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A Pheno-Climatological Assessment of Millets and Other Cereal Grains in Tropical Cropping Patterns

by

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A PHENO-CLIMATOLOGICAL ASSESSMENT OF MILLETS AND OTHER CEREAL GRAINS IN TROPICAL CROPPING PATTERNS

by

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ARNEL C. CARDENAS

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UNIVERSITY OF NEBRASKA, 1983

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ABSTRACT

A study was conducted using growth chamber and field experiments to identify the phenological stages of proso millet. Eight numerical indices are enumerated to distinguish and describe the growth and developmental phases of proso.

An analysis of the effects of planting dates on the growth and development behavior of some varieties of proso millet, pearl millet and sorghum are also presented. Later planted crops showed slightly faster rates of development than early planted ones, but the difference was not significant. However, growth rates were found to be slower with late plantings.

A procedure was used to assess the suitability of some rice-based cropping patterns in the tropics using degree-day estimates and agroclimatic normals. This procedure, when properly evaluated may eventually serve as a guide for agricultural planning and production.

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A PHENO-CLIMATOLOGICAL ASSESSMENT OF MILLETS AND OTHER CEREAL GRAINS IN TROPICAL CROPPING PATTERNS

I. INTRODUCTION

Millets are small-grain, warm-season cereal crops used in various ways throughout the world. China and India share about 56 percent of the total world production of millet, while Manchuria, French West Africa, and the Soviet Union account for 32 percent. In the United States, roughly 15,000 tons of seeds are produced, principally for livestock feed. Millets have out-performed other grain crops like sorghum in marginal areas where scanty rainfall, high temperature and infertile soils persist. This is because of the short growing season required by most millets. Nevertheless they respond well to good management and high fertility levels.

There are five genera of millets: Panicum, Setaria, Echinochloa, Pennisetum, and Paspalum, of which the Panicum and Pennisetum are the most widely grown in the United States. Others are popularly cultivated in Asia, Africa, and the U.S.S.R.

The pearl millets (Pennisetum sp.) grow better than sorghum in dry conditions. These are grown in areas where yields are limited by sorghum pests, such as stemborers

and midges. Pearl millet is a highly flexible crop, this is attributed to its rapid growth and wide tolerance of moisture conditions. It can be grown as a principal season, off-season, or catch crop if its minimal moisture and temperature conditions are met. The availability of new, high-yielding hybrids offers considerable opportunities for expanding the role of millets as a main-season crop and for multiple cropping schemes following rice, wheat, potatoes, or vegetables during the hot or rainy seasons.

Similarly, proso (Panicum miliaceum) or hog millet (Fig. 1) is a dryland grain crop that is common in Europe and used mostly in the U.S. as a full-season crop or a catch crop when other crops have failed. It will reach maturity in about 60 to 90 days depending upon the variety. Proso has a lower water requirement than most crops (Nelson and Roberts 1960; Nelson 1973), but because of its shallow rooting habit proso millet cannot withstand prolonged drought. The plant may lodge early if the surface soil remains dry over extended periods. Flowering is the stage that has the greatest demand for water. Yields of 1,000 to 2,500 lbs per acre can be expected depending on variety, farming practices and growing conditions. Too high or too low seeding rates can cause yield reductions. In general, rates of 15 to 35 lbs of seeds per acre give best yields (Malm and Robison 1969).

Figure 1. The proso millet (Panicum miliaceum).

Proso millet contains more total protein, crude fiber, and oil but less vitamin A than most corn. However, the quality of this protein may be less than corn due to a lower L-lysine component, an essential amino acid according to Grabouski and Danielson (1970). They found that if proso replaced corn in the diet of swine, it would almost equal corn in pounds of pork produced per day per pound of feed, provided a small quantity of L-lysine was added to the ration. Early studies have shown that the nutrient composition of proso millet is comparable to oats (Grabouski 1967) and wheat (Leonard and Martin 1970). Ground or rolled proso is about 90 percent as good as corn for fattening cattle and lambs, 85 percent or higher for swine and 95 percent for laying hens.

Not only can proso be used in feeding rations for cattle, hogs, sheep and poultry, but it also serves as an ingredient in the cereal diets of many Asian and African people. Preparations made from dehulled and unground grains are processed as hot breakfast cereals or "puffed cereal", bread and cakes, or other delicacies. On the other hand, the ground flour can readily substitute for a portion of the wheat flour in some recipes.

Proso is contrasted from the other kinds of millet by its low palatability as a forage. It grows well on almost any kind of soil especially in heavy soils of summer-fallowed land. Some growers reported that yields

of millet tend to improve with continuous cropping.

Little research has been done with proso millet in spite of its growing popularity in comparison with other cereal grains. Although it constitutes a very small percentage of the total world grain production, the fact still remains that it has been in existence since prehistoric times. It was only during the 19th century that millet was superseded by wheat, rye, rice, maize and potatoes because of their higher yields and excellent eating characteristics.

1.0 Objectives

The growth and development of proso millet have not been well documented in the literature. This thesis was prepared with the following objectives:

1. To provide a simple description of the developmental stages of proso millet using a phenological scale or index;

2. To compare the effects of planting dates on the developmental and growth behavior of some millets and a sorghum hybrid;

3. To assess some rice-based cropping pattern schemes for the tropics involving millets, corn and sorghum using degree-day concepts and agroclimatic normals.

II. REVIEW OF LITERATURE

2.1 Definition Of Phenology

The term phenology has been used to define the relationship between periodic biological events in an organism and the climate in which they live. These physical changes can be observed and quantified without necessarily injurying the individual. In plants, there are three major events that broadly describe their life cycle: the vegetative period, flowering or reproductive period, and the grain-filling or ripening period. Each period consist of more specific phenological stages that are predominantly dependent upon the environment in which the plants are grown.

Many plant reactions to certain climatic alterations have been explained by numerous researchers through phenological changes. Observations on successive phenological events of similar species over a large geographical region are normally related to recorded macro-climatic variables as seasonal temperature, weighted expressions of diurnal temperature, effective rainfall and average daylength. Wang (1963), Neild and Seeley (1977) and Robertson (1983) enumerated several important applications of phenological relationships in agricultural activities. These relationships are put forward as simplified numerical models that directly relate certain environmental factors to the relative rate

of crop development. Most of the earliest phenological studies were based on temperature and rainfall records since these were readily measurable (Reamur 1735, Merriam 1894, Abbe 1905 and Livingstone 1916). Gilmore and Rogers (1958) and Holmes and Robertson (1959) stated that the overall plant growth and development follows a close relationship with temperature of the environment. Efforts to classify crop maturity on the basis of temperature showed more promising results than counting calendar days. However, this does not prove that plant maturity is totally dependent on temperature and moisture conditions. Other factors may also make a significant contribution in the normal crop development.

Newman and Beard (1960) summarized four approaches to the recording of phenological observations. These are: (1) identifying morphological or physical changes in structure of the organism; (2) recording changes in mass and growth rate; (3) observing changes in activities or behaviors; and (4) using quantitative and qualitative chemical analyses to detect any biochemical change within the organism. Through statistical analysis, it is then possible to determine the influence of known environmental factors, both separately and collectively, on vital growth and development processes of the species.

Plant hormones, enzymes and growth regulators are the main biological controls that influence the rate of change taking place in any plant tissue. The natural

synthesis or destruction of these compounds, which are generally temperature sensitive, are influenced by the external environment. It was probably on this premise that phenological models were created to explain the total or partial dependence of crop development on its physical environment. Some models assumed linear relationships while others did not (Brown and Chapman 1960, Robertson 1968 and Major et al 1975). In spite of these assumptions, it has been observed that different species and varieties responded differently to different climatic variables.

2.2 Use Of Temperature In Phenology Models

The most commonly used model with a single characteristic coefficient involves temperature. The effects of temperature on the physiological and morphological development of crops in the field can be assessed to certain extent by interpretation of their phenological data. In general, the actual plant temperature at any particular time regulates the rate of development of the tissues. Seeley (1917) observed that plant temperature, on the average, may exceed the air temperature by 14.9 °F (8.3 °C) in full sunshine at noon, by 9.7 °F (5.4 °C) in partial sunshine, but less than 1.8° F (1 °C) on a cloudy day. This is probably the major reason for variability in response existing among genotypes of plant species. But because of real-time

difficulty in measuring plant temperature on a routine basis the use of integrated daytime and nighttime temperature has been well accepted for predicting phenological developments since this is easily measurable. Some approaches used the accumulated mean hourly or daily temperature to make a reasonable prediction of most phenological events. However, Wang (1963) believed that the extremes of temperatures were better indicators than the accumulated temperatures.

The more widely applied method of predicting maturity of some crops is with the use of growing degree-day summations (GDD) other than day summations. Day summations were found to vary widely among locations, years, seasons and planting dates for the same variety because of climatic differences. GDD summations from daily temperature records, however, showed lesser variability and therefore have been frequently used for varietal maturity ratings and predicting certain developmental stages of some crops. McCloud, Bula and Shaw (1964) pointed out that this concept focuses on the integration of phenology, physiology and climatology for making reasonable estimates of plant growth, development, maturity and yield. GDD summations and phenological observations have been employed on several crops such as corn (Brown 1963, Newman et al 1968, Neild and Seeley 1977, Neild and Richman 1979, Shaw 1975, Gilmore and Rogers 1958, Aspiazu and Shaw 1972, Cross and Zuber 1972

and Mederski et al 1973), canning peas (Phillips 1950, Katz 1952), sorghum (Downs 1972, Neild and Seeley 1977, Logan 1981), rice (Nuttonson 1965, Flynn and Downey 1979, Stansel and Fries 1980), wheat (Nuttonson 1948 and 1966), barley (Nuttonson 1957), forage maize (Phipps et al 1975), sunflower (Robinson 1971, Doyle 1975), soybean (Major et al 1975, Lawn and Byth 1973, Brown et al 1960), apples (Eggert 1960), and on numerous vegetable crops (Madriaga and Knott 1951, Holmes et al 1959, Neild and Greig 1971, Edey 1977).

2.3 Growing Degree-Day Concept

What then is the growing degree-day concept? The most common terms applied to growing degree-days are thermal units, heat units and energy units, all of which designate the total summation of degree days above a base temperature needed to reach a particular development stage in plants. This was based on Van Hoft's rule of chemistry, that the rate of any chemical reaction doubles with each 18 ^{o}F (10 ^{o}C) increase in temperature (Hay 1975). Temperature summations presuppose that the rate of certain biochemical reactions, including growth and development are linearly related to temperature. Went (1957) claimed the use of the "heat unit" term was a misnomer when referring to GDD as there are no specific heat involved (in a physical sense). Robertson (1983) indicated that the use of the term "growing" degree-days

was also inaccurate because this concept deals primarily with the influence of temperature and other meteorological parameters on crop development rather than growth. For this basic reason, he emphasized the term Temperature Remainder Index Summation (TRIS) to circumvent these two objections to "heat" and "growth" while actually referring to the same principles. He used the following linear functions with the assumption that temperature is the only factor controlling development.

$$R = a + b(Tm) = b(Tm + a/b) \qquad (1)$$

Here, R refers to the daily rate of crop development, a and b are coefficients derived by regression analysis and Tm is the mean daily temperature given by the average between the maximum and minimum temperatures for a day. Then summing daily over time or phenological stages, S1 and S2, gives;

$$\Sigma R = \Sigma b(Tm + a/b) = 1 \qquad (2)$$

and dividing by b;

$$\Sigma(Tm + a/b) = 1/b = K \qquad (3)$$

or

$$\Sigma(Tm - To) = K \qquad (4)$$

where K is the degree-day summation constant (GDD or TRIS) between two phenological phases, and To = -a/b is the base temperature which is indefinite and crop specific. This base temperature may vary with external conditions, crop age and stage of crop growth. Canning peas and potatoes require a base temperature of 41 °F (5°

C), rice, snap beans, sorghum, sweet corn, and tomatoes have 50 °F (10 °C), pumpkins and field corn have 55 °F (13 °C), while 40 °F (4.4 °C) is preferred for barley, oats and spring wheat (Dethier and Vittum 1963, Iwata 1975, Holmes et al 1959, Nuttonson 1955, Treidl 1978 and Wiggans 1956).

2.4 Determination Of Threshold Temperature

Arnold (1959) argued that this base temperature or "apparent" threshold may not always be representative of the true physiological threshold temperature. Where, in truth, R would be a function of several daily weather factors, F(W), then the assumption that temperature and development show a linear relationship may lead to inherent errors in the variations between the true physiological threshold and the apparent threshold temperatures. Some methods of estimating K have likewise considered an upper and lower limit for temperature. The range between these critical temperatures have since then been termed "effective temperature".

When working with temperature summations, it is customary to determine the proper base temperature. There are two simple procedures for determining the threshold temperature and summation constants for various species or varieties (Iwata 1975 and Robertson 1983). One such procedure uses the coefficient of variation which is defined as the ratio of the standard deviation to the

mean value of the observations, multiplied by 100. Using this approach the arbitrary To value that gives the smallest standard deviation for estimating number of days to maturity and the minimum coefficient of variation in calculating the temperature summation constants, is most likely the ideal threshold temperature for the variety in question. It is also assumed that no daily temperatures occur below this threshold during the phenological period. This approach is so troublesome and time-consuming for many researchers.

The other procedure requires the use of an iterative regression or least squares technique to eliminate daily temperatures less than the assumed base temperature value. Bassett et al (1961) developed this procedure for studying blooming of perennial trees and shrubs in Canada. They noted that this procedure gives the best estimate of the To and degree-day summations with neither trial and error nor interpolations. Kontturi (1979) modified this approach for his study on wheat. Details of his procedure and that of Bassett et al can be found from the original articles or in Robertson (1983).

Edey (1977) believed that the currently available summation constants are not truly representative values which influence a crop either singly or in conjunction with some other factors. Some of these may be associated with the soil properties, plant population, photoperiod, varietal characteristics and local management practices.

Soil and water temperatures (in the case of paddy rice) differ from air temperature considerably and affect the plants more than the air temperature during the seeding to early vegetative development. Caution should therefore be taken when accumulating degree-day units under certain environmental conditions.

2.5 Criticism Of The Degree-Day Procedure

Like any other models for predicting phenological events in relation to meteorological variables, the degree-day summation or TRIS model has its own shortcomings and range of practical usage. It is highly probable that certain species or varieties respond best to a wide range of temperature, or to diurnal fluctuations of the maximum and minimum temperatures, yet still others do not show significant manifestations of thermal regulations while being masked by other responses to more dominant factors (Wang 1960). One major criticism or drawback to this procedure is its failure to account for the duration of temperature above or below the threshold temperature value. It simply considers the mean daily temperature calculated from the daily maximum (occurring after solar noon) and minimum (occurring shortly after sunrise) temperatures. A refinement of the model called growing degree-hours (GDH) was therefore proposed by Lindsey et al (1956) to overcome this weakness and provide more accurate accounting of the

temperature effects on some phenological developments. Arnold (1960) argued that when the minimum temperature drops below the base temperature the degree-day value is less accurate. For this reason, other models have incorporated the duration of daytime and night time periods into the degree-day summation approach.

Numerous procedures have been attempted to develop accurate degree-day methods for estimating flowering and maturity of crops. But the success or failure of this method to predict the dates of phenological events depends on: (1) how well the assumption of linearity between temperature and crop development holds true for any species or variety and (2) the proper choice of threshold temperature. Some plant processes may be linearly dependent on temperature, others may be logarithmically dependent, and still others may be temperature insensitive. A plant activity does not respond at equivalent rate to different temperatures. Thus, this implicit assumption in the use of temperature summations is an over-simplification. Often times a photoperiodic reaction can override the thermal effect of the environment especially on highly photoperiod-sensitive species. Therefore, the degree-day summation procedure may work fairly well for some crops while failing in others.

Many environmental conditions may contribute directly to the fluctuations in summation constants of a crop.

Like photoperiod, humidity and soil conditions lead to confusion in consistency of the heat unit requirements. This is often the case when the degree-day theory is applied in dryland agriculture where deficient rainfall and excessively high temperatures are of major concern. High temperatures above the optimum and low humidity are associated with depressed crop growth, but the heat units increase.

