soil has to be able to supply about 138 and 112 mm of ET water , respectively, to the crop.

The yield-WAT functions were used to calculate the percentage increase in yield from the N2 to N3 level rather than the yield-ET functions. This was done because the former functions had one less source of error compared to the latter. This error is what is associated with the estimation of ET and will be discussed at the end of this section. Therefore, all further yield comparisons between N2 and N3 levels will be done using the yield-WAT functions.

The analysis of the Y/G ratio versus ET function (figure 11) indicates that even though the slope of this line is small, there is a 74 percent probability that it is not zero (table A.4). This means that there is a definite, even though small, decrease in the Y/G ratio over the ET range. As ET increases proportionally less root growth occurs resulting in a decreasing Y/G ratio. The continued foliage production requires the input of additional ET causing the G-ET functions (figure 8) to keep increasing.

The G-WAT function for the N2 level (figure 9) reaches a maximum yield of 110 MT/Ha[3] for 376 mm of applied water. As with root yield, the function for the N3 level does not reach a maximum in the range of applied water and it appears that at this level of nitrogen higher yields can be obtained by applying more water. However, with the high decreasing rate of increase in G the highest yield achieved should be near the maximum and the function should be leveling off. No extrapolation beyond the maximum water applied would be correct however since the current equation is not complete. If the current form of the function for N3 level is used the maximum increase in total yield from addition of nitrogen is around 6.4 percent [4]. These two functions are statistically the same (α=5%) but are reported separately (table A.2) since one is not complete.

Low probabilities of being zero were associated with the coefficients of the second degree terms of independent variables in the above functions which indicated a definite curvature in these functions. The

(3) The derivative of G(WAT) for N2 gives WATmax=376 mm which then gives Gmax=110 MT/Ha.

(4) The N3 level Gmax @ WAT=376 mm is 117 MT/Ha. Then percent increase over N2 is = (117-110)*100/110 = 6.4 percent .

curvilinearity in both G and Y yields versus WAT functions conforms well with similar functions reported in the literature. However, the curvilinearity in G and Y yields versus ET functions is in the present study thought to be the result of errors associated with the estimation of seasonal crop ET. If these errors are overlooked the predictive capabilities of the yield-ET functions could be seriously affected. These errors and their sources and magnitudes are discussed in detail below.

In the absence of lysimeters which are very accurate in their measurements of ET, other methods of ET measurement have to be used. In this experiment the neutron probe (Van Bavel et al.,1956) was used as a semi-direct measurement of ET. Several factors reduce the accuracy of estimating ET from neutron probe data. First is the deep percolation of irrigation water which occurs whenever irrigation becomes excessive and a part of applied water passes through the root zone without having been used for evaporative need by the crop. If this deep percolation is not measured or estimated it will make the production functions overestimate ET for any given yield. The extent of deep percolation in this experiment is not known but it is assumed to be non-existant or minimal since the most heavily irrigated plots received less than the intended amounts.

Second is the problem of water accretion upwards into the root zone from a water table below in which water is used by plants from sources other than the surface applied water. Water accretion into the root zone causes higher water contents to be registered by neutron probe and as a result the seasonal depletions are computed to be smaller and ET is underestimated. The contribution to ET from a water table is very unlikely in this experiment since the permanent water table was more than 3-4 meters below the root zone.

Third is the accuracy with which the surface moisture content is measured by the neutron probe. Neutron probe measurements for the surface 15 cm of soil are not highly accurate (Van Bavel et al.,1954; Lawless et al., 1963) primarily due to the great spatial variability in the physical properties of surface soil from one point in the field to another. Changes in bulk density affect the water content and change the sphere of influence of the probe. This will change the number of neutrons which escape out of the soil and therefore affects the count rate. Specially notorious are cracks which develop when the soil surface becomes dry and these cracks may cause large errors in neutron counts (Greacen and Hignett, 1979).

Other sources of error in surface measurements are the organic matter present in the soil and the growing vegetative material above the surface. Lawless et al. (1968) did not observe any appreciable effect of large amounts of green matter on neutron counts. However, for plants like beets a large accumulation of water occurs in the actively growing roots below the surface. Also small errors in positioning the probe at the desired depth can result in errors in measurement (Hauser, 1984). However, calibration equations for neutron probe's surface measurements have been used with some success (Braunworth and Mack,1987; Garrity et al.,1981). When care and caution are taken in obtaining soil samples a reasonable calibration equation can be developed.

Figure 5 shows the data and calibration equation developed for the surface soil for this experiment. Even though more samples in the water content range of 26 to 34 percent by volume were not obtained, the remainder of the data indicate a linear relationship between the actual water contents determined by gravimetric method and their estimate by the neutron probe. The errors in ET estimation associated with this are random and could either over- or under-estimate ET. The fairly good fit of the neutron probe's surface calibration equation shows that the error in the estimation of surface moisture content is rather small.

Another potential source of curvilinearity in yield-ET functions is the effect of water deficit in a sensitive growth stage on the final yield of beets. Turk et al. (1980) found that drought during flowering and bud filling of cowpeas reduced yield substantially but did not affect yield during the vegetative growth. Flowering was also found to be the critical stage for corn (Robins and Domingo,1953) and beans (Robins and Domingo,1956). Yield and quality of wheat are decreased by water stress during stem extension and early grain filling (Miller and Hang,1982). Water stress was found to damage yield of soybeans during pod filling (Cox and Jolliff, 1986). Water stress at any stage of growth reduces the sunflower yield though stress at flowering to late flowering appears to be the most damaging (Cox and Jolliff,1986). The growth stage versus ET need relationship for table beets has not been investigated, but it may be assumed that since the crop is harvested before it flowers or enters into the reproductive stage, there is no specific sensitive stage of growth during vegetative developement.

b. 1985 Experiment

The six irrigation treatments imposed during 1985 were on the average respectively only 95, 75, 60, 40, 18, and 8 percent of Penman estimated ET as measured by neutron probe. This is thought to be the primary factor which caused the Y-WAT functions (figure 10) to not reach maxima for either of the two nitrogen levels. The maximum yields indicated by the functions for the lower and higher nitrogen rates are 56.4 and 60 MT/Ha at 278 and 293 mm, respectively, of applied water. When the two functions are extended to WAT=0 line the minimum yield achievable are respectively, about 28 and 26 MT/Ha. There was no statistical difference between the two functions (α= 5%) and the largest increase in yield from the lower to the higher nitrogen rate is about 3 MT/Ha and is about 6 percent of N2 level yield at a WAT of about 210 mm. It decreases however as WAT changes in either direction. The functions for the two nitrogen levels and their statistical information are reported in table A.3.

B. Dry Matter Production

The percent dry matter in root yield (hereafter referred to as percent dry Y) was computed by multiplying the percent dry matter of each size grade by its fresh yield, adding them all together and dividing this sum by Y. Figure 12 shows the percent dry Y versus ET function. Since there was no statistical difference between the functions fitted to the data of each nitrogen level (α= 5%), the data were combined to yield the equation of this function (table A.5). It shows a clear decrease in the dry matter production as ET increases. The minimum percent dry matter of 12.4 occurs at ET of 412 mm. As ET increases more water is stored in the roots and less dry matter per total weight is produced.

The same trend in percent dry Y versus ET function is seen in the percent dry leaf matter versus ET function (figure 12). The percent dry leaf matter is less than the percent dry Y at each ET level and decreases to a minimum of 9 at an ET of 403 mm. This ET level is practically the same as the ET level at which the minimum percent dry Y was reached. Again the data of the two nitrogen treatments have been combined since the statistical difference between the functions for each nitrogen treatment was not significant (α= 5%) (table A.5).

II. SIZE DISTRIBUTION OF ROOTS

A. Production Functions

a. 1986 Experiment

The distribution of the G1, G2, and G3 size grades for the two nitrogen levels as functions of ET are given in figures 13 and 14 and as functions of WAT are given in figures 15 and 16. The G2 and G3 size grades are emphasised since these currently bring the most revenue to the growers.

The G2 size yield versus ET data for the two nitrogen levels produced functions (figure 17) which were not statistically different (table A.1).The N2 and N3 level G2 size yields reach maxima of 30.4 and 33.4 MT/Ha,respectively, at ET levels of 435 and 429 mm, respectively. The maximum G2 yield for the N2 level is reached at an ET level which is very close to the ET associated with the maximum Y for this nitrogen level of 460 mm. This is important since it assures one that if the maximum Y is reached, the maximum G2 size yield is also nearly obtained. It also provides the information needed to maximize the production of G2 size for the N3 level since a complete Y-ET function can not be developed for it. In fact if the objective of beet production is more to maximize the yield of this size rather than the total root yield, the G2-ET and G2-WAT functions contain the necessary beet versus water need information for the optimum use of the water resource. The G2 versus WAT functions for the two nitrogen levels (figure 18 and table A.2) reach maxima. The maximum G2 yields for the N2 and N3 nitrogen levels are 31 and 33

MT/Ha, at applied water depths of 331 and 391 mm, respectively. The increase in G2 yield from N2 to N3 level is computed to be about 6.5 percent.

Size G3 versus ET functions (figure 19) for the two nitrogen levels do not reach maxima in the ET range. These functions are statistically similar (α=5%) and can in fact be approximated by linear models since there is essentially no difference in R^2 between the second degree polynomial and the linear functions fitted to the data. Also the probability of the coefficient of the second degree term to be zero is 81 percent for the N2 and 76 percent for the N3 level function (table A.1). The G3 versus WAT functions (figure 20 and table A.2) do not have maxima in the range of applied water. However, the percent increase in G3 yield from N2 level to N3 at the WAT level of 427 mm is about 4 MT/Ha or about 22 percent of N2 level yield.

Figure 11 gives the ratios of G2 and G3 over Y as functions of ET. The data indicate a small change of G2/Y ratios over the ET range. The small R^2 of this function (table A.4) coupled with a 77 percent chance of the slope of this function to be zero indicates that no matter what the ET level, about 50 percent of the root yield will be in the G2 size grade. If this is established through further research it can be used to closely estimate the G2 size yield from the field measurements of Y.

The relationship between G3/Y and ET is much greater and there is a very low probability that the slope of this line is equal to zero. The data indicate that the G3-size portion of yield increases as ET increases likely because as more water becomes available there is less competition for water and more of the roots can pass through the G2 size and attain the higher sizes. The data of the two nitrogen levels for the G2/Y and G3/Y ratios have been combined since there was no statistical difference (α= 5%) between them.

b. 1985 Experiment

The size distribution of G1, G2, and G3 grade sizes for the two nitrogen levels are given in figures 21 and 22. The G2 versus WAT functions (figure 23) for the lower and higher nitrogen levels reached maximum yields of 38 and 37 MT/Ha for WATs of 233 and 237 mm, respectively. These two yields are essentially the same and are obtained at similar WAT depths. The two functions are statistically the same (α=5%). The G2-WAT functions do not reach maxima when Y-WAT functions do as was the case in 1986 for N2 level treatment.

The G3 size yield versus WAT data for the two nitrogen levels give equations which are statistically not different (α=5%) (figure 24). The individual equations are reported in table A.3. These functions do not reach a maximum and are almost linear.

SUMMARY AND CONCLUSIONS

Table beet root yield showed a marked response to irrigation during the 1985 and 1986 summer seasons for two nitrogen levels. Irrigation levels were based on calculations of atmospheric demand using a modified Penman relationship. The average increase in beet root yield over the no-irrigation treatments during 1986 was 197 percent for the higher and 191 percent for the lower nitrogen level. The highest yields achieved in each nitrogen level were in response, respectively, to 406 and 339 mm of irrigation water applied via overhead sprinkler systems. At the high nitrogen level, more water may have further increased yield. In 1985 the increases were 104 percent for the higher and 88 percent for the lower nitrogen level in response, respectively, to 276 and 261 mm of irrigation water. It should be noted that the amount of irrigation water needed to keep the soil at an uptimum level for the seeds to germinate and the effective rainfall from planting to emergence should be added to the above applied water depths to obtain total water applied from planting to harvest.

The smaller amount of irrigation water applied in 1985 than in 1986 may have been the cause of the difference in yield response between the two years even though the amounts in both years were based on the same method. Because of this smaller amount of applied water neither of the functions for 1985 reached maximum which indicated that higher yields could be obtained by applying more water.

