EFFECTS OF WEATHER ON ORANGE SUPPLIES

By

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A two-stage procedure was developed to estimate the relationship between the production of Florida oranges and weather. The relationship was estimated by counties for Early and Midseason, and Late varieties. The first stage (Stage I) expressed average production as a function of the numbers of trees by age. The estimated average production from Stage I was used to remove that portion of the variability in reported production data which was due to changes in number and age of trees. The Stage I results were used to express reported production data as the signed percentage deviation of actual production from estimated average production. In the second stage (Stage II) specified relationships between these signed percentage deviations and weather were estimated with classical least squares regression. The analysis was conducted on a county by county basis. Data were also pooled over counties and over regions in alternative specifications of the model in Stage II.

Weather indexes and average yields per tree by counties for Early and Midseason, and Late varieties were estimated in Stage I. Also, the numbers of orange trees by ages for the years 1948 through

1968 were estimated (from tree census data) for the state and for each county for both Early and Midseason and Late varieties. These estimates provide useful by-product information from the research.

The data covered the general period 1948 through 1968. Eighteen counties and two varieties were included in the study. Numerous variables were used to describe weather. Soil moisture and minimum daily temperature explained more of the variation in the dependent variable of the Stage II relationship than other measures of weather available. In general, the signs of the estimated coefficients were reasonable. For the county equations the uncorrected coefficient of multiple determination ranged from .12 to .84. Many of the relationships estimated from pooled data were not significant. However, the results provide reasonable bounds on the size of the effects of freezing temperature and certain levels of soil moisture on the production of Florida oranges. The estimation procedure would have benefited from measurements of the duration of freezing temperatures and from more accurate measurements of soil moisture. The weather index for the state for Early and Midseason oranges varied from .68 to 1.33 indicating that unfavorable weather could reduce the crop 32 percent and that favorable weather could increase it 33 percent. For Valencia oranges the range of the state weather index was .60 to 1.22. This range indicated that the effect of unfavorable weather could be approximately twice that of favorable weather.

CHAPTER I

THE PROBLEM

Introduction

The supply of Florida oranges is quite variable. The freezes of 1957 and 1962 exerted a marked influence on the total state production of oranges. The December estimate of the Florida Crop and Livestock Reporting Service for the 1962-63 season placed Florida orange production at 120.5 million boxes. However, due to two icy nights in December, 74.5 million boxes were ultimately harvested (19, p. 7). Furthermore the freeze reduced the per-box yield of processed products. Prior to the freeze a yield of 1.55 gallons per box was estimated for that portion of the crop utilized for frozen concentrated orange juice. The actual yield was 1.09 gallons (19, p. 82). Florida orange production fell to 58.3 million boxes the following season (1963-64) because of the lagged effect of the freeze. It was not until the 1966-67 season or the fifth season following the freeze that production exceeded its 1961-62 level.

An earlier freeze in 1957 was also severe. Total production of Florida oranges was 93.0 million boxes the season before the freeze. The freeze dropped production to 82.5 million boxes for the 1957-58 season. And production was only 86.0 million for the 1958-59 season.

Intercounty variability in annual output also exists. Polk county's production figures for Early and Midseason oranges during the four seasons 1961-62 through 1964-65 were 10.7, 9.8, 4.7 and 10.2 million boxes, respectively. Polk's Valencia productions were 14.1, 8.1, 8.9, and 10.8 million boxes, respectively, for the same seasons. However, production data did not reflect the same distribution pattern throughout the state. For the same four seasons Valencia production in Indian River County was 0.9, 0.8, 1.1 and 0.8 million boxes.

The effects of other weather variables were not always reflected by the data as clearly as freeze damage. The 1955-56 season was shocked by severe drought (50). However, of the three major producing counties, Polk and Orange suffered a reduction in output of Early and Midseason oranges while Lake increased its output of these. All three counties increased their output of Valencias. It was not until the season following the drought that its effect showed up in Valencia production.

The Florida Crop and Livestock Reporting Service estimated that Early and Midseason orange trees twenty-five years old and over yielded 7.0 boxes per tree during the 1966-67 season. One season later they estimated that the same age group produced only 4.0 boxes per tree. Valencia estimates for the same two seasons were 5.7 and 3.2 boxes per tree, respectively. Sites (78) in a 1947 study of fruit quality as related to production practices noted that weather conditions can cause differences in fruit quality and quantity as great or greater than differences which can be induced by any cultural or nutritional treatment.

The large variations in orange supplies due to weather have not only had great impact on the market for oranges but have also obscured any relationship which may exist between orange production and other production inputs. Detailed analysis of this latter relationship requires that data be adjusted for the effects of weather.[1]

The Florida orange industry is believed to face a demand curve which is inelastic at high prices and very elastic at low prices (18, p. 4). This demand curve creates the possibility of an industry pricing strategy. Historically the industry (particularly the FCOJ[2] portion) has tended to "overprice" and to show a definite tendency toward price rigidity.[3] If the Florida orange industry is to develop an acceptable and enduring pricing and marketing policy it is necessary that the factors that affect orange supplies be understood. Weather is a major source of orange supply variation and as such was the concern of this study.

Objectives

The major objectives of this study were (1) to specify relationships between weather and Florida orange production that were meaningful from the point-of-view of what is known about factors affect-

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[1]For example, successful estimation of grower response to the price of oranges requires that some variable(s) be used to reflect the variation in output due to weather.

[2]Frozen concentrated orange juice.

[3]The Federal Trade Commission considers the Florida FCOJ industry to be an oligopolistically structured industry with few firms, substantial barriers to entry, little threat of outside competition, and a high degree of vertical integration between grower and processor (18, p. 3).

ing orange production and (2) to empirically measure these relationships. In attempting to satisfy these major objectives certain kinds of useful by-product information resulted from work on supporting or minor objectives. These minor objectives were as follows:

1. To describe the groves in the state by counties, tree numbers, ages of trees, and varieties over time.

2. To estimate county differences in the "expected" yield of orange trees by age and variety assuming "average" weather and average levels of other inputs.

3. To compute yearly indexes for citrus-producing counties and the State for the 1951-52 through 1967-68 production seasons. Each index provides a comparison between actual and "expected" orange production. It was hypothesized that deviations of actual production from expected production were largely attributable to weather and as a consequence estimated indexes were termed "weather" indexes.

4. To develop forecasting procedures to make long-run predictions of production (under very restrictive conditions to be discussed later) and to predict the change in production should portions of the orange belt be suddenly shocked by severe or unusual weather patterns.

Method of Analysis

A two-stage procedure was developed to estimate the relationship between the production of Florida oranges and weather. The relationship was estimated by counties for Early and Midseason and Late varieties. The first stage (Stage I) expressed the relationship between average production and numbers of trees by age. It was used to remove that portion of the variability in reported production data due to changes in number and age of trees. The Stage I results were used to express reported production data as the signed percentage deviation of actual production from average production. In the second stage (Stage II) specified relationships between these signed percentage deviations and weather were estimated with classical least squares regression.

Data were also pooled over counties and over regions in alternative specifications of the model in Stage II.

Definition of Terms

Weather is a collection of various conditions of the atmosphere including such phenomena as rainfall, humidity, amount of sunshine, length of day, light intensity, atmospheric pressure, temperature, and other meteorological factors (81, p. 1153). It is beyond the control of farmers. Weather influences the crop-growing environment and affects crop yield. Some writers make a distinction between the direct and the indirect influences of weather on production. For example, weather affects production directly through rainfall and temperature and indirectly through insects and diseases (81, p. 1156). For purposes of this study, weather is defined as the net effect on production of variations in environmental factors which are neither under the control of farmers nor in constant supply over time (91, p. 264). In contrast, technology is defined as the sum total of controllable resources and how they are utilized.

The difference between a forecast of crop production and an annual estimate of crop production is noted as follows. An annual estimate of crop production indicates a measure of an accomplished fact at harvest time or later. A forecast of crop production refers to an estimated future production on the basis of known facts on a date prior to the period for which a forecast is being made.

While Florida orange trees produce a new crop each twelve months, the harvesting of a given crop spans two calendar years. Picking usually begins in September and continues through July of the following year. Consequently, when discussing Florida oranges one would not refer to the 1948 crop or 1949 crop but to the 1948-49 season.

Most commercial trees consist of two parts — the rootstock which includes the roots and trunk and the scion which is the upper framework. A tree is almost two years old before it is ready to leave the nursery. However, it may stay in the nursery a longer period. Therefore, the convention has been adopted that the age of a commercial tree is referenced to the year in which the tree was actually placed in the grove (i.e. year-set).

This report is limited to round oranges. Early, Mid-Season, and Late are the three general classes of round oranges.[1] The term orange will be used in this analysis as a synonym for round oranges.

The expression "variety (macro)" will be used to refer to the groups of Early and Midseason oranges and Late oranges. "Variety (micro)" will be used when referring to varieties such as Hamlin, Parson Brown, Navel, Jaffa, Pineapple, and Valencia. The term

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[1]Name is related to time of maturity or harvest.

variety will be used whenever the information being presented is applicable to both levels of aggregation. Since Late oranges are almost entirely Valencias, the terms Late oranges and Valencia oranges are used interchangeably and the terms will be used as synonyms in the analysis.

The Phenology of Florida Oranges

Commercial production of an orange tree begins at three to four years of age, increases rapidly to ten years, levels off and reaches a maximum at twenty-five years (94, p. 14). Plant development, flowering and fruiting tend to combine into an orderly process. By fruiting time many of the factors of heredity and environment which affect the plant's capacity to produce fruit have already exerted their influence and yield potential tends to develop unless inhibited by abnormal growing conditions (45). For the orange tree, as with other plants, time is relative to phenological development, that is, relative to the dates of flowering and the setting of fruit.

All orange varieties tend to bloom at the same time within a given year but with considerable year-to-year variability. Peak bloom usually occurs around the end of March or in early April. The blooming process usually takes about 50-60 days for the first regular bloom. Varying weather conditions often cause a second or third bloom.[1] After flowering, fruit setting is a continuous process and the young

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[1]Bloom information summarized from personal conversations with Dr. W. A. Simanton, Professor, University of Florida, Institute of Food and Agricultural Sciences, Citrus Experiment Station. His data will be published at a later date.

fruit generally reach a size of one inch or more by June or July (48, p. 1725). Early oranges mature from September through November, Midseason oranges from December through January, and Late oranges from February through July. The Hamlin is the principal Early orange. The Pineapple is the leading Midseason variety, and the Valencia is the predominant Late orange (98, p. 23).

Florida Climate

The climate of the citrus-growing regions of Florida is classified as humid subtropical. From April to October temperatures are moderately high. The highest daily temperatures in summer are usually from 93 to 95 F. Higher temperatures do occur at irregular intervals but they seldom exceed 100 F. From November through March lower temperatures prevail and readings below 32 F. are expected every winter. The presence of the Atlantic Ocean and the Gulf of Mexico (one of which is within 75 miles of any point in the citrus belt) serves to moderate both summer maxima and winter minima temperatures.

The average annual rainfall within the citrus belt has been estimated to be approximately 52 inches with a range from 37 to 84 inches (98, p. 13). Likewise, the proportion of the annual precipitation which falls in any given month varies from year to year. Together these annual and monthly variations give a highly variable pattern of rainfall in Florida. A Florida Citrus Commission report (19, p. 35) noted that, although the average interval between severe freezing weather in Florida's citrus belt appears to be approximately ten years, such conditions may occur at any time, that is, they are not regular. Butson and Prine (6) in a study of Florida rainfall concluded that variations in rainfall frequencies are probably random fluctuations. Frost is likely to occur anywhere on the mainland of Florida on still, cloudless nights in winter.

Freezes, hurricanes, and other weather phenomena are discussed in more detail in a later section.

Weather Cycles

Bean (3) noted that most crop forecasters view weather as not predictable but considers such a view to be erroneous. Bean admitted that weather data seem to behave like random numbers, that statistical tests in common use fail to differentiate between series known to be random and constructed series that are not random, and that a moving average of time series automatically produces what looks like cyclical movements. He contended that weather fluctuations represent law and order and are therefore predictable He cited personal research on rainfall, river stages, wheat, corn, cotton and potatoes to support his position. Palmer (64) reported that an analysis of the meteorological record beginning in 1887 showed a surprising degree of regularity in the occurrence of severe and extreme droughts in the western third of Kansas and that an examination of the longest continuous meteorological record in the middle United States[1] indicated that there is some statistical evidence for suspecting that serious drought tends to occur about every twenty years in the central United States.

[1]The St. Louis, Missouri weather record is continuous from January 1838 to date.

However, Palmer noted that the subject requires more research in greater detail and with more powerful methods and techniques.

Tree ring studies indicated the existence of alternate wet and dry periods particularly in the subhumid and semiarid regions of the United States (88, p. 26). Auer and Heady (1) using U. S. corn production data for 1939-61 and corresponding weather data concluded that years tended to bunch—good weather years tended to bunch together and bad weather years tended to bunch together. Tefertiller and Hildreth (85) in an article dealing with Great Plains agriculture also suggested the possibility of bunchiness or runs of good and bad years. Specifically they reported a tendency for rainfall to bunch in Oklahoma and Montana but that rainfall in Texas appeared to be random. Shaw and Thompson (77) reported that in an Iowa study weather was found to be periodic, but in a Kansas study the reverse was true.

Mitchell (58) reported that most investigators who research weather data for cycles have failed to support the hypotheses of their predecessors. Instead they turn up new hypotheses about periodicities. Mitchell admitted the existence of two real climatic periodicities—precipitation follows the lunar period of 29.53 days and a cycle of approximately two years in winds and temperature at high altitudes[1] over the tropics. However, he noted that as yet there is no generally accepted physical explanation for either. Mitchell (58, p. 225) wrote that variations of climate appear to be very irregular.

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[1]This cycle is absent at all elevations of less than ten miles.

Hathaway (28, p. 492) in research devoted to the problem of the cyclical relationship between agriculture and the non-agricultural economy concluded that factors other than weather were needed to explain the change in crop yields which were associated with the cyclical change in the demand for farm products. Clawson (10) stated that random annual variations in farm output are primarily due to random weather conditions. Griliches (24) wrote that annual fluctuations in farm output were dominated by random fluctuations in weather.

Thompson (88, p. 27) wrote that the weather cycle idea carried the connotation of a regularity in favorable and unfavorable weather for crops. He reported that a more acceptable interpretation is that periodic changes in weather patterns do exist but that they do not occur in any regular cyclical pattern. Thompson stated that the popular notion is that wide deviations from average weather tend to occur at random. However, in another study, Thompson (89) cautioned that the researcher may not be able to treat the weather variables as random. Specifically, he found evidence that weather had not been random but had improved for grain crops since the mid-thirties in the central United States.

The 18 years of time series data available for this study provided no meaningful basis for assuming that departures of weather variables from their average values occurred in a systematic and estimable way. Therefore, such deviations were assumed to occur randomly.

A Brief History of Oranges

Oranges are native to the tropical regions of Asia. They have spread from there to practically all regions of the world with suitable climates. Since their first discovery, oranges have moved westward. From their native habitat oranges traveled to India, to the east coast of Africa, to the eastern Mediterranean, to Italy, to Spain, and finally to the Americas (61, p. 1021).

Oranges were probably introduced into the western hemisphere by Columbus when he established a settlement on the island of Hispaniola on November 22, 1493. And Ponce de Leon probably introduced oranges to mainland North America when he discovered Florida in 1513, since Spanish law required that each sailor carry one hundred seeds with him (57, p. 89).

Wherever Spanish settlements were made orange plantings soon appeared, and in Florida the Indians carried oranges with them and dropped their seeds in the hammocks and heavily forested areas so that years later the forests were found populated with wild sour orange trees. In some cases these trees had been topworked to sweet oranges and constituted some of the very early groves (7, p. 6). By 1579, plantings existed in the Spanish settlement of St. Augustine (7, p. 6).

By 1800 there were numerous groves planted by the Spanish and other settlers along the coast south of St. Augustine, along the St. Johns River and around Tampa Bay. With the annexation of Florida by the United States in 1821 settlers steadily expanded the groves. This expansion suffered a sharp setback in 1835 when a severe freeze killed many of the trees to the ground. After the Civil War development was rapid. In 1886 the Florida crop reached a volume of one million boxes. Railroads were coming into the state and made possible the development of citrus groves away from the waterways. Expansion was steady from 1886 through 1894 (7, p. 6).

Consequently, by the latter part of the 19th century the orange industry had been firmly established in Florida. However, in the winter of 1894-95, a severe freeze hit Florida and practically destroyed all groves. Before this freeze, production had climbed to 6 million boxes. Fourteen years passed before that level was reached again (72).

Early plantings had been made on locations selected primarily because of the character of the soil. The freeze of 1894 and 1895 brought to the fore the problem of cold protection and resulted in a spread of the industry to the south. By 1920 it had been discovered that trees could be produced on the high, warm, sandy ridges of central Florida by using rough lemon rootstock. Prior to the introduction of rough lemon rootstock, sour orange and sweet orange rootstock had been used and neither was satisfactory or the light sandy soils with their low fertility and irregular moisture supply. Therefore, in a sense the industry's present size is based mainly on the discovery of rough lemon rootstock because it made possible the use of land not formerly suited to citrus production (7, p. 7).

By the late 1930's, production had grown to the extent that prices were suffering. Growers and processors searched for new uses and outlets. The development of FCOJ (frozen concentrated orange juice) in about 1945 was a major breakthrough in this direction. This new product grew at a phenomenal rate. The initial output of 226,000 gallons for the 1945-46 season grew to 30 million gallons within 5 years, to 70 million gallons in 10 years, and to 116 million gallons by the 1961-62 season. For the 1963-64 season, production of FCOJ utilized more than 65 percent of the orange crop and fresh fruit used approximately 15 percent. This figure for fresh fruit compares to 85 percent prior to the introduction of FCOJ (18).

In the 1948-49 season, 18.2 million bearing trees produced 58 million boxes. In the 1966-67 season, 43 million bearing trees produced 144.5 million boxes, and in December, 1967, there were an estimated 16 million non-producing trees in Florida groves. In 1966-67 Florida produced approximately 78 percent of the U. S. supply of oranges and more than the combined total of the second, third, and fourth largest producing countries--Spain, Italy and Mexico.

Commercial orange groves extend from Putnam, Marion, and Volusia counties in the north to Collier and Broward counties in the south and production spans the entire breadth of the Florida peninsula. The center of the orange belt has tended to shift south over time. This movement is attributed primarily to the desire of growers to reduce the probability of freeze damage and to land pressures (55). The present center of the citrus belt is on the high pines soils of the ridge section of Polk, Lake and Orange counties. In 1966-67 these counties produced 52 percent of the 144.5 million boxes produced in the state -- Polk produced 34.0, Lake 24.0, and Orange county 16.5 million boxes.

CHAPTER II

THE STUDY OF WEATHER EFFECTS ON CROPS

General Problems

The cause and effect relationships between weather and crop production have been the subject of considerable research. With the increasing grain surpluses of the late 1950's effective agricultural policy required that the increases in agricultural production be separated into that attributable to favorable weather and that due to technological improvements (24, p. 282). Consequently, agricultural economists have had a renewed interest in weather--particularly the problem of separating the effects of weather and technology on production.

The biophysics of the weather-plant interaction is complex. Most of the functional relationships between individual meteorological variables and plant growth are not known (15, p. 81). Besides being related to yield in some complex, unknown manner, most of the weather variables are believed to interact with each other in varying degrees. Yields are also affected by changing levels of technological factors such as changes in residual soil fertility, differences in fertilizer rates, changing insecticides, new varieties, crop densities, mechanization, and increases in irrigation. Other factors such as crop diseases and insect infestation which affect yields are closely associated with weather (15, p. 80). Because of the many factors affecting yield, the estimation of an exact functional relationship between these factors and yield has often been viewed as impossible from an empirical point of view.

Rainfall and temperature have been used synonymously with weather, partly because they are the dominant meteorological influences on yields, and partly because the data on these variables are readily available. Plants grow in the soil as well as in the air--and soil temperature may be more important than air temperature (76, p. 3). Likewise, rainfall is not synonymous with moisture available for plant use. Although temperature and precipitation are the variables usually considered, more exact indicators of the influence of meteorological factors such as soil moisture and drought indexes have been proposed. Agricultural drought should be defined on the basis of soil moisture conditions and resultant plant behavior, rather than on some direct interpretation of the rainfall record (92, 93). For some years, rainfall and actual soil moisture available for plant growth may have little correlation. Monthly averages of rainfall can be especially misleading (74, p. 224).

Problems of spatial aggregation can occur for two reasons. First the relationship between crop yields and meteorological factors are not monotonic (74, p. 223). Suppose a total June rainfall of 6 inches is optimal for yield and that the effect of 5 inches is the same as the effect of 7 inches; then the average rainfall for two counties ((5+7) / 2 = 6) is at the optimal but the true yield at this level of rainfall will be underestimated. Secondly, a weather measure is usually accurate for only a small area, and spatial aggregation creates a problem because weather conditions at only a few locations are available to represent rather large crop reporting districts (76, p. 22).

Variation in agricultural output associated with variation in weather is often greater than that associated with nonweather variables.[1] While irrigation, mechanization, and improved cultural practices have given some degree of weather-proofing to crop yields, weather is still an important factor in determining yield (59, p. 1172).

Yields can be greatly influenced by brief periods of exceptionally favorable or unfavorable weather. Palmer (64, p. 178) notes that 1955 was a drought year and early prospects for wheat yields were dim. However, one or two good rains at exactly the right time produced long, well-fitted heads and subsequently good yields. This example further illustrates the difficulties of estimating yields directly from meteorological data.

The initial forecast for a given season may be desired a considerable time in advance. Unusual weather can cause considerable change before actual harvest.[2]

Since 1940 a substantial part of the variation in yields has been attributed to technological changes (74, p. 219). A yield series can be visualized as a function of weather and trend due to technology and other factors. The economic and other factors which trend represents will depend upon the data source used (15, p. 81). The

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[1]Some writers have classified the variation in output associated with weather as random and that associated with other variables as non-random (73, p. 1). This classification scheme leaves something to be desired since it attributes all randomness to weather.

[2]*Supra*, p. 1.

use of a linear time trend assumes a constant rate of technological change and it fails to capture occasional sudden changes in technology.

Also, to assume independence of the technology variable and the meteorological variable may be incorrect. Shaw (74, p. 222) cites as an example the fact that in 1930 a two-inch deficiency in rainfall cut corn yield 25 percent, but in 1960 the same deficiency cut yields only 10 percent. It is reasonable to hypothesize that for most agricultural crops weather and technology are not independent and that an interaction exists at each point in time. Technological advances permit man to bring more of the environment under his control.

Empirical models of weather response must of necessity be crude abstractions of real world complexities. However, there must be justification for their form if such models are to be relevant approximations of the real world. For example, if one could assume that weather variables were distributed randomly and that the effects of all other variables were determined by trend, it would be feasible to use a time trend to estimate the influence of technology and attribute the fluctuation in yield around the trend line to weather variables. However, if the weather has improved during the period of study, then a time trend overestimates the effect of technology and the other variables (89, p. 75). Likewise, when weather is random and the rate of technology is irregular, moving averages as discussed by Shaw and Durost (73) provide a better estimate of the rate of technological development than a linear time trend. In such a case, deviations from the "technology line" may approximate deviations due to weather. Thompson (89, p. 75) uses hypothetical sets of yield and rainfall data and presents a case for multiple regression analysis. In his model yield is estimated as a function of time (technology) and a set of meteorological variables. He argues that the approach gives a better estimate of the rate of technological development than simple linear time.

Even with annual crops the problem of separating yield variability into that portion due to weather and that due to technology can be difficult. With corn yields Thompson (88, p. 1) found that weather was the more important variable, while Shaw and Durost (76, p. 3) in an independent study of the same general data found the weather effect to be negligible.

Past Research

Numerous techniques have been proposed to aid in the analysis of the crop-weather relationship and the sometimes troublesome companion problem of the technology-weather interaction. Each approach tends to have a few advantages and numerous disadvantages. Historically, the most frequent method of studying the crop-weather relationship has been to estimate an equation using multiple regression techniques (71, p. 219). Usually the dependent variable is yield, measured as an average for some geographical area,and the independent variables are trend and some collection of weather variables. Most often the simplifying assumption that trend can be approximated by linear time has been used. As noted by Stallings (81, p. 1155) very early studies often regressed yield on a single meteorological variable such as total rainfall during the growing season. Other studies, as discussed by Morgan (59, p. 1173), have attempted to explain yield by using monthly rainfall and/or temperature during the critical month of the growing season. Quadratic and interaction terms have been included.

Classical multiple regression analysis has not been the only technique proposed. Weather indexes have been constructed (75, 81). Aridity indexes (62) have also been included in models. More direct measures of the plant-weather relationship such as the use of evapotranspiration rates (46) have been proposed. Non-linear regression has been used to iterate between a weather index generating function and a function relating yield to the weather index and other variables (15).

Basically, four general techniques have been used to study the problem--classical regression, weather indexes, aridity indexes, and an ad hoc group which has been labeled as hybrid techniques. In the next section each of the four general procedures are reviewed and one or more sample studies of each type are discussed in some detail.

Classical Regression

The classical regression approach to the crop-weather relationship includes studies in which classical least squares was used to estimate crop yield or production as a function of measures of meteorological variables such as total monthly rainfall and/or average monthly temperature.

Regression coefficients in such models provide an easily understood method of describing the effects of variations in meteorological variables. However, such models are not suitable for predicting yields over a wide range of weather conditions. The multiple regression approach is most suited for studies at the micro-level of the crop yield-weather relationships. Shaw (74, p. 218) states that difficulties associated with statistical attempts to measure the influence of weather, which requires detailed specification of important variables and their functional relationship to yields, are perhaps insuperable and that conceivably the task could be equivalent to a full project for each crop in every county or other small geographical unit where it is grown. Specifying appropriate variables and functional relationships as well as problems of aggregation have tended to limit the usefulness of multiple regression when data are aggregated over geographical regions.

Most multiple regression studies have been disappointing, both as forecasting formulae and as indicators of cause and effect relationships. Even when statistical indicators have been favorable, the models have failed to give reliable answers (74, p. 218). A difficulty with regression analysis is that researchers attempt to explain variation due to weather by using an incomplete and poorly measured set of weather variables.