Other models have become more complex in that they include other factors of the environment with the intention of getting more precise predictions of phenological periods from year to year and with changes in location, or otherwise improve the model's flexibility of application to agricultural planning and operations (Thompson 1962, Robertson 1968, Cornia and Pochop 1973, Baier 1973, Keig and McAlpine 1974, Neild et al 1978, Coelho and Dale 1980, Stern and Coe 1982).

2.6 Confidence In Using GDD - Phenology Models

The increasing number of crop-weather models have therefore raised the question of reliability and accuracy under a variety of conditions in which a crop could be grown. However, many have claimed that the simple degree-day summation procedure has been quite valid for various purposes (Cross and Zuber 1972, Mederski et al 1973, Neild et al 1978), provided that an accurate threshold temperature has been used and where conditions

other than temperature are fairly uniform. Several methods of calculating GDD have been tested for corn and the 50/86 method (Gilmore and Rogers 1958), Ontario method (Mederski et al 1973) and Heat Stress method (Cross and Zuber 1972) appeared more precise than the others. Extensive reviews of the crop-weather model were done by Nuttonson (1953) and Baier (1973).

When sufficient information on GDD requirements of crops are available, it should be easy to determine stages of crops with a degree of certainty. Nuttonson (1948, 1955 and 1956) noted that the variation in GDD summations for a specific variety of wheat, barley, and rye was small from year to year for a given locale, but strongly related to daylength over a range of latitudinal locations. Wiggans (1956) observed the same response on varieties of oats. The GDD requirement changes with varietal differences, maturity classes of crops and growing conditions. With some plants grown in cooler areas, the summation of degree-days is lower than for those adopted to warmer places.

It is therefore indispensable to make adjustments of the temperatures above or below the optimum range for crop growth when determining accurate GDD units. And because of its merits and demerits, the thermal unit theory is not infallible for wide application under most conditions. Moreover, the use of GDD summations calculated from a single station or season experiment,

for different locations and seasons is hardly acceptable. Individual experimentation across regions and seasons are recommended at the current state. Prospective users of this method must be guided by their own judgement and critical insight of the problem at hand.

Stansel and Fries (1980) reported that a stress can contribute significantly to the delay in phenology. He cited as an example the effect of moisture stress on the lengthening of the vegetative phase through a slowdown in hormonal accumulation process. When the stress is alleviated, hormone accumulation resumes to normal level and development can thus proceed. "Shock effects" are stress induced by occurrences of temperatures beyond the favorable range. Generally, the magnitude and degree of stress effect on phenology will vary with the stage of crop development.

2.7 Critical Stages In Crop Development

All crops have their own critical stages when they become susceptible to environmental alterations or manipulations. A critical stage in crop development has been defined by Klages (1942) as that stage in which a high degree of correlation exists between an environmental component and the final yield. Since these critical stages often occur in short span of time, the use of long-term climatic summaries may be inadequate. The inclusion of daily or even hourly normals gives more

meaningful and accurate assessment of the phenology of crops from year to year variations. Klages recognized the limitations involved in the use of monthly normals. The availability of daily or even weekly records have been difficult to acquire for any given location. For this reason the application of monthly summaries have gained popularity during the past years. Neild et al (1978) and Smith et al (1983) developed a computer- oriented program that generates daily normals for temperature, GDD50 (base 50 ^{o}F), precipitation, potential evapotranspiration, and some accumulated values, using monthly climatic data. Logan (1981) used this program to create an agroclimatic analysis of sorghum growing areas in the United States and some selected locations in the tropics.

A. DEGREE-DAY - PHENOLOGY ASSESSMENT OF MILLETS AND SORGHUM

III. EXPERIMENTAL PROCEDURE

3.1 Growth Chamber Study

In order to determine the phenological stages of proso millet, an experiment was conducted in the greenhouse using reach-in growth chambers. Seeds of Dawn millet were dibbled to about 1.0 in.(2.5 cm) depth in 8 in. (20.3 cm) diameter plastic pots containing artificial soil mixture and watered with Hoagland nutrient solution. Thereafter, all the pots were placed in the growth chambers with 80 °F (27 °C)/ 70 °F (21 °C) day-night temperature setting. At the seedling stage (about 2-3 leaves visible) the growth chambers were programmed to the desired treatment combinations.

Treatment 1 was a combination of 85 °F (29 °C) / 75° F (24 °C) day-night temperatures with 13 hours light and 11 hours dark cycle. Treatment 2 was set at 80 °F (27 °C) / 70 °F (21 °C) day-night temperatures with the same light and dark cycles. Treatment 3 was programmed for 80° F (27 °C) / 70 °F (21 °C) day-night temperatures with 15 hours of light and 9 hours of dark period. Illumination of the plant chambers was provided by six 100-watt incandescent bulbs and ten fluorescent (cool-white)

tubes. Before and after the light period, 20 minutes of illumination with incandescent light was provided to simulate sunrise and sunset stimuli. During the actual light period, a combined incandescent-fluorescent illumination was imposed to substitute for daylight condition. Total irradiance measured with a quantum sensor at 24 in. (61 cm) distance from the light source ranged from 125 to 150 watts per meter square in different sections of the chamber.

Plants were thinned to two plants per pot by selecting uniform plants within each chamber environment. Nutrient solution was applied intermittently so as to maintain adequate nutrition and moisture in each pot.

Observations were made at 1-2 day intervals from the time of emergence until all plants reached maturity. Photographs and descriptions were taken at progressive developmental stages for later analyses. Numerical values similar to those used for corn (Hanway 1971), sorghum (Vanderlip 1972), cereals (Zadoks et al 1974), soybean (Fehr and Caviness 1980), sunflower (Coultas 1981), and pearl millet (Maiti and Bidinger 1981) were assigned for different phenological stages. These values represented the mean of all plants within each chamber environment. Decimal fractions were used to mark developments between known stages. Mean temperature, number of days to reach each particular stage, number of leaves, and plant height were recorded to describe the various phenological

stages.

3.2 Field Study

Three varieties of proso millet, two of pearl millet and a sorghum hybrid (Table 1) were planted at the Lincoln Horticulture Farm during the summer of 1982. All were planted in blocks representing four planting dates beginning with June 10, June 21, July 9 and July 19. The schedule of planting was originally set in May but the first two dates were rained out in spite of attempts to move back the schedule. Some other dates were likewise rained out thus accounting for the large gap between the second and third planting dates.

Each planting was done by a mechanical seeder at double the recommended seeding rates to assure adequate plant stand. Seedlings were thinned to attain desired spacings within rows. Sprinkler irrigation was provided when rainfall was insufficient to maintain adequate soil moisture.

Crop and weather data were recorded at 6 day intervals to determine phenological stages, growing degree-day summations (GDD) above base 50 °F using equation 4 and crop responses to planting dates. Results of the growth chamber study served as a guide in assigning numerical values for each observed stage of proso millet. The developmental stages of pearl millet (Maiti and Bidinger 1981) and sorghum (Vanderlip 1972)

Table 1. Variety, species classification and maturity class of hybrids used in research plots at Lincoln, Nebraska in 1982.

Variety	Species	Maturity Class
Cope	Proso millet	Late maturity, 1978 Colorado release
Dawn	Proso millet	Early maturity, 1976 Nebraska release
Panhandle	Proso millet	Medium early, 1968 Nebraska release
RS-671	Sorghum	Early maturity, (Redlan X Tx 415)
Senegal Bulk	Pearl millet	Medium maturity, short height
Serere-3A	Pearl millet	Medium early, tall height

Table 2. Developmental stages of pearl millet (Maiti and Bidinger 1981) and grain sorghum (Vanderlip 1972).

Stage	Sorghum	Pearl Millet
0.0	Emergence	Emergence
1.0	Collar of third leaf visible	Lamina of third leaf visible
2.0	Collar of fifth leaf visible	Lamina of fifth leaf visible
3.0	Growing point differentiation	Growing point differentiation
4.0	Flag-leaf visible	Flag-leaf visible
5.0	Boot	Boot
6.0	Half-Bloom	Half-bloom
7.0	Soft dough	Milk stage
8.0	Hard dough	Dough stage
9.0	Physiological maturity	Physiological maturity

were used to make phenological observations of these crops (Table 2). All observations represented the mean of five random samples per variety over four planting treatments. The GDD summations were calculated from the mean of the maximum and minimum temperatures recorded for the day above base 50 °F and summed over the period of each phenological stage.

Regression analysis was used to study the relationship between phenological stages and accumulated GDD. Composite data were obtained by pooling observations from all planting dates for each variety.

3.3 Testing For Homogeneity Of The Regression Coefficients

Regression coefficients were tested for homogeneity for each group using the approach given by Gomez and Gomez (1976). This homogeneity of the regression coefficients was not equivalent to having homogenous regression lines.

$$MSp = \frac{(n1 - 2)MS(1) + (n2 - 2)MS(2)}{n1 + n2 - 4} \qquad (5)$$

= pooled residual mean squares

where MS(1) and MS(2) are the residual mean squares for the first and the second data set with n1 and n2 paired observations, respectively. Then a t-test was computed using;

$$t = \frac{b1 - b2}{\left[MSp\ (1/\Sigma X_1^2 + 1/\Sigma X_2^2)\right]^{1/2}} \qquad (6)$$

where b1 and b2 are the two estimated regression coefficients, and ΣX_1^2 and ΣX_2^2 are the corrected sums of squares for the first and second sets of data, respectively. The computed t-value was compared with a tabular t-value at 0.01 level of significance and n1+n2-4 degrees of freedom. A paired regression coefficient was declared homogenous when the computed t-value was less than the tabulated t-value. Otherwise, the null hypothesis was rejected.

Data from the growth chamber study and from each planting date were analyzed separately for each particular variety. Plant samples were dissected periodically for the purpose of determining the internal morphological development of the primordium. No observations were made for the three proso millets planted on July 9 and July 19 because a black sheath rot infection had destroyed the remaining seedlings in each block. Similarly, no grain yield data were obtained due to severe bird feeding in the experimental area.

Plots of the available data on temperature and rainfall including those on height and phenology stages were made using the spline option in SAS graph to obtain a smooth graphical relations between different variables.

IV. RESULTS AND DISCUSSION

4.1 Phenology Of Proso Millet

The series of photographs and accompanying text in Figures 2-15 describe the growth and development of proso millet. The timing of appearance of each of the stages may vary among hybrids, seasons and locations but all are expected to follow the same growth trends. Other factors like soil fertility, soil moisture condition, pest or disease infection, crop competition and level of crop management practices may affect the rate of progress between successive stages as presented. These descriptions may be considered arbitrary for the time being, but are intended to serve as a preliminary guide on proso millet which has been gaining popularity in more recent years.

PHENOLOGICAL STAGES OF PROSO MILLET

The growth and development of proso millet can be divided into vegetative, reproductive and ripening phases, which may be further sub-divided into physiologically distinct stages.

The seeds vary in color, depending on the variety. Some may appear as slightly off-white to bright yellow in color (Fig. 2) while others may be orange, brown, or red. Good seeds must be selected for planting to obtain a good germination and seedling stand.

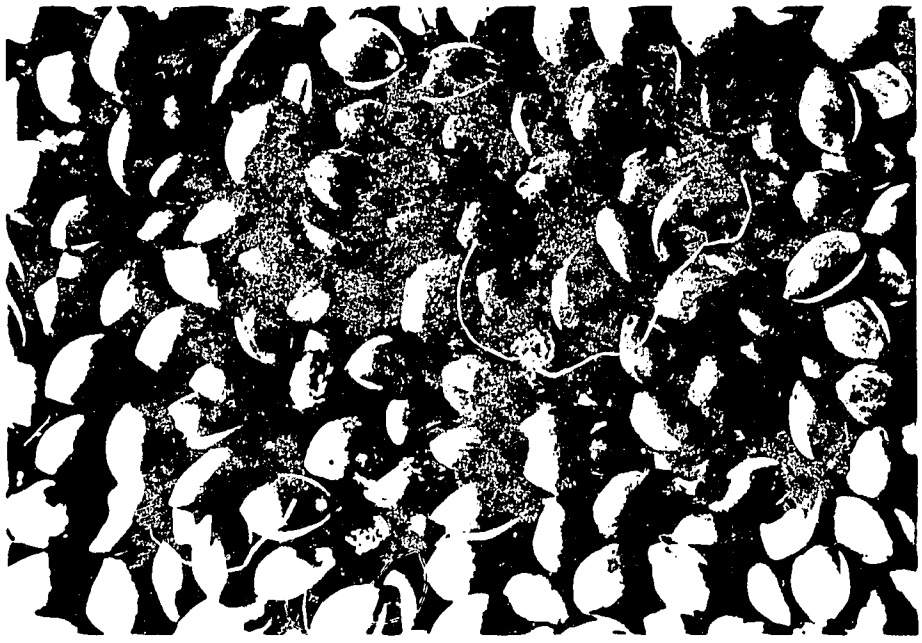


Figure 2. Seeds of proso millet.

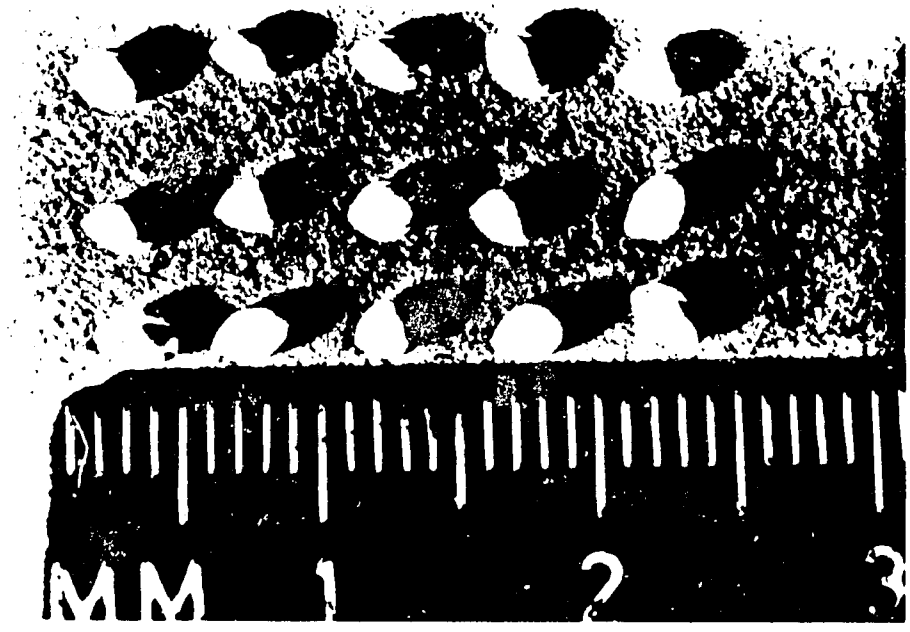


Figure 3. Size of proso seeds.

The seeds are generally oval in shape with a rounded dorsal side and measure about 0.09-0.12 in. (2.25-3.0 mm) in length and 0.08 in. (2.0 mm) in width (Fig. 3). In Figure 4, proso seeds (left) are smaller than pearl millet (center) and grain sorghum (right).