Relatively more water was applied during 1986 than in 1985 and the root yield versus water applied function for the lower nitrogen level reached a maximum. However, at higher nitrogen level the same function did not reach a maximum indicating that the application of more water would result in higher yields. The 1986 data indicate that the functions for the two nitrogen treatments are statistically similar at the 5 percent level of significance. They also indicate that there may be more than 13 percent increase in yield from the lower to the higher nitrogen level. This increase in yield is the result of a 20 percent increase in applied water and a 100 percent increase in nitrogen fertilizer rate.

Past research (Hemphill et al., 1982) has shown that there is a good response of table beet yield to the addition of nitrogen fertilizer from about 125 to about 250 Kg N/Ha. Although our results showed only a small increase in yield when the 125 and 250 Kg N/Ha rates were compared the functions for the lower nitrogen level may reflect some of the effect of nitrogen stress on yield in addition to water stress.

A question arises whether production functions can be used in other regions and at different years? Since the production functions are statistical in nature, they are invariably site specific. Normalized functions of yield over maximum yield ratios versus ET over maximum ET ratios help relate the functions derived for a specific location to another. Yaron (1971) concluded that the production functions for a given crop in the same location but different years tended to be parallel to each other with the difference being one of yield magnitudes. This difference in magnitude may be explained as Yaron put it by annual changes in weather, the extent of pest and weed infestations, and the like. Annual changes in weather are almost always unpredictable and undefendable against and since they affect the crop ET directly and drastically they largely work to weaken the predictive capability of any production function.

The water production functions are most usefull when they are looked at in conjunction with the water-fertilizer interaction effects on the crop production. Boron, for instance, is a fertilizer much needed by beets and the irrigation-boron interaction should be of particular interest to beet growers.

Even though our data and production functions do not offer information on the economics of deficit irrigation of table beets, the form of the functions suggests that any additional unit of yield brings less and less profit. At any level of soil fertility the slope of these functions decreases untill a point on the graph is reached where the incremental return from a unit of applied water is less than the incremental cost of application. The location of this point on the function which represents the highest feasible level of deficit irrigation, depends on the cost of water and the price of beets.

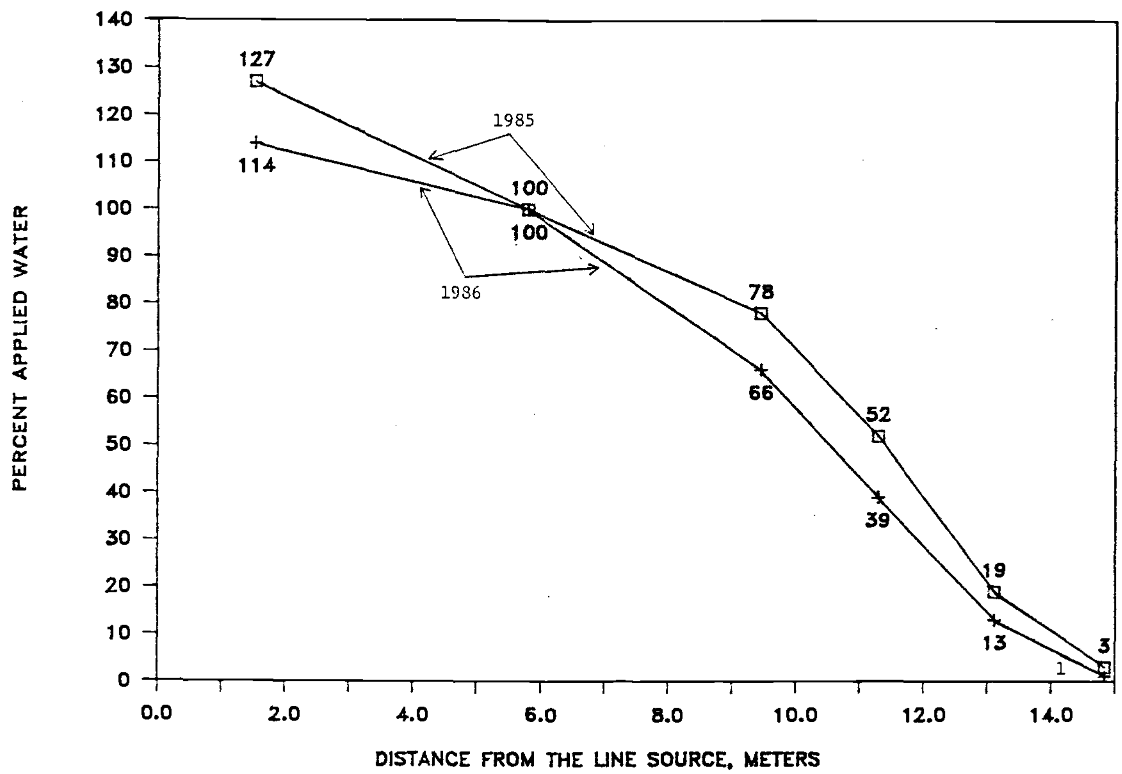

Figure 1. 1985 and 1986 water application percents compared to the water received at 5.79 meters from the line (the 10th row) as functions of distance from the sprinkler line.

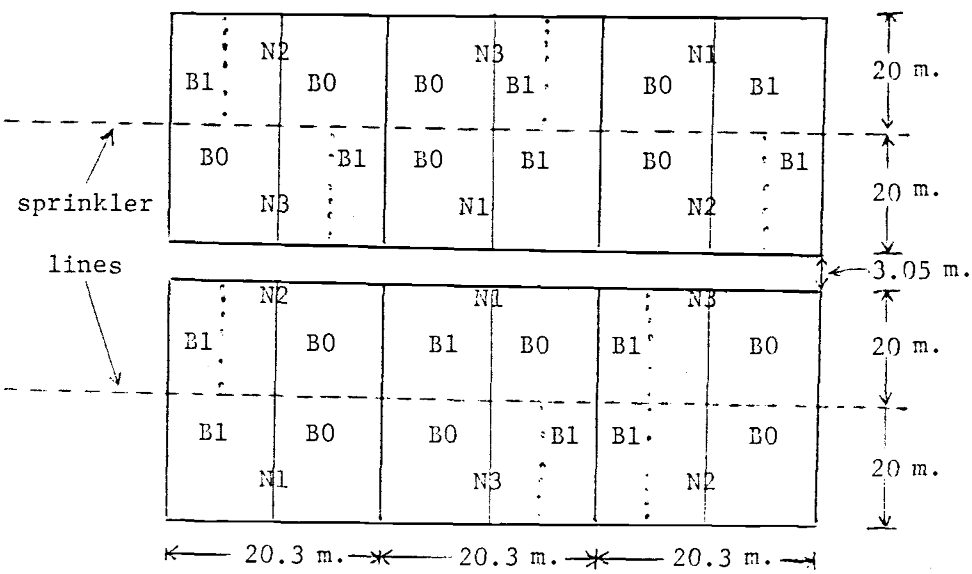

Figure 2. Experimental design layout for 1985.
° are the neutron probe access tube positions.
N1 = 50 Kg N/ Ha
N2 = 125 Kg N/ Ha
N3 = 250 Kg N/ Ha
B0 = 0 Kg B/ Ha
B1 = 5 Kg B/ Ha

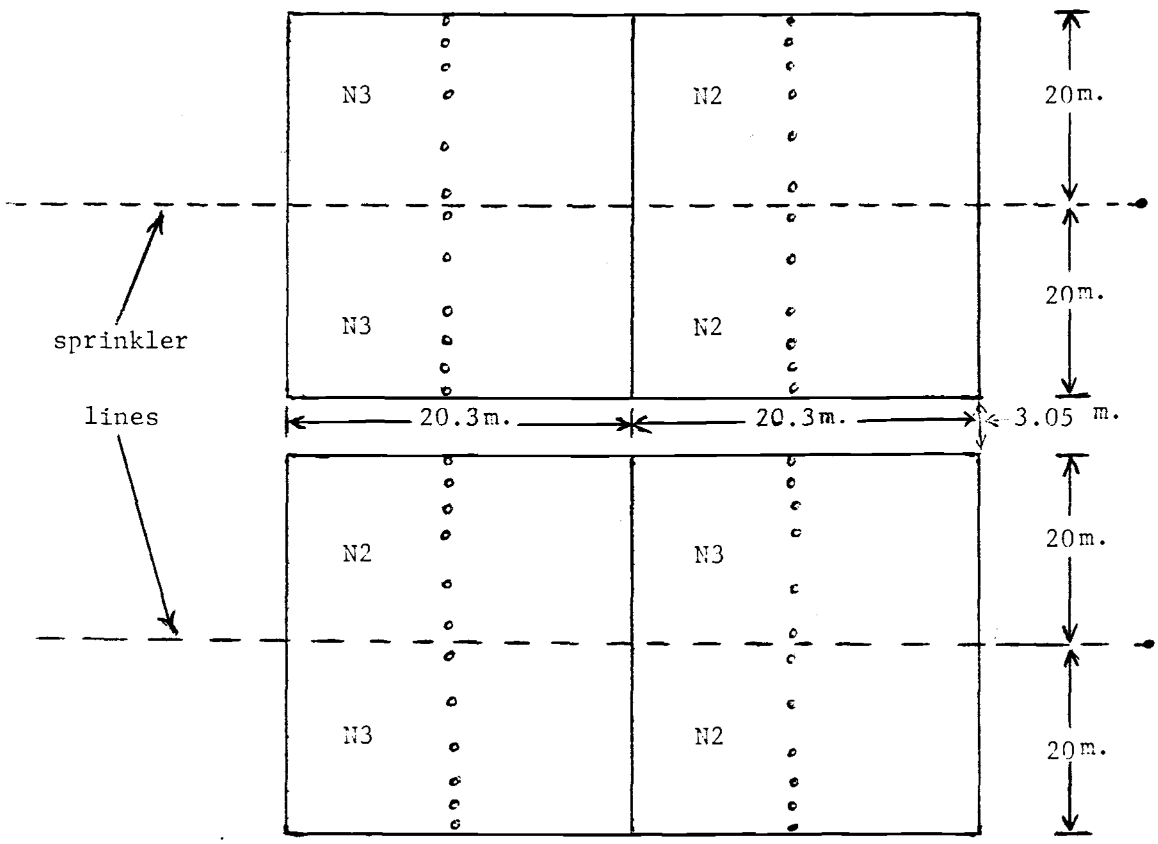

Figure 3. Experimental design layout for 1986.
° are the neutron probe access tube positions.
N2 = 125 Kg N/ Ha
N3 = 250 Kg N/ Ha

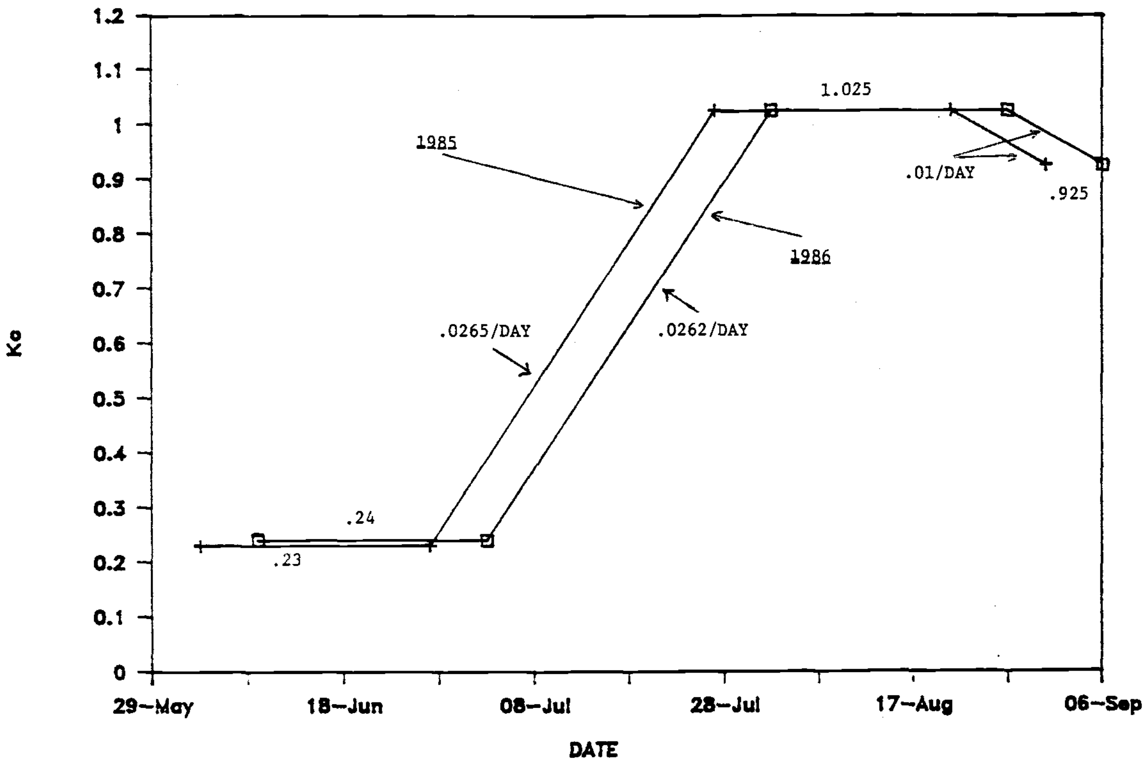

Figure 4. Crop coefficient (Kc) curves developed for table beets at Corvallis for 1985 and 1986 based on FAO Paper no. 24 guidelines closest to the conditions in Corvallis.