Another criticism centers around the fact that with regression analysis the functional form of the relationship between yield and the technology variable must be specified in advance. Similarly, the assumption of independence of the technology variable and the weather variables has been discussed as a disadvantage. While this assumption is not necessary, the technology-weather interaction is difficult to estimate. Shaw (74) contends that much more must be known about the pattern of technological change if weather is to be studied by traditional multiple regression.

Because of the biases which may be introduced due to faulty specification of the model and use of aggregated data plus a history of failure in forecasting, many persons place little confidence in any conclusions reached by multiple regression analysis of aggregate crop yield-weather relationships.

Thompson (87, 88, 89) has been a heavy user of multiple regression techniques in the evaluation of the effects of weather and technology on crop production. For a detailed look at some of his work, the following terms are defined:

Y = Yield of corn in bushels per acre

X_1 = Year

X_2 = Preseason precipitation

X_3 = May temperature

X_4 = June rain

X_5 = June temperature

X_6 = July rain

X_7 = July temperature

X_8 = August rain

X_9 = August temperature

Thompson (88) used multiple linear regression to estimate the relationship between Y and X_1, X_2, ..., X_9 for each of the five corn belt states. He noted that while such multiple linear regression coefficients indicate the effects of slight departures from average rainfall or average temperature, they are not suitable for predicting yields over a wide range of weather conditions. For example, with linear regression it is assumed that each additional inch of rain in a given month will have the same effect on yield as the first inch. Such is not the case.

Thompson's multiple linear regression model tended to overestimate in poor weather years and underestimate in good weather years. A multiple curvilinear regression model including the rainfall-temperature interaction terms corrected this difficulty (88, p. 5).

His multiple curvilinear model included the nine terms of the multiple linear model plus X_2 through X_9 squared and the rainfall-temperature interaction term for each of the three months.

Thompson was quick to caution that large numbers of variables in multiple regression analyses may provide high correlations (R^2) even though the variables are meaningless. He noted that Robert Shaw and Robert Dale (88, p. 9) drew random numbers within logical ranges for rainfall and temperature, and used actual corn yield data for a 27-year period in Iowa. They had 21 variables in their equation and obtained a multiple correlation coefficient of .86. However, none of the "t" values for the weather coefficients were significant at the 95 per cent level. Therefore, Thompson noted that when large numbers of variables are used in multiple regression analysis, the multiple correlation coefficient may be misleading. He suggests that while analysis of variance (ANOV) will not "correct" the problem, it should make the difficulty of misleading structural estimates of parameters and high R^2 values easier to identify.[1]

Thompson used a linear trend for technology. He states that a linear trend is more logical than any curvilinear trend (88, p. 16). However, he notes that the data probably reflect a weather-fertilizer interaction which his equations do not measure. Interaction between extra soil moisture and fertilizer is well known (86). However, for

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[1]Thompson is probably referring to an individual "t" test of the regression coefficients and not to the usual ANOV table for regression which generally does not include the "t" values. Actually a corrected R^2 (23, p. 217) which penalizes functions with large numbers of estimated coefficients might be a better statistic on which to base such decisions.

the period of his data, Thompson felt technology had been adopted at a fairly steady rate. He verified this assumption by examining the residuals from his estimated function to see if they increased or decreased over time. He argued that homogeneity in the residuals supports the assumption that technology has been gradually adopted over time. Thompson used a cubic in time for technology in his studies on grain sorghums and wheat because the data did not reflect a linear trend.

Weather Indexes

The weather index approach results in an index such that actual yield figures may be adjusted to reflect yields had average weather prevailed. This approach has been used in an attempt to avoid the difficulties commonly associated with regression analysis.

Various techniques have been proposed for the construction of weather indexes. The differences among these techniques are slight and tend to depend on the data used. To measure the influence of weather by the index approach, a time series of yields is required. A trend is usually fitted to the data to describe the yield effect due to changes in factors which were not controlled. The weather index is calculated in each year as that year's actual yield as a percentage of the computed trend.

If experimental plot data with most nonweather variables being controlled are used to calculate the weather index, the index may be an indicator of the weather alone. However, if a time series of actual yields is used to calculate an index, then the effect of weather may depend on the level of technology which is not controlled. In such a case the index obtained would be an indicator of all uncontrolled factors which affect yields and which are not reflected in trend (73, p. 7).

Stallings (81) has computed indexes for the influence of corn, oats, barley, wheat, soybeans, cotton, and tobacco. The method he uses has been called the experimental plot data approach. This method is based on the assumption that if time series of yields for a crop can be obtained from experimental plots in the areas where the crop is grown and where as many variables as possible have been controlled the remaining variation in yield from year to year (after trend has been removed to account for increases or decreases in the fertility level of the soil) will give an indication of the influence of weather. Since the net effects of weather are measured, this approach allows for all the influences of weather whether direct or indirect. Stallings assumed that the yield trend due to fertilizer applications on the plot was approximately linear and could be removed by a linear regression on time.

For a given crop and a given location the technique is quite simple. First, remove trend from each series by fitting a linear regression line to the data. Second, compute indexes for each series as the ratio of the actual to the computed yield of the regression line. Third, average indexes for each series to obtain an index for that location. Finally, if desired, indexes for larger areas can be formed by weighing the index for each location within the area by the percent of average production for the area that the location represents.

Ideal data for this approach would come from experimental plots with everything held constant, except for weather, over the period of time for which indexes are to be calculated. Stallings notes, however, that calculated trends could be partially or entirely due to improved technology and management of the experimental plot. Also, the data might not reflect the varieties, practices and technology level representative of the production in the area to be represented by the index. He stated that in cases of less than ideal data, judgment and familiarity with the situation be used to help resolve data problems. When using the experimental plot approach to generate weather indexes, the data are subject to all the criticisms and shortcomings normally associated with field experiments. Researchers often incorrectly assume that because the data come from experimental plots their accuracy is superior to most secondary data.

Shaw and Durost (75) have modified the above procedure somewhat for data from corn variety tests which were conducted under actual farming conditions. They took the following steps to develop a weather index for each location: (1) compute a 9-year moving average as a first approximation of the trend in yields due to factors that were not held constant, (2) extrapolate the moving average forward and backward to the terminal years, (3) divide actual experimental yields by the corresponding moving average yield. Consider any year in which this percentage ranges from 85 to 115 as an "average-weather" year, and (4) regress yields in "average-years" on time, (5) compute the weather index as actual test yield divided by estimated trend test yield.

An advantage of the weather-index approach is that the specification of the exact cause and effect relationship between yield and an individual meteorological variable is avoided. Any assumed mathematical function requires more knowledge about the rate of technological change than we now possess (74, p. 227). Shaw notes that the deflated yield series should indicate the form of the technological relationship. One major use of weather indexes is to measure technological change indirectly by using the index as a deflator for the influence of weather variation. The advantage of this approach toward trend is that no assumption need limit its form.

One basic weakness of the experimental plot data approach is its assumption that factors other than fertility levels are constant over the experimental period. Experimenters often attempt to optimize nonexperimental variables (65, p. 1161). It is likely that insect control and other production practices are altered over the experimental period to keep abreast of technological advances. If such is the case, it will be reflected in the index by diminished indirect effects of weather.

A final disadvantage of weather indexes is that they cannot be used to predict yields on the basis of meteorological observations. However, as indicated earlier they are useful if the purpose of the analysis is to simply remove the weather effect so that other factors affecting the yield of a crop may be studied in greater detail.

Aridity Indexes

Oury (63) has proposed that some aridity index[1] be used as an independent variable in relating weather to yield rather than such

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[1] Oury's term.

meteorological variables as rainfall and temperature. He stated that the use of a composite aridity index may provide a relatively simple approach to a difficult problem encountered in agricultural supply analysis. The concept is simple and is not confined to a single agricultural area and/or crop and the indexes can be calculated whenever basic weather data, rainfall and temperature, are available.

This approach rests on the assumption that evapotranspiration is the key weather-related variable that influences yields. Note the following definitions:

I = Aridity index

P = Precipitation or rainfall

T = Temperature

Recognizing that temperature is the major factor affecting evaporation various workers have suggested formulae substituting temperature for evaporation. Several such formulae discussed by Oury are as follows:

Lang: $I = P/T$

De Martonne: $I = P/(T + 10)$

Koppen: $I = 8P/(15T + 120)$

$I = 2P/(T + 33)$

$I = P/(T + 7)$

Angstrom: $I = P/1.07^{T}$

Lang's formula indicates that the effectiveness of rainfall varies directly with precipitation and inversely with temperature. De Martonne added the constant 10 to avoid negative values. Basically all three of Koppen's formulae are similar to those of Lang and De Martonne. In accordance with Van't Hoff's Law the denominator of Angstrom's formula doubles with each rise of ten degrees centigrade.[1]

Oury estimated three models of crop yields by least squares to determine the suitability of using De Martonne's and Angstrom's aridity indexes. Oury "fitted" the following three functions:

$$Y = b + b_t t + b_P P + b_T T + e \qquad [1]$$

$$Y = b' + b'_t t + b_M (P/(T + 10)) + e' \qquad [2]$$

$$Y = b'' + b''_t t + b_A (P/1.07^T) + e'' \qquad [3]$$

where:

Y = Yield per acre

t = Time

P = Precipitation during selected period

T = Temperature during selected period

Equation [1] implies that the marginal yield response to P and T is constant. Agronomically the aridity index approach (equations [2] and [3]) has more intuitive appeal. It implies that the marginal yield response to P is not constant and is a function of T and likewise that the marginal yield response to T is not constant and is a function of P and T.

Oury found P and T to be highly negatively correlated. The "t" statistics indicated b_M and b_A to be significant at the 1 per-

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[1]Van't Hoff's Law states that the velocity of a chemical reaction doubles or trebles with each rise in temperature of ten degrees centigrade.

cent level and b_P and b_T at the 10 percent level. Similarly Oury reported that the Durbin-Watson d-statistic indicated the superiority of equations [2] and [3]. Likewise, Oury reported that equations [2] and [3] gave more logical structural estimates of the parameters.

Hybrid Techniques

Knetsch (46) used the drought-day technique to study the effect of moisture and fertilizer on Tennessee Valley corn. A drought-day was considered to occur when the available moisture in the soil reached a critical level as estimated from a moisture-balance computation of daily rainfall and evapotranspiration data.

The number of drought-days occurring during the growth period does not give an appropriate index of drought effects on yield. The effect of a drought depends on the stage of development of the plant. Therefore, it was necessary to weight the drought in accordance with the time of occurrence. The relative importance of drought in the different growth periods was unknown, so Knetsch developed the following estimate from separate data:

$$Y = 99.04 - .096A - 1.376B + 5.232C - 1.736D - .403C^2 - .146CB - .055CD + .042BD \qquad [4]$$

where:

Y = Yield

A through D = The number of drought-days in successive periods through the growing season.

The coefficients of equation [4] were used to assign weights to the individual drought-days which occurred during the three years of the experiment. From experimental data with various levels of nitrogen Knetsch estimated:

$$Y = 92.95 + .4834N - .001N^2 - .5981D - 0028ND \qquad [5]$$

where:

Y = Estimated yield in bushels

N = Pounds of nitrogen

D = Drought value

Knetsch's interest was in estimating the optimum level of nitrogen to apply. He specified a model with a drought-nitrogen interaction term on the basis of prior agronomic research.

The important point for purposes of the present study is that the drought-day criterion provides an alternative specification hypothesis for weather in models used to study crop yields.

The drought-day approach requires that one know the maximum water the soil can hold, the level or levels of soil moisture at which growth is appreciably depressed, and the rate at which the soil dries out due to evaporation. Daily precipitation records are also required. Knetsch used the Thornthwaite formula to estimate evapotranspiration. This procedure requires that rainfall be added each day and evapotranspiration be subtracted. Soil moisture is of course bounded by zero and its maximum storage value. A drought-day is defined to occur when the storage value equals zero or some critical value (wilting point).

Doll (15) used data for the period 1930-63 for 37 Missouri counties to estimate average corn yield for Missouri as a function of weather and trend. He used an iterative non-linear regression procedure suggested by Edwards (17).

Because corn yields have increased rapidly in Missouri since 1930, a cubic time function was used to estimate trend. Doll's results were:

$$Y_t = -5.1443 + 3.7902Z_t - .1164Z^2_t + 2.1882t - .1158t^2 + .0026t^3 \qquad R^2 = .90 \qquad [6]$$

$$Z_t = -.689X_{t1} + .0373X_{t2} + \ldots. + .0912X_{t8}$$

where:

Y_t = Predicted average corn yield for Missouri.

X_{tk} = Rainfall variable for year t for week k, k=1,...,8.

Z_t = A measure of the impact of the rainfall variable in year t.

t = Time.

If Z_t and Z_t^2 are substituted into equation [6], the result is an estimate of average yield given average weather for the time period under consideration. A weather index was computed as the ratio of predicted yield to the predicted yield given average weather.

Doll listed three advantages of the technique: (1) the index is based on a functional relationship between yield and meteorological variables (and two years with similar meteorological patterns will have similar indexes), (2) the formulation of the model can allow decreasing returns to meteorological variables within a time period and interactions among time periods, (3) the inclusion of meteorological variables in the model improved the estimate of trend to the extent that weather phenomena such as runs and extremes are "explained" by the meteorological model.

Added Problems Associated with Forecasting Florida Orange Production

Oranges are a perennial crop and the meaningful technical unit for measuring yield is a tree rather than an acre. The yield of an orange tree is a function of its variety, age, location (soil type and depth), planting pattern (tree density and how they are physically arranged), and average weather to which it is subjected.

A forecast based on bearing surface would be better than one based on tree numbers or acreage, but such information would be impossible to keep current (94, p. 12).

The 1940-44 period was characterized by two low and two high solids seasons. However, Sites (78, p. 56) reported that no element of weather was sufficiently outstanding to enable one to conclude that it was the cause.

Generally, the more the acreage is concentrated, the more susceptible the total production is to weather variability. Usually if spread over a large area, good and bad weather may tend to average out. While the acreage devoted to Florida oranges is fairly concentrated, the same climatic conditions of rainfall and temperature tend to have varying effects due to the vast differences that exist among soil types, depth, and water-holding capacity. However, due to the fact that the citrus belt is concentrated geographically freeze effects tend to be more general in nature.

Stout (84) reported that a considerable amount of the year to year variation in the production of oranges could be explained by the following factors: (1) tree numbers; (2) number of fruit per tree; (3) size of fruit; (4) droppage rate. He considered Early and Midseason oranges and Valencia oranges independently and reported the following results as given in Tables 1 and 2 below.

Table 1: Relative importance of factors affecting average annual change in Florida's Valencia orange production.

Factor	Percent variation explained
Tree Numbers	11.1
Number of fruit per tree	29.8
Size of fruit	14.4
Droppage rate	30.4
Other factors	14.3

Source: Stout (84, p. 30).

Table 2: Relative importance of factors affecting average annual change in Early and Midseason orange production.

Factor	Percent variation explained
Tree numbers	4.3
Number of fruit per tree	44.3
Size of fruit	21.5
Droppage rate	9.5
Other factors	20.4

Source: Stout (84, p. 30).

Stout (84, p. 10) noted that the number of fruit per tree is related to the area of bearing surface[1] of the tree and to freeze damage. He reported a tendency for years with low sizes to follow years with high sizes and vice versa (84, p. 12).

In summary, while many of the problems associated with forecasting Florida orange production are due to the numerous factors related to yields and the impossibility of stating the functional relationship of these factors to yield and to each other, the major difficulty is due to the fact that oranges are a perennial crop and a considerable percentage of the year-to-year variation is due to the changing distribution of trees by age classes. Also, the relationship between tree age and average production is not clearly understood (especially differences in the relationship from one region within the state to another).

Recent Analytical Approaches

Two recent studies have attempted long-range forecasts. Raulerson (67), in a 1967 study, investigated the problem of fluctuating orange supplies and grower profits in the frozen concentrated orange juice (FCOJ) sector of the Florida citrus industry. Polopolus and Lester (66), in a 1968 study devoted entirely to forecasting, estimated Florida's orange production over a fifteen years period.

Raulerson updated an existing DYNAMO simulation model (39) of the Florida citrus industry to appraise alternative supply control policies which were designed to reduce the fluctuation in orange

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[1]Bearing surface is a function of the size of the root system (95).

supplies and grower profits. In simplest terms, Raulerson considered a given year's production to be a function of productive trees and boxes per trees. Boxes per tree were in part dependent on the level of average grower profits. The level of productive trees was increased by new planting and by hatracked trees coming back into production, and decreased by a normal mortality rate and by productive trees lost by freeze.

The author expressed the freeze effects on crop size and tree numbers by defining three possible categories according to the severity of the particular freeze encountered. Trees were killed completely, hatracked, and/or suffered only yield losses. The severity of the particular freeze encountered was based on 29 seasons of weather data, 1937-38 through 1964-65. A procedure of random sampling with replacement was used to obtain 14 years of freeze effects. The industry was simulated for a 20-year period, 1961-62 through 1980-81. The actual weather for the first six years, 1961-62 through 1966-67, was used.

Raulerson noted that a more accurate DYNAMO model of the citrus industry would benefit from expanded research in some areas. An incomplete list of research needs is given below:

1. Supply response of growers — particularly when they are facing declining prices.

2. Effects on yields of less intensive cultural practices — especially if the reduced level of cultural practices existed for only a few years and normal cultural practices were resumed.[1]

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[1] Items 1 and 2 are interrelated and Raulerson discussed both as a single topic.

3. Effect of freezes upon present and future crops.

Polopolus and Lester used a random sampling technique to estimate Florida's orange production over the next fifteen years on the basic assumption of year to year variability in average yields per tree. Their method of estimation considered each future year's production to be an "event" drawn randomly from a set of six alternative events. The "events" were defined to represent the range of yield possibilities likely to occur in the future. Each of the six events had equal probability of being selected for any given year. The six alternative events were specified as follows:

Event[1]	Description of average tree yield
A	Slightly above average
B	Slightly below average
C	High
D	Low
E	Average
F	Related to freeze damage

Given a random drawing of a freeze, the intensity of the freeze was defined by another random drawing of various possibilities of freeze damage. Five alternative levels of freeze damage were developed from historical records. They were as follows:

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[1] Events B, C, and D directly relate to historical tree yields obtained in the 1965-66, 1966-67, and 1967-68 seasons, respectively.

Freeze possibility	Percent of total Tree loss	Yield loss
	Percent	
1	11	15
2	8	35
3	0	17
4	0	10
5	0	5

The researchers assumed a net planting rate of zero except for the years immediately following freezes. The experiment was "run" fifty times for each of the fifteen seasons, 1968-69 through 1982-83. For the fifty experiments the standard error of the estimate averaged 36.7 million boxes -- indicating the extreme year to year variability in Florida orange production.

The authors cautioned their readers to interpret the production estimates in a general fashion and to avoid placing undue emphasis upon specific numbers in specific years. The biggest difficulty lies in the fact that any random event drawn in the sample may tend in the opposite direction from the real event. Likewise, the authors mentioned that the net planting rate was not treated properly and that the limited number of possible yield events with equal probabilities tends to place limitations on the analysis.

Both the above studies indicated a need for a more accurate description of the relationship between weather and orange production.

CHAPTER III

TOWARD A THEORETICAL MODEL

A General Model

The yield of a specific orange tree can be viewed as a function of its variety, age, rootstock, density of planting, terrestrial location, the soil in which it is planted, weather conditions prior to bloom, weather conditions through the growing season including maturity, plus the cultural practices and nutritional programs to which the plant has been subjected. This relationship between the yield of an orange tree and the many factors affecting the final level or yield is probably unique for each tree and may be represented in functional notation as.

$$Y_{it}^{*} = Q^{*}_{i}\ (Z^{*}_{it},\ C^{*}_{it},\ G^{*}_{it},\ U^{*}_{it})^{1},\ i=1,\ldots I; \quad t=1,\ldots,T. \qquad [7]$$

Y^{*}_{it} = Observed level of yield of i^{th} tree in t^{th} year.

Z^{*}_{it} = Set of variables which represent all physical attributes of the i^{th} tree which affect the yield in the t^{th} year.

C^{*}_{it} = Set of all weather variables affecting the i^{th} tree's yield in the t^{th} year.

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[1]Asterisk superscript was placed on each variable to emphasize that it differs from similar variable notations to be used later.

G^*_{it} = Set of all cultural, nutritional, and technological variables affecting yield of the i^{th} tree in the t^{th} year.

U^*_{it} = Disturbance term which represents that portion of yield of the i^{th} tree in the t^{th} year which was not explained by the arguments in Z^*, C^*, and G^*.

I = Number of trees and T represents the number of years.

The variables included in Z^*_{it} should describe all the physical characteristics and attributes of the i^{th} tree such as variety, age, rootstock, planting pattern and density, and type and depth of soil. The set C^*_{it} would include such variables as the soil moisture condition experienced by the tree, temperature, and wind. Temperatures are critical--particularly low temperatures which cause yield loss due to freeze damage. The collection G^*_{it} would include such variables as those which measure fertilizer, pesticide, and water applications and other management practices including freeze protection.

The Q^*_i would not be separable functions in the three sets of variables but would include inter- as well as intra-set interactions.

The necessary knowledge to specify the form of equation [7] for each tree will probably never be available and if it were, the resulting complexity would be as intractable as the real world. Later, assumptions will be used to abstract from the complexities of the real world. But, now we turn to a discussion of what is known about factors affecting the yield of an orange tree.

Factors Affecting the Yield of an Orange Tree

The factors affecting yield can be broadly classified as physical, weather, and management and cultural practices.

Physical Factors

The major physical factors affecting the yield of an orange tree are age and soil depth. These factors affect the tree's bearing surface which is a major determinant of its average yield. Since oranges are a perennial crop, tree size and average yield increase over time. Other physical factors affecting yield are variety, rootstock, and planting density.

Age

The fundamental relationship between average yield and age of tree has been developed only in a very general manner using aggregate state figures and rather wide age group classifications. Deviations in the effects of age among the various areas of the state have not been studied in detail. Average production per tree by age classes has been estimated for the entire state for selected seasons. The results are summarized in Table 3.

This information is too aggregative to be useful on a county by county basis since it implies that the average age of the trees within each age group classification is the mean of that particular group. For example, if in a given county the trees in the 4 - 9 age group (mean age 6.5 years) had an average age of 5 years, then the coefficient in Table 3 would yield a biased estimate for that age group. Such aggregative figures also fail to reflect county differences in average yield by age. Two writers, Chern (9) and Savage (71), have

Table 3: Florida Oranges - Average production per tree by age classes, 1965-66 to 1968-69.

Crop year	4-9 Years	10-14 Years	15-24 Years	25 Years & older
	-----------------------90 pound boxes-----------------------			
		Early and Midseason		
1965-66	.9	1.4	3.7	5.1
1966-67	1.1	3.0	5.7	7.0
1967-68	1.2	1.6	3.4	4.0
1968-69	1.1	2.9	4.3	5.1
Average	1.1	2.2	4.3	5.3
		Valencia		
1965-66	.5	1.7	3.1	4.0
1966-67	1.2	2.8	4.2	5.7
1967-68	1.0	1.8	2.6	3.2
1968-69	1.1	2.0	3.4	4.2
Average	1.0	2.1	3.4	4.3

Source: Unpublished information provided by the Florida Crop and Livestock Reporting Service to the Department of Agricultural Economics, University of Florida. See Polopolus and Lester (66).

estimated average yield per tree in more detail. Their findings are reported in Table 4.

Examination of these estimates reveals some rather extreme differences between results found by the two researchers. For example, Savage estimated that a 3- and a 4-year old Valencia tree would yield a combined total of 1.1 boxes while Chern would expect only one-half of a box.

Similarly, Savage estimated that a 25-year-old Valencia tree would produce 5.5 boxes on the average, while Chern estimated 4.3.[1]

Soils

Soil depth is an important factor affecting the average yield of an orange tree since soil depth determines the size of the root system which is directly related to bearing surface (20). Citrus roots will not penetrate the hardpan found in some sections of Florida and they will not grow below the highest level of the fluctuating water table (21).

The root distribution of citrus planted in the coastal soils in Florida is often restricted to a rather shallow zone. Young (95, p. 52) in a 1953 study of citrus in the East Coast area of Florida found the principal root zone to be in the surface twelve inches with few roots below eighteen inches. The shallow water tables that have persisted over long periods have seriously restricted root development and over-

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[1]Savage's coefficients were based on the analysis of grove records of cooperating growers. If his sample included mostly better than average growers or if he did not use proportional sampling from all areas of the state, then his coefficients are not estimates of average yield for the entire state. Chern's source was the statistical Crop and Livestock Reporting Service. His coefficients are based on a 100 percent sample of the commercial groves in the state.

Table 4: Estimated average yield per tree by age and variety, Florida.

	Savage	Savage	Chern	Savage	Chern
Age	Early	Midseason	Early & Midseason	Late	Late
	90 pound boxes				
1	0.0	0.0	0.00	0.0	0.00
2	0.0	0.0	0.00	0.0	0.00
3	0.2	0.3	0.00	0.4	0.00
4	0.7	0.7	0.69	0.7	0.50
5	1.2	1.1	0.85	1.0	0.70
6	1.7	1.6	1.02	1.4	0.90
7	2.2	2.0	1.18	1.7	1.10
8	2.7	2.4	1.35	1.9	1.30
9	3.1	2.8	1.51	2.2	1.50
10	3.5	3.1	1.67	2.5	1.70
11	3.9	3.4	1.84	2.7	1.90
12	4.3	3.7	2.00	3.0	2.10
13	4.6	4.1	2.29	3.2	2.26
14	4.9	4.4	2.59	3.4	2.42
15	5.2	4.6	2.88	3.7	2.58
16	5.5	4.8	3.17	3.9	2.74
17	5.7	5.1	3.47	4.1	2.90
18	5.8	5.3	3.76	4.3	3.06
19	5.9	5.4	4.05	4.5	3.22
20	6.0	5.6	4.30	4.6	3.39
21	6.1	5.7	4.50	4.7	3.57
22	6.2	5.8	4.70	4.9	3.75
23	6.3	5.9	4.90	5.0	3.94
24	6.4	6.0	5.10	5.1	4.12
25 & above	6.8	6.0	5.30	5.5	4.30

Source: Chern (9, p. 58) and Savage (71, p. 3).

all plant growth. Hunziker (34) in a 1959 study found that the lowering of the water table in the Indian River area of Florida from 20 to 40 inches doubled the quantity of feeder roots in four years and consequently increased the size of the trees.