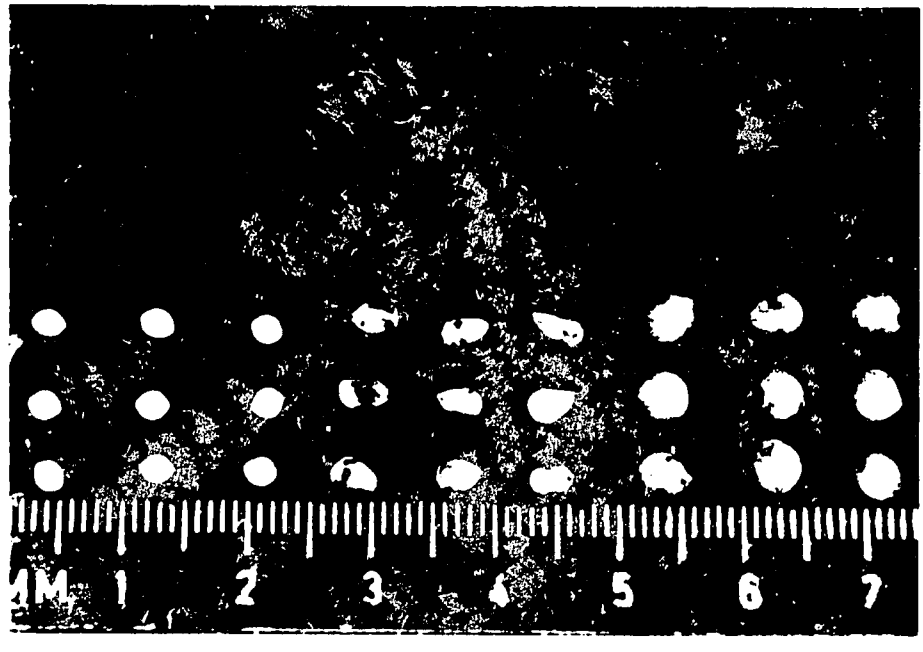


Figure 4. Comparative seed size of proso millet.

VEGETATIVE PHASE

This phase is marked by the beginning of germination to panicle initiation stage. Accompanying this phase is an increase in number of leaves and tiller buds. The vegetative phase is usually completed in 16 to 20 days after planting. This may vary depending on variety used and climate in the area. In most varieties, high temperature and short davlength reduce the duration of vegetative growth.

Stage 0.0 Seed Germination and Seedling Emergence (Fig. 5). When the seed absorbs moisture from the surrounding soil, several metabolic activities are triggered including the activation of the embryo. Germination is said to occur with the emergence of the radicle and later by the coleoptile which then ruptures to reveal the primary leaf. When the coleoptile emerges from the soil surface, it is at seedling emergence stage. This usually occurs in 4 to 8 days after seeding. depending on planting depth and soil conditions. The recommended depth of planting is about 1 in. (25.4 mm). Seeding must be done on fairly moist soil to improve germination.

Figure 5. Seed germination and seedling emergence.

Stage 1.0 Seedling Stage (Fig. 6). In about 3 to 6 days after emergence, two leaves are extended from the whorl. The first leaf is differentiated from succeeding leaves by having a rounded tip. Leaf collars (attachment of the leaf blade to the leaf sheath) are not distinct. Growing point is still below the soil surface. This stage covers the period from emergence to the time of first tillering.

Figure 6. Seedling stage.

Stage 2.0 Tillering and Growing Point Initiation (Fig. 7). This stage, also referred to as panicle initiation, is characterized by the shift of the growing point from vegetative to reproductive stage. The panicle primordium appears as a dome-shaped structure and is at, or above, the soil surface as the lower internodes continue to elongate. The plant increases in height and tillers actively. Tillering follows the seedling stage and begins at the lower internodes. The rate of tillering is faster at higher temperatures and when nutritional condition is good. Growing point initiation usually occurs about 10 to 15 days after emergence beginning with the main culm and later in the tillers. Vegetative growth may continue when no panicle primordium is initiated in the tillers.

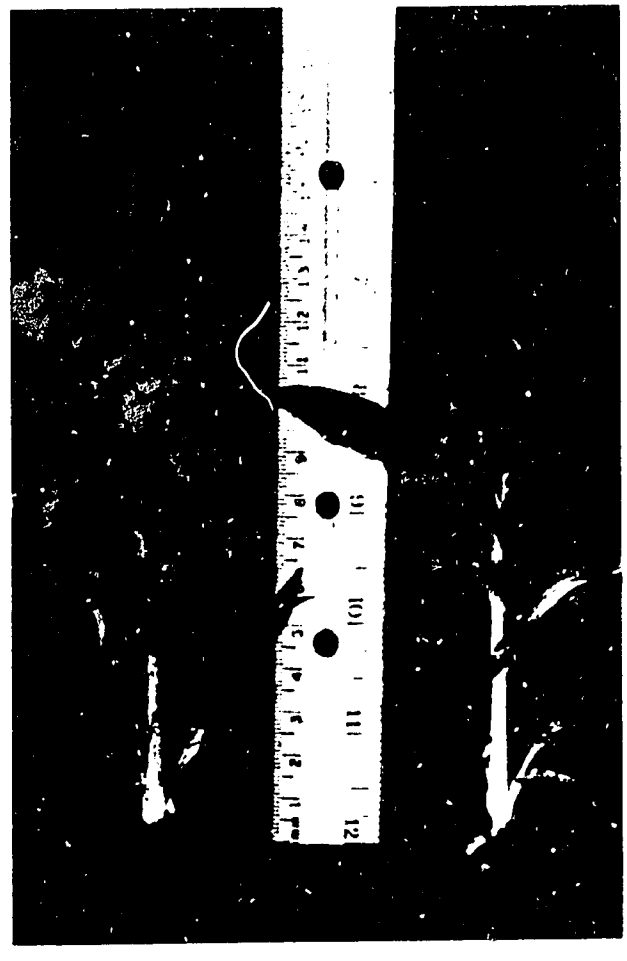


Figure 7. Tillering and growing point initiation stage.

REPRODUCTIVE PHASE

This phase starts when the panicle primordium is greater than .02 in. (0.5 mm). It covers the period from panicle differentiation to flowering of the main culm. This phase is accompanied by an increase in leaf area and rapid elongation of stem internodes. More tillers may emerge as the plant grows and matures. These increases are promoted by high temperature or abundant nitrogen supply. The duration of this phase is fairly constant at about 20--25 days but may be somewhat shorter at high temperatures.

Stage 2.5 Panicle differentiation (Fig. 8). The panicle is quite visible to the naked eye. The panicle primordium begins to differentiate slowly from the base to the tip (acropetal). This is followed by the initiation of branch primordia in the same sequence. When completed, the spikelet primordia begin to initiate from the base going up. At a later date the spikelets differentiate from top to bottom (basipetal) of each formed panicle branch.

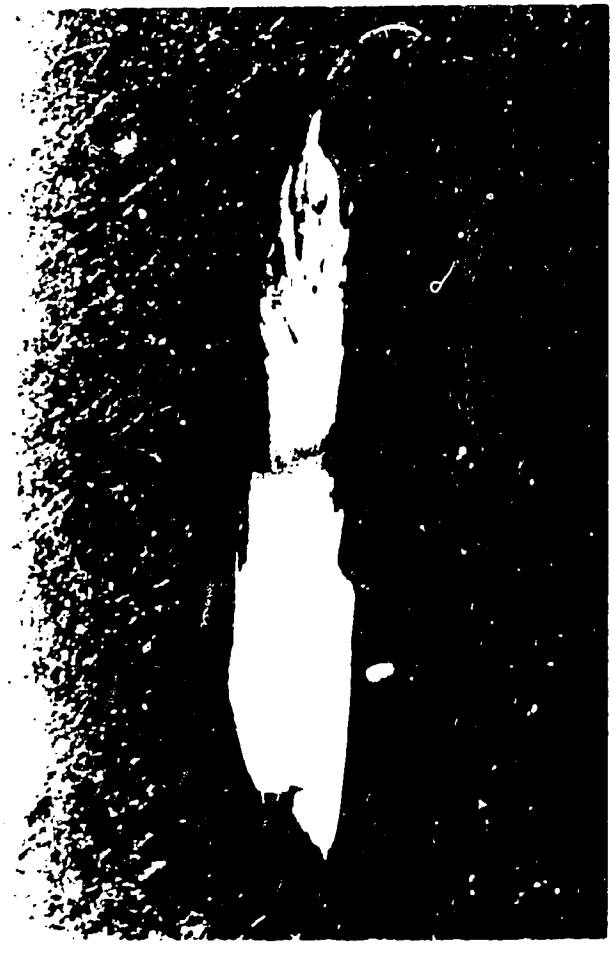


Figure 8. Panicle development stage.

Stage 3.0 Flag-leaf Stage (Fig. 9). The final leaf of the main culm is partly extended from the whorl with majority of its lower portion still enclosed in the preceding leaf. There are about 2-3 leaves surrounding the flag-leaf all of which are not yet fully open. Other leaves are expanded while the lowest two have begun to senesce. The flag-leaf has no other leaf lamina rolled inside it. The panicle is already distinguishable but still inside the flag-leaf. Leaf number on the main culm differs among varieties, but each variety will produce definite numbers of leaves before flowering.

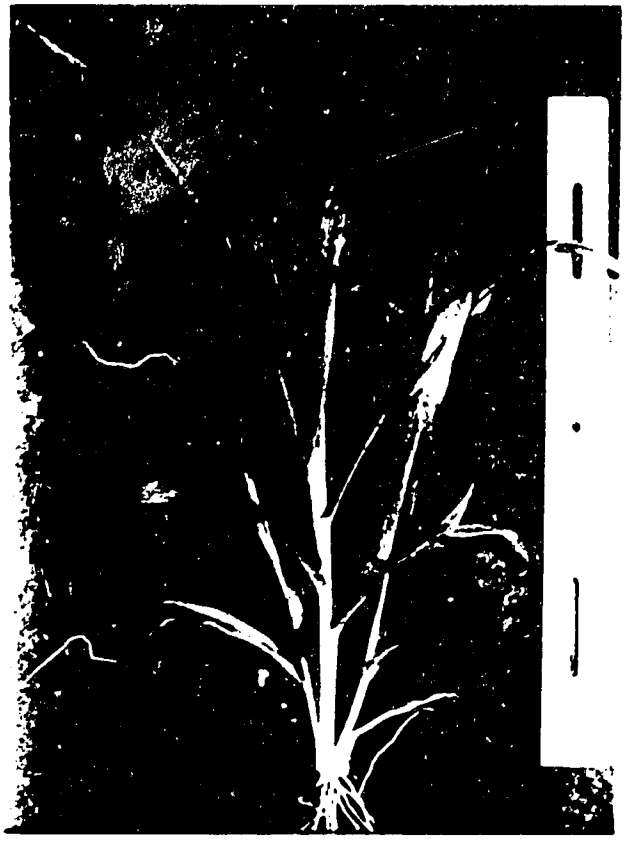


Figure 9. Flag-leaf stage.

Stage 4.0 Boot Stage (Fig. 10). The flag-leaf is partially rolled in the whorl of the preceding leaf. The panicle is enclosed within the flag-leaf sheath causing a bulge, and the peduncle continues to elongate rapidly. Leaf senescence proceeds while tillering slows down considerably.

Figure 10. Boot stage.

Stage 5.0 Half-bloom Stage (Fig. 11). This stage is defined by the opening of spikelets in the upper half of the main panicle. Anthesis may begin in 1-3 days after portions of the panicle have been exerted from the flag-leaf sheath. Spikelet opening proceeds from top to bottom (basipetal). At the beginning of anthesis, spikelets open showing the anthers and stigma. A single spikelet consist of two unequal glumes, a sterile lemma, and a fertile floret. The fertile floret consist of a lemma, palea and caryopsis. The flower is normally self-fertilized although cross-pollination frequently occurs. Soon after completing pollination, the fertilized stigma withers while the unfertilized stigmas remain fresh for a few more days.

Figure 11. Half-bloom stage.

RIPENING PHASE

This phase begins at flowering or blooming to the end of physiological maturity. The endosperm starts filling up after floret fertilization. Throughout this period, the plant actively accumulates dry matter, particularly in grains, while more tiller panicles develop in sequence with the panicle of the main culm. Only a few upper leaves maintain photosynthesis to support the maturing grains. Younger tillers may develop at the upper nodes of the main culm. The duration of this phase is almost constant among varieties from about 20-30 days.

Stage 5.5 Full-Bloom Stage (Fig. 12). The lower half of the main panicle is already in bloom. Most florets in the upper half have completed anthesis. It takes 3-5 days for all spikelets in the same panicle to complete anthesis. The peduncle is actively extending from the flag-leaf by now and distinctly exposing the panicle or head.

Figure 12. Full-bloom stage.

Stage 6.0 Milk-Grain Stage (Fig. 13). The grains fill up gradually accompanied by an increase in size and weight. The endosperm cells are green to light yellow and filled with starch grain suspensions which appear as white milky juice or semi-solid constituency. Leaf senescence extends from the lower leaves upward as the plant matures. More tiller panicles are in bloom stage by now.

Figure 13. Milk-grain stage.

Stage 7.0 Hard-Dough Stage (Fig. 14). The grains are somewhat tough and waxy as more solid materials are deposited. This is followed by the gradual loss of moisture in the endosperm as grain-filling nears completion. The grain color changes from green to yellow beginning at the top of the panicle.

Figure 14. Hard-dough stage.

Stage 8.0 Physiological Maturity (Fig. 15). The grains of the main panicle have reached maximum dry weight and continue to dry as moisture decreases in the endosperm due to the formation of a small dark layer at the hilar region of the seed. Physiological maturity proceeds from top to ottom of the panicle. Grain growth is more rapid and grain-filling is shorter at higher temperatures. As temperature increases, water content drops rapidly to about 20% or less at maturity. A thorough scrutiny of the grain is required to actually reveal the black layer because of the tiny size occupied by this layer in the seed. New tillers are emerging from the base of the plant.

The stem and panicle branches remain green even when the seeds have ripened. Tiller number may increase to a certain age and declines afterwards due to tiller competition for light and nutrition. Tillers produced at near maturity are unproductive and may die, or produces panicles which are small and unable to ripen by harvest time. Half-filled spikelets may persist at harvest.

Figure 15. Physiological maturity.

4.2 Growth Chamber Study

Table 3 shows the result of the regression analyses of stage number with days after planting and stage number with GDD for proso millet under controlled conditions. The coefficients of determination (R^2), intercepts (a) of the regression lines and coefficients of variation (C.V. %) between stage and days and between stage and GDD are similar for each treatment. When all the data were pooled to create a composite data set, the regression of days on stage number showed somewhat better fit than GDD and stage, as given by the R^2 value of .973 and a lower coefficient (9.1%). The regression analysis for treatment 3 showed that GDD and days separately accounted for 96.0 percent of the total variation observed in developmental stages which in effect was the lowest for all treatments.

The test of homogeneity shows that the slopes of the regression lines between stage and days for treatments 2 and 3 are homogenous but both are significantly different from treatment 1. This means that plants grown in the high temperature range were progressing faster at the rate of 0.16614 stage units per day. The 5 ^{o}F difference in mean temperature between treatment 1 and treatments 2 or 3 accounted for much of the rapid development. Fewer days were required to reach maturity at higher temperature (Appendix Table 1). However, slightly more days were needed to reach blooming (stage 5) at longer photoperiod. It would be reasonable to speculate that a

Table 3. Regression analysis between stage number with days after planting and stage number with GDD50, for proso millet grown in the growth chamber. Shown are the coefficient of determination (R^2), intercept (a), regression coefficient (b), and coefficient of variation (C.V.%).

Treatment	Stage vs. days after planting				Stage vs. growing degree days			
	(R^2)	a	b[1]	C.V.%	R^2	a	b[1]	C.V.%
1	.994	-.70950	.16614a	4.3	.994	-.70950	.00554b	4.3
2	.991	-.36559	.15112b	5.1	.991	-.36559	.00604a	5.1
3	.959	-.55918	.14611b	12.6	.959	-.55918	.00584ab	12.6
Composite	.973	-.48100	.15291b	9.1	.961	-.44780	.00569ab	10.9

Treatment 1: Temperature range 85°F - 75°F day/night temperature with 13 hours light period.
Treatment 2: Temperature range 80°F - 70°F day/night temperature with 13 hours light period.
Treatment 3: Temperature range 80°F - 70°F day/night temperature with 15 hours light period.

[1]Regression coefficients with the same letters are not significantly different at 0.01 level.

certain degree of photoperiodism was exhibited by the experimental variety. A more thorough study on this aspect is desired to enable the complete characterization of daylength response by proso millet.