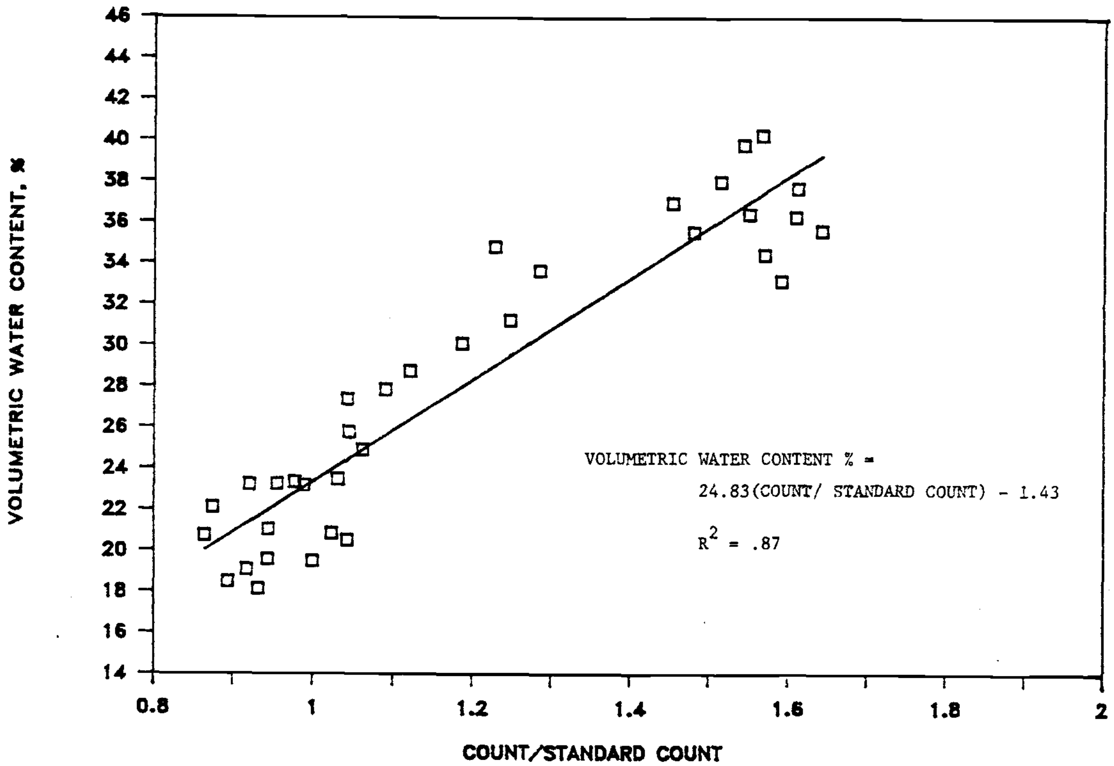

Figure 5. 1986 calibration regression for the neutron probe for the Ø-15 cm soil profile at the OSU Vegetable Research Farm (Chehalis silty clay loam).

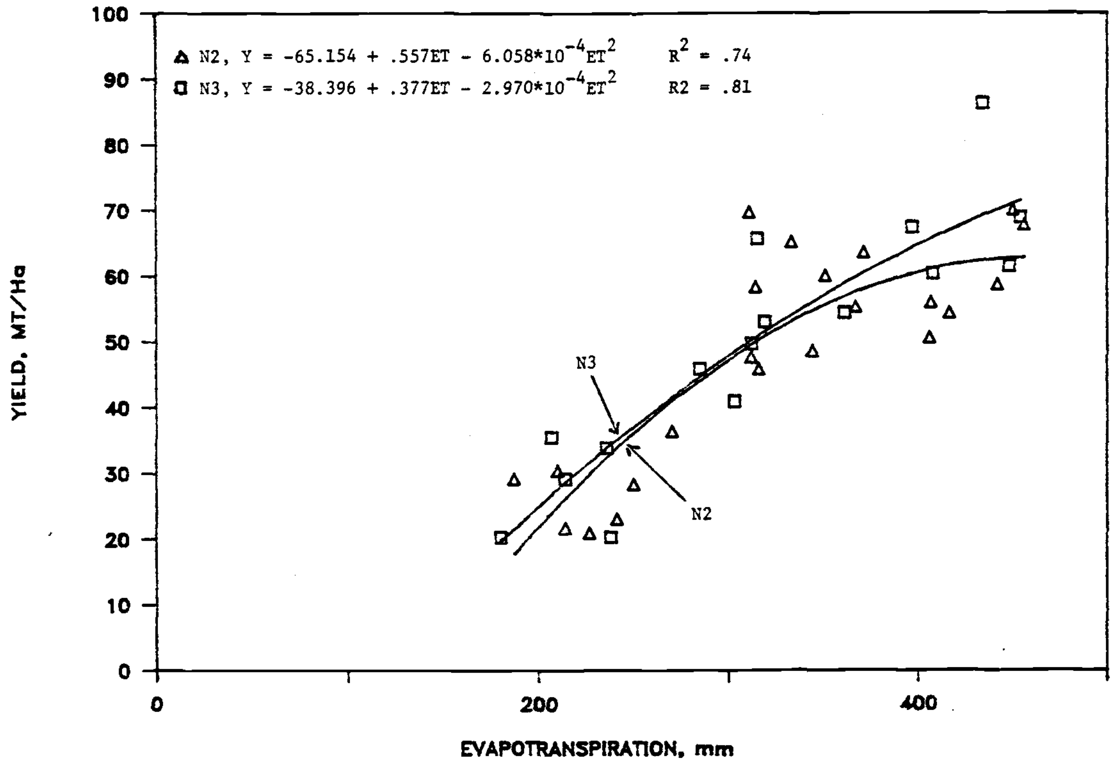

Figure 6. 1986 root yield versus evapotranspiration functions for each nitrogen level.

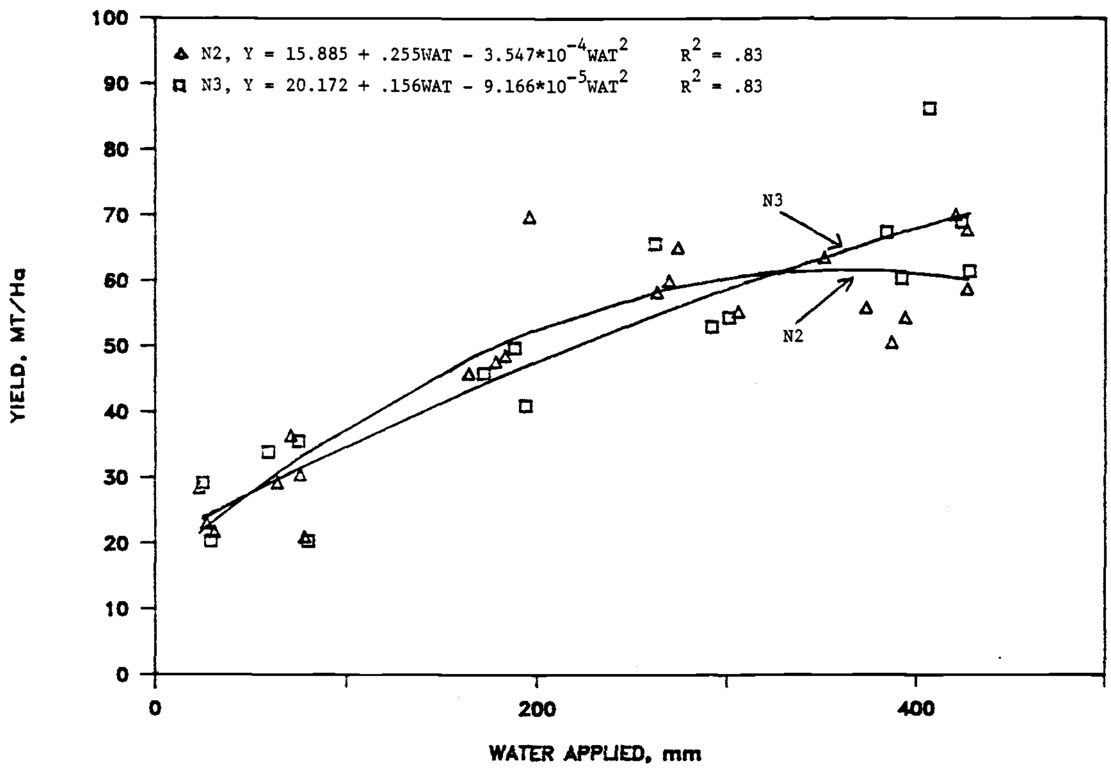

Figure 7. 1986 root yield versus water applied functions for each nitrogen level.

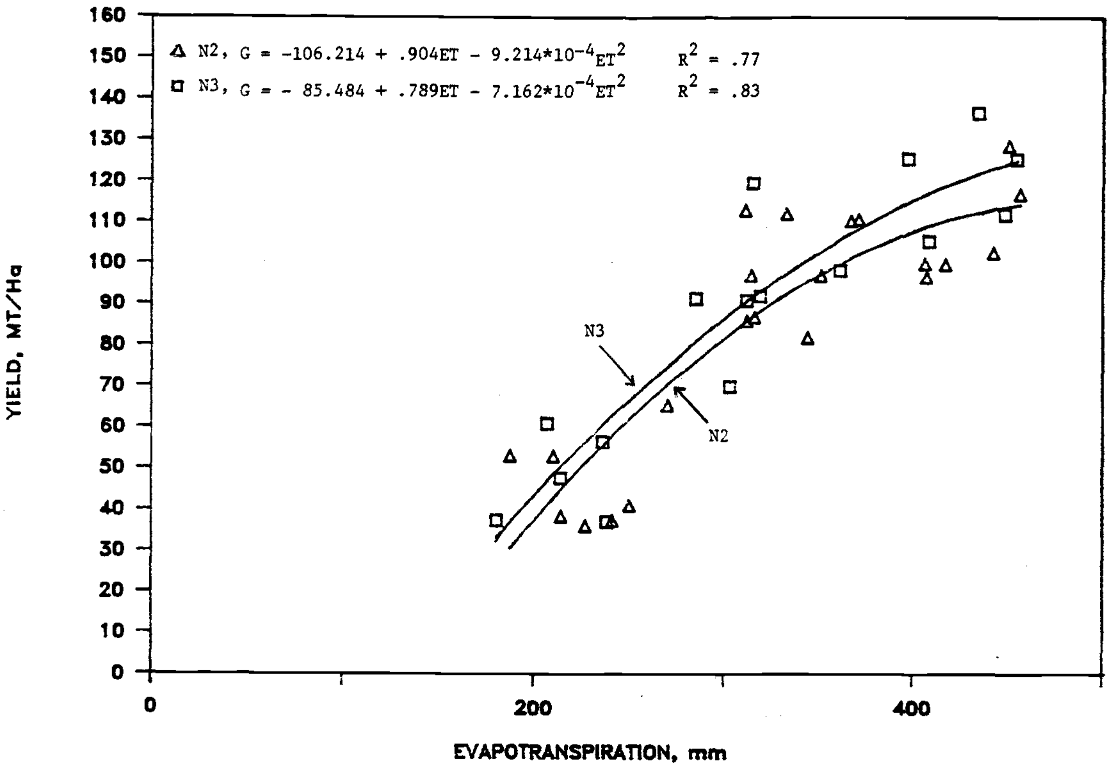

Figure 8. 1986 total yield versus evapotranspiration functions for each nitrogen level.