Koo <u>et al</u>. (50) divided soils planted to citrus in Florida into two major groups---well-drained and imperfectly to poorly drained soils. Sites and Hammond (79) reported that the rapid expansion of the Florida citrus industry between 1950 and 1960 resulted in an almost complete utilization of all well-drained land suitable for citrus and noted that the water table fluctuates widely in the poorly drained soils. During the wet season 10-20 inch depths are common while 40-60 inches are generally expected in the dry season.

Lawrence (55) divided Florida soils planted to citrus into four broad groups.

1) Flatwoods soils are the low, flat, poorly drained areas normally underlaid with hardpan. These lands, although somewhat more fertile than the high pinelands, are usually considerably colder than the surrounding better drained soils. Groves are affected by a fluctuating water table (too wet and then too dry) and frequently cold weather. The soils also require special preparation for oranges -- e.g. ditching, bedding and other measures of water control.

2) Low hammock soils are better than flatwoods soils for citrus but are often poorly drained and usually lack adequate air drainage.

3) High pinelands soils are usually light, well-drained sands of low natural fertility which are found on higher elevations. They contain the largest expansion of citrus and are suitable for citrus only with cold protection through proper air drainage and close proximity to lakes.

4) High hammock soils are best. The surface layer of this soil type is usually thicker and darker because of higher organic matter content.

Since the bulk of Florida's orange acreage is located on the ridge section, Florida soils planted to citrus can be generally characterized as being of low fertility and moisture-holding capacity.

Planting density

Dow (16) has noted that planting densities for all citrus has been steadily increasing. In 1951 new planting had an average of 72.0 trees per acre. By 1967 this average had increased to 103.0 for all citrus and to 110.0 for Early and Midseason oranges. Koo et al. (50, p. 22) found that fruit production per tree varied little in the range of 45 to 84 trees per acre. However, they reported that yield per tree was reduced approximately thirty percent with 80 to 116 trees per acre.

Variety and rootstock

Harding and Sunday (27) reported that the quantity of Florida oranges was related to variety (micro) and to rootstock. Hodgson (31) reported size differences due to variety (micro) and rootstock.

Horanic and Gardner (32), in a Florida study, found rough lemon rootstock to have a greater drought resistance than other rootstocks because of its more extensive root system.

Varietal (macro) differences in yield are shown in Tables 3 and 4.

Weather Factors

The major components of weather, rainfall and temperature, are discussed in this section. For levels of rainfall and temperature that would be considered as normal the yield effect of these factors is probably due to their interaction effect on the level of soil moisture. Unusual levels of either variable may affect yield directly by damaging fruit and/or plant.

Rainfall

Ziegler (96) indicated that total rainfall in Florida is sufficient for citrus production but that its distribution is often bad. Rains of 16 inches accompanying hurricanes have been experienced. Hurricanes are threats to Florida citrus. Significant crop reductions due to hurricanes occurred in 1926, '28, '41, '44, '45, '46, '47, '48, '49, '50, '60 (68, p. 24). Such rains are harmful because they supply more moisture than the sandy soils can hold and cause serious leaching of soluble nutrients through percolation. May to September is the rainy summer season and usually accounts for about two-thirds of the precipitation in most sections of Florida. During this period rainfall is generally sufficient for the needs of citrus trees. From October through April and occasionally through May or early June rainfall is often insufficient for the needs of the trees.

The two periods in the annual growth cycle of the orange tree when it is most sensitive to soil moisture deficiency are in the early spring when the new flush of growth is tender and fruit is setting and in the late spring and early summer when the fruit is rapidly increasing in size. The most critical period is in the spring, particularly during the months of March, April, and May — especially if the rainfall was deficient the preceding fall (98, p. 92). Deficiency of soil moisture in May and June may limit fruit size. Shortage of rainfall during October and November is not critical unless the tree experiences severe wilting (98, p. 93).

Whenever the moisture content of a given soil is above its field capacity the excess gravitational water will percolate away. Usually an accumulation of greater than two and one-half inches within a few days will cause such percolation (51). Koo and Sites (51) reported wide variations in water transpired by months. In a study of 15-year-old Marsh grapefruit trees on Lakeland fine sand average daily transpiration was estimated to be 34.2 gallons per tree. However, in February, 1952, it soared to 53 gallons per tree per day.

Because of the very low water holding capacities of most Florida soils, the distribution of rainfall is more important than the total amount (49, p. 2). Rainfalls of one-tenth inch or less are of little use to citrus trees since the precipitated moisture evaporates from the soil surface without affecting soil moisture. Rainfalls of from one to three inches are ideal for Florida groves since the soil is wet deep enough to supply moisture over a long period. Heavier rains usually cause percolation. Koo and Sites (51) reported that the quality of fruit is negatively correlated with total annual rainfall.

Temperature

Florida's freezes are produced by cold, dry polar air moving into the state from northern areas. During the initial influx, winds are rather strong, and high and low ground locations may be equally cold. This is called cooling by advection. When a polar air mass remains over the state the wind becomes light to calm at night. The surface of the earth after sunset loses its heat to the very cold sky without a return by radiation; this is called radiational cooling. Under these conditions the surface of the soil soon becomes cooler than the lower layer of the atmosphere; the air in contact with the soil begins to lose heat to the soil by conduction. This cooling is confined to a relatively shallow surface layer of the air, the temperatures of which may drop to critical values while the air just a few feet above may remain much warmer. This is called temperature inversion. This accounts for the phenomenon of damaged citrus fruit and foliage at lower portions of a tree without damage to the upper portions of a tree, or, damage decreasing as one goes up a slope (79, p. 8). Cold air is more dense than warm air. When the ground is sloping, gravity acts to move the thin layer of heavier cold air down the slope where it gathers in depressions or frostpockets which become quite cold (79, p. 11).

Freezes are always general, not local, because they result from large masses of air at subfreezing temperatures. Freezes usually have at least a three day duration in Florida. Ziegler and Wolfe (98) describe the usual Florida freeze in the following manner. Because the air is at the same temperature from top to bottom of the moving mass, there is a tendency for equal temperatures on high and low ground, at least on the first night of the freeze. The first night is usually cold and windy but rarely causes serious damage, although a possibility of damage exists with a period of calm shortly before sunrise which allows the air to stratify. Usually there is little warming of the air or trees during the second day as cold air continues to move south. During the second night the wind usually falls soon after sunset and the stratifying air may reach dangerously low temperatures rather soon, especially in low areas. On the third day the wind usually shifts and begins to replace the cold air with warmer air from the ocean. Therefore, under the usual conditions of freezes in Florida, the second and/or third nights are the more dangerous after the ground and trees have become cold and the wind has ceased.

Freezes may occur in Florida any time from November 15 until March 15. The most severe damage results when an early winter freeze is followed by a period of warm weather sufficient to initiate new growth which in turn is followed by a second freeze in the same winter. Such a freeze occurred in the winter of 1894-95 and is still referred to as the "big freeze" or "great freeze." An early freeze in December of 1894 defoliated the trees and fruit was frozen but wood damage was slight. The weather was mild during January and trees put out new shoots and growers generally felt that their groves were in good shape. However, in a condition of tender growth, the trees were killed to the ground by a second freeze in early February, 1895.

In January, 1949, a freeze of several days' duration caused loss of fruit and considerable injury to the branches but because there was no additional severe cold that winter the new growth in February following the freeze developed normally and the groves were essentially back to normal by summer. The freeze in the winter of 1957-58 was one of repeated cold waves interspersed with periods of sufficient length and warmth for renewal of growth. Damage was severe in many areas.[1]

The meteorological events leading up to the freeze of December, 1962 were numerous and complex. In simplest terms, the air mass that

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[1]This section was summarized from Ziegler and Wolfe (98, p. 84-87).

caused this freeze was a product of the stagnation of air over the snow-covered Arctic region during long winter nights. Its rapid movement from Canada to the Gulf Coast was due to an avenue of vigorous northwest to southeast air flow created by an intense Atlantic coast low pressure and and great high pressure ridge in the western United States. Temperatures fell on an average of 15-20 F throughout peninsular Florida from 7 P.M. December 12 to 7 A.M. December 13 at a rather uniform rate of 1-2 F per hour. This was a classic advection freeze with effective radiative heat loss contributing very little to its severity. Record low temperatures were set at many stations throughout Florida and it was the coldest night of the century for high ground locations in the northern portion of the citrus belt and for the so-called "warm locations" in the heart of the citrus belt.[1]

Past freezes have greatly reduced short-run orange supplies. Probably the most important factors which influence the susceptibility of citrus to freezing temperatures are the degree of dormancy of the trees at the time extreme cold arrives and the general physiological conditions of the tree. Cold weather in itself induces a degree of dormancy in citrus; if it comes gradually it is very effective in increasing the trees' tolerance to freezing temperatures. Trees in active growth are much more severely injured by cold than are those somewhat dormant. Citrus trees, being evergreens, never become fully

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[1]This section on 1962 freeze summarized from Two Days in December! (19). Historical records indicate that severe freezes occurred in Florida in the winters of 1747, 1766, 1774, 1799, 1828, 1835, 1850, 1857, 1880, 1884, 1894-5, 1916-17, 1926-27, 1929-30, 1957-58, and 1962-63 (19, p. 129).

dormant and can never withstand temperatures as low as those tolerated by deciduous trees (54). There are also wide variations in the cold hardiness among orange varieties. Cooper (12) reported that these differences are explained in part by the minimum temperature at which dormancy is induced. Cooper (12, p. 83) in a study of the 1961-62 freeze on Valencia oranges also noted that each freeze differs from other ones in the same area in one or more respects. Trees once injured by cold are more susceptible to further cold damage and disease for several years thereafter (19). The complicated biophysical relationships which explain how temperatures, varieties, cultural practices, and the technology of freeze protection affect yields have not been studied and will not be a part of this research. Some "average" effects of these factors on yield will be assumed.

The exact level of freezing temperatures seems to be critical. Hendershott (30) reported that leaf temperatures of 20 F and colder kills 100 percent of mature leaf tissue while temperatures in the range of 20-21 F can be expected to kill between 50 to 70 percent. At 22 F reading was found to kill only 5 percent and temperatures in the range of 23-24 F killed only 1 percent. Commercial growers tend to consider a hard freeze (one resulting in fruit loss and/or tree damage) to be characterized by temperatures of less than or equal to 26 F for four or more hours (57, p. 49). Cooper (11) has stated that temperatures of 28-30 F will not harm trees or fruit.

There are at least two reasons why the 1962 freeze was less damaging than if it had occurred several years earlier (19, p. 7). Groves were in the best nutritional condition in history and there was a capacity to use and process damaged fruit which did not exist a few years previously.

Cold temperatures limit the northward expansion of the citrus belt and are the most adverse climatic factor with which the Florida grower must contend. However, high temperatures may result in damage also. Relatively high temperatures (in the 70's) during December and January may encourage growth and make trees more easily injured by late cold weather. In March and April, high temperatures increase transpiration and if coupled with a lack of soil moisture can cause permanent wilting. When such drought conditions (high temperature and low rainfall causing a deficiency in soil moisture) exist through May, even if not serious enough for wilting, an excessively heavy "June Drop" of fruit is the usual result. Warm weather during October and November, particularly if nights are warm and rainfall is above normal, usually result in reduced internal quality and poor external color (98, p. 87).

Management and Cultural Practices

Past and present management and cultural practices can affect a tree's yield in a given year. However, this phenomenon has not been studied and is not well understood. Certainly year-to-year variations in nutritional programs, pesticides and insecticides practices and irrigation capacity are capable of causing variation in yield. However, whether or not yield data from commercial groves reflects a variability due to these factors depends on the yield response of these factors and the level of their inputs into the production process. The possibility exists that if commercial groves are managed at or near the optimal level for such inputs that production data from commercial groves will not reflect any variability due to such inputs.

Nutrition

Bitters and Batchelor (4) reported that fruit size was related to: nutrition, spraying with growth regulators, moisture relatives, and to certain pesticides and insecticides. Hodgson (31) in a study including both Florida and California reported that size of fruit was related to nutrition, and to magnesium, zinc, copper, and manganese deficiencies. Harding and Sunday (27) reported a yield response to fertilizers. Koo, Reitz, and Sites (50) found that nitrogen was the only element directly related to fruit production in Florida. Jones and Embleton (43) substantiated this finding in a California study. However, Lenz (56) found that while nitrogen had a beneficial effect on fruit-set, it had a deleterious effect on fruit quality if high nitrogen rates remained in the soil at or near maturity.

Irrigation

In Florida trees can become dormant for either of two reasons, low temperature or lack of soil moisture (2). The greater the degree of dormancy the less the danger from a freeze of a given severity. Therefore an irrigation program designed to reduce soil moisture in the winter months to induce dormancy can reduce the probability of freeze damage (47).

Supplementing rainfall by irrigation has been practiced by Florida citrus growers for many years. Whether irrigation has benefited the grower in financial terms through increased fruit production has not been firmly established (47). Savage (70) in a 1954 article concluded from a survey of grove records accumulated over 21 seasons that it did not pay to irrigate the average grove in the manner irrigation was usually practiced. At that time most growers irrigated when trees showed signs of wilt. Koo (47) reported that the effects of experimental irrigation on fruit production has been variable. He noted that Sites et al. (80) reported in 1951 that irrigation resulted in lower production two out of three years in several orange varieties. Huberty and Richards (33) reported that improper irrigation can reduce navel orange yields as much as 30 to 40 percent. Higher yields due to irrigation were reported by Koo and Sites (51) and Ziegler (97) in later studies. Koo (47) reported that a recent (1959-60 season through 1961-62 season) experiment indicated fruit production was increased substantially by irrigation. He noted that production was increased substantially by maintaining adequate soil moisture in the root zone when fruit was small. He found it necessary to maintain soil moisture at greater than 65 percent field capacity between fruit set (February-March) and until the young fruit has reached 1 inch in diameter (June-July) (48).

Sandy soils with very low water-holding capacity make irrigation necessary and the unpredictable rainfall distribution makes irrigation timing important. The above studies indicate a possible change in yield due to improved irrigation and drainage practices over the range of the data used in this study.

Reuss (68) in a recent study (1969) designed to estimate the costs of developing and continuing irrigation for citrus production, provided information on the effects of irrigation upon yields and upon economic returns. He used experimental plot data supplied by Koo (47) for most of his analysis and concluded that irrigation was economically feasible.

General Models Suggested by Other Researchers

Numerous researchers[1] have worked on the problems of forecasting yield and of estimating harvest size. A few of the representative models are briefly discussed in this section.

Kuznets

Kuznets (52) reported that the yield of a California orange tree was related to:

1. Number of entirely cloudy days (December 16-February 15) preceding bloom.
2. Average temperature (February 15-March 15).
3. Date of peak bloom.
4. Average maximum temperature the 46-75th day after bloom.

Kuznets and Jennings (53) in a California study, found that the following weather variables affected yield:

1. Average temperature in degree F (March 16-31).
2. Date of peak bloom from March 23.
3. Number of entirely cloudy days, December 16-February 15, preceding bloom.
4. Average temperature, February 16-March 18.
5. Date of peak bloom.
6. Average maximum temperature, 48-60th day after bloom.
7. Average maximum temperature, 61-75 days after bloom.

Stout

Stout (83) worked with the following model in a study designed to forecast the harvest size of Florida Valencia oranges.

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[1] See bibliography section entitled "Additional Readings."

$$Y = a + \Sigma B_i X_i + e, \; i = 1, 2, \ldots, 16 \qquad [8]$$

where:

Y = April 1 average volume per fruit in cubic inches (i.e., harvest size).

X_1 = October 1 size.

X_2 = X_1^2.

X_3 = Rainfall in inches (February 1 - October 1).

X_4 = Number of days no rain (February 1 - October 1).

X_5 = Rainfall in inches (July 1 - October 1).

X_6 = Number of days rainfall greater than .10 inches in July, August, and September.

X_7 = Number of days temperature greater than 90° F in July, August and September.

X_8 = July average temperature.

X_9 = August average temperature.

X_{10} = September average temperature.

X_{11} = East coast (0,1).

X_{12} = Interior (0,1).

X_{13} = West coast (0,1).

X_{14} = September to October state average growth rate less than 1.90 cubic inches (0,1).

X_{15} = September to October state average growth rate between 1.90 and 2.35 cubic inches (0,1).

X_{16} = September to October state average growth rate greater than 2.35 cubic inches (0,1).

After analysis of the above model Stout developed two equations, each with five significant (at .05 level) variables, to predict the harvest size of Valencias on October 1.

$$\hat{Y} = 28.81 + .070\,X_1 + .100\,X_2 - .055\,X_3 - .260\,X_4 + 1.926\,X_5 \qquad [9]$$

where:

$\hat{Y}$ = Predicted April 1 size on preceding October 1.

X_1 = October 1 size squared.

X_2 = Total rainfall from July 1 to October 1.

X_3 = Number of days rainfall was .10 or more inches from July 1 to October 1.

X_4 = Average August temperature.

X_5 = One if September to October state average rate of growth greater than 1.90 inches and less than 2.35 inches, zero otherwise.

$$\hat{Y} = 20.51 + 1.211X_1 + .046X_2 - .044X_3 - .232X_4 + 2.140X_5 \qquad [10]$$

where:

$\hat{Y}$ = Same as equation [9]

X_1 = October 1 size.

X_2 = Total rainfall from February 1 to October 1.

X_3 = Same as equation [9]

X_4 = Average September temperature.

X_5 = Same as equation [9]

Others

Hodgson (31) in a study including both Florida and California reported that size of fruit was related to adequacy of heat during the growing period, atmosphere, humidity, and time of bloom. Cooper (13) in a study of Florida, Texas, Arizona, and California concluded that soil moisture was the principle factor affecting size. Caprio et al. (8) in a study of California Valencia oranges concluded that size was a function of: temperatures in fall and early winter; date of bloom; cool temperatures in February and March; mean monthly temperatures and temperature departures from normal. Beutel (5) found harvest size to be related to soil moisture and maximum daily summer temperature. Sites (78) reported that a dry period of three months after fruit is set reduces size and subsequent irrigation will not recover it. Jamison (38) reported that the yield of the Washington navel orange in California was significantly and directly related to the amount of heat during the growing season. However, Furr et al. (22) noted that high temperature is an important factor in causing abnormally heavy drop of fruit. Jones and Embleton (43) found California orange production to be influenced by high temperatures in fruit-setting period. Jones and Cree found differences in yield due to maximum temperature during the June drop period (42) and to harvest time (41). Harding and Sunday (27) reported that the yield of Florida oranges was related to soil moisture. Haas (25), in a 1949 study of Valencia orange in California, concluded that the date of blossom opening was primarily related to yield.

Koo (47) in research devoted to studying the effects of irrigation on yields of orange and grapefruit concluded that optimal fruit production requires adequate soil moisture during the period January through June.[1] Furr et al. (22), studying the Washington navel and Valencia oranges in California, concluded that soil moisture depletion and high temperatures were related to fruit drop. Dhillon and Singh (14) concluded that fruit drop was primarily due to moisture stress.

The Federal Trade Commission (18) in a study on the frozen concentrated orange juice industry after the December, 1962 freeze reported that the severity of a freeze was a function of: duration of low temperatures, the time of year, weather conditions before and after the freeze, surface winds, humidity, and recorded low temperature. They concluded that the recorded low temperature of the freeze was probably the best single indicator of the severity of the freeze.

A Concluding Remark

The many weather variables related to the yield of orange trees point to the importance of a measure or a few measures which could account for most of the yield variability due to weather. Hints that soil moisture is such a measure are scattered throughout the literature. Many researchers have noted that some measure of soil moisture conditions are related to the yield of orange trees. Oury (63) showed the usefulness of the aridity index approach (either de Martonne's or Angtrom's) for explaining yield variation due to weather and suggested their use until more refined indexes such as Thornthwaite's became operational. Knetsch (46) demonstrated that a measure of available soil moisture as estimated from a moisture-balance computation of

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[1]Koo recommended that growers attempt to maintain soil moisture of 70 percent of field capacity during the January-June period.

daily rainfall and evapotranspiration could be useful for explaining yield variation in Tennessee Valley corn. He estimated daily evapotranspiration by using Thornthwaite's empirical formula.

To calculate a measure of available soil moisture it is necessary that the following information be available:

1. Depth of soil to hard-pan or water table (root depth).
2. Soil moisture at field capacity.
3. Soil moisture at which plant growth and development is restricted (wilting point).
4. Daily rainfall and temperature.

Such information is not difficult to obtain for a given field experiment. However, for this research effort (since the sampling unit was an entire county) the lack of such information at the county level presented considerable difficulties.

Evaporation is a component of climate that is seldom measured. The combined evaporation from the soil surface and transpiration from plants, called evapotranspiration, represents the transport of water back from the earth to the atmosphere, the reverse of precipitation. One cannot tell whether a climate is moist or dry by knowing the precipitation alone. One must know whether precipitation is greater than or less than the water needed for evaporation and transpiration. The rate of evapotranspiration depends on four things: climate, soil-moisture supply, plant cover, and land management.

Transpiration effectively prevents the plant surfaces that are exposed to sunlight from being overheated. Most plants require sunlight for growth. The energy of the sun combines water and carbon dioxide in the leaves into foods, which are carried to all parts of the plant for growth. This process, called photosynthesis, is most efficient when the leaf temperatures are between 85 and 90 F. A leaf exposed to direct sunlight would become much hotter if the energy of the sun were not disposed of in some way. Transpiration is a heat regulator, preventing temperature excesses in both plant and air.

Atmosphere elements which influence transpiration are solar radiation, air temperature, wind, and atmospheric humidity. These factors are all interrelated and although solar radiation is the basic factor, temperature of the transpiring part is most closely related to the rate of transpiration and air temperature is correlated to the temperature of the transpiring part.[1]

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[1]The above section on evapotranspiration was summarized from Thornthwaite (90). See this reference for an empirical method for estimating evapotranspiration.

CHAPTER IV

ANALYTICAL METHOD AND THE DATA

The Model Estimated

The mathematical representation of the real world offered as a general theoretical model in equation [7] represented an impossible estimation task due to the lack of information to specify such a disaggregative model and because of inadequate data to fit such a model if specified. To abstract from the detail of the real world, trees whose yields were assumed to respond similarly to the variables of equation [7] were grouped together. Additionally, the data available also placed constraints on the model estimated.

The most disaggregated observational unit on which production data were reported were varieties (macro) by counties. Available production data did not permit classification by such micro units as rootstock, density of planting, or terrestrial location.

Classification by variety (micro), age, rootstock, soil depth, and soil moisture capacity would have been desirable because yield differences exist among the various levels of all five factors and the various levels of each factor interact with weather. For example, fruit loss and tree damage due to freezing temperatures differ among varieties[1] (micro) and some varieties (micro) are more drought resis-

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[1] *Supra*, p. 52.

tant than others.[1] Young trees are more severely injured by a given low temperature than older trees. Differences in rootstock cause differences in the drought resistance of trees and the minimum temperature at which dormancy is induced.[2] Soil depth determines the size of the root structure which limits the bearing surface of the tree.[3] Soil moisture capacity fixes an upper limit on moisture reserves. As a consequence, the same amount of rainfall may cause different levels of wilting conditions depending on the soil moisture capacity of the soil in which the trees are rooted.[4]

While it would be possible to generate a set of time series data of the orange groves in the state of Florida in which the trees were classified by variety, age, rootstock, soil depth, and moisture capacity, such a data set would be useless for estimation because production data could not be sub-divided in a like manner.

The major factors for which observations have been recorded and which contribute to year to year variation in yield by county and variety (macro) are changes in tree numbers, age distribution of trees, and weather (84). Cultural practices and nutritional programs may have varied over time. However, it is doubtful that significant differences in management existed between counties in any given year.

By abstracting from the real world by grouping trees by variety (macro) and by counties, equation [7] may be represented as:

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[1] _Supra_, p. 46.

[2] _Supra_, p. 46.

[3] _Supra_, p. 43.

[4] See Table 9, p. 80.

$$Y_{rst} = Q_{rs} \ (Z_{rst}, C_{rst}, G_{rst}, U_{rst}), \ r = 1,\ldots,R; \quad s = 1,\ldots,S; \ t = 1,\ldots,T. \qquad [11]$$

where:

Y_{rst} = Observed production in 90 pound boxes of r^{th} variety (macro) in s^{th} county and t^{th} year.

Z_{rst} = Set of variables which represent physical attributes of all the trees of r^{th} variety in s^{th} county which affect production in the t^{th} year.

C_{rst} = Set of weather variables affecting the r^{th} variety's production in the s^{th} county and the t^{th} year.

G_{rst} = Set of cultural, nutritional, and technological variables affecting production of r^{th} variety in s^{th} county and t^{th} year.

U_{rst} = Disturbance term which represents that portion of production of the r^{th} variety in the s^{th} county and t^{th} year which is not explained by the arguments Z, C, and G.

R is the number of varieties (macro), S the number of counties, and T the number of years.

The variables and equations represented by the general equation [7] differ from the variables and equations represented by [11]. For example, Y_{it}^{*} represents the yield of a single tree in t^{th} year while Y_{rst} denotes the total production of all bearing trees of r^{th} variety (macro) in s^{th} county and t^{th} year. And while [7] includes a single yield function for each tree, equation [11] represents a production function for each variety (macro) by county.

As with equation [7], the rs^{th} function of [11] would not be separable. And, again because of a lack of information and data, serious and insurmountable specification and estimation problems remain. If in year t, county s had 100 trees of the r^{th} variety and in year t + 10 had 1,000 trees of r^{th} variety, one would not expect the same level of a particular variable, such as 15 drought days, to bring forth the same change in Y expressed in boxes of fruit. This is to say that there is an interaction between the number of trees by age and the weather variables.[1] And, even if information existed to specify the form of equation [11],it would not be possible to estimate this stochastic function with the limited number of observations available.