The regression coefficients for GDD (Table 3) showed homogeneity between treatments 1 and 3 and treatments 2 and 3, but treatments 1 and 2 are significantly different from each other. This difference can be accounted for by the 5 ^{o}F difference in mean temperature between these two treatments. It took fewer days for treatment 1 to reach blooming (stage 5), and it required more thermal units to be accumulated than in treatment 2 (Appendix Table 1). Similarly, a slightly higher GDD accumulation was required to reach flowering at longer daylength.

4.3 Temperature And Precipitation Patterns

Mean weekly temperature profile from sowing to harvest for the first and second planting treatments showed a general constant trend until about the thirteenth week when cooler temperatures were recorded irregularly in Lincoln (Figure 16). The week number for each planting and the corresponding dates are summarized in Appendix Table 2. The temperature profile for the third and fourth planting began to show cooling trends on the nineth week after sowing. The last planting treatment had to be terminated on the 13th week when Lincoln experienced its first frost period. The pearl millets and

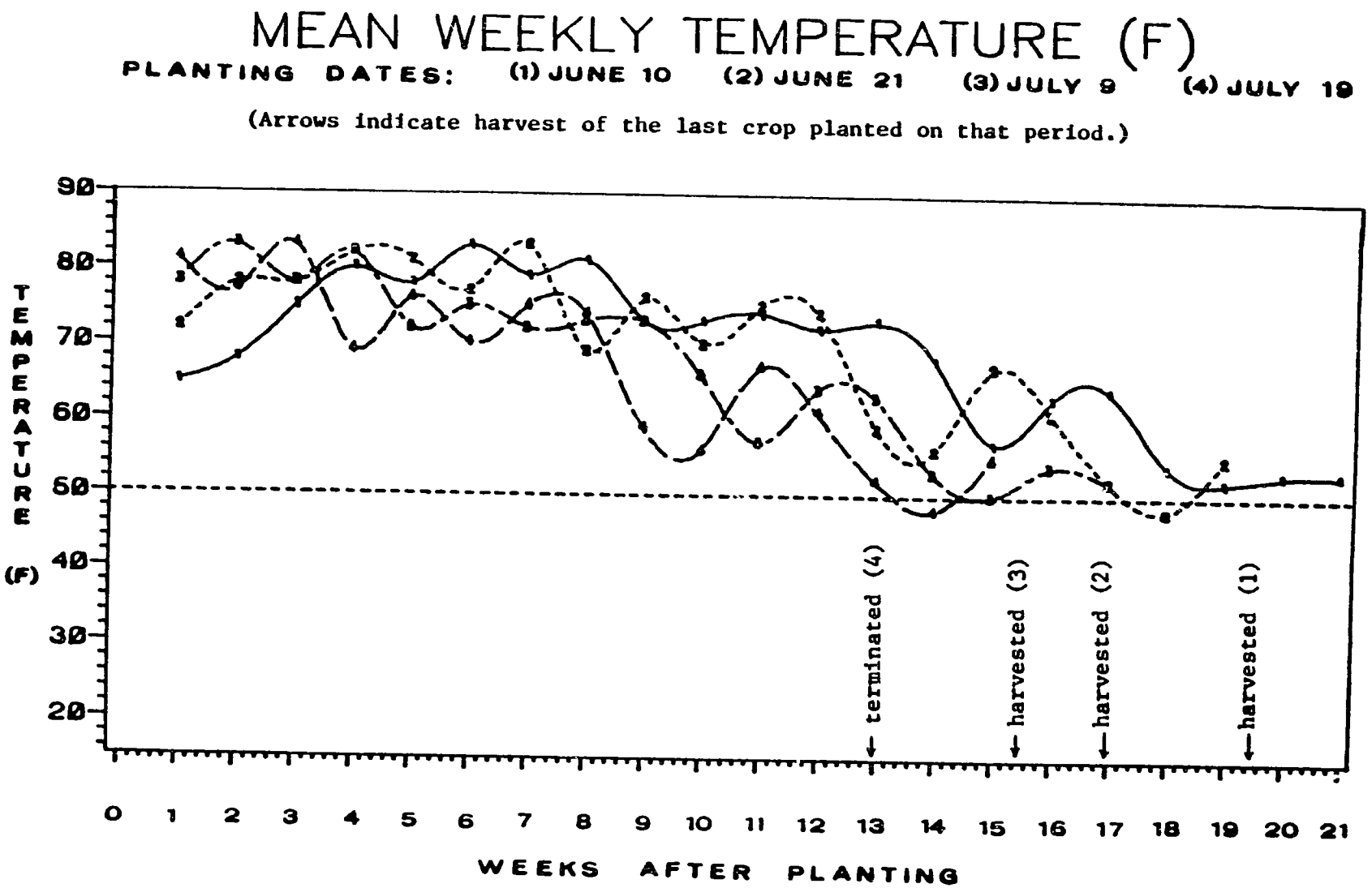


Figure 16. Mean weekly temperature profile for four planting periods in the summer of 1982.

sorghum hybrid were in the early dough stage at this time. Figure 17 shows the minimum weekly temperature profile for each planting schedule. Temperatures did not begin to drop below the base temperature of 50 °F (10 °C) until about the 15th, 13th, 11th and 9th week after June 10, June 21, July 9 and July 19 dates, respectively. All the proso and pearl millets had reached physiological maturity before the minimum temperature fell below 50 F on the first and second planting. The sorghum hybrid was near physiologic maturity and hard dough when this condition occurred in the first and second planting, respectively. The lowest minimum temperature for a week reached about 34 °F (1.1 °C).

Total weekly precipitation for the different periods are given in Figure 18. Peak values ranging from 3.5 to 6.5 inches (89 to 165 mm) were recorded on the 9th, 8th, 5th and 4th weeks of the June 10, June 21, July 9 and July 19 plantings, respectively. Precipitation during the first period was somewhat widely distributed compared to the other periods. A 7 to 10-day dry spell was experienced prior to a peak rainfall incidence.

4.4 Field Results

During the month of the first and second plantings (June), the early stages of growth took place in a period of high to moderate temperatures. During the third and fourth plantings (July) growth and development began with

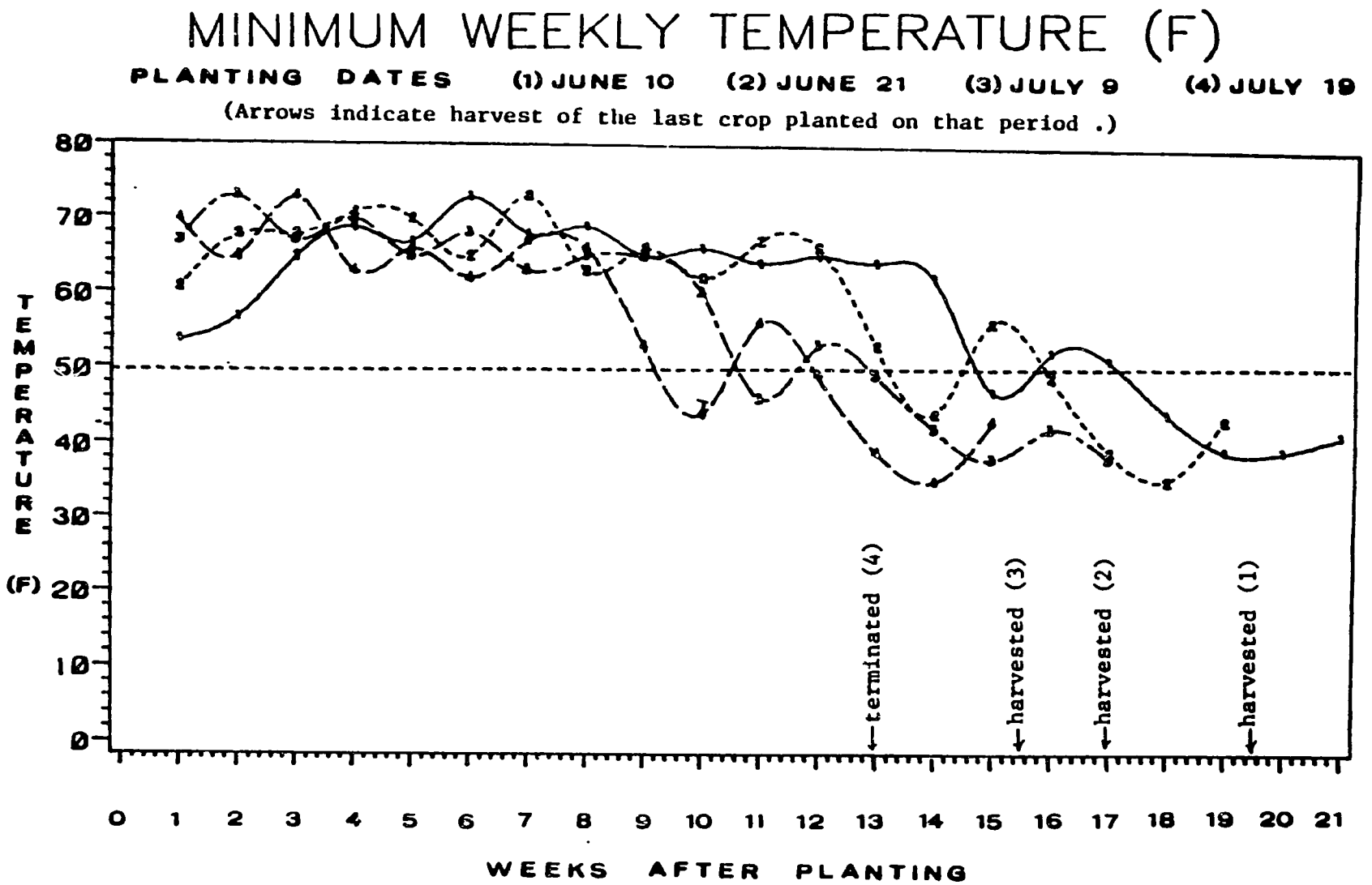


Figure 17. Minimum weekly temperature profile for four planting periods in the summer of 1982.

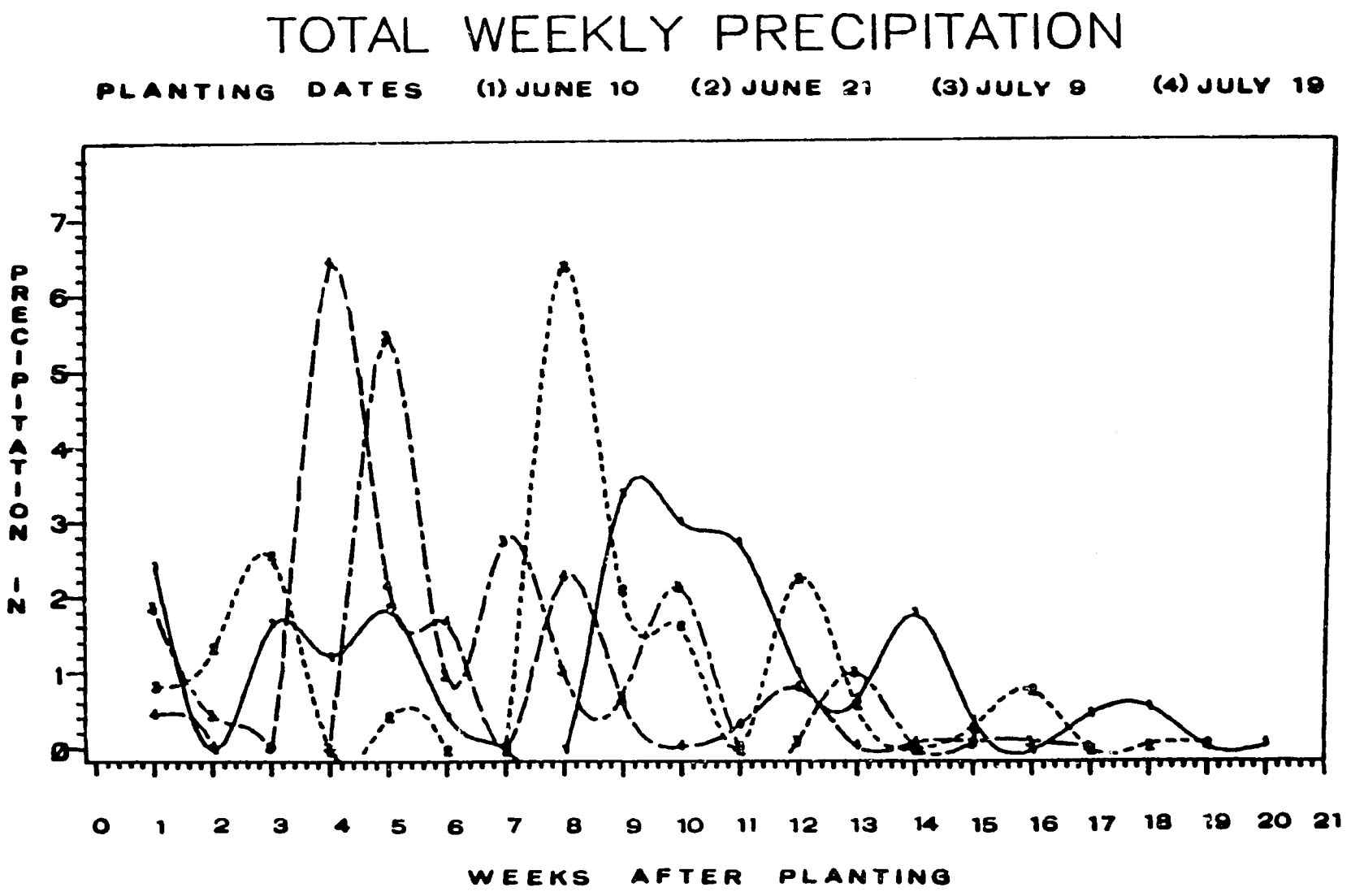


Figure 18. Total weekly precipitation profile for four planting periods in the summer of 1982.

a period of high temperatures and maturity took place in cooler conditions.

The regression analyses for phenological stage and growing degree days accumulated from planting of each grain crop are shown in Table 4. A test of homogeneity of the slopes was done by groups to compare, among other things, the variation in response to planting dates and by variety. There were no significant differences in slopes of the response to planting dates within individual varieties of proso millet. However, there were significant differences between varieties of Dawn and Cope or Panhandle at the 0.01 level. Cope and Panhandle showed homogenous rates of development ranging from 0.00424 to 0.00462 stage units per GDD unit. The early maturing variety Dawn progressed faster from 0.00547 to 0.00569 stage units per unit of GDD. It was inferred that GDD accounted for 96.1 to 98.9 % of the total variations observed in the developmental stages of proso millets. Coefficients of variation for the composite data of Cope and Panhandle were lower than that of Dawn.

Results of the analysis for RS-671 showed homogeneity of the regression coefficients between June 10 and June 21 plantings and also between July 9 and July 19 plantings. Their coefficients of determination varied from 0.981 for July 19 planting to 0.996 for June 21. It also had the lowest coefficient of variation than either proso or pearl millets. Summary of observations from all

Table 4. Regression analysis between stage number and GDD50 for six grain crops planted on different dates at the Lincoln Horticulture Farm, summer 1982. Shown are the coefficient of determination (R^2), interest (a), the regression coefficient (b), coefficient of variation (C.V.%), and standard error of estimate (S.E.).