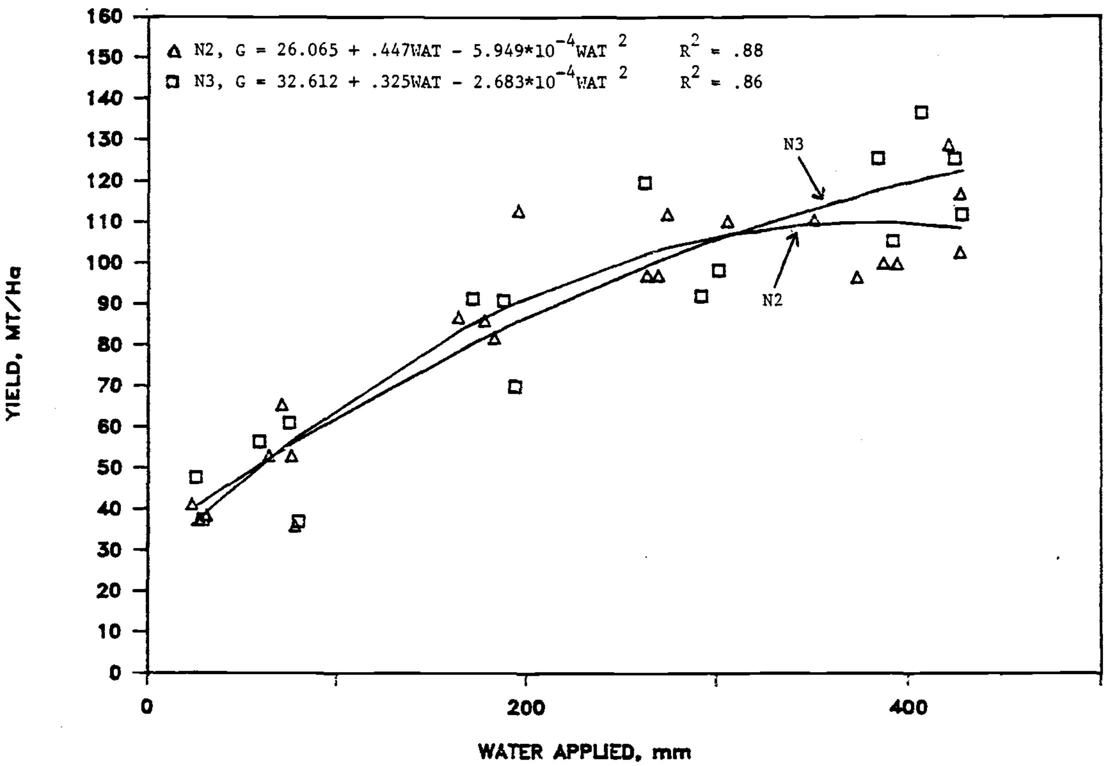

Figure 9. 1986 total yield (roots + tops) versus water applied functions for each nitrogen level.

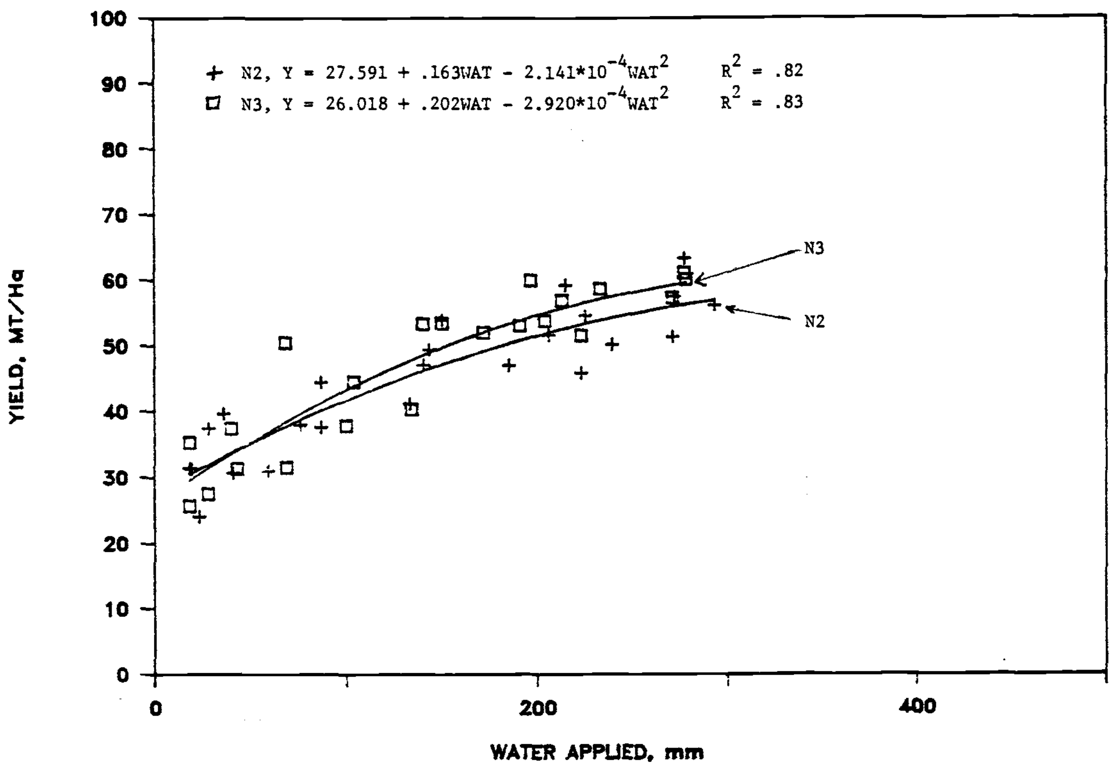

Figure 10. 1985 root yield versus water applied functions for each nitrogen level.

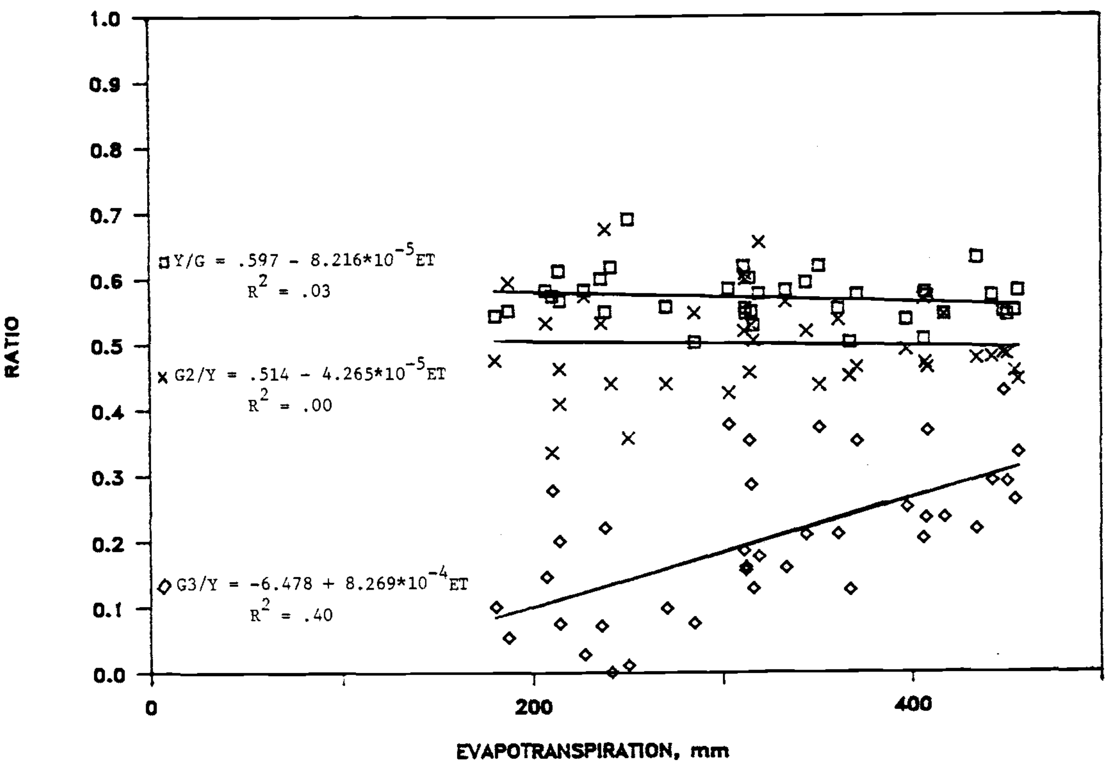

Figure 11. 1986 ratios of root yield to total yield (Y/G), G2 yield to root yield (G2/Y), and G3 yield to root yield (G3/Y) as functions of evapotranspiration. The ratio data of both nitrogen levels were combined to obtain these functions.

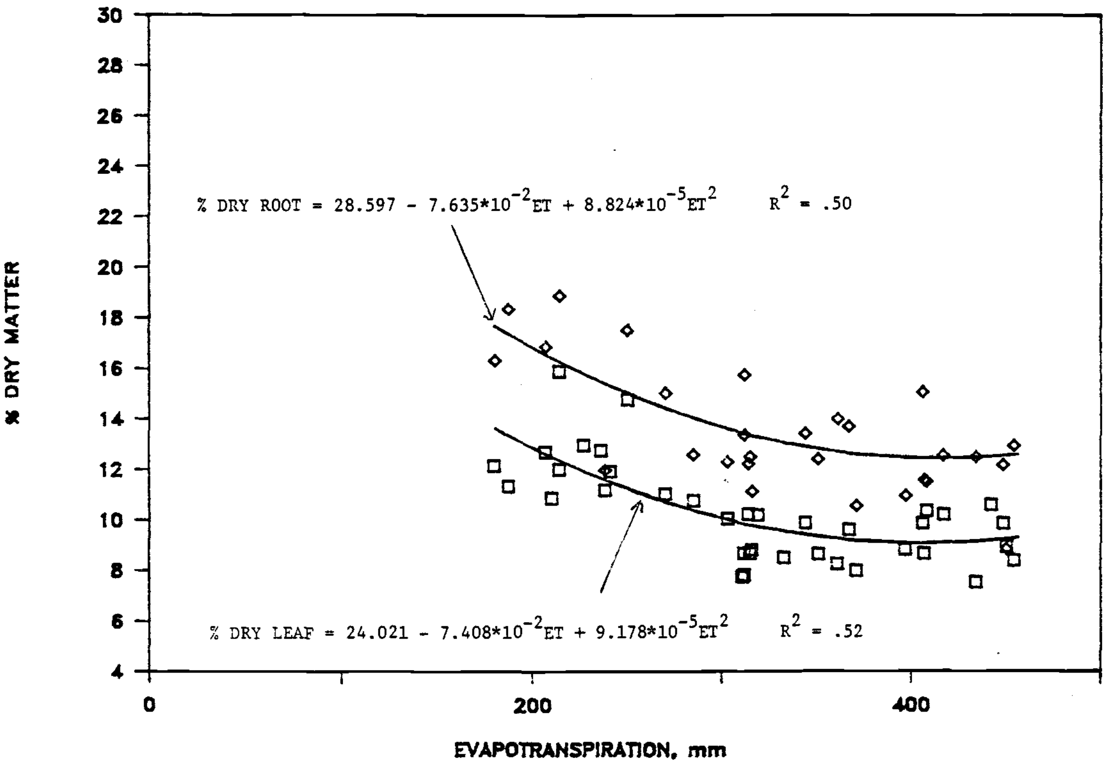

Figure 12. 1986 percent dry root and percent dry leaf matters as functions of evapotranspiration.