As an approach to circumvent the need for estimating the interactions among Z_{rst} and C_{rst} the concept of expected[2] production and a two stage estimating procedure was introduced. Expected production was specified as a conditional function of the number of trees and their age distribution given average levels of all other inputs including weather. Expected production was then used to remove a portion of the year-to-year variation in observed production and to estimate the percentage deviation of observed from expected production for each variety (macro) by counties. These estimates of percentage deviation of observed from expected production for each variety (macro)

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[1]Similarly, there is an interaction among the number of trees by age and the variables in set G.

[2]Expected as used here is not the same concept as mathematical expectation. Rather the term expected production is used to define production estimated by a synthesized average yield function to be defined later.

and county were then expressed as a function of variables in the sets C_{rst} and G_{rst} in a linear single equation model. The coefficients of this model represent the change in this deviation resulting from a one unit change in a variable from C_{rst} or G_{rst}. These coefficients do not depend on the number of trees.

The two-stage approach which was used in an attempt to circumvent the need for estimating interaction among weather variables and variables representing the number and age distribution of trees may be summarized as follows:

Stage I: Average Production Equation

$$\hat{EY}_{rst} = H_{rs}\,(A_{rst} \mid \bar{C}_{rs.},\ \bar{G}_{rs.});\quad r=1,2;\quad s=1,\ldots,18;\quad t=1,\ldots,20. \qquad [12]$$

$\hat{EY}_{rst}$ = Expected production of r^{th} variety in s^{th} county and t^{th} year. Expected as used here is not to be confused with the concept of mathematical expectation (see Footnote 2, page 66).

A_{rst} = Set of variables which describe the number of trees of r^{th} variety (macro) by age group, county and year.[1]

$\bar{C}_{rs.}$ = Set of mean values of weather variables affecting r^{th} varieties in s^{th} county production over all years.

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[1]Specifically, the set A_{rst} included 22 variables. Variable 1 was the number of trees 4 years of age, variable 2 was the number of trees 5 years of age, and so on. Finally variable 22 was the number of trees 25 years of age and older. The estimated coefficient for a particular variable was an estimate of the average yield for trees of that age.

$\bar{G}_{rs.}$ = Set of mean values of cultural, nutritional, and technological variables affecting the production of r^{th} variety in s^{th} county over all years.

There were two varieties (macro), 18 counties, and 20 years finally included in the analysis as will be described later.

Stage II: Weather Equation.

$$P_{rst} = L_{rs}\ (C_{rst},\ G_{rst},\ U'_{rst});\ r=1,2;\ s=1,\ldots,18;\ t=1,\ldots 20. \qquad [13]$$

P_{rst} = (Y_{rst} (as defined in equation [11]) - $\hat{EY}_{rst}$ (as defined in equation [12]) $\div$ $\hat{EY}_{rst}$.

C_{rst} = Set of weather variables affecting production of r^{th} variety in the s^{th} county and t^{th} year.

G_{rst} = Set of cultural, nutritional and other technological variables affecting production of r^{th} variety in the s^{th} county and t^{th} year.

U'_{rst} = Disturbance term which represents that portion of production of the r^{th} variety in the s^{th} county and t^{th} year which is not explained by the arguments of A, C, and G.

As indicated earlier there were two varieties (macro), 18 counties, and 20 years finally included in the analysis. These dimensions will be discussed later.

The major reason for expressing the dependent variable P_{rst} as percentage deviation of observed from expected production was, as discussed earlier,[1] to obtain a variable which was related to C_{rst} and G_{rst} but which did not depend on the number and age distribution of trees in the county.

The Data

The Florida Crop and Livestock Reporting Service annually publishes county production figures in terms of boxes produced (72). Their report also describes the groves within each county in terms of total acres and number of trees by age group and variety (macro). Two complete citrus inventories were conducted under their supervision in 1956 and 1965 resulting in publications in 1957 and 1966. Production and tree data were available from the 1948-49 season to date.

Daily weather observations for twenty-seven weather stations for the period July 1, 1948 through June 30, 1966 were purchased from the National Weather Records Center, Asheville, North Carolina. Additionally, daily weather observations were hand-coded for the period July 1, 1966 through December 31, 1968.

County fertilizer consumption by fertilizer types has been published annually by the Inspection Division, Department of Agriculture, State of Florida (35, 36).

Table 5 indicates that data were available for 18 counties for the 20 seasons 1948-49 through 1967-68 and for 13 counties for at least five seasons 1963-64 through 1967-68. These data were coded and key punched as Y_{rst}.

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[1] *Supra*, p. 66.

Table 5: Counties currently producing Florida oranges and seasons for which production data were available.

Code	[a]County	Seasons of available production data
1	Brevard	1948-49 through 1967-68
2	DeSoto	1948-49 through 1967-68
3	Hardee	1948-49 through 1967-68
4	Highlands	1948-49 through 1967-68
5	Hillsborough	1948-49 through 1967-68
6	Indian River	1948-49 through 1967-68
7	Lake	1948-49 through 1967-68
8	Manatee	1948-49 through 1967-68
9	Marion	1948-49 through 1967-68
10	Orange	1948-49 through 1967-68
11	Osceola	1948-49 through 1967-68
12	Pasco	1948-49 through 1967-68
13	Pinellas	1948-49 through 1967-68
14	Polk	1948-49 through 1967-68
15	Putnam	1948-49 through 1967-68
16	St. Lucie	1948-49 through 1967-68
17	Seminole	1948-49 through 1967-68
18	Volusia	1948-49 through 1967-68
19	Broward	1948-49, 1963-64 through 1967-68
20	Charlotte	1948-49, 1963-64 through 1967-68
21	Citrus	1963-64 through 1967-68
22	Collier	1963-64 through 1967-68
23	Glades	1963-64 through 1967-68
24	Hendry	1948-49, 1963-64 through 1967-68
25	Hernando	1948-49, 1963-64 through 1967-68
26	Lee	1948-49 through 1956-57, 1963-64 through 1967-68
27	Martin	1963-64 through 1967-68
28	Okeechobee	1963-64 through 1967-68
29	Palm Beach	1948-49, 1963-64 through 1967-68
30	Sarasota	1948-49, 1963-64 through 1967-68
31	Sumter	1963-64 through 1967-68

[a]The numerical county codes will be used throughout this report.

Y_{rst} = Observed production of r^{th} variety (macro) in s^{th} county and t^{th} year.

r = 1 for Early and Midseason varieties.

r = 2 for Late varieties.

s = 1, 2, ..., 31.

t = 1,..., 20; the 1948-49 season was coded 1.

In certain seasons Temples were included with the Early and Midseason oranges but reported separately in other seasons. To make the data comparable in all season, Temples were included with the Early and Midseason oranges.

Information on orange trees was available by county, variety (macro), and age group categories. As with the production data, there were 18 counties with 20 years of available data and 13 counties for which data were available for five or more years. Again, Temples were included with Early and Midseason oranges. A major problem existed in the degree of aggregation of the age group categories and in the different ways the trees were grouped. For the years 1948 through 1956, data on tree numbers were grouped into age categories 4 through 5, 6 through 10, 11 through 15, and 16 and older. For 1957 and 1958 the age groups were 0 through 3, 4 through 9, and 10 and older. For the period 1959 through 1961 age group categories were 4 through 9, and 10 and older. From 1962 through 1964 the three age groups were 0 through 4, 5 through 9, and 10 and older. A complete citrus inventory was conducted in 1965.

A matrix of tree data was generated with typical element a_{rstj}.

a_{rstj} = Number of trees of r^{th} variety (macro) in s^{th} county, t^{th} year, and j^{th} age group.

$r = 1, 2.$

$s = 1, \ldots, 31.$

$t = 1, \ldots, 20.$ The year 1948 was coded 1 and paired with production for 1948-49 season.

$j = 4, \ldots, 25.$ Age group 25 included all trees 25 years old and older.

For 1965 the citrus inventory was used to calculate a_{rstj}. Since no severe weather existed in 1966 or 1967 to reduce the number of trees and since there was no reason to expect abandonment of groves during those two years, the a_{rstj}'s were generated for 1966 and 1967 by simply advancing the 1965 census ahead one and two years. This was possible because the model only dealt with bearing trees (4-years-old and older) and a two-year-old tree in 1965 for which data were available was four years old in 1967.

For the other years the a_{ratj}'s were generated by a simple bookkeeping procedure whereby the total number of trees reported in a given year and age group category was distributed according to the percentage in production as reported by the 1965 census. For example, if in 1964 the 5 through 9 age group category was reported to include 200 trees and the 1965 census reported 10 six-year-old trees, 30 seven-year-old trees, 40 eight-year-old trees, 10 nine-year-old trees, and 10 ten-year-old trees; then the 200 trees were distributed 20, 60, 80, 20, 20 for age groups 5 through 9, respectively.

Daily weather observations were available for stations in 27 of the 31 counties studied (Table 6).

Most of the oranges (over 93 percent during the period of study)

Table 6: Weather stations and time interval for which data were available.

County Code[a]	Station	Time interval	Month(s) for which data were missing
01	Titusville	1/1949 - 6/1966	7/1958
02	Arcadia	1/1949 - 6/1966	7/1960
03	Wauchula 2N	1/1949 - 6/1966	9-10/1957
04	Avon Park	1/1949 - 6/1966	11/1951
05	Plant City	1/1949 - 6/1966	
06	Fellsmere 4W	1/1949 - 6/1966	8-10/1963
06	Vero Beach	1/1949 - 3/1965	
07	Clermont	1/1949 - 6/1966	
08	Bradenton Exp. Sta.	1/1949 - 3/1965	
08	Bradenton 5 ESE	4/1965 - 6/1966	
09	Ocala	1/1949 - 6/1966	4-6/1956, 3-4/1960
10	Orlando WBAP	1/1949 - 6/1966	
11	Kissimmee	1/1949 - 1/1959	2/1959-6/1966
12	Saint Leo	1/1949 - 6/1966	
13	Tarpon Sps. Sew. Pl.	1/1949 - 6/1966	
14	Lake Alfred Exp. Sta.	1/1949 - 6/1966	
15	Palatka	1/1949 - 6/1966	
16	Fort Pierce	1/1949 - 6/1966	2/1951
17	Sanford (7977)	1/1949 - 5/1956	6-7/1955
17	Sanford (7982)	6/1956 - 6/1966	
18	Deland 3N	1/1949 - 6/1966	6-12/1959, 2-4/1960
19	Fort Lauderdale	1/1949 - 6/1966	8/1951, 5/1960
24	Clewiston U.S.Eng.	1/1949 - 6/1966	7/1956
29	Loxahatchee	1/1949 - 6/1966	
27	Stuart IN	1/1949 - 6/1966	9/1949, 7/1952

[a]See Table 5 (p. 70) for names of counties associated with code numbers.

were produced in the 18 county study area (Table 7).[1] Since yield data were restricted to only a few years (5 in most cases) and since acceptable weather data could not be generated for the other 13 citrus-producing counties, they were omitted from the analysis. The citrus belt is shifting to the south and most of the deleted counties are in the new expansion area. For long-range forecasting one would like to be able to measure the effect of weather on orange production in these counties which will undoubtedly be providing a larger proportion of the crop. However, the limited number of observations frustrated attempts to use historical data to do so.

Three counties, Indian River, Manatee, and Seminole required two stations to obtain a continuous weather record and one county, Osceola, did not have any weather observations beyond January, 1959. Therefore, a nearby station (Clermont) in an adjacent county (Lake) was substituted for the period February, 1959 through June 1966. Missing observations in other data series (see Table 6) were estimated by the mean value of the weather variable for that day for the station involved.

Daily weather observations were aggregated into quarterly observations for the 18 stations for the period July 1, 1966, through December 31, 1968, to correspond with available production and tree data.

The weather data consistently recorded by the stations were total daily rainfall, minimum daily temperature and maximum daily temperature. A critical weather variable (duration of freezing temperature) was unobserved.

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[1]The counties which made up the study area are the first eighteen listed in Table 5, page 70.

Table 7: Total orange production for the state of Florida and the amount and percentage for the study area by variety (macro) and by seasons, 1948-49 through 1967-68.

Variety	Early and Midseason			Valencia			All oranges		
Season	State	Study area	Per-cent	State	Study area	Per-cent	State	Study area	Per-cent
1948-49	32,000	29,929	94	26,300	24,863	95	58,300	54,792	94
1949-50	33,600	31,451	94	24,900	22,936	92	58,500	54,387	93
1950-51	36,800	34,485	94	30,500	27,854	91	67,300	62,339	93
1951-52	43,800	41,339	94	34,800	32,064	92	78,600	73,403	93
1952-53	42,300	39,882	94	29,900	27,361	92	72,200	67,243	93
1953-54	50,200	48,309	96	41,100	37,881	92	91,300	86,190	94
1954-55	52,000	50,553	97	36,400	34,080	94	88,400	84,633	96
1955-56	51,500	50,337	98	39,500	37,961	96	91,000	88,298	97
1956-57	54,300	52,984	98	38,700	36,718	95	93,000	89,702	96
1957-58	52,700	51,697	98	29,800	28,568	96	82,500	80,265	97
1958-59	47,100	46,243	98	38,900	37,594	97	86,000	83,837	97
1959-60	49,000	48,093	98	42,500	41,174	97	91,500	89,267	98
1960-61	51,000	50,008	98	35,700	34,581	97	86,700	84,589	98
1961-62	56,900	55,624	98	56,500	54,342	96	113,400	109,966	97
1962-63	45,500	44,345	97	29,000	27,530	95	74,500	71,875	96
1963-64	27,800	26,947	97	30,500	28,776	94	58,300	55,723	96
1964-65	46,400	44,884	97	39,800	37,823	95	86,200	82,707	96
1965-66	51,540	49,832	97	48,900	46,340	95	100,440	96,172	96
1966-67	78,200	75,375	96	66,300	62,811	95	144,500	138,186	96
1967-68	55,900	53,636	96	49,100	45,494	93	105,000	99,130	94

The three weather measures available (daily rainfall, minimum temperature, and maximum temperature) were used to synthesize observations on twenty-six weather variables (see Table 8) for each of the 18 stations used to represent county weather. These twenty-six weather variables are those proposed by earlier researchers.

Those variables in Table 8 measuring soil moisture (3-10) and minimum temperature (11-16) were believed to be of primary importance in explaining yield variability due to weather.[1]

A typical element in the matrix of observation or weather variables was w_{stqn}.

where:

w_{stqn} = Average monthly value of n^{th} weather variable in s^{th} county, t^{th} year, and q^{th} quarter.

$s = 1, \ldots, 18$

$t = 1, \ldots, 20$

$q = 1, \ldots, 4.$

$n = 1, \ldots, 26.$

Variables 1 through 16 in Table 8 were reported as three month totals. Variables 17 through 26 were reported as quarterly averages. Degree days were based on heat units[2] in excess of 55 F and the variable

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[1]The major cost in deriving observations on the weather variables was associated with taking information from a large weather data tape. The marginal cost of obtaining observations on additional variables was so small in comparison with the cost of spinning the tape that observations were derived for any variable for which there was a possible need.

[2]See Newman (60) for definition of degree days and heat units.

Table 8: Specific weather variables used in study.[a]

Variable No.	Description of variable
1.	Degree days
2.	Degree days (adjusted)
3.	Number of days soil moisture less than wilt (Thornthwaite)
4.	Number of days soil moisture equal to zero (Thornthwaite)
5.	Number of days soil moisture less than wilt (Harrison)
6.	Number of days soil moisture equal to zero (Harrison)
7.	Number of days soil moisture equal to 100% (Thornthwaite)
8.	Number of days soil moisture greater than 70% (Thornthwaite)
9.	Number of days soil moisture equal to 100% (Harrison)
10.	Number of days soil moisture greater than 70% (Harrison)
11.	Number of days minimum temperature less than or equal to 32 F
12.	Number of days minimum temperature less than or equal to 30 F
13.	Number of days minimum temperature less than or equal to 28 F
14.	Number of days minimum temperature less than or equal to 26 F
15.	Number of days minimum temperature less than or equal to 24 F
16.	Number of days minimum temperature less than or equal to 22 F
17.	Average temperature
18.	Average temperature (maximum)
19.	Average temperature (minimum)
20.	Total rainfall
21.	Total rainfall (adjusted)
22.	Land aridity index
23.	Koppen aridity index (1)
24.	Koppen aridity index (2)
25.	Koppen aridity index (3)
26.	Angstrom aridity index

[a]Observations on these variables were computed from daily weather information on rainfall and temperature.

referred to as degree days (adjusted) consisted of those heat units in the range of 55 F and 90 F.

Variables 3 through 10 were calculated by using a bookkeeping procedure discussed by Harrison and Choate (37). Two estimates of each variables were calculated by using average daily evapotranspiration as reported by Harrison and Choate and by calculating daily evapotranspiration by the Thornthwaite method (90).

The variable referred to as total rainfall (adjusted) was calculated by not considering any rainfall amounts in excess of the field capacity of the soil in the root zone.

Variables 22-26 were generated by using the following standard formulas:

Lang Aridity Index $= P/T$

Koppen Aridity Index (1) $= 8P/(13T+120)$

Koppen Aridity Index (2) $= 2P/(T+33)$

Koppen Aridity Index (3) $= P/(T+7)$

Angstrom Aridity Index $= P/(1.07)^T$

Where P is rainfall measured in millimeters and T is temperature in degrees centigrade.[1]

Calculation of these weather variables associated with the level of soil moisture required information on root depth, maximum water in root zone at field capacity, and wilting point (percent soil moisture at which growth is seriously depressed). Such information was unavailable by counties. Derivation of such information from soil maps was considered. However, it would have been an enormous task to

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[1] *Supra*, p. 28.

compile county estimates of root depth, maximum water in root zone at field capacity, and wilting point from soil maps for a given year and to weight such estimates by the year-to-year changes in the distribution of trees within a county. Therefore, the information which was used (Table 9) was based on the opinion of experts[1] with considerable experience in working with Florida soils. The data in Table 9 represent average county levels for root depth, maximum water in root zone at field capacity, and usable soil moisture[2] for all years included in this study.

The aggregation of information on these variables into averages for a county resulted in some loss of variation. For example, if the average county root zone is 40 inches but some groves within the county had only 10 inches of root depth then those groves might suffer severe wilting conditions which the information on the county averages would not reflect.

There were two basic difficulties associated with the weather variables. First, there were no measures of the severity of low temperatures since the durations of the low temperatures were unknown. Secondly, there were no uniformly best measure of evapotranspiration to include in the estimation of soil moisture. The average daily evapotranspiration rates as reported by Harrison and Choate (Table 10)

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[1]Dr. L. C. Hammond in consultation with Mr. R. G. Leighty and Mr. D. S. Harrison synthesized the information in Table 9. These scientists are all with the University of Florida. Hammond and Leighty are Professors of Soils and Harrison is Professor of Agricultural Engineering.

[2]Information on these three variables permitted the calculation of wilting point as the differences between water in root zone at field capacity and usable moisture.

Table 9: Root depth, water in root zone at field capacity, and moisture available for plant use in soils by counties in the Florida citrus belt.

County code	County	Root depth (inches of soil)	Water in root zone at field capacity (inches of rainfall)	Usable moisture (inches of rainfall)
1	Brevard	30	4.5	4.0
2	DeSoto	30	6.0	4.5
3	Hardee	30	6.0	4.5
4	Highlands	48	4.5	4.1
5	Hillsborough	48	5.0	4.0
6	Indian River	24	4.0	3.4
7	Lake	60	5.2	4.7
8	Manatee	30	6.0	4.5
9	Marion	60	5.2	4.7
10	Orange	60	5.2	4.7
11	Osceola	30	6.0	4.5
12	Pasco	60	5.2	4.7
13	Pinellas	36	5.0	4.4
14	Polk	60	5.2	4.7
15	Putnam	36	6.9	5.3
16	St. Lucie	24	3.5	3.1
17	Seminole	48	4.5	4.1
18	Volusia	48	5.0	4.0
19	Broward	24	3.5	3.1
20	Charlotte	24	3.5	3.1
21	Citrus	60	5.2	4.7
22	Collier	24	3.5	3.1
23	Glades	24	3.5	3.1
24	Hendry	24	3.5	3.1
25	Hernando	48	4.5	4.1
26	Lee	24	3.5	3.1
27	Martin	24	4.0	3.4
28	Okeechobee	24	3.5	3.1
29	Palm Beach	24	3.5	3.1
30	Sarasota	30	6.0	4.5
31	Sumter	36	6.9	5.3

Source: Unpublished information compiled by Dr. L. C. Hammond, Mr. R. G. Leighty, and Mr. D. S. Harrison. Hammond and Leighty are Professors of Soils, and Harrison is Professor of Agricultural Engineering, all at the University of Florida.

measure only that portion of the variability in soil moisture associated with rainfall. Alternatively, the Thornthwaite method allows for variation in soil moisture due to both rainfall and temperature but it tends to overestimate evapotranspiration in the summer months (26).

The average daily evapotranspiration of Florida citrus groves has been estimated by Harrison and Choate (37). Their estimates were based on historical average monthly temperature at Lake Alfred. Their results are reported below.

Table 10: Average daily evapotranspiration of Florida citrus groves.

Month	Average daily evapotranspiration (inches of rainfall)
January	.08
February	.08
March	.10
April	.11
May	.14
June	.17
July	.17
August	.18
September	.17
October	.13
November	.10
December	.08

Source: Harrison and Choate (37, p. 34).

A data search was initiated to locate information on variables suitable to measure changes in levels of cultural and technological practices by counties. Such variables might include an index of irrigation capacity, an index of freeze protection, fertilizer utilization per tree or acre, and pesticide utilization. Only fertilizer use data were available. These data were collected and used as measures of a proxy or representative variable for cultural and technological factors.

Fertilizer data were reported as fertilizer consumption by counties, but they were actually fertilizer sales by counties. The data did not specify that portion of a county's fertilizer sales applied to citrus. The mixed fertilizers and fertilizer materials in Tables 11 and 12 were commonly applied to citrus. These fertilizer analyses were used to estimate the amount of fertilizer being used on citrus.

The typical element in the basic data matrix for fertilizer was f_{stm} where: f_{stm} = consumption in tons of m^{th} type of fertilizer for the s^{th} county and t^{th} year.

$s = 1, 2, \ldots, 18$

$t = 1, 2, \ldots, 20$

$m = 1, 2, \ldots, 5$

1 = Total county consumption of mixed fertilizer.

2 = Total county consumption of those mixed fertilizers coded in Table 11.

3 = Total county consumption of nitrogen for those mixed fertilizers coded in Table 11.

4 = Total county consumption of fertilizer material.

5 = Total county consumption of those fertilizer materials coded in Table 12.

Table 11: Mixed fertilizers commonly applied to citrus.

N - P - K	N - P - K
08-00-08	14-00-14
08-00-10	14-00-16
08-02-08	14-01-14
08-02-10	15-00-12
08-02-12	15-00-14
10-00-10	15-00-15
10-00-12	15-01-15
10-02-10	16-00-16
12-00-10	16-00-17
12-00-12	16-00-18
12-00-14	17-00-17
12-00-15	18-00-16
12-01-12	18-00-18
12-02-12	20-00-20
14-00-12	

Source: Personal conversations with Mr. Larry K. Jackson, Instructor, IFAS, Extension Service, University of Florida.

Table 12: Fertilizer materials commonly applied to citrus.

Ammonium Nitrate
Nitrate of Soda-Potash
Nitrate of Potash
Nitrogen Solutions
Muriate of Potash (50-60%)
Sulfate of Potash-Magnesia

Source: Personal conversations with Mr. Larry K. Jackson, Instructor, IFAS, Extension Service, University of Florida.

The fertilizer data which included fertilizer applied to all citrus were adjusted by the percent of total citrus made up of oranges. The data were then expressed on a per tree basis.

Since fertilizer programs are individual grower decisions the mixed fertilizers and fertilizer materials reported in Tables 11 and 12 do not represent all fertilizer applied to citrus. Specifically the mixed fertilizers 06-06-06, 08-08-08, and 10-10-10 were known to be applied to young groves. But these were omitted because they were also the dominant types used on lawns by homeowners. Other mixed fertilizers and fertilizer materials which were undoubtedly applied to citrus at least in some instances were also omitted.

The Estimation Technique

For each county and each variety (macro) two equations were estimated. The Stage I or average production equation expressed the average relationship between production and tree age. The Stage II equation was designed to explain the production variation due to weather and to cultural practice and technology.

Since there were eighteen counties and two varieties (macro) in the study and since the Stage I and Stage II equations were estimated for each county-variety (macro) combination a total of thirty-six equations were estimated.

Stage I

Bounds on estimates of the average yield per tree by age and variety (macro) were available due to earlier work by the Florida Crop and Livestock Reporting Service and by Savage, and Chern.[1]

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[1] *Supra*, pp. 43 and 44.

The Florida Crop and Livestock Reporting Service average yield estimates reported in Table 3 indicate a range of 4.0 to 7.0 boxes per tree for Early and Midseason trees 25 years of age and older. Likewise, when the figures of Savage's and of Chern's (Table 4) were compared, they also indicated a range for average yield per tree. Since these estimates were for the entire state they do not form rigid upper and lower limits for average yield per tree on a county by county basis. However, they do provide information to enable one to specify the general form of the relationship between average yield and age, and within reasonable limits to enable one to fix upper and lower bounds on the average yield function.

Estimates of the average yield per tree by age and by county were developed in Stage I. Hopefully, the intercounty variation in physical factors (such as soil depth, varieties (micro) and planting densities) which affect production was accounted for in these estimates. The model assumes that such was the case.

The equation estimated in Stage I was:

$$\hat{EY}_{rst} = \sum_{j=4}^{25} B_{sj} X_{rst} \qquad [14]$$

$\hat{EY}_{rst}$ = Expected production[1] for the r^{th} variety (macro) in s^{th} county and t^{th} year.

X_{rstj} = Number of trees of r^{th} variety in s^{th} county, t^{th} year and j^{th} age. For $j = 25$, all trees 25 years and older were included.

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[1]Not mathematical expectation (see footnote 2 page 66).

B_{sj} = Average yield in s^{th} county for j^{th} age.

Observations were not available on $\hat{EY}_{rst}$. Conceivably, an estimate of equation [14] could be obtained with least squares smoothing of the data on production and tree numbers by age. Equation [14] has twenty-two coefficients and since only twenty observations were available, some grouping over age was required.[1]

Data on trees by age were grouped into two year groups and the data were smoothed by least squares regression. A prior information indicated that commercial production of an orange tree begins at three to four years of age, increases rapidly to ten years, levels off and reaches a maximum at twenty-five years.[2] The least squares estimates of the yield coefficients in many cases had older trees bearing less than younger trees and the regression estimates of yields in some cases were actually negative.