Group	Variety	Planting Date	(R^2)	(a)	(b)[1]	(C.V.(%))	(S.E.)
PROSO	COPE	June 10	.970	.26267	.00424c	9.5	0.41
		June 21	.988	-.22412	.00436c	6.6	0.30
		Composite	.975	.02983	.00428c	8.8	0.38
	DAWN	June 10	.981	-.13732	.00547ab	8.4	0.35
		June 21	.978	-.80308	.00559a	10.8	0.43
		Growth Chamber	.961	-.44780	.00569a	10.9	0.46
		Composite	.962	-.45079	.00566a	10.9	0.46
	PANHANDLE	June 10	.979	.33826	.00440bc	7.6	0.35
		June 21	.989	-.22055	.00462bc	6.5	0.28
		Composite	.978	.05457	.00451bc	8.0	0.35
SORGHUM	RS-671	June 10	.995	.37530	.00344c	3.5	0.20
		June 21	.996	.12626	.00349c	3.3	0.18
		July 9	.990	-.20098	.00383ab	5.1	0.24
		July 19	.981	-.13227	.00401a	6.8	0.30
		Composite	.987	.17406	.00356bc	5.6	0.29
PEARL	SENEGAL BULK	June 10	.991	-.18923	.00411b	5.3	0.27
		June 21	.993	-.21410	.00412b	5.0	0.26
		July 9	.973	-.52385	.00441ab	8.4	0.44
		July 19	.973	-.91978	.00479a	9.6	0.43
		Composite	.981	-.39926	.00429ab	7.5	0.37
	SERERE-3A	June 10	.982	-.06782	.00421ab	7.5	0.39
		June 21	.991	-.42897	.00468a	6.0	0.30
		July 9	.977	-.86980	.00475a	8.9	0.43
		July 19	.978	-.94480	.00494a	8.6	0.39
		Composite	.977	-.52896	.00459a	8.5	0.42

[1]Regression coefficients with the same letters are not significantly different between plantings and varieties for each group at .01 level.

planting dates produced a slower rate of development with approximately 0.00356 stage units per GDD unit. Late planting generally resulted in a shorter total growth period than early plantings. This agreed well with observations found by Martin and Sieglingen (1929).

Regression coefficients for both varieties of pearl millet showed only a slight degree of heterogeneity particularly for the June 10 and June 21 plantings of Senegal Bulk; otherwise all were homogenous to each other. Slopes ranged from a high of 0.00494 to a low of 0.00411 stage units per GDD. The coefficients of determination also varied from 0.973 to 0.993 for Senegal Bulk and from 0.977 to 0.991 for Serere-3A. In general, it appeared that observations from the first and second plantings of sorghum and pearl millets had the highest R^2 values and smallest coefficients of variability.

These regression coefficients were used to estimate the GDD requirements from planting to physiologic maturity of each grain crop for different planting dates (Appendix Tables 3 and 4). A family of curves was formed by plotting the phenological stages against accumulated days from planting for each variety (Fig. 19). It was shown that Dawn reached maturity first followed by Panhandle, Cope, Serere-3A, Senegal Bulk and RS-671 in 56, 65, 69, 86, 92 and 107 days, respectively. All varieties except RS-671 reached stage 1 in about 10 days after planting.

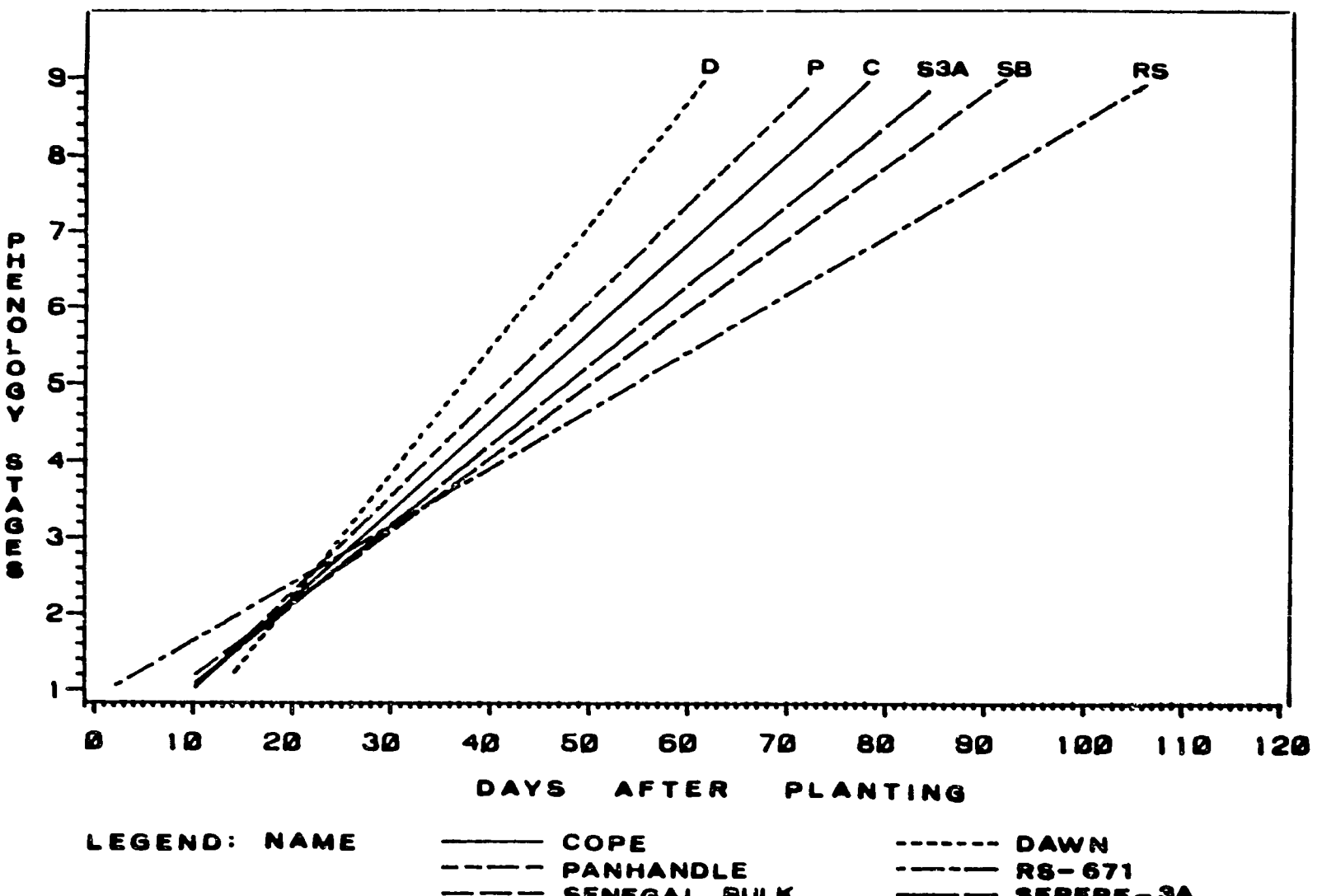


Figure 19. Family of curves for phenological observations and calendar days drawn for six grain crops planted on four different dates in the Lincoln Horticulture Farm, summer 1982.

Figure 20 shows the family of curves for the regression of GDD on phenological stages of each grain crop. All varieties reached stage 1 at approximately 220 degree-days except for both pearl millets which required about 330 degree-days. For the three proso millets, Dawn needed around 1470 degree-days to reach stage 8 while Panhandle and Cope required approximately 1760 and 1860 degree-days, respectively. RS-671 reached physiologic maturity in less than 2500 degree-days. The tall pearl millet variety, Serere-3A, reached stage 9 in about 2070 degree-days while Senegal Bulk needed approximately 2200 degree-days to complete its development.

The developmental and growth rates from emergence to flowering (half-bloom) of each variety per planting treatment were estimated following the approach by Robertson (1983). The reciprocal of the age (1/N) at flowering is a measure of the mean daily rate of development while the quotient of height at flowering by the age gives the average daily rate of growth. For the six varieties used, the rates of development were almost similar between planting dates within a variety (Table 5). However the growth rate seemed to be unrelated between planting dates for individual varieties indicating variations in physiological responses in terms of plant height. Below normal minimum and maximum temperatures especially during the July planting periods favored slower rates of development and reduced the rate

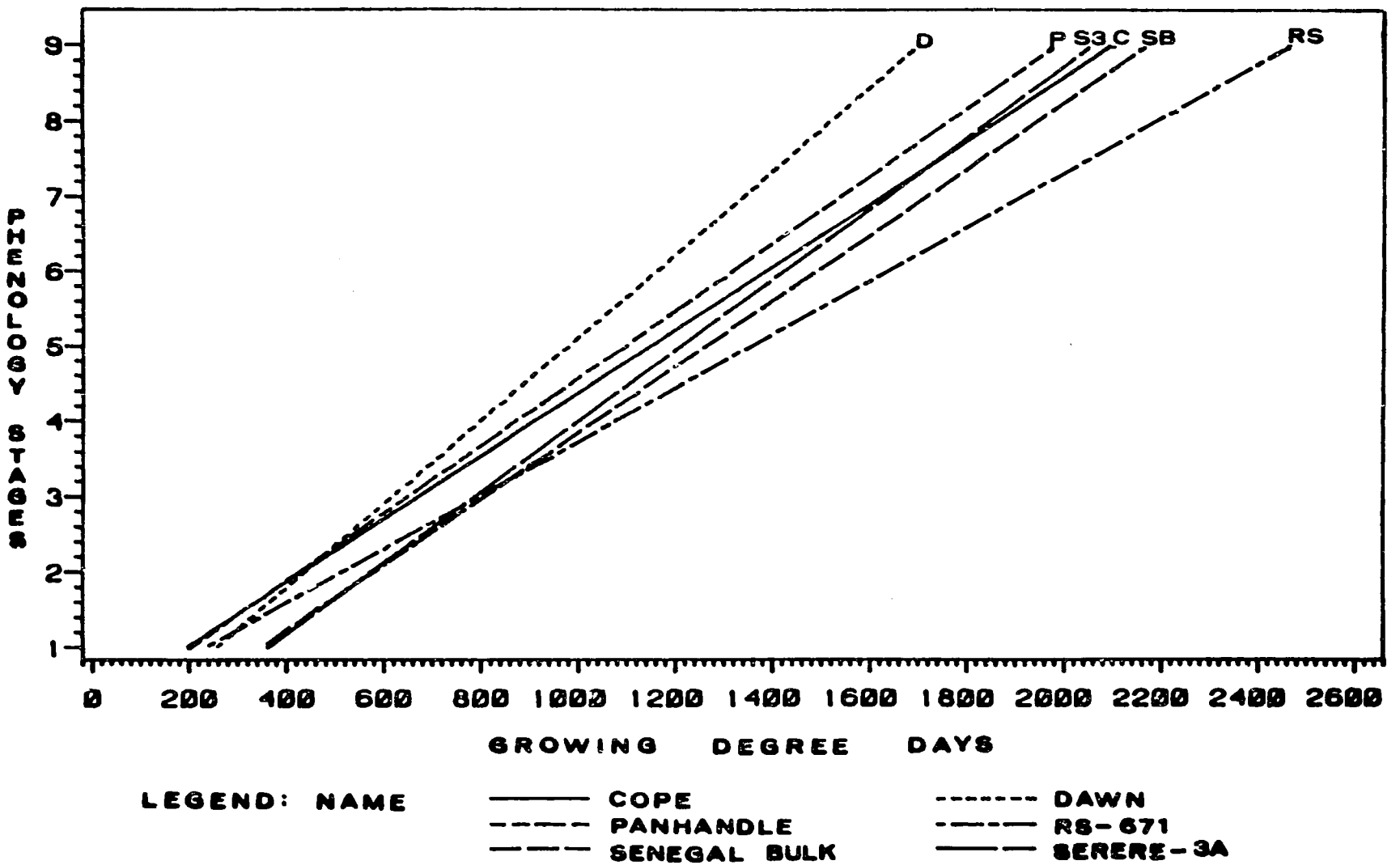


Figure 20. Family of curves for phenological stages and estimated GDD requirements of six grain crops planted on different dates in the Lincoln Horticulture Farm, summer 1982.

Table 5 . Number of days from emergence to flowering (N), height at flowering (h), average daily rate of development (1/N), and growth rate (h/N) for six grain crops planted at different dates during the summer of 1982, Lincoln Horticulture Farm.

Crop	Planting date	N	h (in)	1/N	h/N (in/day)
COPE	June 10	38	28.5	.02632	0.7501
	June 21	37	19.9	.02703	0.5384
DAWN	June 10	31	12.5	.03226	0.4026
	June 21	31	16.9	.03226	0.5448
PANHANDLE	June 10	33	19.0	.03030	0.5750
	June 21	34	17.4	.02941	0.5118
RS-671	June 10	52	33.9	.01923	0.6519
	June 21	59	37.9	.01695	0.6426
	July 9	63	34.2	.01587	0.5424
	July 19	65	36.6	.01538	0.5633
SENEGAL BULK	June 10	51	32.2	.01961	0.6322
	June 21	48	31.7	.02083	0.6611
	July 9	50	25.2	.02000	0.5039
	July 19	61	27.7	.01639	0.4537
SERERE-3A	June 10	47	86.1	.02128	1.8311
	June 21	43	76.6	.02326	1.7817
	July 9	53	81.3	.01887	1.5339
	July 19	55	62.1	.01818	1.1281

of growth of each plant considerably.

Figures 21 through 23 show the actual time sequence of plant height for each variety of proso millet. Plant height for Cope ranged from about 24-30 in. The half-bloom (HB) date occurred six days earlier in the second planting but generally coincided with the time when the optimum height had been reached as in the earlier planting. Height variations only became distinct prior to half-bloom stage of each planting date. Dawn showed a range of approximately 14 to 20 in. with the optimum being reached after half-bloom date. The earlier planted Dawn variety was much shorter than the late seeded group. However, it took a longer time between growing point initiation (GPI) to half-bloom for the earlier planted Dawn, yet both groups reached the half-bloom date at near equal time after planting.

Panhandle had a narrower height variation between plantings. It reached GPI and HB dates at the same length of time from planting. As contrasted from the other two proso varieties the optimum height of Panhandle was not actually reached at half-bloom. This difference could be a varietal characteristic or a varietal response to certain environmental conditions. In general, plants sown earlier in the season were much taller than the late plantings, except for Dawn although all three proso varieties reached maturity well in advance of the first frost date. Figure 24 illustrates the actual time

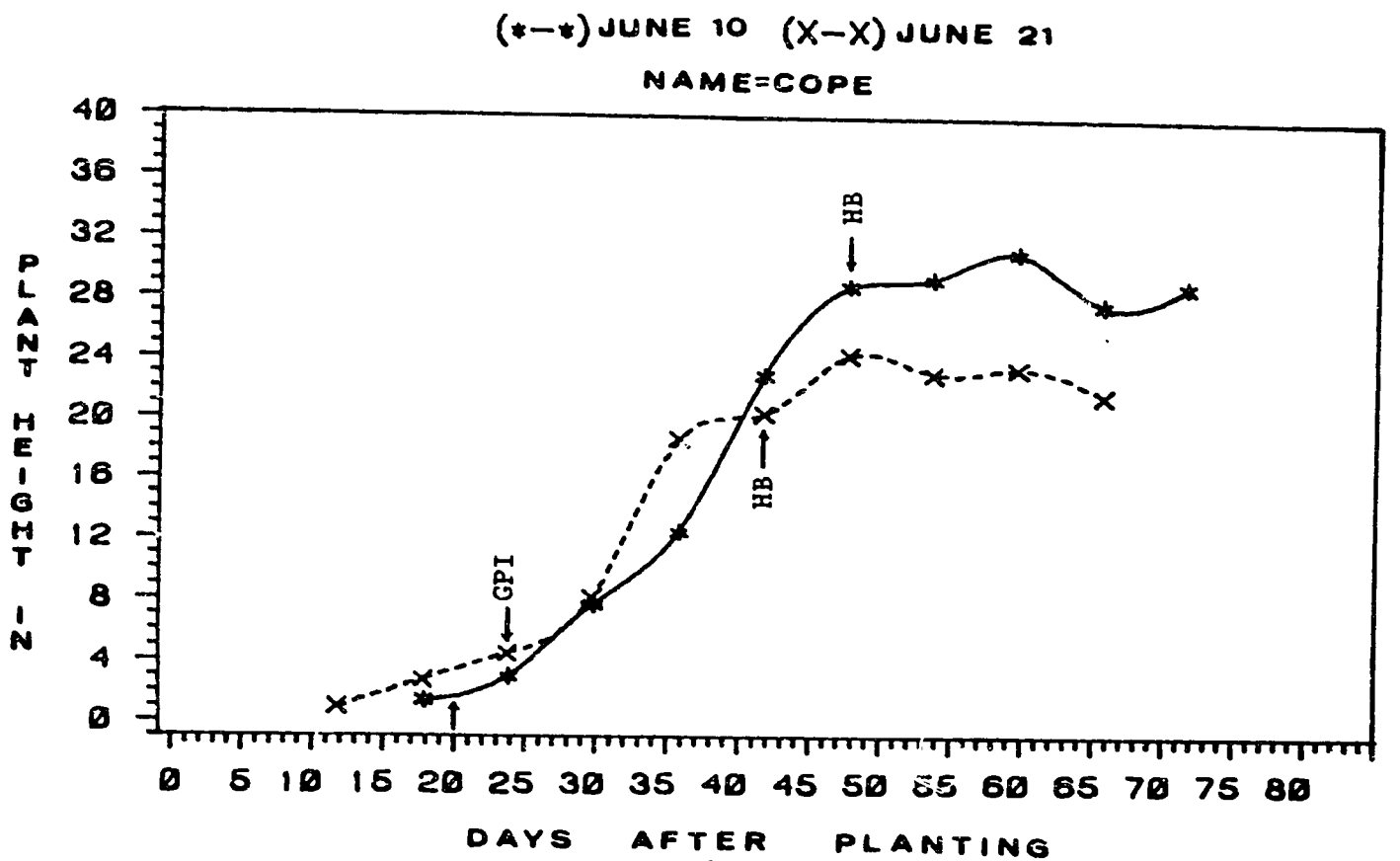


Figure 21. Time sequence of plant height for Cope millet planted on June 10 and June 21 at the Lincoln Horticulture Farm in the summer of 1982. Arrows mark the time of growing point initiation and flowering (half-bloom) in each planting period.