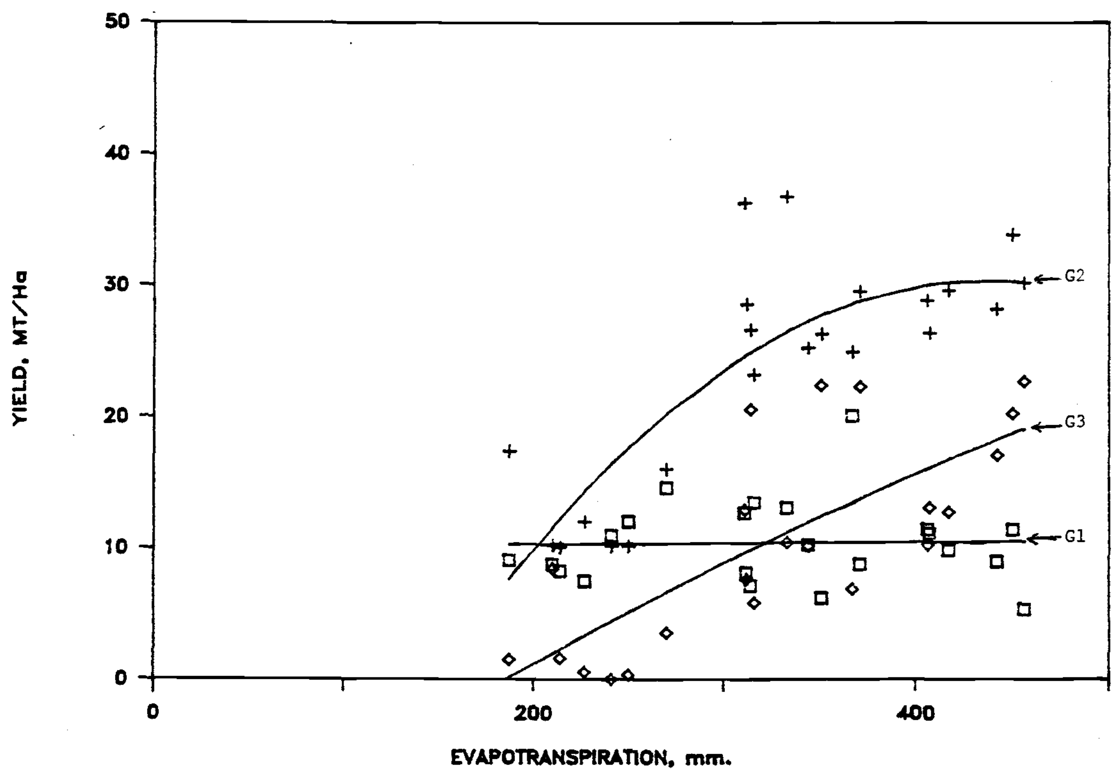

Figure 13. 1986 yield distributions of G1, G2, and G3 size grades as functions of evapotranspiration for N2 nitrogen level.

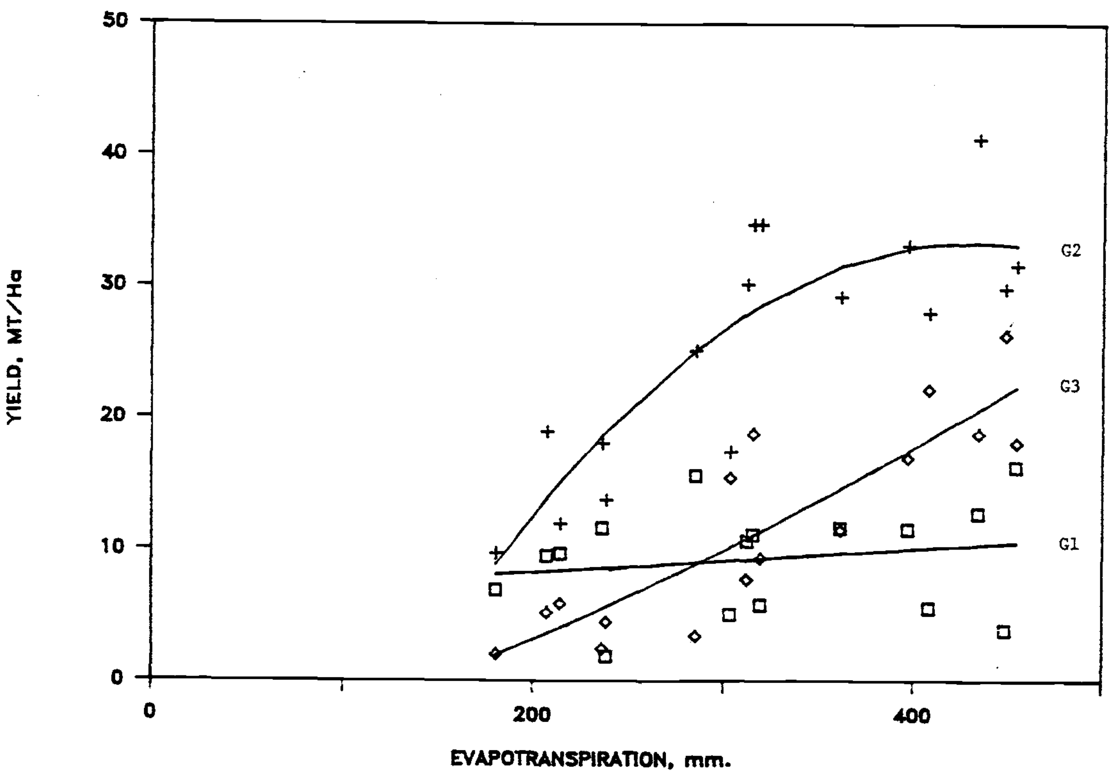

Figure 14. 1986 yield distributions of G1, G2, and G3 size grades as functions of evapotranspiration for N3 nitrogen level.

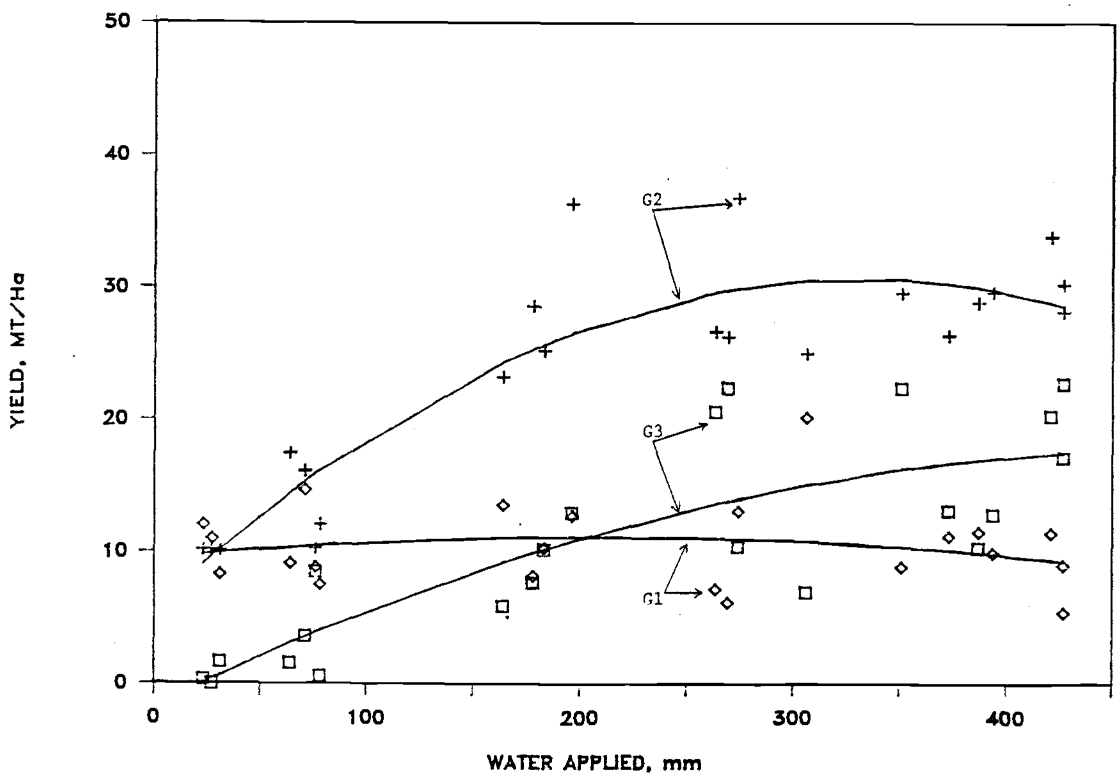

Figure 15. 1986 yield distributions of G1, G2, and G3 size grades as functions of water applied for N2 nitrogen level.

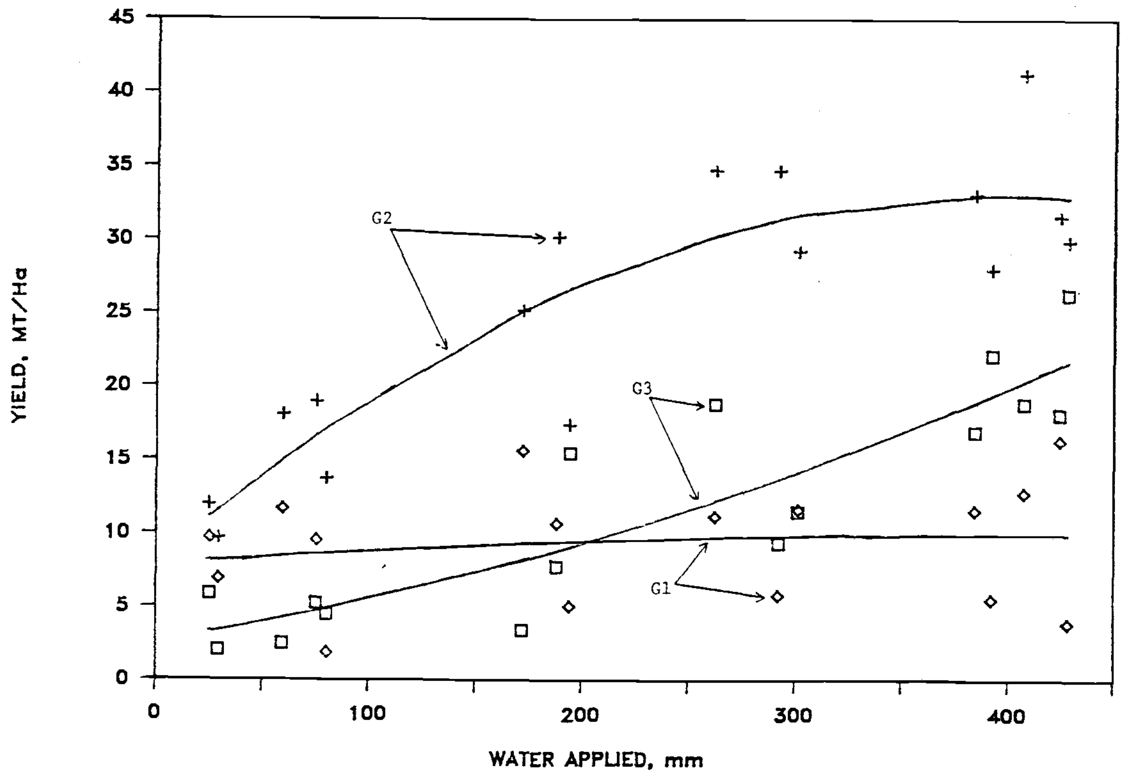

Figure 16. 1986 yield distributions of G1, G2, and G3 size grades as functions of water applied for N3 nitrogen level.

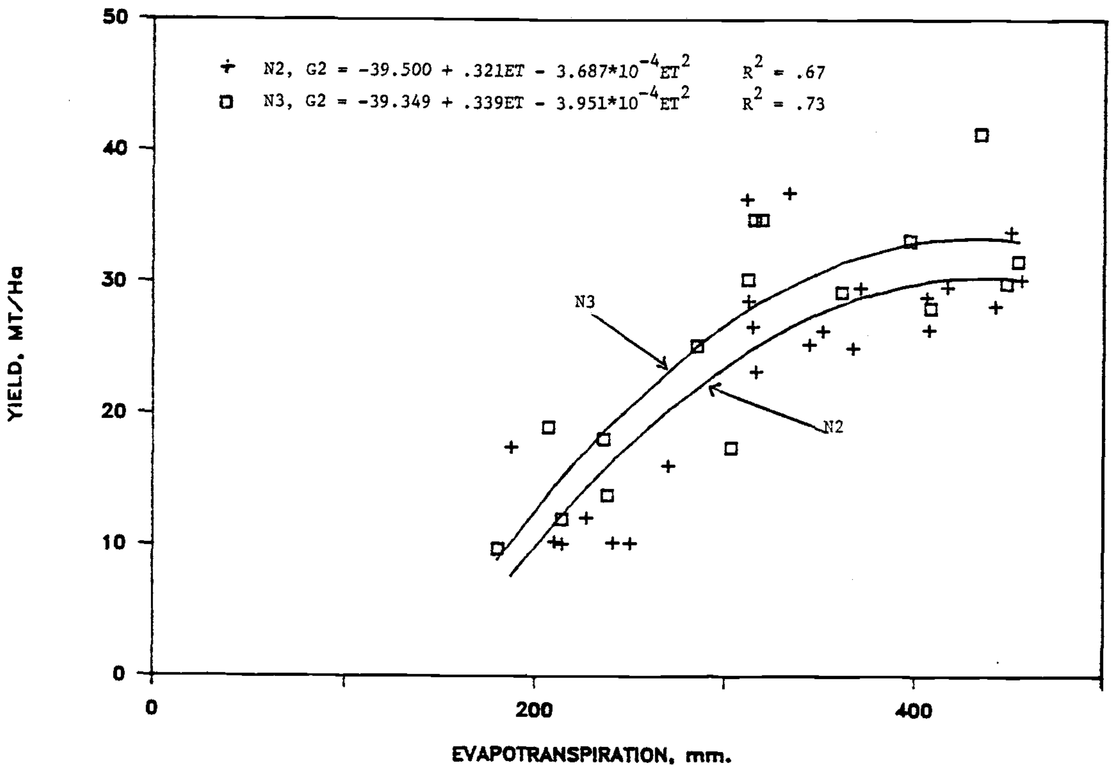

Figure 17. 1986 G2 yield versus evapotranspiration functions for each nitrogen level.