To avoid these problems of negative coefficients and older trees producing less fruit than younger trees and to utilize other prior information an effort was made to estimate yield coefficients with a linear programming model which minimized the sum of the absolute errors.[3] Linear programming was selected due to the ease with which probable bounds on the estimated coefficients could be incorporated into the estimating procedure. First attempts at estimating by linear

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[1]Tree data were grouped into two-year age categories so that only eleven coefficients were estimated as opposed to the twenty-two required in equation [14].

[2]*Supra*, p. 7.

[3]See Havlicek (29) for discussion of methodology.

programming were carried out with the constraints that B_{sj} be greater than or equal to zero and that the B_{sj+1} be greater than or equal to B_{sj} for j=1, 2..., 10. This approach proved unsuccessful because for most counties the linear programming estimates of the coefficients set the first ten coefficients to zero and explained the variation in the dependent variable only as a function of the older trees. Next, additional constraints in the form of bounds which were based on the previous work of the Florida State Crop and Livestock Reporting Service, Savage, and Chern were placed on each of the coefficients. For example, a bound of 4.0 to 7.0 boxes per tree was placed on Early and Midseason orange trees twenty-four years of age and older. This technique tended to underestimate the yield of younger trees, overestimate the yield of older trees and failed to capture the between-county variation in average yield known to exist.[1]

An ad hoc model was finally used to estimate the coefficients of equation [14]. The estimates of state average yield per tree by age reported by Savage and by Chern[2] were used as a base. Both sets of estimates were modified in two ways. First, their estimates were shifted upward or downward by a constant amount over a reasonable range subject to the constraint that no coefficient could be negative. Secondly, the estimates of Savage and of Chern were modified by multiplication by constants which varied over a range of one and a half boxes above and below the reported estimates.

The estimated average yield parameters were then selected which

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[1] Supra, p. 43.

[2] See Table 4, p. 44.

minimized the sum of the absolute errors between actual and estimated production for each county. In over 95 percent of the cases, the estimates derived by adding a constant to Chern's estimates performed best.

Therefore, the estimates derived by modifying Chern's estimates were used in all cases. These estimates of average yields which resulted are presented in the next chapter.

Stage II

The Stage II equation[1] was estimated by multiple regression. Many admissible hypotheses existed for the specification of variables to include in the model. The final choice of variables was somewhat arbitrary in the sense that the specification provided a multiple choice hypothesis. For example, twenty-six weather variables were calculated for each quarter.[2] If each were lagged one year and the six minimum temperature variables were lagged an additional two years there were 220 possible explanatory variables available. Likewise, five fertilizer measures were available.[3] If lagged effects of fertilizer applications were admitted,as is believed to be the case, the number of choices would be augmented again.

Simple correlations, partial correlations, and step-down regressions were used in the process of reducing the number of possible

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[1]*Supra*, p. 68.

[2]*Supra*, p. 77.

[3]*Supra*, p. 82.

regressors for equation [13].[1] For the weather variables, this initial process considered no lagged variables. Therefore 104 weather variables were considered. The five fertilizer variables listed on page 82 were expressed in pounds utilized per orange tree. For the initial reduction process those five variables were considered plus each of the five lagged one, two, and three years. Therefore 20 fertilizer variables were initially considered in an effort to explain a portion of the yield variability due to management and technology.[2]

Of the fertilizer variables considered, none was significant in explaining variation in deviations of actual from expected yields. These variables were finally removed from the model.

For the weather variables, the initial reduction process was quite successful. Results indicated that some measure of soil moisture should be included and that of the eight[3] possible measures of soil moisture (four for the Thornthwaite procedure and four based on Harrison and Choate's average evapotranspiration rates), the four

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[1]The initial reduction process was not necessarily a systematic process and it certainly included a lot of judgmental decisions. In this process only three of the major producing counties were included--two from the ridge section and one from the Indian River section. This initial reduction procedure was a very empirical process. The largest equations estimated by step-down regression required that a matrix of order 125 be inverted. At one point 4,500 simple correlation coefficients (125 for each variety (macro) -- county combination) were calculated and searched for similar correlation patterns over counties.

[2]Because this year's production might not be related to this year's fertilizer consumption but to the sum of fertilizer applications over the past several years, additional combinations of the fertilizer variables were also considered in other models.

[3]There were eight possible measures of soil moisture per quarter or thirty-two per year. (Coded 3 through 10 on p. 77.)

based on Thornthwaite's procedure appeared superior in explanatory power to Harrison and Choate's.

The six[1] available minimum temperature variables did not explain much of the percentage deviation of actual from expected yield which was due to freezing weather.

By combining data over counties to avoid a degrees of freedom problem, step-down regression was used in an effort to explain the effect of freezes with the minimum temperature measures available. The explanatory variables in this model were quarterly measures of soil moisture conditions, six available minimum temperature variables, and the six minimum temperature variables lagged one, two, and three years. While this model did not isolate the particular temperature variable to be used to explain the yield variability due to freeze damage it did provide some information which allowed the reduction of the possible number of candidates. Specifically, this information indicated that the variable which measured the number of days the minimum temperature was less than or equal to 30° F need no longer be considered as an explanatory variable.

A variable which was lagged twice and which was formed as a weighted sum of the number of days the minimum temperature fell within certain temperature intervals performed most satisfactorily in explaining freeze damage.

With this freeze variable and the knowledge that a measure of soil moisture based on the Thornthwaite empirical method of estimating evapotranspiration explained more variation than other variables which

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[1]These variables were coded 11 through 16 on p. 77.

were admissible candidates, the final process of specifying variables to include in the second stage model was to choose from among the four measures of soil moisture based on Thornthwaite's method. However, none of these measures was clearly superior in terms of explanatory power.

The four Thornthwaite variables under discussion are listed as numbers 3, 4, 7, and 8 in Table 8.[1] The same model was fitted for each of the eight largest producing counties for both varieties (macro). The estimating procedure was repeated four times, once for each of the four measures of soil moisture. Three of the variables still remained tied to terms of predictive ability. The tie was broken by selecting the variable for which the most temperature signs were consistent with prior knowledge.

The final form of the Stage II equation was:

$$
\begin{aligned}
P_{rst} = {} & B_{rs0} + B_{rs1} V_{st1} + B_{rs2} V_{st2} + B_{rs3} V_{st3} + B_{rs4} \\
& V_{st4} + B_{rs5} V_{st5} + B_{rs6} V_{st6} + B_{rs7} V_{st7} \\
& + U''_{rst}
\end{aligned}
\qquad [15]
$$

P_{rst} = Signed percentage deviation of actual production of the r^{th} variety in the s^{th} county and the t^{th} year from its corresponding expected production.[2]

V_{stq}; $q = 1,\ldots,4$ = Number of days soil moisture reached field capacity in s^{th} county, t^{th} year, and q^{th} quarter.[3]

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[1] Supra, p. 77.

[2] See p. 68 for formula by which P_{gtk} was calculated.

[3] Number of days based on a soil moisture budget technique (see van Bavel (92) for description of method) using soil moisture information furnished by Dr. L. C. Hammond (see Table 9, p. 80) and estimate evapotranspiration by the Thornthwaite method (90).

V_{st5} = Level of freeze variable[1] in s^{th} county and t^{th} year.

For Early and Midseason oranges only the fourth quarter of the first year of crop season was considered. For Valencia oranges the sum of the fourth quarter of the first year of the crop season and the first quarter of the second year of the crop season was used.[2]

V_{st6} = Level of freeze variable for previous winter. Equivalent to V_{st5} as defined for Valencia oranges lagged one year.

V_{st7} = Level of freeze variable for winter two years removed. Equivalent to V_{st5} as defined for Valencia oranges lagged two years.

B_{rsj}; $j = 1,\ldots,7.$ = Estimated regression coefficients for r^{th} variety, s^{th} county, and j^{th} variable.

U''_{rst} = Disturbance term which accounts for variations in P_{rst} not accounted for by the V's.

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[1] Observations for the freeze variable were calculated by summing 1.0 times the number of days the minimum temperature was less than or equal to 26 F but greater than 24 F, 2.0 times the number of days the minimum temperature was less than or equal to 24 F but greater than 22 F, and 3.0 times number of days the minimum temperature was less than or equal to 22 F.

[2] For example, if the crop season was 1954-55, for Early and Midseason oranges only October, November, and December, 1954 were considered. For Valencia oranges October, November, December, 1954 plus January, February, and March, 1955 were considered. The first quarter of the second year of the crop season (January, February, and March, 1955 in this example) will be referred to as the fifth quarter of the season.

The estimated coefficients for equation [15] are presented in the next chapter.[1]

Model Assumptions

Ideally, data for the estimating equation [14] would have included only those seasons affected by "average"[2] weather or "equal" amounts of "good" and "bad" weather years plus the "average" weather years. The criterion for selecting the estimated coefficients of equation [14] for each of the 36 county-variety (macro) combinations was that of minimizing the sum of the absolute errors of actual from expected production.

An alternative would have been to minimize the sum of the squared errors. This latter alternative would have given more weight to the extreme (unusually "good" or "bad" years) observations. Both procedures would give identical results under the assumption that the weather data available were symmetrically distributed about the average. Had the 20 years of data used to estimate equation [14] been

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[1]An iterative procedure was set up to iterate between the Stage I and Stage II equations in the hope of improving the estimates of both equations. The scheme was to change the estimates of the Stage I equation by addition or subtraction of a small delta or by multiplication by one plus or minus a small delta, recalculate the dependent variable for the Stage II equation and fit the Stage II equation again by Ordinary Least Squares. This procedure was continued until the sum of the squared errors of the Stage II equation was a minimum. An identical procedure was also used with the objective of minimizing the sum of the absolute errors of the Stage II equation. Both schemes failed to significantly improve the estimates (i.e., neither the sum of the squared errors nor the sum of the absolute errors was reduced significantly by the procedure).

[2]These very general terms, good, bad, and average, are used only in a descriptive manner and without precise definition.

generated by 10 years of "good" weather and 10 years of "average" weather or 10 years of "bad" weather and 10 years of "average" weather then the average yield coefficients would have been biased in the corresponding direction. It was assumed that such an asymmetric distribution of "good" or "bad" years did not occur. The data provided no good basis for questioning the validity of this assumption.

Equation [15] was estimated by classical least squares. The estimated coefficients are best linear unbiased estimators (BLUE) under the following assumptions:

1. $E(U''_{rst}) = 0$ for all r, s, and t.
2. $E(U''_{rst}\ U''_{rst^*}) = \sigma^2\ \delta tt^*$ where $\delta tt^* = 1$ when $t = t^*$
   $= 0$ otherwise.
3. The V's are fixed from sample to sample for every combination of r and s, or if variable, the conditional distribution of the U's given a set of observations on the V's has the above properties.

If the U's are normally distributed the least squares estimates are equivalent to maximum-liklihood estimates. The assumption of normality is also required to use t and F tests (44, p. 356). However, such conventional test procedures do not appear to be sensitive to departures from normality (44, p. 356).

Before dealing specifically with the assumptions we turn to a discussion of multicollinearity.

In the case when two explanatory variables are perfectly related the least squares procedure breaks down. This seldom occurs with real world data. From an empirical point-of-view it is usually more relevant to discuss multicollinearity in terms of its severity than its existence or nonexistence. Severe cases of multicollinearity result in estimates that are sensitive to change in the model specification and that have large standard errors.

Empirical estimates of the pairwise relationship among variables in equation [15] are given by some representative simple correlation coefficients in Table 13. These estimates would support the notion that multicollinearity was not a serious problem.

Another problem to be considered is that of autocorrelation. Specification errors may cause autocorrelated disturbances. This creates some anxiety because, as mentioned earlier, an empirical model of the weather effect on orange production can never be completely specified in terms of variables and/or form. The Durbin-Watson d-statistic was calculated and tested[1] for each of the thirty-six "fits" of equation [15]. In 11 of the 36 cases, the test would accept the hypothesis that the disturbance term was non-autocorrelated. In the other 25 cases, the test was inconclusive. In no case would the test lead to a rejection of the hypothesis that the disturbances were non-autocorrelated.[2]

The assumption of homoscedasticity was not tested statistically. However, heteroscedasticity probably existed. For near average levels of soil moisture and temperature one could expect the variance of each U''_{rst} to be finite and homoscedastic. However, levels of soil moisture low enough to kill the tree would result in the yield and its variance falling to zero. Likewise, levels of temperature low enough to kill

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[1]Text values used for d_L, d_u were (.35, 2.41).

[2]Durbin-Watson test assumes that u's are normal, homoscedastic, and non-autocorrelated (44, p. 367).

Table 13: Simple correlation coefficients for the variables included in equation [15] when fitted to data for the Early and Midseason variety, by selected counties.

Variable subscript[a]		County code[b] 2	4	6	10	14	16
		rij					
1	2	-.10	-.22	-.19	.47	-.22	-.03
1	3	-.23	.08	-.24	.46	.16	-.06
1	4	-.24	-.15	-.13	-.19	-.07	-.09
1	5	-.17	-.21	-.13	-.30	-.28	-.23
1	6	.37	.57	.63	.66	.71	-.14
1	7	.16	.28	.01	.31	.36	.28
1	8	.25	.24	.21	-.12	.17	-.07
2	3	.23	-.14	-.22	-.09	-.11	.12
2	4	.21	.32	.35	-.06	-.11	.39
2	5	.19	-.15	.08	-.09	.44	-.15
2	6	-.02	-.19	-.24	.44	-.22	-.15
2	7	-.20	-.17	.21	-.11	.12	.20
2	8	-.03	-.39	-.24	-.12	.27	-.06
3	4	.03	.17	-.02	-.09	-.06	.49
3	5	.39	.14	-.16	-.13	-.11	-.16
3	6	.29	-.27	.05	-.16	-.14	.69
3	7	-.11	.27	-.19	.31	-.05	.05
3	8	.16	.14	-.21	.12	-.17	.25
4	5	-.02	-.13	-.35	-.08	-.11	-.23
4	6	-.20	-.18	.06	-.11	-.15	.33
4	7	-.29	-.18	.06	-.11	-.04	-.23
4	8	-.29	-.24	-.28	.21	-.19	-.06
5	6	.09	-.06	-.17	-.16	-.09	-.06
5	7	.20	-.08	-.17	-.16	-.25	-.06
5	8	.46	.61	.38	-.11	.18	.53
6	7	.02	-.13	-.21	-.20	-.04	-.06
6	8	-.16	.09	.24	-.24	-.23	.44
7	8	.19	.34	.11	-.09	.29	.31

[a]Subscripts refer to variables as defined in equation [15] (p. 91). The subscript 8 refers to the dependent variable.

[b]See Table 5 (p. 70) for names of counties associated with each number.

the tree would result in the yield and its variance falling to zero. Such levels were observed. While too much soil moisture (field capacity for several days) can kill a tree, it is doubtful if such a condition has ever been serious enough in the citrus belt of Florida to be reflected by the data.

The existence of heteroscedasticity does not prevent OLS (ordinary least squares) estimates from being unbiased. It does reduce the efficiency of the estimators.

Classical linear regression assumes that variables are measured without error. Observations on weather conditions at a single point in each county were used to represent the weather experienced by the entire county. If the weather conditions recorded by the single weather station did not accurately describe the average weather experienced by the entire county errors of measurement were encountered. Even when the regressors of equation [15] were considered only as proxy variables for the conditions they represent it was doubtful if the relationship between the proxy variables and the weather conditions they represent was constant over the time period considered.

When data were pooled across county lines the assumption of no measurement errors is questionable for two reasons.

1. The estimates of soil depth and water-holding capacity (Table 8, p. 77) probably vary in accuracy from county to county.

2. The location of weather stations varied between counties. Some stations were located on high ground, some on low ground. Some were located many miles inland and a few were located right on the beaches. Consequently, the estimated relationship between production and a given level of a specific weather variable varied from county

to county. For example, consider two identical counties subjected to identical weather. If one county has a high ground recording station but the other a low ground recording station the observations on a particular temperature variable collected by the two stations would not be identical. Likewise, consider two identical coastal counties subjected to identical weather. If one of the recording stations were located on the beach and the other 15-20 miles inland one would record considerably more rainfall than the other. Efforts were made to minimize these problems when the weather stations were selected. However, due to the small number of weather stations within each county with long-running continuous records the effort was not always successful.

Errors of observation on the regressors result in biased structural estimates.[1] There was no objective basis for estimating the extent to which measurement errors may have biased the results presented in the next chapter.

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[1]See Johnston (40, p. 148), Goldberger (23, p. 282), and Steel and Torrie (82, p. 165).

CHAPTER V

RESULTS OF ANALYSIS

Estimated Average Yields

The estimates of average yield per tree by county, variety (macro), and age are presented in Tables 14 and 15. Such information on difference in yield by such small geographic areas was previously unavailable. The constants which were added to Chern's coefficients to derive these average yield estimates are presented in Table 16.

The estimates of the average yield coefficients were consistent with expectations. The deep soils of the ridge section tended to outyield the shallower soils of the coastal and flatwoods areas. The estimated coefficients for Marion and Seminole counties seemed somewhat inconsistent with expectations since in both cases they indicate that Early and Midseason oranges yielded less than the state average[1] but Valencia oranges yielded more. However, both counties produce very few Valencia oranges, and consequently their average yield coefficients for Valencia oranges were probably over-estimated. It appears that the estimated coefficients for St. Lucie county are too high when compared with the other coastal counties.

The data indicated that Hardee had the highest yields on the

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[1] If the constant added to Chern's coefficients was 0.0, then the particular county would be producing at the state average.

Table 14: Estimated yields in boxes per tree of Florida Early and Midseason oranges (including Temples) by county and age.[a]

	County code[b]								
Age	1	2	3	4	5	6	7	8	9
	---90 pound boxes---								
4	0.00	1.19	1.51	1.26	0.66	0.00	1.26	0.17	0.26
5	0.08	1.35	1.67	1.42	0.82	0.00	1.42	0.33	0.42
6	0.25	1.52	1.84	1.59	0.99	0.08	1.59	0.50	0.59
7	0.41	1.68	2.00	1.75	1.15	0.24	1.75	0.66	0.75
8	0.58	1.85	2.17	1.92	1.32	0.41	1.92	0.83	0.92
9	0.74	2.01	2.33	2.08	1.48	0.57	2.08	0.99	1.08
10	0.90	2.17	2.49	2.24	1.64	0.73	2.24	1.15	1.24
11	1.07	2.34	2.66	2.41	1.81	0.90	2.41	1.32	1.41
12	1.23	2.50	2.82	2.57	1.97	1.06	2.57	1.48	1.57
13	1.52	2.79	3.11	2.86	2.26	1.35	2.86	1.77	1.86
14	1.82	3.09	3.41	3.16	2.56	1.65	3.16	2.07	2.16
15	2.11	3.38	3.70	3.45	2.85	1.94	3.45	2.36	2.45
16	2.40	3.67	3.99	3.74	3.14	2.23	3.74	2.65	2.74
17	2.70	3.97	4.29	4.04	3.44	2.53	4.04	2.95	3.04
18	2.99	4.26	4.58	4.33	3.73	2.82	4.33	3.24	3.33
19	3.28	4.55	4.87	4.62	4.02	3.11	4.62	3.53	3.62
20	3.53	4.80	5.12	4.87	4.27	3.36	4.87	3.78	3.87
21	3.73	5.00	5.32	5.07	4.47	3.56	5.07	3.98	4.07
22	3.93	5.20	5.52	5.27	4.67	3.76	5.27	4.18	4.27
23	4.13	5.40	5.72	5.47	4.87	3.96	5.47	4.38	4.47
24	4.33	5.60	5.92	5.67	5.07	4.16	5.67	4.58	4.67
25[c]	4.53	5.80	6.12	5.87	5.27	4.36	5.87	4.78	4.87

[a]See pages 84 to 88 for a discussion of the method used to derive these estimates.

[b]See Table 5 (p. 70) for names of counties associated with code numbers.

[c]Includes trees 25 years of age and older.

Table 14: Continued.

County code[b]								
10	11	12	13	14	15	16	17	18
---------90 pound boxes---------								
0.92	0.98	0.10	0.00	1.29	0.00	0.73	0.00	0.36
1.08	1.14	0.26	0.00	1.45	0.12	0.89	0.15	0.52
1.25	1.31	0.43	0.17	1.62	0.29	1.06	0.32	0.69
1.41	1.47	0.59	0.33	1.78	0.45	1.22	0.48	0.85
1.58	1.64	0.76	0.50	1.95	0.62	1.39	0.65	1.02
1.74	1.80	0.92	0.66	2.11	0.78	1.55	0.81	1.18
1.90	1.96	1.08	0.82	2.27	0.94	1.71	0.97	1.34
2.07	2.13	1.25	0.99	2.44	1.11	1.88	1.14	1.51
2.23	2.29	1.41	1.15	2.60	1.27	2.04	1.30	1.67
2.52	2.58	1.70	1.44	2.89	1.56	2.33	1.59	1.96
2.82	2.88	2.00	1.74	3.19	1.86	2.63	1.89	2.26
3.11	3.17	2.29	2.03	3.48	2.15	2.92	2.18	2.55
3.40	3.46	2.58	2.32	3.77	2.44	3.21	2.47	2.84
3.70	3.76	2.88	2.62	4.07	2.74	3.51	2.77	3.14
3.99	4.05	3.17	2.91	4.36	3.03	3.80	3.06	3.43
4.28	4.34	3.46	3.20	4.65	3.32	4.09	3.35	3.72
4.53	4.59	3.71	3.45	4.90	3.57	4.34	3.60	3.97
4.73	4.79	3.91	3.65	5.10	3.77	4.54	3.80	4.17
4.93	4.99	4.11	3.85	5.30	3.97	4.74	4.00	4.37
5.13	5.19	4.31	4.05	5.50	4.17	4.94	4.20	4.57
5.33	5.39	4.51	4.25	5.70	4.37	5.14	4.40	4.77
5.53	5.59	4.71	4.45	5.90	4.57	5.34	4.60	4.97

Table 15: Estimated yields in boxes per tree of Florida Valencia oranges by county and age.[a]

Age	County code[b]								
	1	2	3	4	5	6	7	8	9
	----------------------90 pound boxes----------------------								
4	0.00	1.16	1.22	1.62	0.66	0.05	1.29	0.13	0.77
5	0.10	1.36	1.42	1.82	0.86	0.25	1.49	0.33	0.97
6	0.30	1.56	1.62	2.02	1.06	0.45	1.69	0.53	1.17
7	0.50	1.76	1.82	2.22	1.26	0.65	1.89	0.73	1.37
8	0.70	1.96	2.02	2.42	1.46	0.85	2.09	0.93	1.57
9	0.90	2.16	2.22	2.62	1.66	1.05	2.29	1.13	1.77
10	1.10	2.36	2.42	2.82	1.86	1.25	2.49	1.33	1.97
11	1.30	2.56	2.62	3.02	2.06	1.45	2.69	1.53	2.17
12	1.50	2.76	2.82	3.22	2.26	1.65	2.89	1.73	2.37
13	1.66	2.92	2.98	3.38	2.42	1.81	3.05	1.89	2.53
14	1.82	3.08	3.14	3.54	2.58	1.97	3.21	2.05	2.69
15	1.98	3.24	3.30	3.70	2.74	2.13	3.37	2.21	2.85
16	2.14	3.40	3.46	3.86	2.90	2.29	3.53	2.37	3.01
17	2.30	3.56	3.62	4.02	3.06	2.45	3.69	2.53	3.17
18	2.46	3.72	3.78	4.18	3.22	2.61	3.85	2.69	3.33
19	2.62	3.88	3.94	4.34	3.38	2.77	4.01	2.85	3.49
20	2.79	4.05	4.11	4.51	3.55	2.94	4.18	3.02	3.66
21	2.97	4.23	4.29	4.69	3.73	3.12	4.36	3.20	3.84
22	3.15	4.41	4.47	4.87	3.91	3.30	4.54	3.38	4.02
23	3.34	4.60	4.66	5.06	4.10	3.49	4.73	3.57	4.21
24	3.52	4.78	4.84	5.24	4.28	3.67	4.91	3.75	4.39
25[c]	3.70	4.96	5.02	5.42	4.46	3.85	5.09	3.93	4.57

[a]See pages 84 to 88 for a discussion of the method used to derive these estimates.

[b]See Table 5 (p. 70) for names of counties associated with code numbers.

[c]Includes trees 25 years of age and older.

Table 15: Continued.