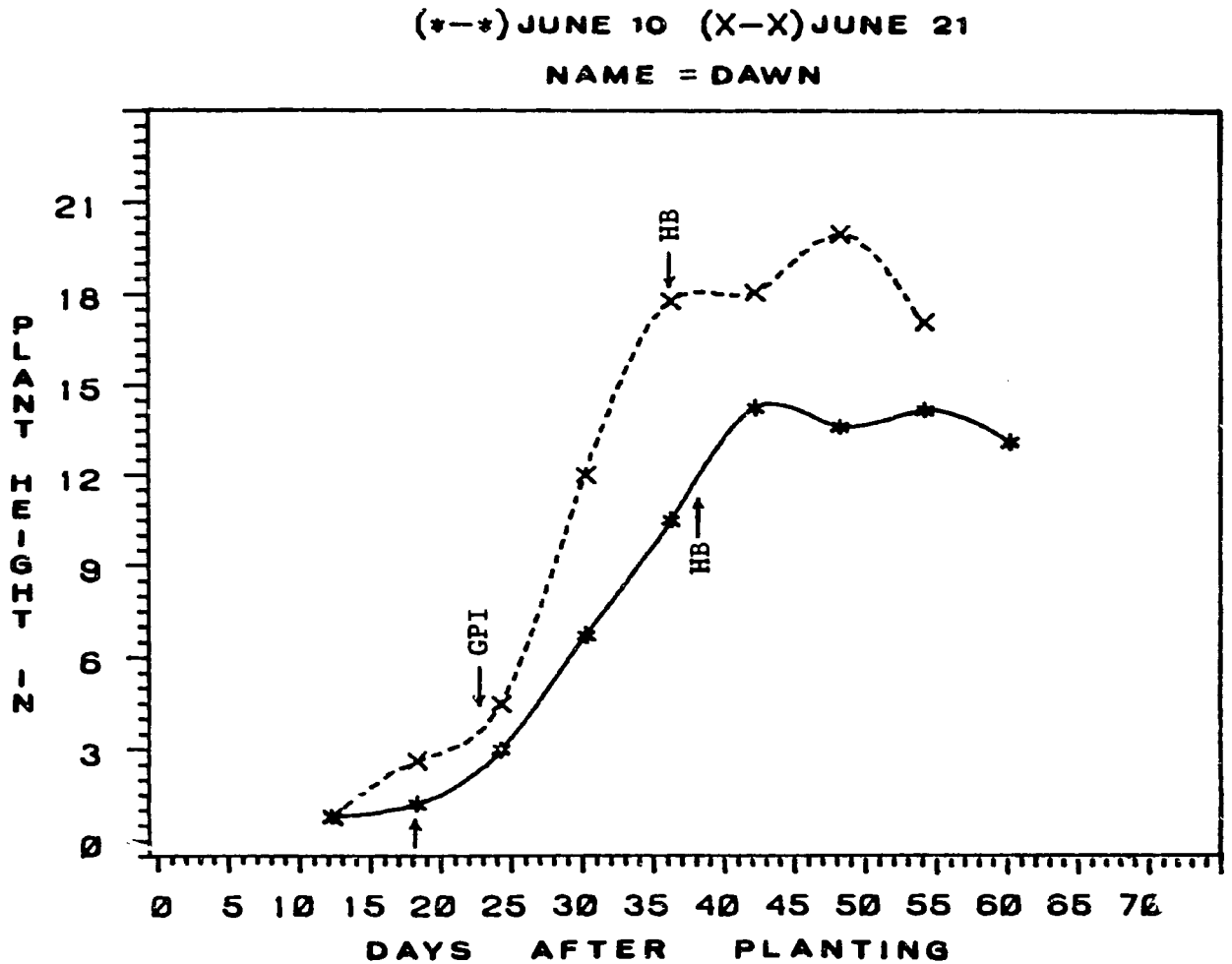


Figure 22. Time sequence of plant height for Dawn millet planted on June 10 and June 21 at the Lincoln Horticulture Farm in the summer of 1982. Arrows mark the time of growing point initiation and flowering (half-bloom) in each planting period.

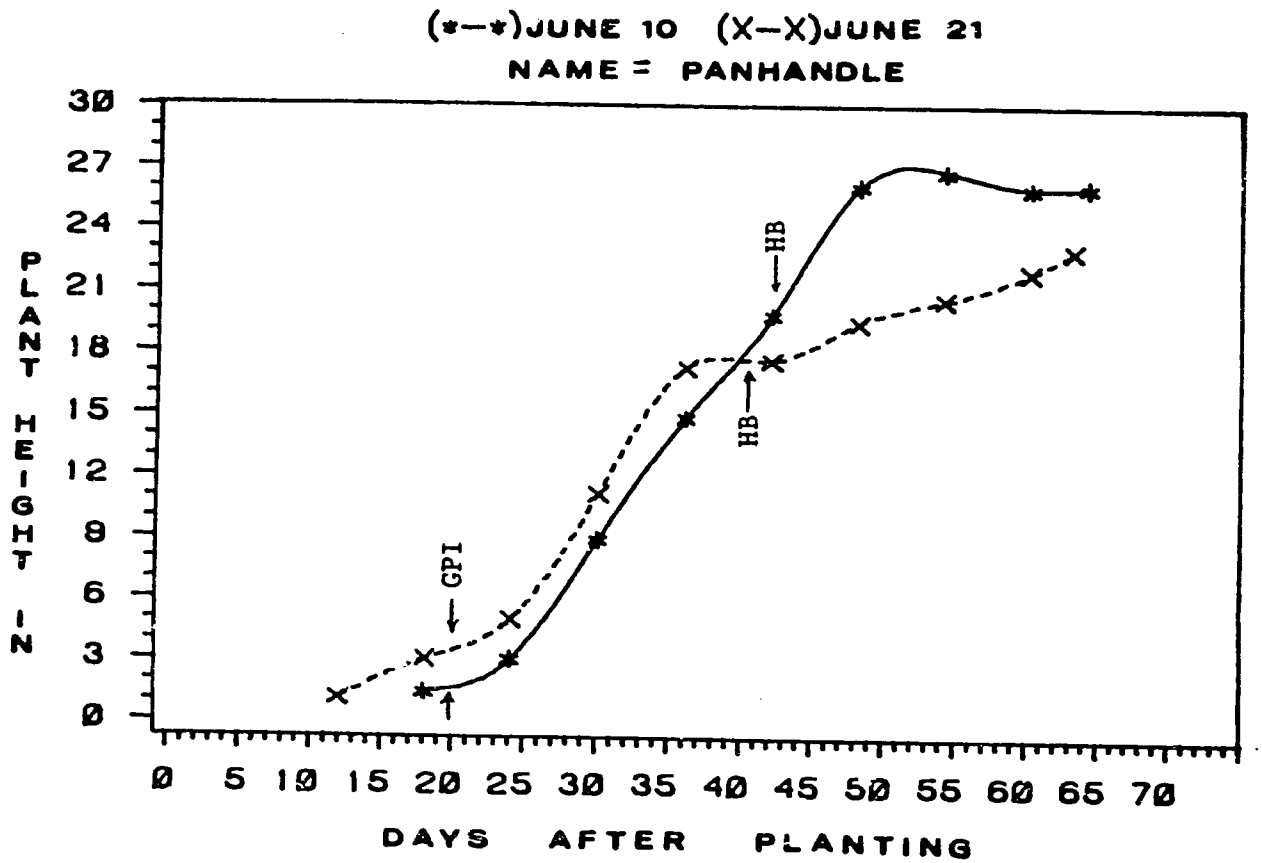


Figure 23. Time sequence of plant height for Panhandle millet planted on June 10 and June 21 at the Lincoln Horticulture Farm in the summer of 1982. Arrows mark the time of growing point initiation and flowering (half-bloom) in each planting period.

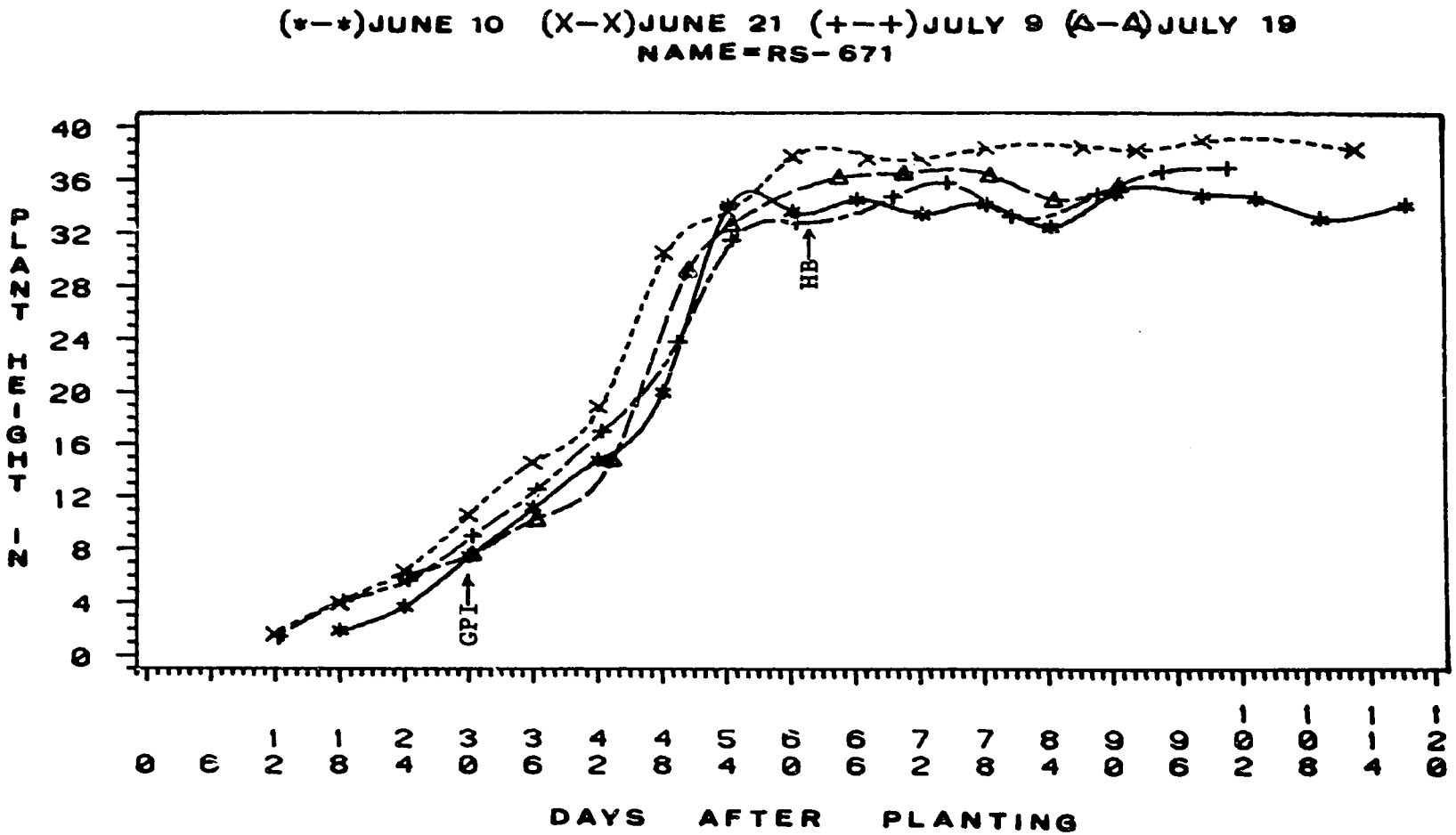


Figure 24. Time sequence of plant height for RS-671 sorghum hybrid planted on four different dates at the Lincoln Horticulture Farm in the summer of 1982. Arrows mark the time of growing point initiation and flowering (half-bloom) in each planting period.

sequence of height for the sorghum hybrid. The curves followed similar patterns reaching optimum height after 54 days from planting. Growing point initiation and flowering occurred at about 30 and 62 days after planting, respectively.

The time sequence of height for Senegal bulk and Serere-3A are given in Figures 25 and 26. Growing point initiation began after about 30 days for all plantings of both varieties while half-bloom date showed more variability in all planting treatments. Optimum height was generally reached after 54 days from planting corresponding roughly with the time of flowering.

Plant height, number of tillers per plant (excluding the main culm) and number of tillers with panicles at flowering and harvest of each crop are summarized in Table 6. There still seemed to be an increase in height after flowering for all six crops. However, these increases appeared to be within the optimum range as observed in Figures 21 to 26. An appreciable increase in the number of tillers per plant and number of tillers with panicles were observed from flowering to maturity. These were due to the emergence of secondary and sometimes tertiary (in proso) tillers which proved to be non-productive. Tillers produced at near maturity were not able to develop completely and the panicles formed in them contained many unfilled spikelets.