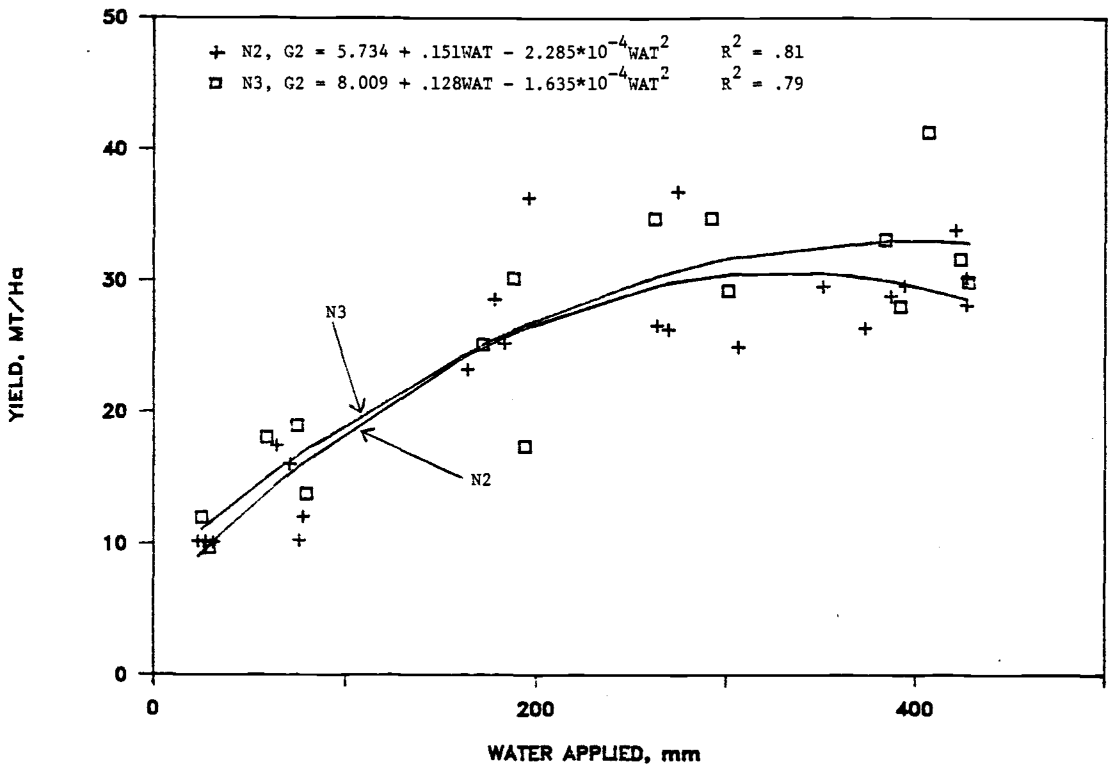

Figure 18. 1986 G2 yield versus water applied functions for each nitrogen level.

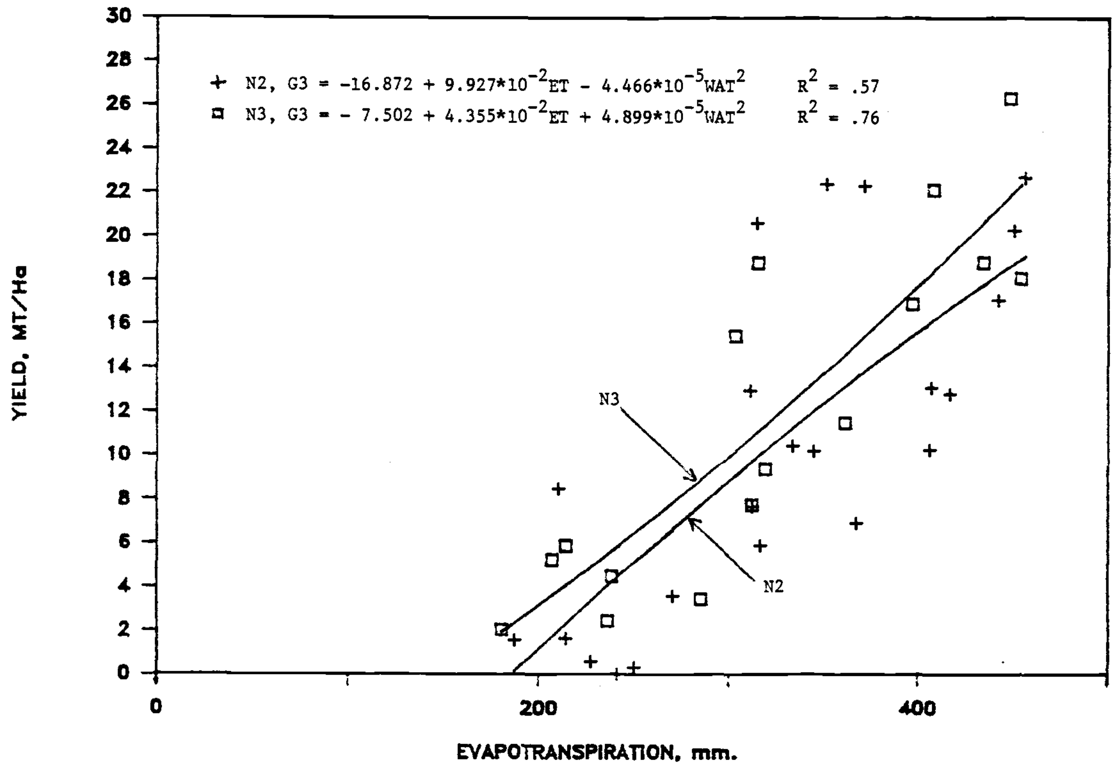

Figure 19. 1986 G3 yield versus evapotranspiration functions for each nitrogen level.

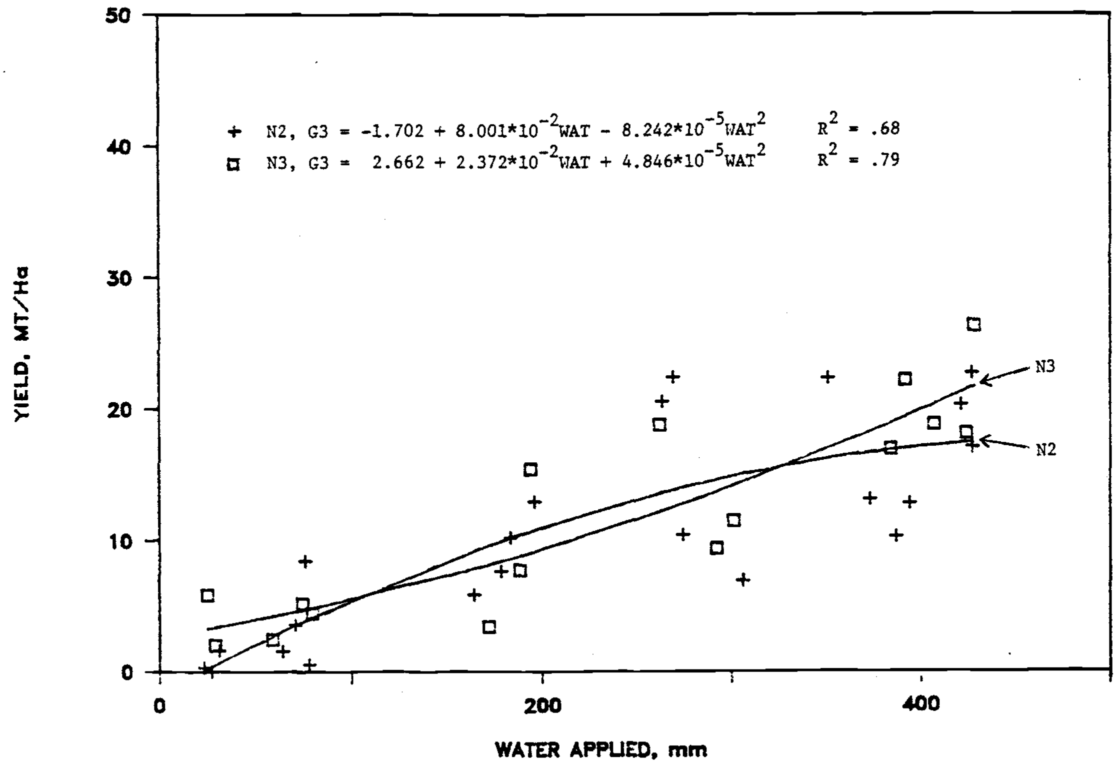

Figure 20. 1986 G3 yield versus water applied functions for each nitrogen level.

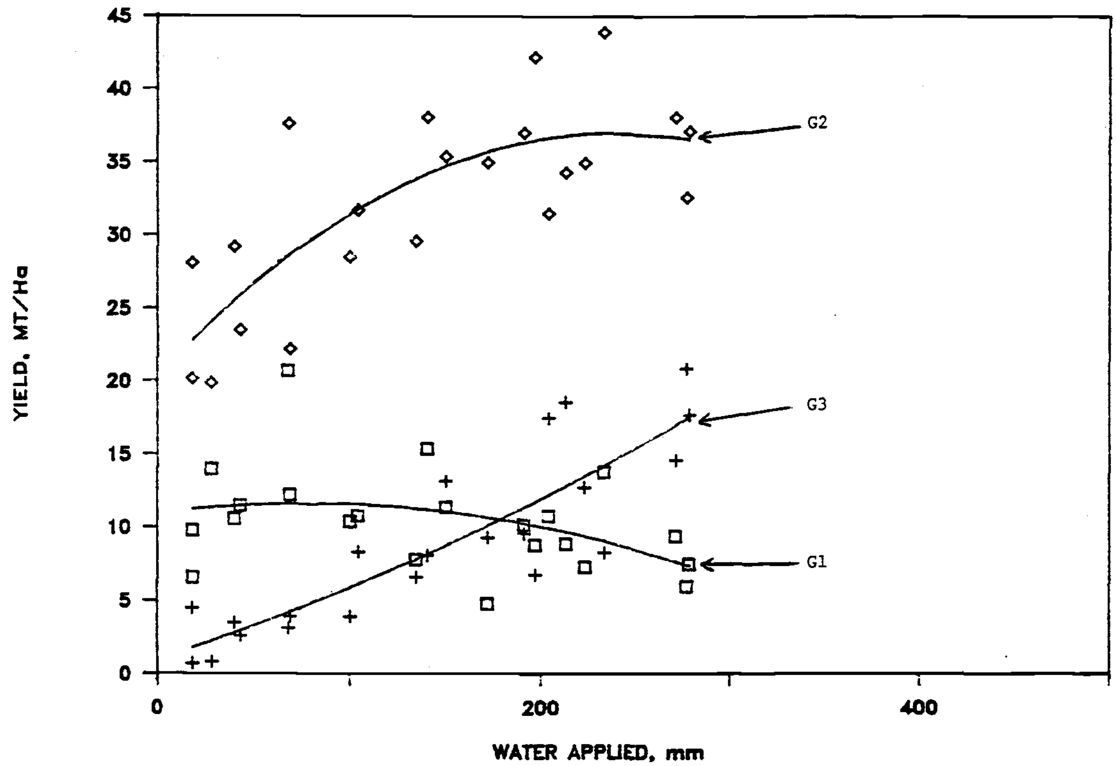

Figure 21. 1985 yield distributions of G1, G2, and G3 size grades as functions of water applied for N2 nitrogen level.