County code[b]								
10	11	12	13	14	15	16	17	18
----------90 pound boxes----------								
1.08	0.41	0.32	0.34	1.15	0.16	0.53	1.07	0.31
1.28	0.61	0.52	0.54	1.35	0.36	0.73	1.27	0.51
1.48	0.81	0.72	0.74	1.55	0.56	0.93	1.47	0.71
1.68	1.01	0.92	0.94	1.75	0.76	1.13	1.67	0.91
1.88	1.21	1.12	1.14	1.95	0.96	1.33	1.87	1.11
2.08	1.41	1.32	1.34	2.15	1.16	1.53	2.07	1.31
2.28	1.61	1.52	1.54	2.35	1.36	1.73	2.27	1.51
2.48	1.81	1.72	1.74	2.55	1.56	1.93	2.47	1.71
2.68	2.01	1.92	1.94	2.75	1.76	2.13	2.67	1.91
2.84	2.17	2.08	2.10	2.91	1.92	2.29	2.83	2.07
3.00	2.33	2.24	2.26	3.07	2.08	2.45	2.99	2.23
3.16	2.49	2.40	2.42	3.23	2.24	2.61	3.15	2.39
3.32	2.65	2.56	2.58	3.39	2.40	2.77	3.31	2.55
3.48	2.81	2.72	2.74	3.55	2.56	2.93	3.47	2.71
3.64	2.97	2.88	2.90	3.71	2.72	3.09	3.63	2.87
3.80	3.13	3.04	3.06	3.87	2.88	3.25	3.79	3.03
3.97	3.30	3.21	3.23	4.04	3.05	3.42	3.96	3.20
4.15	3.48	3.39	3.41	4.22	3.23	3.60	4.14	3.38
4.33	3.66	3.57	3.59	4.40	3.41	3.78	4.32	3.56
4.52	3.85	3.76	3.78	4.59	3.60	3.97	4.51	3.75
4.70	4.03	3.94	3.96	4.77	3.78	4.15	4.69	3.93
4.88	4.21	4.12	4.14	4.95	3.96	4.33	4.87	4.11

Table 16: Signed constants added to Chern's state estimates of average yield per tree to estimate average yields by counties and orange variety (macro).[a]

County	Early and Midseason	Valencia
	---------Boxes per tree---------	
Brevard	-.77	-.60
DeSoto	.50	.66
Hardee	.82	.72
Highlands	.57	1.12
Hillsborough	-.03	.16
Indian River	-.94	-.45
Lake	.57	.79
Manatee	-.52	-.37
Marion	-.43	.27
Orange	.23	.58
Osceola	.29	-.09
Pasco	-.59	-.18
Pinellas	-.85	-.16
Polk	.60	.65
Putnam	-.73	-.34
St. Lucie	.04	.37
Seminole	-.70	.37
Volusia	-.33	-.19

[a]See footnotes to Tables 14 and 15 and pages 87 and 88 for an explanation of the derivation of these constants.

average in the production of Early and Midseason oranges and that Highlands county had the highest average for the production of Valencias. This result was probably due to the fact that these counties seldom experienced the more severe freezing temperatures experienced by the counties in the more northern portions of the ridge. The results indicated that Pinellas was the lowest yielding county on the average for the production of Early and Midseason oranges and that Brevard was the lowest yielding county on the average for the production of Valencias. In both cases the low yields were probably due to a combination of shallow soils and the frequency of low temperatures.

Weather Indexes

The average yield estimates were used in conjunction with data on tree numbers to obtain an estimate of production. The ratio of total production to expected production provides a binary comparison or index. The deviation of this index from 1.0 indicates the combined effect of all factors whose influence was not measured in the estimation of expected production. Since weather factors were a major influence in the deviation of actual from expected yield the index provides an estimate of a weather index.

These indexes (see Tables 17, 18, and 19) indicate a considerable year-to-year variation.

Weather Equations

By Counties and Varieties (Macro)

The estimated regression coefficients for the weather equation are summarized in Tables 20 and 21. Thirty-six equations were estimated.

Table 17: "Weather" indexes for Early and Midseason oranges (including Temples), by Florida counties and seasons, 1951-52 through 1967-68.[a]

	County codes[b]																	
Season	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1951-52	.72	.65	.72	.97	1.02	1.09	1.06	.52	.94	1.15	.96	1.38	.92	1.00	.87	1.07	.92	1.04
1952-53	.87	.76	.78	.85	.88	1.02	.86	.81	.92	.98	.80	1.24	.89	.88	.96	.94	1.02	1.01
1953-54	.74	.86	.98	.82	.89	.82	1.01	1.09	1.22	1.13	1.12	1.66	1.00	1.06	1.05	.76	1.21	1.09
1954-55	.63	.87	.96	.81	1.07	.81	1.10	.80	1.17	1.18	1.01	1.58	1.41	1.00	1.18	.86	1.23	1.16
1055-56	.74	.83	.89	.64	1.09	.81	1.26	.79	1.20	1.11	1.10	1.43	.98	.88	1.15	.71	1.36	1.17
1956-57	.79	.71	.94	1.06	1.03	.84	.99	.90	1.21	1.13	1.23	1.83	1.42	1.00	1.00	1.08	1.54	1.16
1957-58	1.00	1.26	1.28	1.22	1.17	1.27	1.17	1.38	1.03	1.08	1.26	1.00	1.14	1.15	.89	1.07	.73	.59
1958-59	1.03	1.24	1.20	1.16	1.09	1.00	1.01	1.29	.81	.92	1.00	.82	1.14	1.01	.45	1.05	.58	.36
1959-60	1.44	1.31	1.22	1.12	1.12	1.00	1.09	1.26	.93	1.05	1.03	1.29	1.21	1.15	.72	1.01	.86	.50
1960-61	1.21	1.00	1.17	.93	1.00	.94	1.00	1.09	1.05	1.00	1.08	1.06	.98	.89	1.21	.85	1.39	1.00
1961-62	1.21	1.26	1.38	1.41	1.08	1.40	1.03	1.21	1.01	.92	1.37	.92	.68	1.05	.97	1.07	1.61	.85
1962-63	1.42	1.14	1.23	1.56	.65	1.78	.75	.75	.48	.85	1.08	.72	.54	1.03	.43	1.45	.71	.58
1963-64	1.23	.43	.47	.91	.31	1.49	.69	.30	.83	.73	.47	.43	.46	.53	1.09	1.39	.64	.73
1964-65	1.29	1.04	1.75	1.35	1.28	1.24	1.67	1.58	1.41	1.14	.87	2.25	1.13	1.29	1.61	1.28	.92	1.12
1965-66	1.24	1.00	.87	.96	.60	1.62	.68	.80	.97	.79	.68	.78	.70	.98	1.06	1.12	1.02	.90
1966-67	1.20	1.29	1.16	1.28	1.26	1.58	1.03	1.69	1.48	1.17	1.05	1.63	1.46	1.25	1.60	1.00	1.55	1.35
1967-68	1.03	1.03	1.00	1.07	.72	1.57	.55	1.00	.76	.62	.58	.90	.87	1.06	.75	.86	.77	.67

[a]See pages 84 and 105 for an explanation of how these indexes were estimated.

[b]See Table 5 (p. 70) for names of counties associated with code numbers.

Table 18: "Weather" indexes for Valencia oranges, by Florida counties and by seasons, 1951-52 through 1967-68.[a]

	County codes[b]																	
Season	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1951-52	.71	.97	1.10	1.07	.99	.91	1.16	1.07	1.10	1.26	1.52	1.51	1.12	1.10	1.10	.83	1.17	1.37
1952-53	.83	.98	.95	.83	.89	.99	.94	1.00	1.00	.97	1.09	1.07	.92	.88	.96	.91	.93	1.05
1953-54	1.01	1.05	1.17	1.21	1.34	1.14	1.10	1.52	1.10	1.24	1.79	1.65	1.28	1.20	1.11	1.02	1.44	1.41
1954-55	.69	.98	.80	.97	1.19	1.00	1.06	1.16	1.14	1.17	.96	1.71	1.18	.99	1.00	.83	1.13	1.45
1955-56	.77	.93	1.00	1.02	1.22	.99	1.65	1.14	1.04	1.14	1.00	1.73	.94	1.02	.93	.88	1.09	1.40
1956-57	.78	.89	.79	.76	1.22	.95	.97	.96	1.06	1.10	2.20	1.84	1.00	.80	1.01	1.13	1.22	1.16
1957-58	1.00	.67	.78	.66	1.00	.99	1.16	1.31	.65	.72	1.40	.75	.71	.68	.45	1.01	.61	.29
1958-59	1.05	.97	1.00	1.00	1.41	1.04	1.25	1.64	1.04	.89	1.64	1.00	1.06	.88	.43	1.13	.69	.35
1959-60	1.13	1.01	1.10	1.08	1.52	1.05	1.35	1.71	1.30	1.12	1.77	1.39	1.16	1.19	.94	1.15	1.19	.59
1960-61	1.05	.82	.80	.68	1.04	.94	1.01	.95	1.31	.88	1.76	.95	.86	.76	1.11	.94	1.00	.95
1961-62	1.41	1.49	1.61	1.35	1.15	1.25	1.25	1.69	.88	.84	1.37	1.48	.79	1.24	1.06	1.28	1.09	.92
1962-63	1.03	.68	.69	.89	.34	1.23	.46	.39	.22	.48	.76	.28	.14	.68	.19	1.21	.32	.55
1963-64	1.00	.76	.57	.83	.19	1.50	.76	.25	.73	.80	.47	.19	.17	.78	1.46	1.22	.52	1.20
1964-65	.96	1.00	1.50	1.16	.89	1.15	1.04	1.30	.79	1.05	.97	1.41	1.08	1.12	1.00	.94	.79	1.00
1965-66	1.26	1.05	.95	1.00	.68	1.10	.64	.93	.69	.67	.86	.75	.75	1.20	.80	1.00	.68	.79
1966-67	1.18	1.24	1.18	1.12	1.28	1.00	1.00	1.77	1.08	1.01	1.42	1.46	1.36	1.28	1.36	.89	1.07	1.20
1967-68	1.39	1.04	1.01	.89	.64	1.36	.50	.84	.58	.49	.69	.72	.68	1.00	.65	1.12	.50	.61

[a]See pages 84 and 105 for an explanation of how these indexes were estimated.

[b]See Table 5 (p. 70) for names of counties associated with code numbers.

Table 19: "Weather" indexes for orange production for counties in the study area by variety (macro), and by seasons, 1951-52 through 1967-68.[a]

Season	Variety: Early and Midseason[b]	Variety: Valencia
1951-52	.99	1.12
1952-53	.91	.92
1953-54	1.04	1.22
1954-55	1.06	1.07
1955-56	1.15	1.13
1956-57	1.06	.98
1957-58	1.10	.81
1958-59	.96	1.02
1959-60	1.07	1.22
1960-61	1.00	.90
1961-62	1.07	1.21
1962-63	.92	.60
1963-64	.68	.74
1964-65	1.33	1.08
1965-66	.86	.91
1966-67	1.21	1.16
1967-68	.81	.80

[a]Counties in the study area accounted for over 93 percent of state production during the seasons indicated (see Table 7).

[b]Includes Temples.

Table 20: Estimated regression coefficients, standard errors, uncorrected coefficient of multiple determination, and Durbin-Watson "d" statistic for the Stage II equation for Early and Midseason oranges (including Temples) by Florida counties.

County code[b]	Estimated regression coefficients[a]									
	b_1	b_2	b_3	b_4	b_5	b_6	b_7	b_8	R^2	d
1	-0.2678	0.0275	0.1085	0.1064	-0.0594	0.0914	-0.0768	-0.0214	58	1.91
	(0.2322)	(0.0367)	(0.1748)	(0.0955)	(0.0501)	(0.0614)	(0.1380)	(0.1196)		
2	-0.1438	0.0330	-0.0508	0.1928	-0.0667	0.0684	-0.0602	-0.0072	57	1.68
	(0.2748)	(0.0162)	(0.1132)	(0.2049)	(0.0603)	(0.0323)	(0.0295)	(0.0270)		
3	-1.5815	0.0256	-0.6452	0.0000	2.0325	0.0559	-0.0007	0.1127	84	1.78
	(0.4640)	(0.0116)	(0.1739)	(0.1539)	(0.5720)	(0.0268)	(0.0283)	(0.0271)		
4	0.0230	0.0163	-0.0258	-0.0390	-0.0101	0.1051	-0.0095	0.0359	66	2.29
	(0.1918)	(0.0143)	(0.0283)	(0.0775)	(0.0987)	(0.0320)	(0.0349)	(0.0279)		
5	-0.0084	0.0668	0.0890	-0.1345	-0.0109	-0.0045	-0.1502	-0.0644	79	1.73
	(0.1825)	(0.0145)	(0.1368)	(0.0501)	(0.0431)	(0.0259)	(0.0298)	(0.0273)		
6	0.3594	-0.0086	-0.1326	-0.0462	-0.0173	0.4504	0.3150	0.2478	41	0.96
	(0.3407)	(0.0395)	(0.1401)	(0.0742)	(0.0829)	(0.2952)	(0.3045)	(0.2340)		
7	0.2453	0.0562	-0.7007	-0.3645	0.7116	0.0098	-0.2288	0.0763	58	2.44
	(0.3640)	(0.0243)	(0.3375)	(0.1218)	(0.3283)	(0.0537)	(0.0926)	(0.0519)		
8	0.0573	0.0523	-0.0767	-0.1021	-0.0238	0.0479	-0.2598	0.1141	43	2.00
	(0.3025)	(0.0293)	(0.2434)	(0.0940)	(0.1000)	(0.1138)	(0.1624)	(0.1256)		

Table 20: Continued.

County code[b]	Estimated regression coefficients[a]									
	b_1	b_2	b_3	b_4	b_5	b_6	b_7	b_8	R^2	d
9	-0.1368 (0.1906)	0.0033 (0.0256)	0.3375 (0.2889)	0.1741 (0.1078)	-0.2094 (0.2281)	-0.0573 (0.0404)	-0.0243 (0.0334)	-0.0644 (0.0454)	47	2.00
10	0.0097 (0.4095)	0.0216 (0.0382)	-0.1247 (0.3066)	-0.0338 (0.1261)	0.1199 (0.2183)	-0.0238 (0.0649)	-0.1262 (0.1523)	-0.0921 (0.0881)	18	2.29
11	-0.0876 (0.2674)	0.0482 (0.0179)	-0.4365 (0.2479)	-0.1922 (0.0894)	0.6151 (0.2412)	0.1033 (0.0431)	-0.2400 (0.0680)	-0.0742 (0.0381)	74	2.98
12	-0.2949 (0.7498)	-0.0504 (0.0399)	0.5208 (0.6047)	0.1023 (0.1206)	0.0330 (0.2930)	-0.1004 (0.1112)	0.1527 (0.1303)	0.0078 (0.0724)	29	3.04
13	-0.0326 (0.4391)	-0.0087 (0.0151)	0.1093 (0.1177)	-0.0069 (0.0527)	-0.0218 (0.3558)	-0.0829 (0.0594)	-0.0032 (0.0048)	0.0420 (0.0648)	27	2.43
14	0.3167 (0.1925)	0.0527 (0.0146)	0.0157 (0.0342)	-0.2082 (0.0766)	-0.2177 (0.1327)	0.0216 (0.0199)	-0.0877 (0.0235)	-0.0173 (0.0165)	70	2.21
15	-0.1126 (0.5852)	0.0428 (0.0354)	0.0000 (0.2675)	0.1215 (0.0768)	-0.0552 (0.3889)	-0.0549 (0.0499)	-0.0959 (0.0490)	-0.0643 (0.0326)	61	2.23
16	-0.0398 (0.1080)	0.0024 (0.0142)	0.0061 (0.0222)	-0.0106 (0.0508)	-0.0026 (0.0295)	0.2486 (0.0856)	0.2406 (0.1204)	0.1517 (0.0941)	67	1.52

Table 20: Continued.

County code[b]	Estimated regression coefficients[a]								R^2	d
	b_1	b_2	b_3	b_4	b_5	b_6	b_7	b_8		
17	0.0031 (0.3500)	0.0365 (0.0209)	0.0632 (0.2492)	0.0234 (0.0563)	-0.0372 (0.0991)	-0.0188 (0.0700)	-0.2015 (0.0686)	-0.1081 (0.0704)	63	1.93
18	-0.0498 (0.2726)	0.0289 (0.0266)	-0.0050 (0.1566)	-0.0278 (0.1023)	0.0820 (0.1656)	-0.0577 (0.0299)	-0.0548 (0.0219)	-0.0183 (0.0118)	73	2.50

[a]Standard errors are in parentheses. See pages 88 to 92 for discussion of derivation of these estimates.

[b]See Table 5 (p. 70) for names associated with code numbers.

Table 21: Estimated regression coefficients, standard errors, uncorrected coefficient of multiple determination, and Durbin-Watson "d" statistic for the Stage II equation for Valencia oranges by Florida counties.

County code[b]	Estimated regression coefficients[a]									
	b_1	b_2	b_3	b_4	b_5	b_6	b_7	b_8	R^2	d
1	-0.0021 (0.2824)	0.0014 (0.0446)	0.0701 (0.2127)	-0.0069 (0.1162)	-0.0420 (0.0609)	0.0031 (0.0747)	0.0126 (0.1679)	0.0106 (0.1455)	12	1.41
2	0.2102 (0.2675)	0.0104 (0.0158)	-0.0423 (0.1102)	-0.0454 (0.1995)	-0.0379 (0.0587)	0.0062 (0.0314)	-0.0371 (0.0287)	-0.0378 (0.0263)	32	2.56
3	-1.2110 (0.6038)	0.0161 (0.0151)	-0.4556 (0.2262)	0.0000 (0.2068)	1.5783 (0.7443)	-0.0437 (0.0348)	-0.0341 (0.0369)	0.0939 (0.0353)	67	2.38
4	0.0610 (0.1791)	0.0181 (0.0134)	0.0158 (0.0265)	-0.1638 (0.0724)	0.0248 (0.0922)	-0.0001 (0.0299)	-0.0343 (0.0326)	0.0275 (0.0260)	50	2.61
5	-0.3295 (0.2732)	0.0750 (0.0218)	0.4057 (0.2047)	-0.1490 (0.0750)	0.0818 (0.0645)	-0.0892 (0.0388)	-0.1446 (0.0447)	-0.1275 (0.0408)	76	1.74
6	0.2972 (0.1214)	-0.0400 (0.0141)	-0.1298 (0.0499)	-0.0261 (0.0264)	0.0217 (0.0295)	0.1131 (0.1052)	0.3113 (0.1085)	0.2293 (0.0834)	70	2.05
7	0.0996 (0.4431)	0.0328 (0.0296)	-0.1368 (0.4108)	-0.3079 (0.1482)	0.4322 (0.3997)	-0.0950 (0.0715)	-0.1762 (0.1128)	-0.0646 (0.0632)	56	2.52
8	-0.0336 (0.3041)	0.0501 (0.0295)	0.3272 (0.2447)	-0.1869 (0.0945)	0.0134 (0.1006)	-0.1275 (0.1144)	-0.3558 (0.1633)	-0.0787 (0.1262)	60	2.91

Table 21: Continued.

County code[b]	Estimated regression coefficients[a]								R^2	d
	b_1	b_2	b_3	b_4	b_5	b_6	b_7	b_8		
9	-0.0997 (0.1754)	-0.0176 (0.0235)	0.6433 (0.2657)	0.0475 (0.0991)	-0.4363 (0.2099)	-0.1199 (0.0372)	0.0163 (0.0307)	-0.0691 (0.0418)	66	1.77
10	0.0789 (0.5092)	0.0227 (0.0475)	-0.1390 (0.3813)	-0.0722 (0.1568)	0.0932 (0.2715)	-0.1624 (0.0808)	-0.1360 (0.1894)	-0.0807 (0.1095)	38	1.74
11	-0.7415 (0.5089)	0.0759 (0.0340)	-0.2602 (0.4719)	-0.1980 (0.1703)	1.3220 (0.4590)	-0.0124 (0.0821)	-0.3800 (0.1295)	-0.1405 (0.0726)	76	2.86
12	0.1978 (0.7417)	-0.0191 (0.0395)	0.2462 (0.5982)	-0.0061 (0.1193)	0.0297 (0.2898)	-0.2284 (0.1100)	-0.0290 (0.1289)	-0.0426 (0.0716)	41	2.36
13	-0.4009 (0.4166)	-0.0080 (0.0143)	0.0536 (0.1117)	-0.0063 (0.0500)	0.3266 (0.3376)	-0.1421 (0.0563)	-0.0052 (0.0046)	0.0482 (0.0615)	51	2.19
14	0.6142 (0.2538)	0.0326 (0.0192)	-0.0409 (0.0451)	-0.2629 (0.1010)	-0.2753 (0.1753)	-0.0433 (0.0262)	-0.0687 (0.0311)	-0.0106 (0.0218)	63	1.38
15	-0.3208 (0.6214)	0.0290 (0.0376)	0.0000 (0.2840)	0.0494 (0.0815)	0.2087 (0.4127)	-0.1152 (0.2539)	-0.0631 (0.0520)	-0.0451 (0.0346)	58	2.86
16	-0.0037 (0.1095)	0.0066 (0.0144)	-0.0081 (0.0225)	0.0257 (0.0552)	-0.0131 (0.0299)	0.1037 (0.0868)	0.0794 (0.1220)	-0.0560 (0.0954)	33	2.33

Table 21: Continued.

County code[b]	Estimated regression coefficients[a]								R^2	d
	b_1	b_2	b_3	b_4	b_5	b_6	b_7	b_8		
17	-0.7464 (0.2633)	0.0263 (0.0157)	0.4264 (0.1874)	0.0693 (0.0424)	0.0962 (0.0745)	-0.0630 (0.0526)	-0.1362 (0.0516)	-0.1239 (0.0530)	75	1.81
18	0.0796 (0.3859)	-0.0048 (0.0377)	0.0210 (0.2217)	0.0649 (0.1499)	0.0728 (0.2345)	-0.1198 (0.0423)	-0.0306 (0.0310)	-0.0253 (0.0167)	69	2.03

[a] Standard errors are in parentheses. See pages 88 to 92 for discussion of derivation of these estimates.

[b] See Table 5 (p. 70) for names associated with code numbers.

Only 19 equations had one or more estimated coefficients significant at the .05 level (t-test). However, of the 288 coefficients estimated (eight per equation) 141 had t-values greater than 1.0. Disregarding the intercept, 130 of 252 (over 50 percent) had t-values in excess of 1.0. Only two equations (Orange county for Early and Midseason oranges and Brevard county for Valencia oranges) had no coefficients with t- values greater than 1.0.

The signs of the coefficients for a particular variable (see the columns of Tables 20 and 21) behave quite erratically. However, some order does exist when counties are grouped by areas. Tables 22 and 23 are presented to aid in the discussion of these estimates by areas.

When only those estimates of Table 23 with absolute values for the t statistic in excess of 1.0 are considered, the directions of the relationships are as expected in a majority of the cases.

Early and Midseason

For Early and Midseason oranges B_2 was estimated positive 11 times and negative only once indicating a positive marginal response to adequate soil moisture in the first quarter. Only four of the eighteen coefficients for the soil moisture variable in the second quarter (B_3) had t-values in excess of 1.0.[1] This result probably indicates that normal rainfall patterns supplemented by irrigation has provided enough soil moisture in the second quarter over the years covered by this study so that variation in the yields of Early

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[1] In the remainder of this paper reference to t-values in excess of 1.0 refers to absolute values in excess of 1.0.

Table 22: Counties included in the study by areas.[a]

Area			Counties
Area 1:	East Coast	1	Brevard
		6	Indian River
		16	St. Lucie
		18	Volusia
Area 2:	West Coast	5	Hillsborough
		8	Manatee
		12	Pasco
		13	Pinellas
Area 3:	Lower Interior	2	DeSoto
		3	Hardee
		4	Highlands
Area 4:	Upper Interior	7	Lake
		9	Marion
		10	Orange
		11	Osceola
		14	Polk
		15	Putnam
		17	Seminole

[a]This grouping differs slightly from the usual grouping employed by the Florida Crop and Livestock Reporting Service.

Table 23: Signs of estimated regression coefficients for Stage II equations by varieties (macro), areas, and counties.[a]

Area code[b]	County code[c]	Early and Midseason (including Temples) b_2	b_3	b_4	b_5	b_6	b_7	b_8	Valencia b_2	b_3	b_4	b_5	b_6	b_7	b_8
		Variety													
1	1	0	0	+	-	+	0	0	0	0	0	0	0	0	0
1	6	0	0	0	0	+	+	+	-	-	0	0	+	+	+
1	16	0	0	0	0	+	+	+	0	0	0	0	+	0	0
1	18	+	0	0	0	-	-	-	0	0	0	0	-	0	-
2	5	+	0	-	0	0	-	-	+	+	-	+	-	-	-
2	8	+	0	-	0	0	-	0	+	+	-	0	-	-	0
2	12	-	0	0	0	0	+	0	0	0	0	0	-	0	0
2	13	0	0	0	0	-	0	0	0	0	0	0	-	-	0
3	2	+	0	0	-	+	-	0	0	0	0	0	0	-	-
3	3	+	-	0	+	+	0	+	+	-	0	+	-	0	+
3	4	+	0	0	0	+	0	+	+	0	-	0	0	-	+
4	7	+	-	-	+	0	-	+	+	0	-	+	-	-	-
4	9	0	+	+	0	-	0	-	0	+	0	-	-	0	-
4	10	0	0	0	0	0	0	0	0	0	0	0	-	0	0
4	11	+	-	-	0	+	-	-	+	0	-	+	0	-	-
4	14	+	0	-	-	+	-	-	+	0	-	-	-	-	0
4	15	+	0	+	0	-	-	-	0	0	0	0	-	-	-
4	17	+	0	0	0	0	-	-	+	+	+	+	-	-	-

[a]Zeros indicate that the t statistic had an absolute value less 1.

[b]Area code 1 = East Coast, 2 = West Coast, 3 = Lower Interior, 4 = Upper Interior.

[c]See Table 5 (p.70) for names of counties associated with each number.

and Midseason oranges was not significantly affected by variations in soil moisture.

The expected sign for the coefficients of the soil moisture variable in the third and fourth quarters was negative. While more estimates were negative than positive in both quarters, the results were inconclusive.

Estimates for the variable measuring the freeze effect in the current year (B_6) appears at first glance to be reversed with eight positive and four negative. However, during the years covered in this study, only two major freezes occurred and both came after all or the majority of the Early and Midseason oranges had been harvested. The positive signs could have resulted for two reasons. First, the freezing temperatures were experienced after harvest in which case the coefficients measure a relationship which did not exist. Second, in the case of the more southern counties (note that all three counties of the lower interior section indicated a positive response) the low temperatures probably existed for only a few minutes shortly before sunrise and were not sustained for the length of time necessary to cause damage. The positive estimates of B_6 should certainly not be interpreted to mean that if a freeze occurred in October or November it would have a positive effect on the current crop.

It should be pointed out that the four negative estimates occurred in the northern counties of Volusia, Pinellas, Marion, and Putnam. These estimates would come closer to describing the true relationship between freezing temperatures and current production since these counties probably experience low temperatures of sufficient duration to cause damage to the current crop.

The results indicated by estimates B_7 and B_8 are quite clear. Freezing temperatures have a negative effect on the production of Early and Midseason oranges for at least two years after the freeze. Of the seven signs which were positive, four occurred in the southern counties of Indian River and St. Lucie where most of the minimum temperatures observed probably existed for only a few minutes. In such cases one would not expect a negative lagged effect.