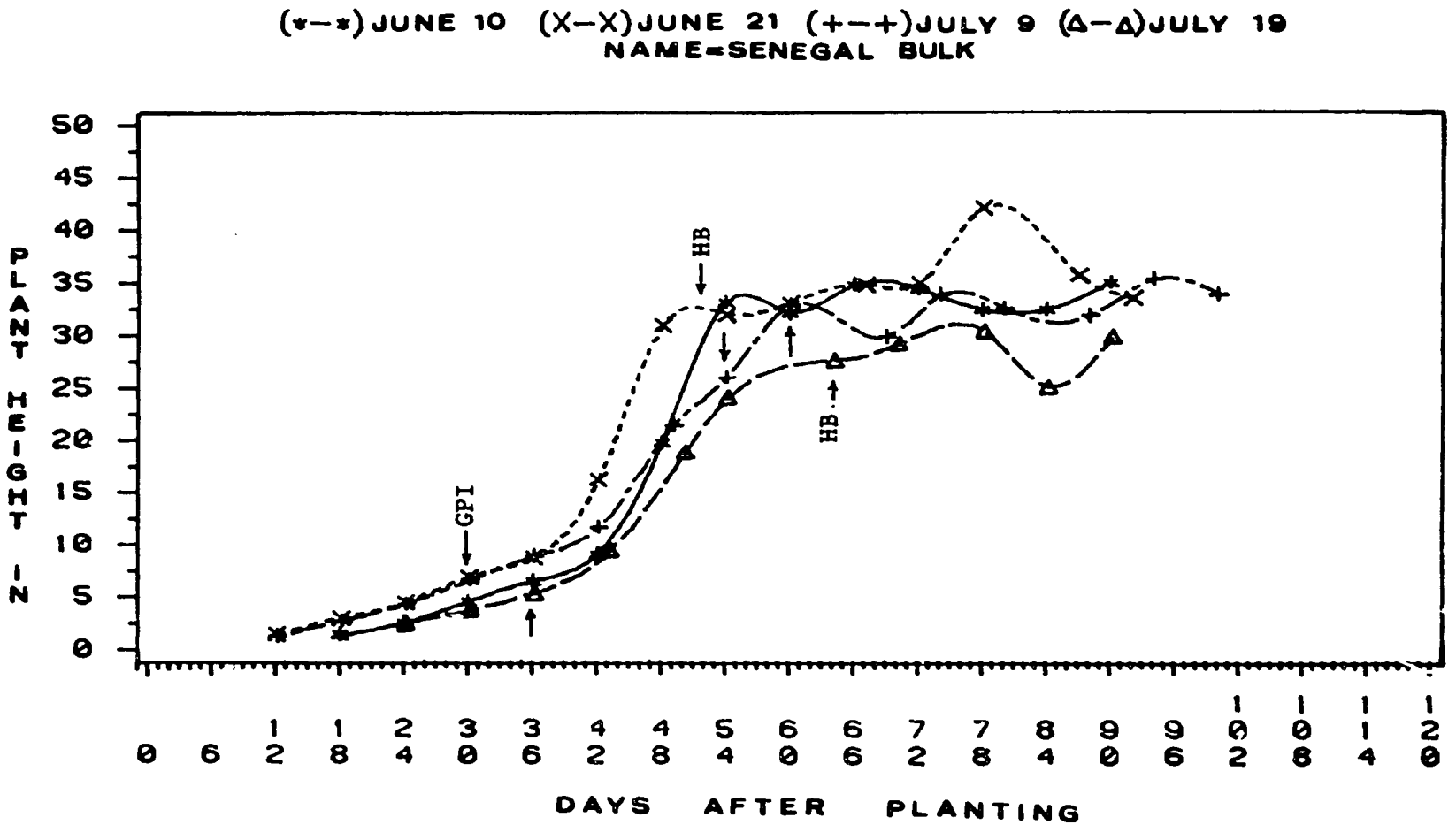


Figure 25 . Time sequence of plant height for Senegal Bulk millet planted on four different dates at the Lincoln Horticulture Farm in the summer of 1982. Arrows mark the time of growing point initiation and flowering (half-bloom) in each planting period.

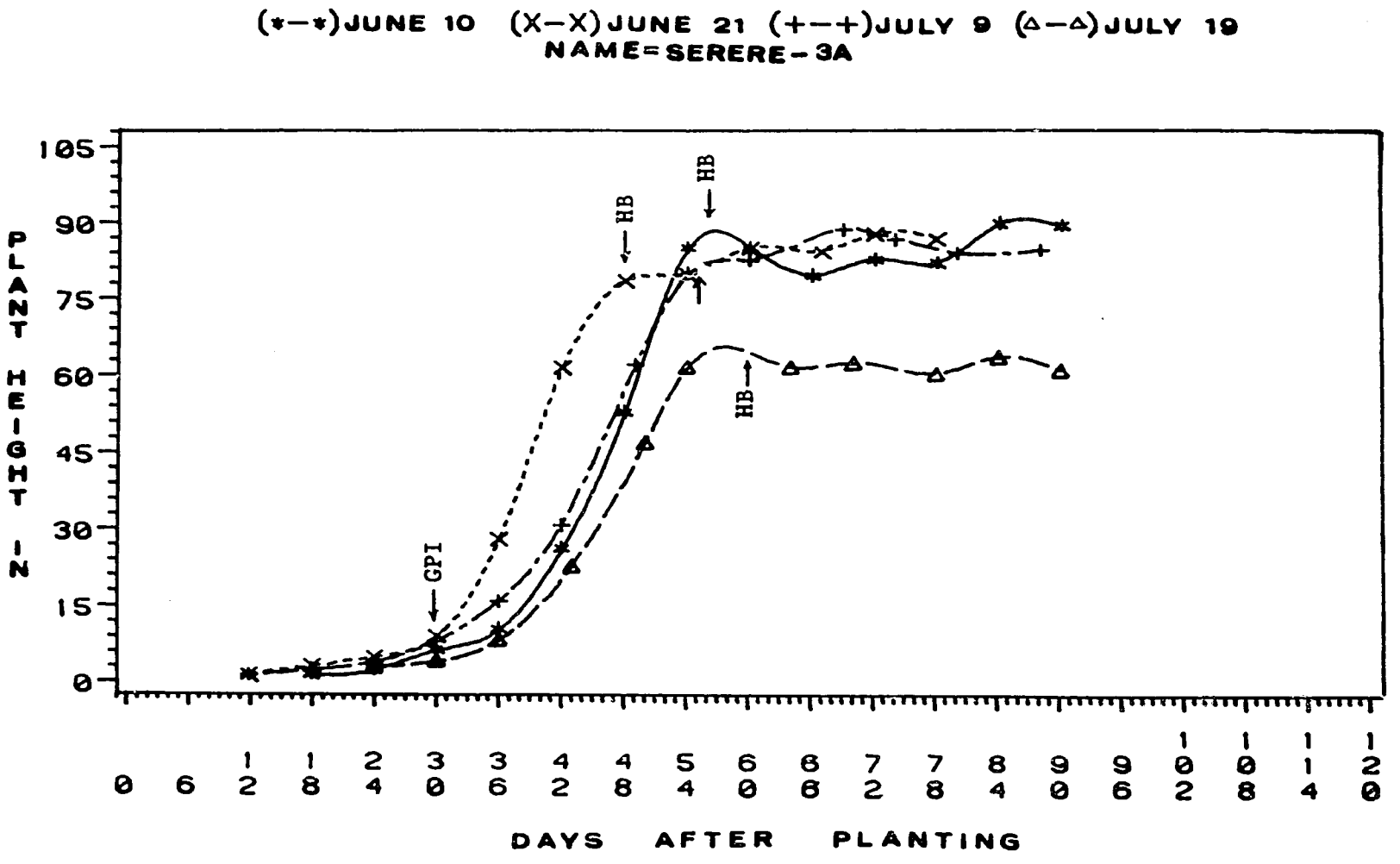


Figure 26 . Time sequence of plant height for Serere-3A millet planted on four different dates at the Lincoln Horticulture Farm in the summer of 1982. Arrows mark the time of growing point initiation and flowering (half-bloom) in each planting period.

Table 6. Plant height (in), number of tillers per plant, number of tillers with panicle at flowering and harvest of six grain crops planted on different dates at the Lincoln Horticulture Farm, Summer, 1982.

Group	Crop	Planting date	AT FLOWERING			AT HARVEST		
			height	tillers/plant	tillers w/ pan.	height	tillers/plant	tillers w/ pan.
PROSO MILLET	CORE	June 10	25.6	20.5	9.4	27.9	24.6	23.4
		June 21	21.5	19.4	10.1	22.2	26.9	23.8
	DAWN	June 10	11.9	11.8	8.1	13.7	25.2	22.5
		June 21	17.8	16.0	9.8	18.6	18.5	17.5
	PANHANDLE	June 10	20.9	12.9	8.6	26.1	18.7	17.6
		June 21	17.6	17.5	9.2	22.5	32.6	31.6
SORGHUM	RS-671	June 10	34.1	1.4	1.4	34.2	2.2	1.9
		June 21	37.8	1.1	0.9	39.8	2.0	1.2
		July 9	34.8	0.7	0.5	36.8	1.0	0.5
		July 19	36.7	1.1	1.1	35.2	1.1	0.5
PEARL MILLET	SENEGAL BULK	June 10	32.2	14.0	4.9	33.9	15.6	7.5
		June 21	32.7	11.2	3.3	34.7	10.1	4.8
		July 9	30.7	7.5	2.3	34.7	11.1	5.7
		July 19	28.0	8.4	3.4	27.6	7.4	3.3
	SERERE-3A	June 10	86.1	12.6	4.3	90.8	14.3	8.8
		June 21	80.1	8.2	2.2	88.4	8.8	3.1
		July 9	82.2	9.5	2.6	84.9	6.2	3.3
		July 19	62.0	5.5	1.9	62.9	5.8	3.3

B. ASSESSMENT OF RICE-BASED CROPPING PATTERNS FOR THE TROPICS USING AGROCLIMATIC NORMALS

V. REVIEW OF LITERATURE

5.1 Climatic Considerations In Tropical Agriculture

The seasonal temperature range in the tropics is not as large as in the temperate regions. However, temperature in the tropics does vary with altitude. Aside from temperature, other climatic factors such as rainfall, solar radiation, vapor pressure deficit and wind conditions exert an influence on crop growth and yield in one or two ways. First, they alter the rate and duration of growth between various phenological stages. Second, they also indirectly influence grain yield through the impact of pest and disease incidence.

Solar radiation has a profound effect on grain yield. Low yields in the tropics during the monsoon season have been frequently associated with low light intensities; especially during the ripening phase (Rao and Deb 1974, Tanaka et al 1966). The number of filled spikelets increases with high solar radiation (Wada et al 1973). The general practice of adopting photoperiod insensitive varieties offsets the importance of light duration and allows potential flexibilities in the growing of crops. Daily solar radiation during the monsoon season in the

tropics was reported to be one and a half times lower than that available in temperate rice growing regions (De Datta 1981). Moomaw et al (1967) found significantly high correlations between grain yield and solar radiation occurring during the last 30 days of crop growth. De Datta and Zarate (1970) observed similarly high correlations over a 45 day period before harvest (panicle initiation to maturity). Stansel (1975) concluded that the period from panicle initiation to 10 days before maturity was the most crucial stage in rice for solar radiation requirement.

In the humid tropics, the duration of cropping season depends primarily on rainfall except in irrigated areas. Defined cropping patterns in rainfed (unirrigated) areas are generally rationalized on the basis of rainfall distribution and probability of occurrence of certain quantity over time.

In the monsoon regions of Asia, rainfall is characterized by high spatial and temporal variability. The beginning of the monsoon determines planting time and the temporal distribution influences growth and development of crops. In predominantly rainfed areas, crop production has been timed to coincide with the period having the most available moisture during the year to grow a variety of crop commodities. Still there appears to be a disturbing unpredictable variability in rainfall amount and distribution for a given location

from year to year. Too little or too much rainfall at any crop stage can lead to partial or total crop failure. It is therefore cumbersome to find a simple relationship between rainfall and grain yield. At best, only the probable occurrence of agricultural drought can be predicted based on long-term records.

A period of consecutive days with low rainfall can lead to drought conditions while high rainfall can cause flooding or water logging. Even a short duration of wet days may favor pest and diseases. Sastry (1976) observed that the prevalence of high temperatures and evaporation are associated with the non-occurrence of rainfall during the rainy season in both the tropics and sub-tropics.

Understanding the rainfall distribution and pattern in the tropics in relation to crop physiology and soil conditions is a primary prerequisite for successful crop planning and productivity. Slatyer (1960) believes that information on the daily, weekly or monthly frequency distribution of specified amounts of rainfall and their probabilities of occurrence are needed to make a general analysis of rainfall patterns for specific locations. Conventionally, daily monitoring of meteorological variables for crop-weather assessment is preferable for more accurate results. Whenever sufficient rainfall data and other climatic informations are available, it is important, as a first approach, to demarcate the regions which are climatologically homogenous and to identify

marginal areas for broad cropping pattern decisions. The maximum production potential on a single-crop basis occurs in areas where the levels of available sunshine and moisture at critical stages are non-limiting.

Relative humidity and wind speed in Southeast Asia seldom inhibit crop production, except during the passing of devastating cyclones. Tropical cyclones emanate generally outside a 7-degree belt north and south of the equator, mostly in late summer and over tropical oceans (Oldeman and Suardi 1977).

5.2 Moisture Requirement Of Rice And Selected Crops

Rice (Oryza sativa L.) is most commonly grown in wet-land or "paddy" fields which allow retention of water on the surface over extended periods. Some varieties are adapted to dry-land farming. These are grown in areas with fairly heavy rainfall during the growing season. Successful culture of rice is dependent on adequate sunshine, fairly high temperature summations during the growing season, and either an abundant or timely rainfall supply. Because rice is so diversely grown, compared to other cereal grains, the local cultural methods of production, varieties, maturity, moisture requirement, eating quality, etc. are likewise diverse from region to region around the world. It may be interesting to summarize the relative water use (transpiration ratio) in rice and some other crops under similar environments by

indicating the amount of water consumed to form a unit of dry matter ---- millet= 200 to 250, corn (maize)= 250 to 300, cotton= 300 to 600, wheat= 450 to 600, and rice= 500 to 800 (Nuttonson 1965).

The water requirement of rice is about .20 in. (5-6 mm) per day (Ridders 1972, Chabrolin 1977, Stansel and Fries 1980) or 7.87 in. (200 mm)/mo. during the vegetative stage, 11.81 in. (300 mm)/mo. during the reproductive to hard dough stage (Yoshida 1977). These monthly values of effective moisture exclude losses due to run-off and percolation. The risk of drought injury during the main growing season becomes high when the soil shows very low moisture holding capacity, especially in the top 7.87 in. (200 mm) of soil layer (Moormann and Veldkamp 1978, Lawson 1980). Rainfall must meet the water requirement in terms of ET plus possible losses through infiltration and percolation. The faster the percolation rate the higher the rainfall intensity and frequency required to produce a crop.

5.3 Temperature Requirement Of Rice And Selected Crops

Grist (1975) reported that the temperature requirement of rice from planting to maturity ranges from 68 to 100 ^{o}F (16-38 ^{o}C). When diurnal temperatures fall below 50 ^{o}F (10 ^{o}C) for 3 or more consecutive days during the grain-filling period, serious yield reductions occur in indica (tropical rice) varieties. For most crops

however, a low night time temperature is beneficial and fluctuations in day and night temperatures promote kernel maturity.

Table 7 shows the range of GDD (base 50 °F) requirement from planting to maturity of different cereal grains. These ranges may be considered arbitrary depending on the hybrid used, maturity class, location and growth environment involved, especially for rice. In general, these ranges cover a wide maturity class for each crop being evaluated. The GDD value for rice was transformed from the straight forward temperature summation (in °C) from planting to ripening into a base 50 °F value. Using this threshold temperature, the temperature summations for several rice varieties grown in the tropical areas of Mexico (18° 50'N) and Australia (15° 7' S) ranged from about 3,200 to 6,000 (base 50°F) from planting to maturity (Nuttonson 1965).

Stansel and Fries (1980) reported that about 900 GDD50 (500 GDD10 °C) units, not exceeding 27 units per day, are required during the reproductive period. This may vary between 900-1080 GDD50 (500-600 GDD10) at high and uniform plant population or 900-1260 GDD50 (500-700 GDD10) for transplanted rice. Other cultivars require a base accumulation of temperature units plus a certain daylength to stimulate panicle development. After the vegetative period, all maturity classes in rice are temperature-unit dependent for the remainder of the

Table 7. Range of degree-day requirements (base 50) from planting to maturity of each grain crop and the references used.

Crop	Ranges	References
Rice (*Oryza sativa* L.)	2100 - 4300	Stansel (1975), Yoshida (19[illegible]), Grist (1977)
Corn (*Zea mays* L.)	2100 - 3200	Neild and Seeley (1977), Seeley (1977)
Sorghum (*Sorghum bicolor* L.)	2000 - 2700	Neild and Seeley (1977), Logan (1981)
Pearl millet (*Pennisetum glaucum* L.)	2000 - 2500	Observations from Part A
Proso millet (*Panicum miliaceum* L.)	1400 - 1900	Observations from Part A

growing season.