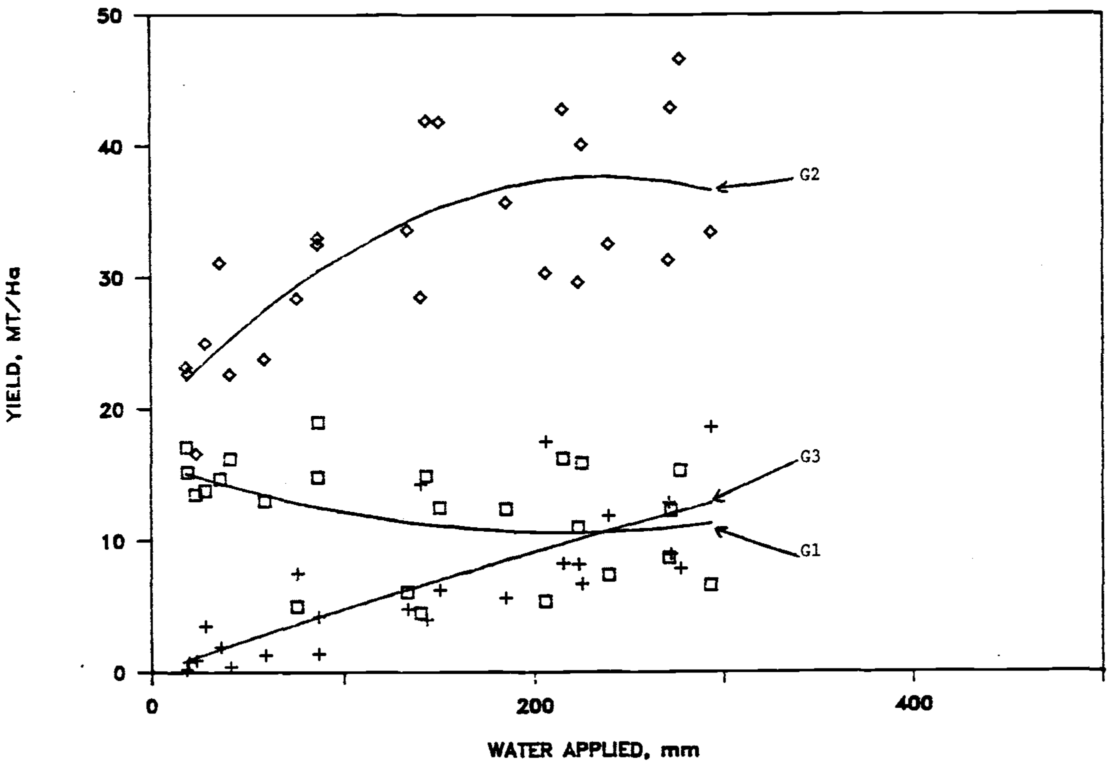

Figure 22. 1985 yield distributions of G1, G2, and G3 size grades as functions of water applied for N3 nitrogen level.

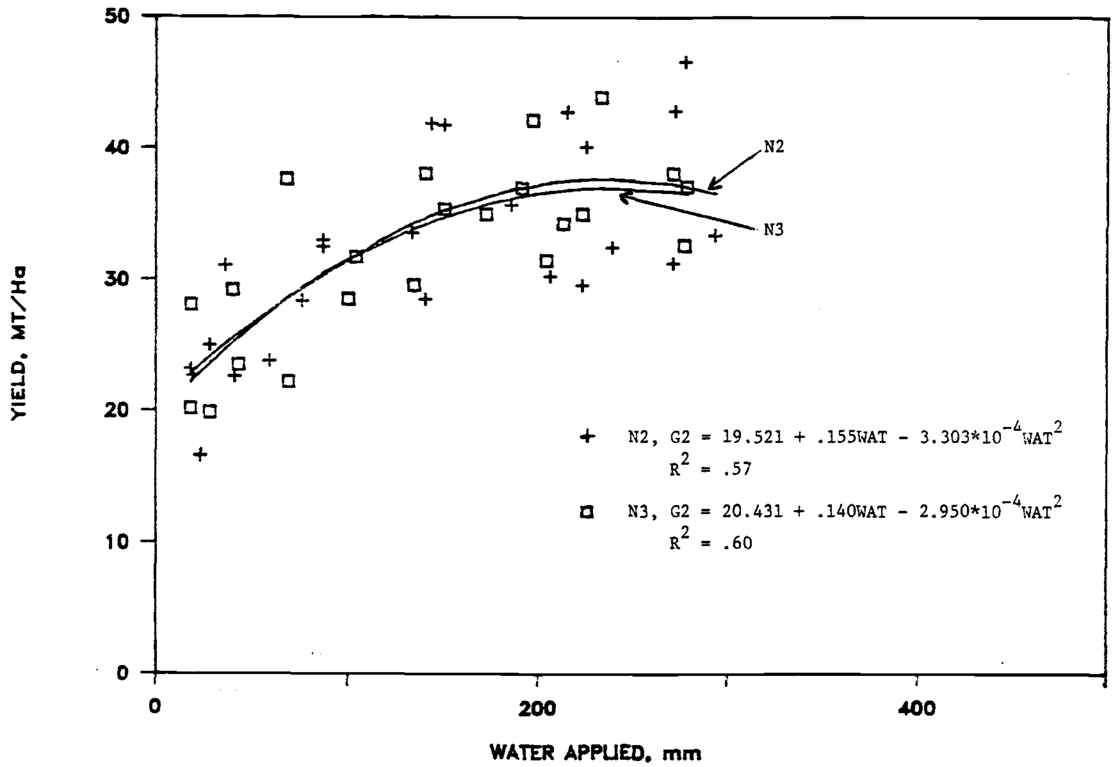

Figure 23. 1985 G2 yield versus water applied functions for each nitrogen level.

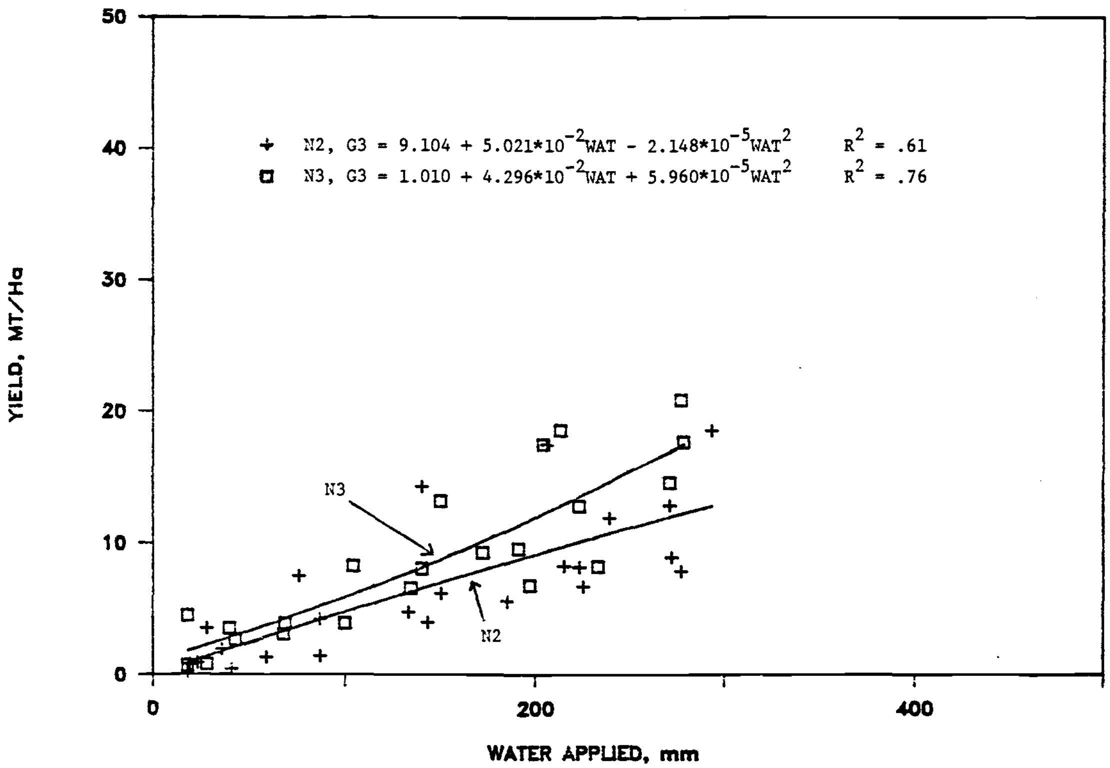

Figure 24. 1985 G3 yield versus water applied functions for each nitrogen level.

BIBLIOGRAPHY

Beckett,S.H., and M.R. Huberty. 1928. Irrigation investigations with field crops at Davis, California, and at Delhi, 1909-1925. Bulletin 450, U.C. College of Agriculture, Davis, California.

Beese,F., R. Horton, and P.J. Werenga. 1982. Growth and yield response of chile pepper to trickle irrigation. Agron J. 74:556-561.

Braunworth,W.S. Jr., and H.J. Mack. 1987. Effect of deficit irrigation on yield and quality of sweet corn. J. Am. Soc. Hort. Sci. 112(1):32-35.

Clyde,H.S., W. Gardner, and O.W. Isrealsen. 1923. The economical use of irrigation water based on tests. Engineering News Record, vol.91, No 14, pp 548-552.

Cox,W.J., and G.D. Jolliff. 1986. Growth and yield of sunflower and soybean under soil water deficits. Agron. J. 78:226-230.

Doorenbos,J. and W.O. Pruitt. 1977. FAO Irrigation and Drainage Paper No. 24. Guidelines for predicting crop water requirements.

de Wit,C.T. 1958. Transpiration and crop yields. Institute of Biological and Chemical Research on Field Crop and Herbage, Wageningen, The Netherlands, Verse-Landbouwk, onder 2. No 64.6-S Gravenhage.

Downey,L.A. 1972. Water-yield relations for nonforage crops. J. of the Irrig. and Drain. Div.,ASCE.98(IR1):107-115. Proc. Paper 8772.

Garrity,D.P., D.G. Watts, C.Y. Sullivan, and J.R. Gilley. 1982. Moisture deficits and grain sorghum performance: ET,Y relationship. Agron. J. 74:815-820.

Greacen,E.L. and C.T. Hignett. 1979. Sources of bias in the field calibration of a neutron meter. Aus. J. Soil Res. 17:405-415.

Grimes,D.W., H. Yamada, and W.L. Dickens. 1969. Functions for cotton (Gossypium hirsutum L.) production from irrigation and fertilization variables: I. Yield and evapotranspiration. Agron. J. 61:769-773.

Gupta,U.C. 1979. Boron nutrition of crops. Adv. in Agron. J. 31:273-307.

Gupta,U.C. 1983. Boron deficiency and tixicity symptoms for several crops as related to tissue boron levels. J. of Plant Nutrit. 6:387-395.

Hanks,R.J., H.R. Gardner, and R.L. Florian. 1969. Plant growth evapotranspiration relation for several crops in the central great plains. Agron. J. 61:30-34.

Hanks,R.J. 1974. Model for predicting plant yield as influenced by water use. Agron. J. 66:660-665.

Hanks,R.J., J. Keller, V.P. Rasmussen, and G.D. Wilson. 1976. Line source sprinkler for continuous variable irrigation crop production studies. Soil Sci. Soc. Am. Proc. 40:426-429.

Hang,A.N., and D.W. Evans. 1985. Deficit sprinkler irrigation of sunflower and safflower. Agron. J. 77:588-592.

Hang,A.N., and D.E. Miller. 1986. Responses of sugar beet to deficit, high-frequency sprinkler irrigation: I. Sucrose accumulation and top and root dry matter production. Agron. J. 78:10-14.

Hang,A.N., and D.E. Miller . 1986. Yield and physiological responses of potatoes to deficit, high frequency sprinkler irrigation. Agron. J. 78:436-440.

Hauser,V.L. 1984. Neutron meter calibration and error control. TRANS. ASAE. 27:722-728.

Hemphill,Jr.,D.D., M.S. Weber, and T.L. Jackson. 1982. Table beet yield and boron deficiency as influenced by lime, nitrogen, and boron. Soil Sci. Soc. Am. J. 46:1190-1192.

Hillel,D. 1980. Fundamentals of soil physics. Acad. Press. New York, NY.

Hipp,B.W. 1977. Influence of nitrogen and length of growing season on yield and size distribution of table beets. J. Am. Soc. Hort. Sci. 102:598-601.

Jackson,T.L., W.A. Sheets, N.S. Mansour, and H.J. Mack. 1974. Linming response in spinach and other vegetables. Oreg. Veg. Digest 23(2):1-2.