Valencia

For Valencia oranges the results were approximately the same. The estimates of B_2 indicate a positive marginal response to adequate soil moisture in the first quarter with eight positive and only one negative. As with Early and Midseason oranges the results indicated by the estimates of B_3 were inconclusive with four positive and two negative. Again, this would seem to indicate that during the second quarter normal rainfall patterns supplemented with irrigation provided sufficient soil moisture so that fruit production was not significantly affected by variations in soil moisture. As expected the results indicated a negative marginal response to the soil moisture variable in the third quarter with six negative and only one positive. However, the fact that eleven of the eighteen estimates had t-values which were less than 1.0 only provides a basis for conjecture and not for substantive argument. The expected sign for B_5 was negative. However, five were positive and two were negative. This seemingly inconsistent result may be traceable to a confounding of temperature - soil moisture effects.

The results indicated by the estimates of B_6, B_7, and B_8 were as expected. The production of Valencia oranges was negatively related to freezing temperatures in the current season and for at least two lagged seasons. The six estimates which were positive were all in the southern counties of Indian River, St. Lucie, Hardee and Highlands where the minimum temperature observed probably did not exist long enough for serious damage.

To reduce the difficulties associated with presenting the results of weather equations the following three terms were defined. Actual production denotes reported production. Expected production refers to estimated average production from Stage I of the model. It is based on tree numbers by age and estimated average yield. Estimated production refers to production estimated with the additional information from Stage II. It is the estimated value of actual production and is based on expected or estimated average production adjusted for weather. For example, if the expected production for a given county was 200 units and the predicted signed percentage deviation of expected from actual production was -.10 then the estimated production would be 180 units.

Actual and estimated production figures are reported in Tables 24 and 25 for counties and in Table 26 for the study area. Expected (estimated average) production are also included in these later tables for purposes of comparison.

The forecasting ability of the estimating procedure is expressed in terms of percent error in Tables 27 and 28. As expected, the addition of Stage II and the available weather information helped to explain more of the variation in production by variety (macro) and county.

Table 24: Actual and estimated production of Early and Midseason oranges (including Temples) by Florida counties and by seasons, 1951-52 through 1967-68 (in thousands of boxes).

County	Brevard			DeSoto			Hardee		
		Stage			Stage			Stage	
Season	Actual[a]	I[b]	II[c]	Actual	I	II	Actual	I	II
1951-52	1,250	1,733	1,586	1,047	1,609	1,445	1,627	2,275	1,888
1952-53	1,562	1,802	1,411	1,239	1,630	1,137	1,805	2,321	2,571
1953-54	1,421	1,908	1,511	1,453	1,680	1,449	2,334	2,383	2,334
1954-55	1,217	1,933	1,769	1,476	1,706	1,646	2,332	2,425	2,140
1955-56	1,462	1,969	1,802	1,441	1,742	1,680	2,232	2,486	2,194
1956-57	1,591	2,010	1,815	1,217	1,725	1,041	2,270	2,428	2,015
1957-58	1,554	1,551	1,561	1,410	1,122	1,455	2,710	2,118	2,983
1958-59	1,605	1,563	1,611	1,386	1,118	1,333	2,597	2,168	2,734
1959-60	1,611	1,121	1,309	1,392	1,066	932	2,650	2,164	2,505
1960-61	1,566	1,297	1,534	1,132	1,131	1,119	2,760	2,363	2,612
1961-62	1,637	1,358	1,280	1,422	1,133	1,401	3,834	2,782	4,020
1962-63	2,074	1,465	2,072	1,308	1,150	1,313	3,578	2,918	3.238
1963-64	1,867	1,524	1,814	467	1,074	822	1,263	2,692	1,443
1964-65	1,521	1,175	1,609	1,236	1,185	1,327	3,625	2,061	3,349
1965-66	1,901	1,534	1,404	1,252	1.248	1,129	3,424	3,942	3,378
1966-67	1,900	1,589	2.114	1,845	1,433	1,621	5,120	4,421	4,575
1967-68	1,700	1,650	1,651	1,630	1,576	1,623	4,950	4,947	4,667

Table 24: Continued.

County	Highlands			Hillsborough			Indian River		
		Stage			Stage			Stage	
Season	Actual[a]	I[b]	II[c]	Actual	I	II	Actual	I	II
1951-52	1,156	1,192	1,026	2,253	2,205	1,878	608	556	476
1952-53	1,102	1,297	1,251	2,112	2,405	2,256	630	620	668
1953-54	1,147	1,395	1,218	2,360	2,650	2,360	581	707	741
1954-55	1,189	1,460	1,229	2,901	2,722	2,727	566	697	688
1955-56	969	1,523	1,518	2,953	2,716	3,084	607	751	861
1956-57	1,296	1,227	1,171	3,057	2,965	3,169	688	819	894
1957-58	1,647	1,349	1,587	3,225	2,748	3,132	799	629	910
1958-59	1,584	1,369	1,643	3,016	2,764	2,539	663	665	925
1959-60	1,570	1,396	1,647	3,094	2,765	3,187	674	676	716
1960-61	1,328	1,424	1,378	3,010	3,009	3,010	661	703	644
1961-62	2,013	1,426	1,558	3,471	3,201	3,567	863	617	702
1962-63	2,327	1,490	2,440	2,181	3,341	2,261	1,135	637	1,023
1963-64	1,336	1,469	1,420	738	2,417	1,223	1,029	689	907
1964-65	1,707	1,260	1,663	2,370	1,852	2,376	837	676	907
1965-66	1,727	1,792	1,740	2,289	3,845	3,275	1,079	665	728
1966-67	2,480	1,943	2,128	5,405	4,305	5,238	1,090	689	941
1967-68	2,253	2,104	2,180	3,426	4,758	2,418	1,124	716	1,005

Table 24: Continued.

County	Lake			Manatee			Marion		
		Stage			Stage			Stage	
Season	Actual	I	II	Actual	I	II	Actual	I	II
1951-52	6,310	5,949	5,638	268	511	463	2,384	2,544	2,850
1952-53	5,606	6,528	6,921	429	527	465	2,301	2,501	2,642
1953-54	6,915	6,855	6,882	568	521	559	3,143	2,579	3,143
1954-55	7,737	7,059	6,690	425	531	537	3,023	2,591	3,029
1955-56	9,155	7,247	7,276	427	538	488	3,068	2,559	3,016
1956-57	9,224	9,349	9,224	518	573	520	3,264	2,692	3,191
1957-58	9,725	8,284	8,014	647	469	470	2,486	2,424	2,000
1958-59	8,836	8,756	8,977	596	461	650	1,983	2,461	2,195
1959-60	9,094	8,345	8,960	584	465	557	2,052	2,205	2,052
1960-61	9,270	9,271	10,094	558	511	522	2,684	2,567	2,454
1961-62	9,935	9,609	11,361	638	526	559	2,633	2,604	2,204
1962-63	6,861	9,169	7,467	390	520	521	1,018	2,099	1,736
1963-64	4,501	6,553	5,131	136	461	229	1,160	1,395	1,362
1964-65	7,616	4,570	6,992	489	309	499	1,754	1,244	1,754
1965-66	8,310	12,185	13,163	462	580	526	2,052	2,120	2,080
1966-67	13,415	13,037	11,159	1,115	658	564	3,265	2,201	2,208
1967-68	7,690	13,879	8,274	753	749	766	1,748	2,287	1,919

Table 24: Continued.

County	Orange			Oseceola			Pasco		
		Stage			Stage			Stage	
Season	Actual	I	II	Actual	I	II	Actual	I	II
1951-52	8,063	7,001	6,950	708	740	701	1,137	825	1,137
1952-53	7,286	7,435	7,702	626	786	820	1,161	934	1,131
1953-54	8,997	7,942	8,398	883	789	785	1,697	1,020	1,697
1954-55	9,529	8,050	7,992	825	817	773	1,760	1,111	1,457
1955-56	9,096	8,207	8,325	879	798	794	1,765	1,235	1,618
1956-57	9,187	8,100	9,187	1,068	871	1,068	2,340	1,279	1,812
1957-58	8,636	8,002	7,563	1,309	1,037	1,197	1,588	1,593	1,448
1958-59	7,706	8,396	7,706	1,028	1,030	1,122	1,340	1,634	1,577
1959-60	8,069	7,707	7,871	1,033	1,001	941	1,594	1,240	1,049
1960-61	8,368	8,364	9,442	1,170	1,081	1,284	1,812	1,714	1,998
1961-62	8,036	8,781	9,096	1,640	1,199	1,491	1,788	1,937	2,051
1962-63	6,124	7,175	6,765	1,545	1,426	1,667	1,091	1,513	1,224
1963-64	4,058	5,596	4,765	574	1,212	594	460	1,066	1,350
1964-65	5,703	5,007	4,738	945	1,081	912	1,489	663	1,063
1965-66	6,938	8,797	8,923	975	1,431	1,318	1,512	1,936	2,911
1966-67	10,605	9,085	8,883	1,665	1,580	1,423	3,400	2,089	2,538
1967-68	5,833	9,404	8,792	1,011	1,733	1,052	2,045	2,267	2,913

Table 24: Continued.

County	Pinellas			Polk			Putnam		
		Stage			Stage			Stage	
Season	Actual	I	II	Actual	I	II	Actual	I	II
1951-52	669	725	754	8,266	8,287	7,353	803	922	803
1952-53	667	752	775	7,713	8.741	7,713	908	943	979
1953-54	788	788	788	9,870	9,337	9,940	1,022	973	1,136
1954-55	1,110	786	817	9,780	9,769	9,371	1,176	998	995
1955-56	772	787	804	8,883	10,048	10,697	1,165	1,013	1,227
1956-57	796	561	574	9,060	9,074	9,182	1,034	1,032	1,249
1957-58	818	717	895	10,526	9,121	10,787	656	737	533
1958-59	746	652	688	9,469	9,420	9,041	319	702	507
1959-60	762	631	717	9,661	8,427	10,163	386	540	393
1960-61	680	692	635	8,827	9,868	8,827	748	618	780
1961-62	417	613	615	10,722	10,259	11,905	633	653	630
1962-63	239	441	231	9,840	9,571	9,244	239	561	327
1963-64	95	205	186	4,752	8,979	6,413	414	380	443
1964-65	230	203	234	10,251	7,975	9,485	583	363	569
1965-66	261	376	384	11.516	11,743	10,031	725	681	701
1966-67	560	382	372	15,510	12,443	14,565	1,110	691	669
1967-68	338	389	330	13,895	13,121	13,475	527	704	551

Table 24: Continued

County	St. Lucie			Seminole			Volusia		
		Stage			Stage			Stage	
Season	Actual	I	II	Actual	I	II	Actual	I	II
1951-52	1,093	1,021	984	1,245	1,352	1,421	2,452	2,350	2,363
1952-53	1,151	1,221	1,163	1,137	1,119	1,300	2,447	2,411	2,740
1953-54	1,043	1,369	1,321	1,414	1,169	1,639	2,673	2,450	2,716
1954-55	1,173	1,364	1,348	1,437	1,169	1,316	2,897	2,497	2,427
1955-56	1,055	1,485	1,400	1,506	1,105	1,325	2,902	2,481	2,631
1956-57	1,578	1,465	1,373	1,872	1,217	1,397	2,914	2,503	2,951
1957-58	1,787	1,674	1,596	1,037	1,424	1,471	1,137	1,935	1,209
1958-59	1,807	1,725	1,682	851	1,456	1,102	711	1,975	736
1959-60	1,825	1,813	1,729	1,069	1,244	1,069	973	1,958	904
1960-61	1,622	1,902	1,787	1,809	1,303	1,891	2,003	2,005	1,765
1961-62	1,796	1,684	1,638	2,428	1,513	1,922	1,718	2,016	1,974
1962-63	2,361	1,625	2,361	1,158	1,635	1,058	876	1,516	854
1963-64	2,507	1,808	2,507	763	1,184	552	827	1,138	1,030
1964-65	2,190	1,709	2,190	1,151	1,250	1,130	1,187	1,063	1,103
1965-66	2,642	2,356	2,257	1,326	1,301	1,514	1,441	1,602	1,535
1966-67	2,580	2,581	2,532	2,090	1,350	1,840	2,220	1,644	1,703
1967-68	2,399	2,803	2,685	1,087	1,404	1,480	1,127	1,687	1,683

[a] Actual or reported annual production.

[b] Estimated average production from Stage I.

[c] Estimated production from Stage II.

Table 25: Actual and estimated production of Valencia oranges by Florida counties and by seasons, 1951-52 through 1967-68 (in thousands of boxes).

County	Brevard			DeSoto			Hardee		
		Stage			Stage			Stage	
Season	Actual[a]	I[b]	II[c]	Actual	I	II	Actual	I	II
1951-52	525	742	757	545	560	592	909	828	712
1952-53	637	765	647	553	566	534	806	846	971
1953-54	784	775	695	640	612	608	1,017	868	1,017
1954-55	565	818	835	610	625	684	732	909	874
1955-56	657	848	865	605	654	716	932	931	893
1956-57	680	870	809	632	712	622	940	1,187	1,021
1957-58	701	701	717	441	662	602	745	950	971
1958-59	831	792	825	640	661	711	958	960	924
1959-60	834	741	822	682	675	576	1,057	958	1,052
1960-61	855	817	825	618	757	767	922	1,151	1,164
1961-62	1,243	882	901	1,247	837	892	2,764	1,719	2,146
1962-63	981	950	975	585	864	677	1,531	2,229	1,430
1963-64	1,044	1,045	1,044	647	853	637	1,201	2,125	1,211
1964-65	749	783	824	991	989	921	1,991	1,325	2,043
1965-66	1,010	802	818	1,210	1,147	1,214	2,290	2,406	2,272
1966-67	983	834	990	1,610	1,303	1,405	3,209	2,719	2,781
1967-68	1,228	883	905	1,505	1,442	1,352	3,010	2,980	2,943

Table 25: Continued.

County	Highlands			Hillsborough			Indian River		
		Stage			Stage			Stage	
Season	Actual	I	II	Actual	I	II	Actual	I	II
1951-52	2,324	2,171	2,212	1,457	1,471	1,382	542	597	541
1952-53	1,889	2,282	2,182	1,361	1,531	1,464	617	624	666
1953-54	2,913	2,402	2,653	2,211	1,653	2,211	757	661	742
1954-55	2,398	2,461	2,674	2,043	1,716	1,860	675	677	702
1955-56	2,496	2,455	2,436	2,184	1,797	2,218	720	724	784
1956-57	2,230	2,917	2,861	2,293	1,872	2,170	738	779	872
1957-58	1,850	2,800	1,802	1,970	1,971	2,381	744	752	742
1958-59	2,608	2,604	2,805	2,855	2,029	2,255	781	754	810
1959-60	2,647	2,452	2,563	2,934	1,935	2,531	822	780	809
1960-61	1,876	2,752	1,979	2,340	2,259	2,340	755	800	762
1961-62	3,906	2,898	2,776	3,046	2,660	3,060	948	758	791
1962-63	3,029	3,392	3,278	846	2,459	509	828	671	830
1963-64	2,747	3,298	2,797	337	1,816	1,020	1,156	769	1,081
1964-65	3,192	2,744	3,174	1,261	1,411	1,509	831	721	847
1965-66	4,340	4,325	4,065	2,050	3,002	2,821	1,080	981	927
1966-67	5,204	4,629	4,823	4,145	3,243	4,083	1,031	1,032	1,090
1967-68	4,408	4,942	4,996	2,233	3,499	1,443	1,488	1,096	1,482

Table 25: Continued

County	Lake			Manatee			Marion		
		Stage			Stage			Stage	
Season	Actual	I	II	Actual	I	II	Actual	I	II
1951-52	3,558	3,060	3,426	474	443	518	252	229	268
1952-53	3,023	3,233	3,831	444	445	527	231	231	210
1953-54	3,824	3,467	3,996	666	438	646	258	235	258
1954-55	3,917	3,694	4,137	510	439	557	281	247	281
1955-56	6,329	3,839	4,424	509	448	525	285	273	296
1956-57	6,378	6,583	6,378	435	453	530	286	270	283
1957-58	5,950	5,125	4,765	402	307	281	145	223	93
1958-59	8,606	6,888	9,306	494	301	553	236	226	233
1959-60	8,986	6,664	8,309	496	291	467	249	192	249
1960-61	7,582	7,524	8,326	326	345	318	318	244	242
1961-62	10,897	8,703	10,058	655	387	511	323	365	244
1962-63	4,142	9,073	5,410	160	411	268	69	318	197
1963-64	5,053	6,674	4,962	82	334	123	164	226	200
1964-65	7,485	7,182	7,039	323	248	319	241	306	241
1965-66	6,400	10,048	10,931	510	547	640	210	305	240
1966-67	10,631	10,648	9,426	1,079	608	617	347	322	336
1967-68	5,594	11,218	5,674	570	677	739	198	339	244

Table 25: Continued.

County	Orange			Osceola			Pasco		
		Stage			Stage			Stage	
Season	Actual	I	II	Actual	I	II	Actual	I	II
1951-52	5,029	3,985	3,920	355	233	279	1,558	1,033	1,558
1952-53	4,051	4,157	4,278	281	258	348	1,299	1,209	1,705
1953-54	5,541	4,463	4,695	471	264	336	2,097	1,272	2,097
1954-55	5,275	4,524	4,450	268	278	333	2,277	1,330	1,926
1955-56	5,491	4,800	4,830	287	287	366	2,462	1,419	2,056
1956-57	5,221	4,748	5,221	654	297	654	2,781	1,510	2,044
1957-58	3,313	4,631	3,051	616	441	518	1,401	1,869	1,000
1958-59	4,388	4,925	4,388	812	494	913	1,982	1,985	1,755
1959-60	5,062	4,507	4,526	832	469	736	2,150	1,552	1,622
1960-61	4,576	5,195	5,285	985	560	943	1,911	2,016	2,449
1961-62	5,036	6,028	6,204	1,511	1,103	1,643	3,838	2,591	3,506
1962-63	2,474	5,140	2,668	1,053	1,380	1,165	768	2,721	1,352
1963-64	3,098	3,892	3,214	517	1,109	498	348	1,814	1,968
1964-65	4,482	4,261	3,610	892	920	865	1,176	833	749
1965-66	3,830	5,700	5,736	700	811	920	1,860	2,481	2,988
1966-67	5,918	5,879	5,655	1,252	880	1,080	3,865	2,644	3,045
1967-68	2,956	6,064	5,538	658	954	788	2,034	2,814	3,421

Table 25: Continued.

County	Pinellas			Polk			Putnam		
		Stage			Stage			Stage	
Season	Actual	I	II	Actual	I	II	Actual	I	II
1951-52	929	827	798	10,876	9,858	9,444	166	151	166
1952-53	781	851	815	8,895	10,114	8,895	146	153	151
1953-54	1,090	855	1,090	12,317	10,287	11,653	170	153	166
1954-55	1,056	892	860	10,431	10,547	11,261	163	164	158
1955-56	863	923	876	11,026	10,801	12,236	163	175	194
1956-57	750	749	711	9,220	11,511	12,665	176	174	194
1957-58	600	845	804	7,357	10,816	7,785	85	188	74
1958-59	791	747	659	8,990	10,182	9,548	81	188	150
1959-60	845	731	710	10,555	8,898	10,281	102	108	83
1960-61	676	782	667	7,576	9,978	7.576	146	131	140
1961-62	648	821	766	14,142	11,434	12,335	191	181	157
1962-63	85	622	60	8,114	11,876	8,348	31	165	49
1963-64	60	348	288	8,975	11,570	9,598	115	79	81
1964-65	230	212	239	10,884	9,759	11,669	148	148	180
1965-66	410	550	522	16,880	14,069	13,905	120	149	147
1966-67	761	559	503	18,554	14,522	16,561	212	156	148
1967-68	387	570	365	14,956	14,961	15,087	105	162	133

Table 25: Continued.

County	St. Lucie			Seminole			Volusia		
		Stage			Stage			Stage	
Season	Actual	I	II	Actual	I	II	Actual	I	II
1951-52	1,009	1,216	1,185	460	393	477	1,096	798	924
1952-53	1,112	1,229	1,189	384	414	382	851	808	937
1953-54	1,364	1,340	1,376	582	405	530	1,179	836	1,206
1954-55	1,124	1,358	1,220	497	439	394	1,258	866	1,016
1955-56	1,196	1,364	1,391	540	494	469	1,216	871	1,036
1956-57	1,644	1,458	1,449	636	522	569	1,024	882	1,117
1957-58	1,665	1,655	1,646	380	606	414	203	710	280
1958-59	1,851	1,642	1,729	437	636	436	253	726	340
1959-60	1,904	1,661	1,680	609	511	609	408	691	364
1960-61	1,696	1,805	1,923	678	681	878	745	784	720
1961-62	2,213	1,724	1,731	911	836	756	823	898	920
1962-63	2,096	1,726	2,096	342	1,060	396	396	719	320
1963-64	2,318	1,895	2,318	368	710	372	546	453	422
1964-65	1,761	1,881	1,761	514	647	432	672	672	687
1965-66	2,440	2,444	2,478	430	630	554	570	722	821
1966-67	2,410	2,714	2,855	704	659	710	896	746	729
1967-68	3,350	3,004	3,045	346	687	550	468	770	814

[a]Actual or reported annual production.

[b]Estimated average production from Stage I.

[c]Estimated production from Stage II.

Table 26: Total actual and estimated production of Florida oranges for the study area by variety (macro) 1951-52 through 1967-68 (in thousands of boxes).[a]

	Variety					
	Early and Midseason (including Temples)			Valencia		
Season	Actual	Estimated Stage I	Estimated Stage II	Actual	Estimated Stage I	Estimated Stage II
	---------------------1,000 boxes---------------------					
1951-52	41,339	41,797	39,716	32,064	28,595	29,159
1952-53	39,882	43,973	43,647	27,361	29,716	29,732
1953-54	48,309	46,515	48,617	37,881	30,986	35,975
1954-55	50,553	47,685	46,951	34,080	31,984	34,322
1955-56	50,337	43,690	50,740	37,961	33,604	36,611
1956-57	52,984	49,890	51,833	36,713	37,494	40,170
1957-58	51,697	46,934	48,811	28,568	35,252	27,926
1958-59	46,243	48,315	46,768	37,594	36,740	38,340
1959-60	48,093	44,764	46,701	41,174	33,816	37,989
1960-61	50,008	49,823	51,776	34,581	38,581	37,304
1961-62	55,624	52,011	57,974	54,342	44,825	49,397
1962-63	44,345	48,252	45,802	27,530	45,776	30,028
1963-64	26,947	39,852	42,191	28,776	39,009	31,834
1964-65	44,884	33,646	41,900	37,823	35,042	37,109
1965-66	49,832	58,134	56,997	46,340	51,119	51,999
1966-67	75,375	62,121	65,074	62,811	54,097	56,837
1967-68	53,636	66,178	57,464	45,494	57,062	49,519

[a] Counties in the study area accounted for over 93 percent of the state production during the seasons indicated (see Table 7).

Table 27: Total actual and estimated production of Florida Early and Midseason oranges (including Temples) for the study area with percent errors when actual production is estimated by Stages I and II, by seasons 1951-52 through 1967-68 (in thousands of boxes).

Season	Production: Actual	Estimated: Stage I	Estimated: Stage II	Percent error: Stage I	Percent error: Stage II
1951-52	41,339	41,797	39,716	-01	04
1952-53	39,882	43,973	43,647	-10	-09
1953-54	48,309	46,515	48,617	04	-01
1954-55	50,553	47,685	46,951	06	07
1955-56	50,337	43,690	50,740	13	-01
1956-57	52,984	49,890	51,833	06	02
1957-58	51,697	46,934	48,811	09	06
1958-59	46,243	48,315	46,768	-04	-01
1959-60	48,093	44,764	46,701	06	03
1960-61	50,008	49,823	51,776	01	-03
1961-62	55,624	52,011	57,974	06	-04
1962-63	44,345	48,252	45,802	-09	-03
1963-64	26,947	39,852	42,191	-48	-56
1964-65	44,884	33,646	41,900	25	07
1965-66	49,832	58,134	56,997	-17	-14
1966-67	75,375	62,121	65,074	18	14
1967-68	53,636	66,178	57,464	-23	-07

Table 28: Total actual and estimated production of Florida Valencia oranges for the study area with percent errors when actual production is estimated by Stages I and II, by seasons 1951-52 through 1967-68 (in thousands of boxes).

Season	Production: Actual	Estimated: Stage I	Estimated: Stage II	Percent error: Stage I	Percent error: Stage II
1951-52	32,064	28,595	29,159	11	09
1952-53	27,361	29,716	29,732	-09	-09
1953-54	37,881	30,986	35,975	18	05
1954-55	34,080	31,948	34,322	06	-01
1955-56	37,961	33,604	36,611	11	04
1956-57	36,718	37,494	40,170	-02	-09
1957-58	28,568	35,252	27,926	23	02
1958-59	37,594	36,740	38,340	02	-02
1959-60	41,174	33,816	37,989	18	08
1960-61	34,581	38,581	37,304	-12	-08
1961-62	54,342	44,825	49,397	18	09
1962-63	27,530	45,776	30,028	-66	-09
1963-64	28,776	39,009	31,834	-36	-10
1964-65	37,823	35,042	37,109	07	02
1965-66	46,340	51,119	51,999	-10	-12
1966-67	62,811	54,097	56,837	14	10
1967-68	45,494	57,062	49,419	-25	-09

By Groups of Counties and Variety (Macro)

The estimates (particularly their signs) presented in Tables 20 and 21 indicate considerable unexplained variability between counties. The data were pooled across counties in an attempt to obtain estimates of the structural relationship between production and weather consistent with a priori expectations based on what is known about the effect of weather on orange supplies. The pooling of data across counties made it possible to include more variables in the model. Other measures of soil moisture were included with the idea that perhaps two soil moisture variables--one to measure positive response such as number of days soil moisture was greater than or equal to 70 or 100 percent of field capacity, and one to measure negative response such as number of days the level of soil moisture was less than the wilting point but greater than zero might be included in the model for each quarter. The possibility that some soil moisture variable for the fifth quarter of the growing season might be significantly related to the production of Valencias was also investigated. Likewise, the single freeze variable used as a regressor in equation [15] was expanded in an effort to obtain more consistent estimates of the relationship between production and freezes of varying severities.

The freeze variable used as a regressor in equation [15] had been "arbitrarily" formed as a weighted sum of the number of days the minimum temperature was less than or equal to 26 F but greater than 24 F, less than or equal to 24 F but greater than 22 F, and less than or equal to 22 F. In the expanded equation a separate coefficient for each of the three levels of freeze severity was included.

To explore these possibilities ordinary least squares was used to fit the following model for Valencias only, using Valencia data of the 18 counties.

$$
\begin{aligned}
P_{2st} = {} & \underset{(0.403)}{.0823}^{1} + \underset{(0.199)}{.0008V_1} - \underset{(0.834)}{.0031V_2} + \underset{(0.614)}{.0018V_3} - \underset{(0.113)}{.0002V_4} \\
& + \underset{(2.508)}{.0117V_5} + \underset{(0.598)}{.0036V_6} - \underset{(0.516)}{.0017V_7} - \underset{(0.314)}{.0008V_8} + \underset{(0.301)}{.0005V_9} \\
& - \underset{(1.558)}{.0100V_{10}} + \underset{(0.653)}{.0038V_{11}} - \underset{(1.079)}{.0274V_{12}} - \underset{(0.362)}{.0097V_{13}} \\
& + \underset{(0.123)}{.0030V_{14}} - \underset{(0.792)}{.0049V_{15}} + \underset{(1.148)}{.0018V_{16}} + \underset{(0.135)}{.0006V_{17}} \qquad [16] \\
& + \underset{(0.101)}{.0007V_{18}} + \underset{(0.841)}{.0033V_{19}} + \underset{(0.435)}{.0006V_{20}} + \underset{(0.027)}{.0006V_{21}} \\
& - \underset{(0.600)}{.0260V_{22}} - \underset{(5.866)}{.3032V_{23}} + \underset{(6.152)}{.0126V_{24}} - \underset{(0.336)}{.0146V_{25}} \\
& - \underset{(4.024)}{.2045V_{26}} + \underset{(3.679)}{.0076V_{27}} + \underset{(0.117)}{.0130V_{28}} - \underset{(0.402)}{.0226V_{29}} \qquad R^2 = .35
\end{aligned}
$$

P_{2st} = signed percentage deviation of actual production of Valencia oranges in the s^{th} county and the t^{th} year from corresponding

---

[1]The estimated coefficients will be referred to as subscripted B's. For example, the estimated coefficient for V_{27} will be referred to as B_{27}. Numbers in parentheses are t-values.

expected of estimated average production. There were 306 observations--18 counties and 17 years.

V_j, $j=1,\ldots,5$ = number of days soil moisture was less than or equal to wilting point in j^{th} quarter of season.

V_j, $j=6,\ldots,10$ = number of days soil moisture was equal to zero in $(j-5)^{th}$ quarter of season.

V_j, $j=11,\ldots,15$ = number of days soil moisture equal to field capacity in $(j-10)^{th}$ quarter of season.

V_j, $j=16,\ldots,20$ = number of days soil moisture was greater than or equal to 70 percent of field capacity in $(j-15)^{th}$ quarter of season.

V_{21} = number of days minimum temperature was greater than 24 F but less than or equal to 26 F during winter of growing season.[1]

V_{22} = number of days minimum temperature was greater than 22 F but less than or equal to 24 F during winter of growing season.

V_{23} = number of days minimum temperature was less than or equal to 22 F during winter of growing season.

$V_{24} = V_{23} * V_{23}$

$V_{25} = V_{22}$ lagged one season.

$V_{26} = V_{23}$ lagged one season.

---

[1] Winter of growing season would include 4th and 5th quarters for Valencias.

$V_{27} = V_{24}$ lagged one season.

$V_{28} = V_{23}$ lagged two seasons.

$V_{29} = V_{24}$ lagged two seasons.

The most surprising result from estimating equation [16] was that the estimated coefficient for V_{21} (number of days minimum temperature was greater than 24 F but less than or equal to 26 F) was not significant and had a smaller t-value than any of the other variables. This result may reflect growers' use of freeze protection devices to the extent that temperatures were raised above the critical level in the groves. A second explanation is offered by the nature of the weather observation. Under normal conditions the temperature usually falls 3 to 4 F for 30 to 40 minutes around sunrise. Consequently, one might observe a minimum temperature in the range of 24 to 26 F when, in fact, the temperature was experienced for such a brief period that it had no effect on the trees or was beneficial.[1] Such temperatures under normal conditions would exist only for a short time, rather than for the four hours required to do serious damage.

The squared terms, V_{24}, V_{27}, and V_{29}, were placed in the model because results of the simple linear model (equation [15]) had consistently overestimated production in the freeze years. However, the coefficients of these variables were inconsistent in sign (positive) in two cases and the one negative coefficient was not

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[1]This brief exposure to cold might help condition the tree against future damage by inducing dormancy.

significantly different from zero. The signs of the coefficients of the other freeze variables were as expected, except for B_{28}.

Of the soil moisture variables considered the ones which measured the number of days soil moisture was greater than or equal to 70 percent of field capacity had estimated coefficients which were all positive. While not exactly consistent with prior expectations, the estimated coefficients could be rationalized.[1]

Due to signs which were inconsistent with expectations, efforts to include two soil moisture variables for each quarter, one to measure a positive response and one to measure a negative response, were abandoned.

Based on the information obtained from estimating equation [16], another model was formulated and estimated by OLS for Valencias only. The emphasis was on estimating the interactions among adequate soil moisture and freezing temperatures in the winter months. Seventeen variables were included in the model.

$$P_{2st} = \underset{(1.396)}{.0823} + \underset{(1.982)}{.0017V_{16}} + \underset{(1.819)}{.0053V_{17}} - \underset{(0.571)}{.0020V_{18}}$$

$$+ \underset{(0.734)}{.0018V_{19}} - \underset{(2.566)}{.0022V_{20}}$$

---

[1]Adequate soil moisture stimulates growth. However, too much soil moisture when the fruit is nearing maturity (winter months) may prohibit it from reaching legal maturity standards and will increase freeze damage (83). Levels of soil moisture in the winter months which do not keep the fruit from maturity and not accompanied by low temperatures could account for the signs of all the estimated coefficients being positive.

$$- .0138V_{22} - .3543V_{23} + .0124V_{24}$$
$$(0.330) \quad (1.177) \quad (5.244)$$

$$+ .0261V_{25} - .2654V_{26} + .0081V_{27} \qquad [17]$$
$$(0.590) \quad (0.850) \quad (3.526)$$

$$- .0981V_{28} + .0275V_{29} + .0008V_{30}$$
$$(1.142) \quad (0.641) \quad (0.159)$$

$$+ .0007V_{31} + .0143V_{32} + .0004V_{33}$$
$$(0.200) \quad (1.127) \quad (0.109) \qquad R^2 = .29$$

The variables in this equation have the same meaning as they do in equation [16], except:

V_{30} = interaction between V_{22} and V_{19}

V_{31} = interaction between V_{22} and V_{20}

V_{32} = V_{30} lagged one season

V_{33} = V_{31} lagged one season

The interaction terms V_{30}, V_{31}, V_{32} and V_{33} were included because soil moisture tends to stimulate growth and deter dormancy during the winter months, thereby making the trees more susceptible to freezing temperatures. However, the signs of the estimated coefficients for interaction terms were inconsistent (positive) with a priori knowledge. The signs of the soil moisture variables became negative for the 3rd and 5th quarter. The effect of these variables may have been confounded with the interaction terms. The estimates of the coefficients for the squared temperature terms remained positive. This result would indicate that over the years studied some freezes that lasted fewer days than others actually did more damage. Some of the temperature variables reversed themselves and became positive. A problem of multicollinearity between the soil moisture variables for the 5th quarter and freezing winter temperatures was expected. If adequate soil moisture during the winter months and low winter temperatures were positively related, the inconsistent signs on the interaction terms would be easier to explain. The largest simple correlation coefficient involved was .30 and did indicate a positive relationship. However, its level would not lead one to suspect serious multicollinearity problems.

Because the estimated coefficient for the soil moisture variable in the 5th quarter was highly significant, the interactions variables (V_{30} through V_{32}) and the squared temperature variables (V_{24}, V_{27}, and V_{29}) were removed from equation [17] and the model reestimated. The results were:

$$\begin{aligned} P_{2st} = {} & \underset{(2.308)^{1}}{.1392} + \underset{(2.064)}{.0017V_{16}} + \underset{(2.201)}{.0067V_{17}} - \underset{(0.016)}{.0001V_{18}} + \underset{(0.180)}{.0004V_{19}} \\ & - \underset{(5.148)}{.0044V_{20}} - \underset{(1.737)}{.0722V_{22}} - \underset{(0.025)}{.0003V_{23}} - \underset{(2.643)}{.0311V_{26}} \qquad [18] \\ & - \underset{(0.024)}{.0011V_{28}} \qquad R^2 = .15 \end{aligned}$$

The variables in this equation have the same meaning as in equation [16].

The F-value for equation [18] indicated that the regression was

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[1]Parentheses enclose t-values.

highly significant. The significant coefficients for V_{16} and V_{17} agree with the a priori information that adequate soil moisture is important during the first six months of the year.[1] The significant negative coefficient for V_{20} is probably measuring an interaction between adequate soil moisture and freeze damage rather than a simple negative response to soil moisture. However, too much soil moisture near maturity may prevent the fruit from maturing. The signs of the temperature variables are all consistent and the magnitudes are about as expected except for the coefficient of V_{23}. One would expect the coefficient for V_{23} to be more negative than the coefficient for V_{22}.[2]

Equation [18] provides additional information on the structural relationship between production and weather. However, as indicated by its low R^2 it would not be useful for forecasting total state production of Valencia oranges.

Equation [18] was fit to the Early and Midseason data with V_{20} removed. The results were:

$$P_1st = .0015 + .0002V_{16} - .0006V_{17} + .0072V_{18} - .0018V_{19} \quad [19]$$
$$\qquad (0.033)\ (0.224)\quad (0.209)\quad (1.975)\quad (0.765)$$

$$+ .0527V_{22} + .0087V_{23} - .0182V_{26} + .0610V_{28} \qquad R^2 = .04$$
$$\quad (0.851)\quad (0.792)\quad (1.624)\quad (1.487)$$

---

[1] Supra, p. 47.

[2] The difficulty with the relative size of the coefficients of V_{22} and V_{23} was not due to their being correlated. Their simple correlation coefficient was .08.

P_1st is defined here for Early and Midseason oranges as it was in equation [16] for Valencia.

The F-value for equation [19] was not significant. Equation [19] indicates that there has not been enough observations on freezing temperatures to estimate an unlagged relationship between the production of Early and Midseason oranges and freezes for the state as a whole.

The possibility of using dummy variables to estimate regional differences in the relationship between production and weather was considered. Equation [18] was reformulated by adding three dummy variables to measure regional differences. The first ten variables remained as defined for equation [18]. V_{34} took on the value 1 if an observation was from the East Coast[1] and zero otherwise. V_{35} and V_{36} were defined for the West Coast and Upper Interior in an analogous manner. The average effect for the Lower Interior was included in the intercept. The results were disappointing. None of the dummy variables were significant at the .05 level and the R^2 value was only increased from .15 to .16. The sign of the freeze variable lagged twice (V_{28}) was reversed, indicating a positive marginal response to freezing temperatures two years removed. However, the estimate was not significantly different from zero. Other signs were unaffected.

Because the dominant weather factor explaining most of the year-to-year variability of actual from expected production seemed to be some measure of freezing conditions and since the use of all data included numerous observations without freeze damage, it was decided

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[1]See Table 22 (p. 116).

to use only the data from the Upper Interior region (the region which had suffered the most freeze damage over the range of the data) to estimate equations [18] and [19] in an attempt to obtain estimates of the relationship between production and freezing temperature which were more consistent with a priori expectations.

P_{2st} is the signed percentage of actual production of Valencia oranges in the s^{th} county and the t^{th} year from corresponding expected production. P_{1st} is defined similarly for Early and Midseason oranges. Other variables were defined in equation [16].

The results were:

$$
\begin{aligned}
P_{2st} = {} & \underset{(1.458)^{1}}{.1951} + \underset{(0.289)}{0.0004V_{16}} + \underset{(2.642)}{0.0138V_{17}} - \underset{(0.818)}{0.0058V_{18}} + \underset{(0.074)}{0.0004V_{19}} \\
& - \underset{(2.195)}{0.0036V_{20}} + \underset{(0.331)}{0.0217V_{22}} - \underset{(3.788)}{0..3223V_{23}} - \underset{(1.442)}{0.1189V_{26}} \qquad [20] \\
& - \underset{(0.493)}{0.0378V_{28}} \qquad R^2 = .30
\end{aligned}
$$

Since only data from the Upper Interior region were used, there were 119 observations--7 counties and 17 years. The variables in this equation have the same meaning as they do in equation [16].

$$
P_{1st} = \underset{(0.186)}{0.0145} + \underset{(0.235)}{0.0003V_{16}} + \underset{(0.025)}{0.0001V_{17}} + \underset{(0.376)}{0.0022V_{18}} - \underset{(0.180)}{0.0008V_{19}} \qquad [21]
$$

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[1]Parentheses enclose t-values.

$$+ \underset{(0.221)}{0.0121V_{22}} - \underset{(1.611)}{0.1143V_{23}} - \underset{(2.416)}{0.1625V_{26}} + \underset{(0.664)}{0.0427V_{28}} \qquad R^2 = .09$$

Equation [21] was not significant. Equation [20] was highly significant. The magnitude of the extimated coefficients for the freeze variables V_{22} and V_{26} increased while those for V_{23} and V_{28} decreased from the estimates of the same coefficients in equation [18].

CHAPTER VI

CONCLUSIONS AND IMPLICATIONS

Summary and Conclusions

The major research objectives were to specify and estimate relationships between weather and Florida orange production. Relationships were specified and then estimated by counties. Data were also pooled over counties and the relationships estimated by groups of counties and for the state. Efforts to estimate the sepcified relationships indicated that soil moisture and minimum daily temperature explaincd more of the variation in production than the other measures of weather available.

In general, the signs of the estimated coefficients were reasonable. For the county equations the uncorrected coefficient of multiple determination ranged from .12 to .84. The estimation of the relationships between orange production by counties and weather would have benefited from measurements of the duration of freezes and from more accurate measurements of soil moisture.

Weather indexes and average yields per tree by counties for Early and Midseason, and Late varieties were estimated. Also, the number of orange trees by ages for the years 1948 through 1968 were estimated (from tree census data) for the state and for each county for both Early and Midseason and Late varieties.

Data in Tables 14, 15, and 16 reveal that the average per tree yield of either variety (macro) can be expected to vary over 1.5 boxes between counties with the lowest and highest yields. A large part of the between county variation in average yield is due to soil depth (size of root system) and to the fact that severe freezing temperatures are not experienced with the same frequencies in all counties.

The weather effect on Florida orange production has been large. The state weather index for Early and Midseason oranges for the 1964-65 season was 1.33, while for Valencia oranges in the 1962-63 season it was .60 (Table 19). The weather effect also differs among varieties (macro) in a given season. For example, in the 1962-63 season the state index was .92 for Early and Midseason oranges and .60 for Valencia oranges. The relative effect of favorable and unfavorable weather also varies by varieties (macro). For the years under study the state index for Early and Midseason oranges varied from .68 to 1.33 indicating that unfavorable weather could reduce the crop 32 percent and that favorable weather could increase it 33 percent. However, for Valencia oranges the range of the weather index was from .60 to 1.22. This range indicated that the effect of unfavorable weather could be approximately twice that of favorable weather.

The weather effect also differs between counties in a given season. For the 1962-63 season the weather index for Valencia oranges was .14 for Pinellas county and .19 for Putnam county while it was 1.21 for St. Lucie county and 1.23 for Indian River county (Table 18).

Data in Tables 26, 27, and 28 reveal that for most years the estimated average yield equations (Stage I) or the weather equations (Stage II) estimated actual production reasonably well. In years of unusual weather the weather equations explained more of the variation in total production than did the average yield equations.

Some general comments can be made concerning the size of the coefficient for the freeze variable. Consider the variable representing the number of days the minimum temperature was less than 26 F.[1] A particular freeze observation could range from 26 F for a few minutes to less than 10 F for several hours. The extreme situations establish bounds on the possible effect of freezing temperatures.

Equation [15] for counties 5, 7, 8, 10, 11, 17[2] (see Table 21) and equation [20] indicate that one "freeze day" could reduce Valencia orange production 6 to 38 percent. The reduction one would expect within these bounds would be a function of both the duration and level of the freezing temperature. The weather indexes for Valencia oranges (Table 18) indicate that the combined effect of several "freeze days" could be as large as an 80 to 85 percent reduction in a given county. Reduction of production the following season might range from zero to 35 percent. Again weather indexes indicate that the combined effect of several "freeze days" could be as high as 70 to 75 percent the following season. The reduction of production two

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[1]Temperatures of 26 F for less than 4 hours are not considered damaging. However, extremely low temperatures that exist for less than four hours may be damaging.

[2]These counties were selected because in the opinion of the author they had the most reasonable estimates of the freeze effect. Equation [15] included three freeze variables as regressors. For these six counties the estimated coefficients for all three were negative. Four other counties (12, 14, 15, and 18) also have estimated coefficients which were negative.

seasons removed may range from zero to 14 percent. The combined effect of several "freeze days" would probably not reduce production more than 25 percent the second year.

For Early and Midseason oranges based on the estimates of equation [15] for counties 5, 9, 10, 15, 17, 18[1] (see Table 20) and equation [21] one "freeze day" could reduce current production 1 to 11 percent. With Early and Midseason oranges the time of the freeze and the portion of the crop already harvested are important. The weather indexes for Early and Midseason oranges (Table 17) indicate that the combined effect of several "freeze days" would not exceed a 50 percent reduction. The effect on production the season following the freeze would be greater. The results indicate that the reduction might range from zero to 16 percent. The weather indexes also indicate that the combined effect of several "freeze days" could result in a 65 to 70 percent reduction the following year. The reduction two seasons removed ranges from 0 to 12 percent, and the combined effect of several "freeze days" would probably not exceed 25 percent the second year.

The estimates presented for equations [18] and [20] may be viewed as additional information on the structural relationship between the production of Valencia oranges and weather conditions. All signs were consistent with apriori knowledge and the magnitudes of the coefficients were reasonable. As previously mentioned strict interpretation of the estimate of the coefficient for V_{20} is questionable

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[1]These counties were selected because in the opinion of the author they had the most reasonable estimates of the freeze effect.

since the variable is probably measuring more than a simple negative response to adequate soil moisture. The estimates for the freeze variables seem to be for two different populations. The estimates for equation [18] are considerably less negative than those for equation [20]. The estimates for equation [20] seem more reasonable in magnitude. In neither case were the coefficients of the two freeze variables for the current year as expected. In equation [18] relative sizes were reversed and in equation [20] the estimate of B_{22} was positive.

Implications

For Citrus Industry

The inter-county and inter-variety variability in production due to weather effects and the inter-county and inter-variety variations in average yields which are indicated by the results of this study have risk implications for persons making investment decisions in new tree planting. The research also furnished the industry with another method of obtaining a mean estimate of production for future years. Since the number of trees is known[1] by variety (macro) county, and age at the beginning of each season and since a tree is not commercially productive until four years of age, mean estimates of the current year and the next four years may be obtained by using the average yield coefficients and tree numbers by county, variety (macro), and age.

These results also provide information on the deviation of actual

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[1]Published annually by Florida Crop and Livestock Reporting Service, Orlando, Florida.

from expected supplies (Table 19). Such information must be considered when and if the industry considers policies of supply control and levels of carry-over from season to season.

The results of this study also provide a basis for estimating the change in production if portions of the citrus belt were shocked by severe weather. In making such an adjustment care should be taken to consider the time of year and the percent of the crop already harvested. For example, if the Early and Midseason oranges have already been harvested, no adjustment need be made of their estimated level of production. Historically, after a freeze there has been extreme pressure within the industry to raise price. This pressure is immediate and is felt days or weeks before the Florida Crop and Livestock Reporting Service can sample the damage and generate an adjusted forecast. The estimated change in production could be useful in helping establish the new fruit prices.

For Research

Variations in production due to weather tend to dominate and hence obscure other sources of variation. For this reason it is necessary to know something about the effects of weather if one is interested in studying other supply shifters. For example, growers' responses to various economic conditions are reflected in their production. However, it is difficult to measure such responses since they tend to be obscured by the effects of weather on production. The weather indexes provide a basis for deflating to remove the weather effect from production data.

The estimates of average yield per tree by variety (macro), county, and age of tree should be useful to the developers of the third generation[1] simulation model of the Florida orange industry. The average yield estimates provide a basis to help simulate production over time. Also, the weather indexes, provide a basis for simulating variation in production.[2]

Limitations

The major difficulties encountered when studying the effect of weather on perennial crops is a combination of specification and estimation. Considerable knowledge exists concerning the physiology of most plants. However, information on the plant-weather interaction is usually lacking or takes the form of some poorly structured hypotheses. Even if a model could be specified with all the weather factors influencing yield and the necessary interaction terms included it could probably never be estimated. Even when assumptions are introduced to limit the number of coefficients in the model the number often remains quite large in comparison with the number of observations available on the variable(s). These problems are aggravated if data from commercial farms must be used because age of plant becomes a factor to be considered.

The level of knowledge may never permit one to avoid specification errors in expressing the relationship between the production of Florida oranges and weather. A linear approximation to the desired

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[1]Charles Powe has recently begun work on such a simulator at the University of Florida.

[2]Both county and state indexes were estimated. However, regional (groups of counties) estimates could be constructed from the results presented.

relationship certainly restricts the predictive accuracy of the model, particularly at more extreme levels of the independent variables. Errors of observation and the aggregation of data over regions may also have affected the estimates presented. Unfortunately, any measurement problems which may have resulted from observational errors and the level of aggregation are unknown and probably unknowable.

The estimates reported in this study are based on an assumption of perfect knowledge of tree numbers by county, age, and variety (macro) at the beginning of each season. The problem of estimating the number of trees over time was not confronted in this study. Also, the effects on the results of stochastic elements in the information on tree numbers was not explored.

Suggestions for Further Research

This study indicated that the level of soil moisture explains more yield variability than most of the usual measures of weather such as average temperature and monthly rainfall. However, this study was not completely successful in efforts to estimate the structural relationship between soil moisture and yield. More accurate measures of soil moisture are needed.

Greater efforts are also needed to determine the extent and effectiveness of man's attempt to modify the effects of weather. For example, irrigation and freeze protection devices are used quite widely in the citrus belt, but we have very few data on how much or in what ways they are used. There is also considerable disagreement about the effectiveness of these devices.[1] This disagreement is

[1] More research of the type done by Koo (47) and recently analyzed from an economic point of view by Reuss (68) is needed.

largely the result of inadequate knowledge. If such practices are effective, their use needs to be reflected in models which attempt to determine the effects of weather on yields.

Reliable long-range weather forecasts would be a major breakthrough for improving crop forecasts, especially when estimates are desired several months in advance, e.g., before the fruit is set.

Research to examine the phenological events such as planting, fruit emergence, and fruit counts by maturity categories and to study the mechanism of growth and development over time as related to accumulated weather factors (59) is needed. Such studies may require that teams of agronomists, plant physiologists, meteorologists, agricultural engineers, and agricultural economists work jointly. In some cases controlled environments may be useful to gather observations on many different weather levels in a few years.

Most oranges are no longer sold by the box but in terms of pounds of solids. Weather also affects this measurement of crop production. Just as there is reason to expect a logical cause and effect relationship between weather and the production of oranges measured in boxes, there is reason to expect a logical cause and effect relationship between weather and the production of pounds of solids. Further research should look more closely into this relationship. Similarly, on the fresh fruit side, little is known about the relationship between weather and size and quality of fruit.

Studies that relate weather to the actual units in which the crop is sold would facilitate an economic interpretation of weather effects. Such an interpretation would also be of use in an estimation of potential payoff from such practices as irrigation, freeze protection, and fertilization.

More exact indicators of the influence of meteorological factors such as precipitation and temperature have been proposed. Soil moisture is an indicator of moisture available for plant growth. Drought indexes measure variation in soil moisture relative to the capacity of the soil or to the wilting point.

This study relied heavily on the empirical estimation of evapotranspiration by the Thornthwaite method though it is known to overestimate evapotranspiration in the summer months. Additional efforts should be undertaken to measure evapotranspiration or evaporation[1] at several points within the citrus belt or to empirically estimate it with greater accuracy.

Additional work should be undertaken to specify the form of the relationship between the production of Florida oranges and weather with greater accuracy and structural estimates of the parameters attempted. Alternative measures of freeze variables might explain more yield variation. The lowest level of freeze severity measured in this study was the number of days the minimum temperature was less than or equal to 22 F. Perhaps lower minimum temperature categories would have given results that explained more of the variation in production. The importance of the duration of freezing temperatures cannot be overstressed. Data on the duration of damaging temperatures should be collected.

More accurate estimates of the structural relationship between

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[1]The majority of the weather stations in the citrus belt do not record observations on evaporation. It would be helpful if several more did. The information would be useful in research efforts similar to this one and properly modified could be used by growers for irrigation scheduling.

soil moisture and yield in all probability cannot be made until methods are developed to accurately measure the level of soil moisture in the various areas of the citrus belt.

However, regardless of the data difficulty, future effort in the area must confront the problem that the relationship between yield, soil moisture, and freezes is not linear and that interactions do exist. Special emphasis should be placed on estimating the interaction between adequate soil moisture in the winter, warm winter temperatures, and freezes.

Since the expected maturity date for Early versus Midseason oranges is fairly distinct (69) and since Savage (70) has estimated that the two varieties are expected to yield at different average rates, it might be beneficial to separate the Early and Midseason varieties into two groups. Then if a freeze occurs after the usual harvest date for Early oranges a total forecast of Florida orange production might be improved by considering that the Early oranges are unaffected by the freeze until the next season while the Midseason and Late varieties might be expected to suffer a direct effect as well as a lagged effect due to the freeze.

Lastly, the inter-county and inter-variety difference in average yields and in production variability due to weather effects should be analyzed in an economic risk model to determine the implications on optimum decision strategies with regard to grove investments.

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This dissertation was prepared under the direction of the chairman of the candidate's supervisory committee and has been approved by all members of that committee. It was submitted to the Dean of the College of Agriculture and to the Graduate Council, and was approved as partial fulfillment of the requirements for the degree of Doctor of Philosophy.

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