Kallsen,C.E., T.W. Sammis, and E.J. Gregory. 1984. Nitrogen and yield as related to water use of spring barley. Agron. J. 76:59-64.

Lawless,G.P., N.A. MacGillivray, and P.R. Nixon. 1963. Soil moisture interface upon readings of neutron moisture probes. Soil Sci. Soc. Am. Proc. 27(5):502-507.

Mack,H.J. 1965. Effects of nitrogen and boron on table beets. Oreg. Veg. Digest 14(4):7-8.

Mack,H.J. 1970. Fertilizers affect yield and boron deficiency of table beets. Oreg. Veg. Digest 19(3):3.

Mack,H.J. 1979. Effects of row spacings, fertilizers, and harvest dates on table beets. J. Am. Soc. Hort. Sci. 104(5):717-720.

Mack,H.J. 1985. Present day boron uses for vegetable crops. Paper presented at Boron Symposium, Pasco, Washington, August 6, 1985.

Miller,D.E., and A.N. Hang. 1982. Deficit, high frequency sprinkler irrigation of wheat. Soil Sci. Soc. Am. J. 46:386-389.

Petersen, K.L., H.J. Mack, and R.H. Cuenca. 1985. Effect of tillage on the crop-water production function of sweet corn in Western Oregon. HortScience 20(5):901-903.

Power,J.F., J.J. Bond, W.A. Selluer, and H.M. Olson. 1973. The effect of supplemental water on barley and corn production in a sub-humid region. Agro. J. 65:464-467.

Robins,J.S., and C.E. Domingo. 1953. Some effects of severe soil moisture deficits at specific growth stages of corn. Agron. J. 45:618-621.

Robins,J.S., and C.E. Domingo. 1956. Moisture deficit in relation to the growth and development of dry beans. Agron. J. 48:67-70.

Sammis,T.W. 1981. Yield of alfalfa and cotton as influenced by irrigation. Agron. J. 73:323-329.

Shalhevet,J., D. Shimshi, and T. Meir. 1983. Potato irrigation requirements in a hot climate using sprinkler and drip methods. Agron. J. 75:13-16.

Shannon,S.,R.F. Becker, and M.C. Bourne. 1967. The effect of nitrogen fertilizers on yield, composition, and quality of table beets(Beta vulgaris L.). Proc. Am. Soc. Hort. Sci. 90:201-208.

Stewart,J.I., and R.M. Hagan. 1969. Predicting effects of water shortage on crop yield. J. of the Irrig. and Drain. Div., ASCE, 95(IR1):91-104. Paper 6443.

Stewart,J.M., and R.M. Hagan. 1973. Functions to predict effects of crop water deficits. J. of The Irrig. and Drain. Div., ASCE, 99(IR1):421-439.

Turk,K.J., A.E. Hall, and C.W. Asbell. 1980. Drought adaptation of cowpea. I. Influence of drought on seed yield. Agron. J. 72:413-420.

U.S.D.A., Soil Conservation Service. 1969. Soil Survey of Linn County area, Oregon.

Van Bavel,C.H.M., E.E. Hood, and N. Underwood. 1954. Vertical Resolution in the neutron method for measuring soil moisture. TRANS of the Am. Geophysics Union. 35(4):595-600.

Van Bavel,C.H.M., N. Underwood, and R.W. Swanson. 1956. Soil measurement by neutron moderation. Soil Sci. 82:24-41.

Yaron,D. 1971. Estimation and use of water production functions in crop. J. Irrig. Drain. Div. ASCE 97(IR2)291-303.

APPENDICES

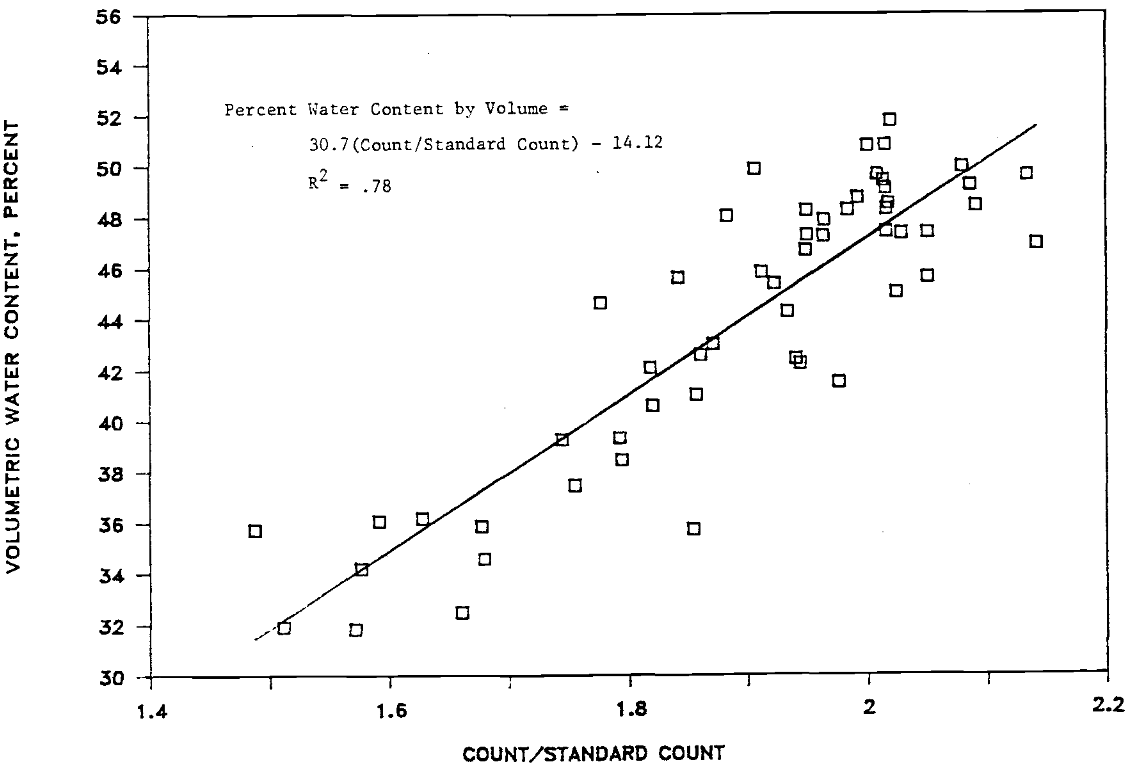

Figure A.1. 1986 calibration regression for the neutron probe for the 15-150 cm soil profile at the O.S.U. Vegetable Research Farm (Chehalis silty clay loam).

Table A.1. 1986 yield versus evapotranspiration production functions for total yield (G), root yield (Y), and the yields of G2 and G3 size grades for each nitrogen level. The probability of being zero of each coefficient is also given.

Dep Vari.	N level	Constant term	1st Degree		2nd Degree		Model R^2
			Coeff.	p	Coeff.	p	
G	N2	-106.214	.904	.013	-9.214E-4	.085	.77
G	N3	-85.484	.789	.045	-7.162E-4	.212	.83
Y	N2	-65.154	.557	.012	-6.058E-4	.064	.74
Y	N3	-38.396	.377	.105	-2.970E-4	.388	.81
G2	N2	-39.500	.321	.016	-3.687E-4	.061	.67
G2	N3	-39.349	.339	.020	-3.951E-4	.065	.73
G3	N2	-16.872	9.927E-2	.425	-4.466E-5	.813	.57
G3	N3	-7.502	4.355E-2	.669	4.899E-5	.755	.76

Table A.2. 1986 yield versus water applied production functions for total yield (G), root yield (Y), and the yields of G2 and G3 size grades for each nitrogen level. The probability of being zero of each coefficient is also given.

Dep Vari.	N level	Constant term	1st Degree Coeff.	1st Degree p	2nd Degree Coeff.	2nd Degree p	Model R^2
G	N2	26.065	.447	.000	-5.949E-4	.001	.88
G	N3	32.612	.325	.007	-2.683E-4	.233	.86
Y	N2	15.885	.255	.000	-3.547E-4	.003	.83
Y	N3	20.172	.156	.029	-9.166E-5	.512	.83
G2	N2	5.734	.151	.000	-2.285E-4	.001	.81
G2	N3	8.009	.128	.003	-1.635E-4	.050	.79
G3	N2	-1.702	8.001E-2	.017	-8.242E-5	.225	.68
G3	N3	2.662	2.372E-2	.442	4.846E-5	.460	.79

Table A.3. 1985 yield versus water applied production functions for root yield (Y), and G2 and G3 size grades for each nitrogen level. The probability of being zero of each coefficient is also given.

Dep Vari.	N level	Constant term	1st Degree Coeff.	1st Degree p	2nd Degree Coeff.	2nd Degree p	Model R^2
Y	N2	27.591	.163	.002	-2.141E-4	.162	.82
Y	N3	26.018	.202	.001	-2.92 E-4	.106	.83
G2	N2	19.521	.155	.006	-3.303E-4	.061	.57
G2	N3	20.431	.14	.006	-2.95 E-4	.069	.60
G3	N2	9.104	5.021E-2	.148	-2.148E-5	.847	.61
G3	N3	1.010	4.296E-2	.196	5.960E-5	.587	.76

Table A.4. Functions relating the 1986 ratios of root yield to total yield, G2 size yield to root yield, and G3 size yield to root yield to ET. The combined data of both nitrogen levels have been used to obtain these functions.

Dep. Vari.	Constant	Slope	p-level For Slope	R^2
Y/G	.597	-8.216E-5	.265	.03
G3/Y	-6.478	8.269E-4	.000	.40
G2/Y	.514	-4.265E-5	.768	.00

Table A.5. Functions relating the 1986 percent Dry root and percent dry leaf matters to ET. The combined data of both nitrogen levels have been used to obtain these functions.

Dep. Vari.	Constant	1st Degree		2nd Degree		Model
		Coefficient	p	Coefficient	p	R^2
%Dry Root Matter	28.597	-7.635E-2	.032	8.824E-5	.101	.50
%Dry Leaf Matter	24.021	-7.408E-2	.004	9.178E-5	.017	.52

Table A.6. Effects of amounts of water applied and N fertilizers on yield and size distribution of table beet roots. 1985.

Water Applied mm	N Rate Kg/Ha	Yield in MT/Ha by --Grades (Root Diameter, mm)-- -25	25-44	45-70	71-95	+96	Total
22	125	3.2	14.9	21.9	1.4	.0	31.0
	250	2.1	10.1	22.7	2.0	.0	29.5
54	125	2.1	12.2	26.5	2.8	.0	34.8
	250	2.0	13.8	28.1	3.3	.0	37.7
116	125	1.9	11.1	31.9	6.2	.0	42.6
	250	1.6	11.1	32.0	6.7	.4	44.0
175	125	1.8	11.3	37.4	8.3	1.4	50.5
	250	1.2	8.8	37.4	9.7	2.4	54.6
222	125	2.0	12.6	36.3	8.8	1.6	52.5
	250	1.6	10.2	36.2	14.3	.0	55.3
277	125	1.4	10.7	38.6	12.1	3.6	57.1
	250	1.1	7.6	35.9	17.7	5.7	59.5

Rainfall emergence to harvest, 17 mm, included in total water applied.

Water applied and yields are averages for each irrigation treatment.

Table A.7. Effects of amounts of water applied and N fertilizers on yield and size distribution of table beet roots. 1986.

Water Applied mm	N Rate Kg/Ha	Yield in MT/Ha by --Grades (Root Diameter, mm)-- -25	25-44	45-70	71-95	+96	Total
27	125	3.2	10.4	10.2	.6	.0	24.5
	250	1.7	8.3	10.9	4.0	.0	24.8
71	125	1.5	10.0	13.9	3.6	.4	29.3
	250	1.3	7.7	17.0	4.0	.0	29.9
183	125	3.1	11.2	28.3	9.2	1.2	53.0
	250	1.1	10.4	24.2	8.9	.9	45.5
281	125	2.2	11.7	28.7	15.1	2.1	59.8
	250	1.8	9.5	32.9	13.2	.3	57.7
385	125	1.6	10.3	28.6	14.6	2.1	56.2
	250	5.9	10.0	34.1	19.3	2.1	71.4
425	125	2.7	8.6	30.8	20.0	3.6	65.6
	250	1.2	10.1	30.8	22.8	1.1	65.3

Rainfall emergence to harvest, 22 mm, included in total water applied.

Water applied and yields are averages for each irrigation treatment.