Moomaw and Vergara (1965) reported possible high correlations betweeen grain yield and mean temperature, temperature summations, range, distribution pattern, and diurnal changes, or any combination thereof, throughout the growing season. Rice was reported to show variations in critical temperature at different growth stages (Van Royen 1954, Nishiyama 1965, Yoshida 1981, and De Datta 1981). It is a unique species among the cereal crops due to the ability of the different varieties to meet the highly diverse conditions of temperature prevailing over a wide range of latitudes of the world. There seems to be sufficient varietal differences in rice and a fair degree of interaction between temperature and other environmental factors with regard to different growth stages to disallow specification of cardinal temperature values. Osada (1964) reported a range of 77-95 °F (25-35° C) as optimum for photosynthesis by indica rices.

Analysis by Nuttonson (1965) on rice revealed that a 50 °F temperature threshold was close to the minimum thermal requirement for germination as well as for growth of rice. Using three base temperatures (40, 45, and 50° F), he concluded that the use of 50 °F base provided better consistency on a year to year summation and that degree-day summations for many rice varieties did not differ widely with conditions of climate and latitude. Nuttonson's findings showed relatively small standard

deviations and coefficients of variation compared to those obtained from the other base temperatures. Similarly, evidence presented by Nuttonson suggested that it is neither necessary nor desirable to use upper temperature limits in calculating GDD requirements of different rice varieties. For other cereral grains, the base 50 °F has been used widely in the United States as the critical threshold temperature below which physiological processes within a plant cease.

5.4 Influence Of Water Temperature On Paddy Rice

In the early vegetative stage of paddy rice, the water temperature is potentially more influential on rice seedling development and growth than air temperature. This is because the growing point is still under water (Adair and Engler 1955, Raney 1963, Matsushima et al 1964). Leaf elongation and plant height are, however influenced by both air and water temperatures presumably because these are completed in an aerial environment. A water temperature below 69 °F (21 °C) resulted in retarded germination, prolonged maturity, and caused severe yield reduction, but no damage appeared in the field when water temperature was between 69 and 77 F (21-25 °C). The roots developed poorly when water temperature was above 80 °F (27 °C), perhaps due to low oxygen content of warm water. IRRI (1963) reported that water temperature between 77 and 90 °F (25-32 °C) is

critical to rice.

Chapman and Peterson (1962) reported that seedling establishment of pre-germinated rice seeds is favored by water temperatures between 77 and 86 °F (21-30 °C). Shoot emergence from the water was most rapid at 86 °F (30 °C), but the optimum range for root elongation and penetration of the soil was 68 °F (20 °C) to 77 °F (25 °C). The effects of water temperature are determined by the depth of water and the magnitude of air temperature. Therefore the use of air temperature in estimating degree-day summations in early stages may show an underestimation. Thus, caution should be taken when applying this approach to determine phenological stages of paddy rice using temperature summations.

VI. SITE SELECTION AND DESCRIPTION

Three locations in the Philippines were selected to analyze the feasibility of success for some cropping patterns using degree-day phenology concepts rather than counting the calendar days with shifts in planting dates. The Philippines is an archipelago that is closely scattered within a region bounded between 21°25' north and 4° 23' north latitude and between 116° east and 127° east longitude (Fig. 27). These locations are : (a) Tuguegarao (17°37' N, 22 m msl), (b) Iloilo (10°42' N, 14 m msl) and (c) General Santos (06°07' N, 15 m msl). All

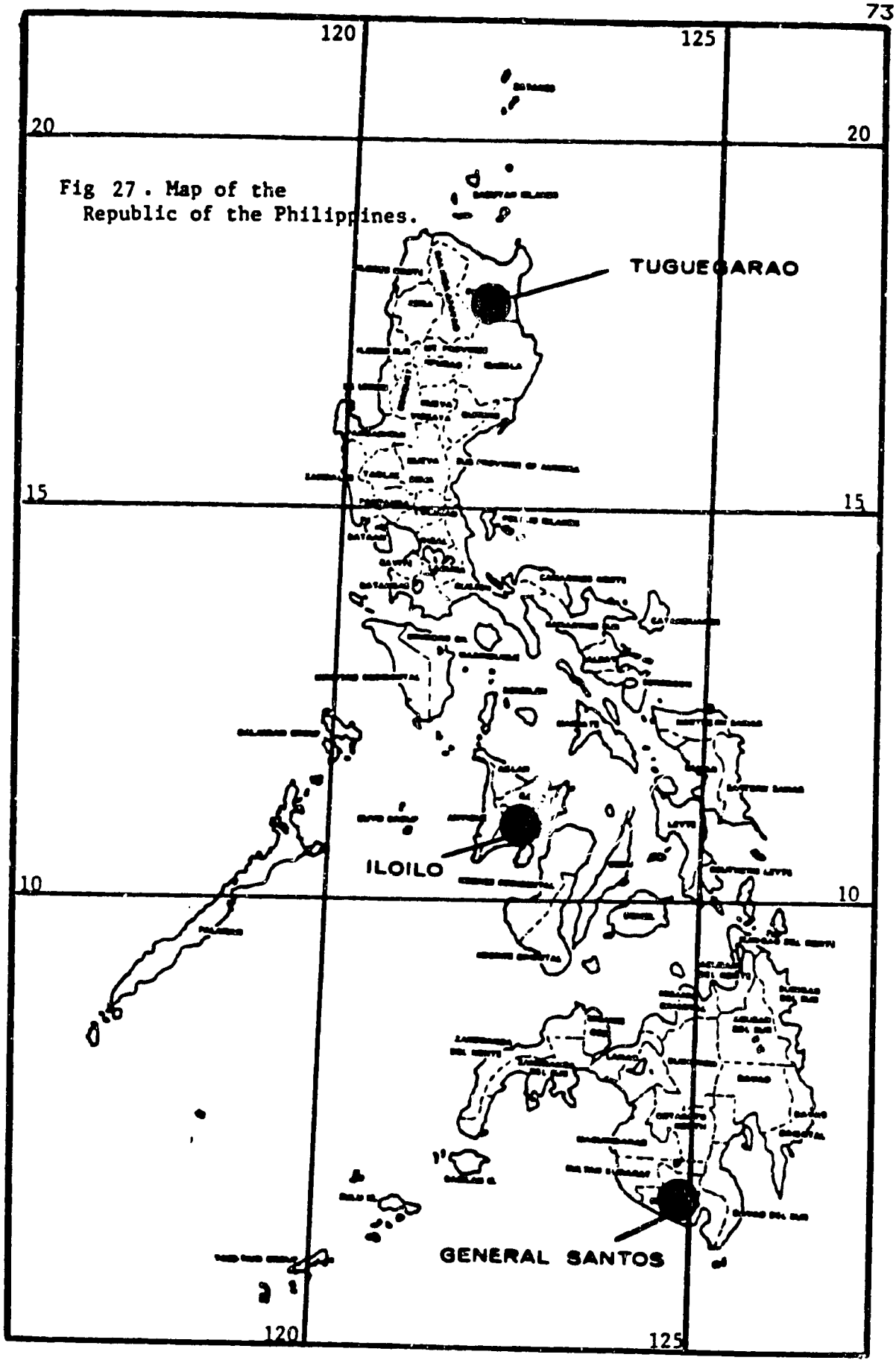


Fig 27. Map of the Republic of the Philippines.

locations have large areas of rainfed crop land but all three differ in their rainfall distribution during the main growing season.

It is important to point out some factors that have a direct consequence on the climatological environment of the archipelago, namely: the size, configuration and orientation of the islands; proximity of the mountain ranges; altitude and distribution of lands and bodies of water. These factors may affect the climate of different regions in the country in varying magnitudes. The Philippines' climatic environment is classified on the basis of its rainfall distribution rather than on temperature. The precipitation pattern is characterized by uneven distribution, especially in the central and northern regions of the country. The country is influenced by monsoon currents, tropical cyclones, and inter-tropical convergence zones (ITCZ) which divide the year into distinct wet- and dry-seasons. Months having an average rainfall of less than 3.94 in. (100 mm) per month are considered dry while those receiving greater than 7.87 in. (200 mm) per month are classified as wet months.

The country experiences the passing of about 19 tropical cyclones or typhoons annually which, more often than not, result in tremendous flooding losses to agricultural production. These contributions to rainfall from depressions and cyclonic storms are considered significant. The frequency, intensity and path traversed

by these low-pressure systems as they cross the land masses determine the spatial variability of rainfall pattern in any single season (Sastry 1976). Figure 28 shows the frequency of typhoon occurrence over different parts of the archipelago. From 90-years of accumulated data (1882-1972) on monthly typhoon incidence, it was observed that 50 percent of the typhoons crossing the country occurred during the months of July, August and September. Only 25 percent occurred from October to November over the central regions (PAGASA 1976). During the months from February through April drought problems became high risk.

Mean temperature fluctuations are slight (78 °F to 82° F) over the whole year but differences in altitude among locations show temperature variability. This variability does not limit crop production per se. December and January are the cooler months while April through June are the warmer months.

Pantastico and Cardenas (1980) categorized the rice production areas in the Philippines into four groups: very stable, stable, less stable, and unstable, based on a set of climatic and edaphic information for each region. These classifications were offered to dramatize the extent of risk or success involved in rice production for a given year. They emphasized the urgent need to consider climate when formulating strategies aimed at increasing and stabilizing crop production.

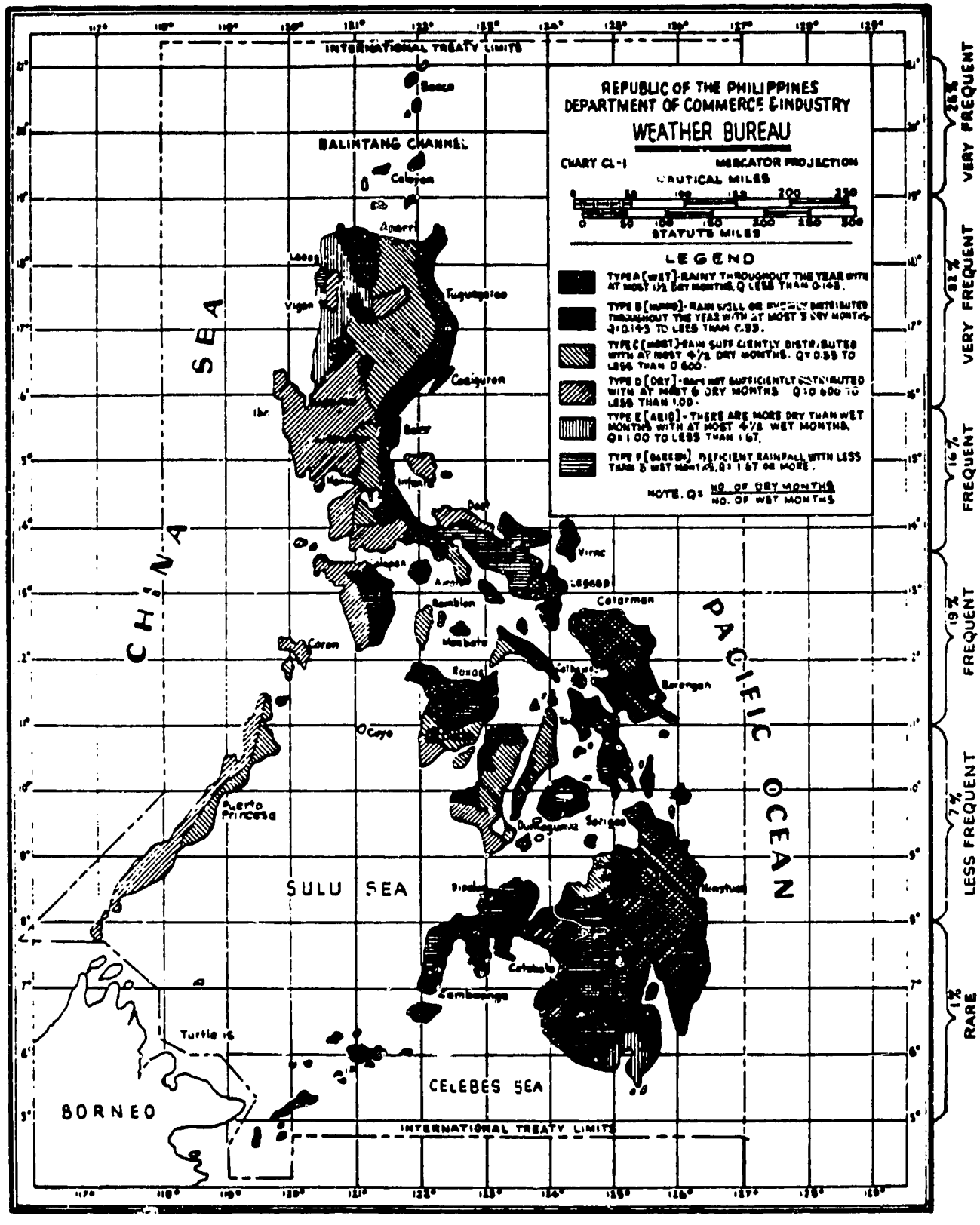
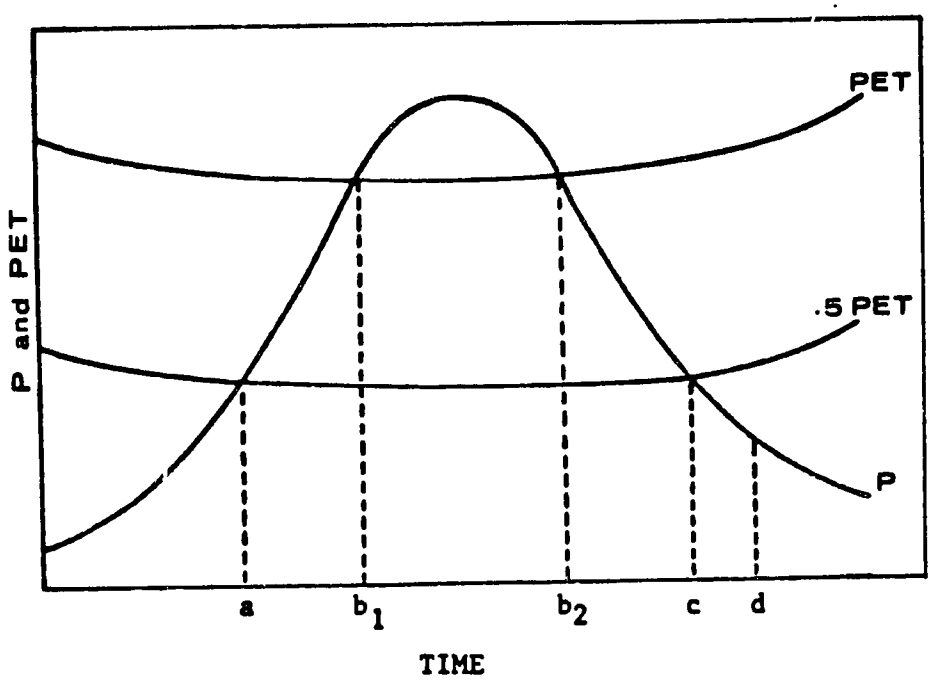


Figure 28. Rainfall types and typhoon frequency in the Philippines.

VII. DESIGN APPROACH

Daily normals of precipitation and temperature were computed from daily actual records of each station over a period of 27-30 years. The daily normals for potential evapotranspiration (PET) were derived from the mean monthly temperature summary and sunshine hours per day using a computer program called CLIGEN (Climate Generation) (Smith et al 1983) which utilized a harmonic analysis and Thornthwaites's (1948) method. This was deemed appropriate in lieu of the unavailability of daily actual evapotranspiration (ET) values. However, it is suggested that whenever actual ET data are available that these should be used in place of the potential ET values.

The procedure described by Bunting (1961), Kassam et al (1978) and Kassam (1979) to determine the growing season in seasonally-dry and tropical regions, was used in this assessment (Fig. 29). The start (a) of the growing season for a given location is defined as the date when normal precipitation (P) is equal to or exceeds one-half of PET for the remainder of the growing season, provided that no dry periods of 5 day duration or longer occur immediately after the said date. The season terminates on the date (d) that rainfall falls below half the PET value plus a certain number of days needed to evaporate 3.94 in. (100 mm) of stored soil moisture at



a = beginning of growing season
b_1 and b_2 = start and end of humid period, respectively
c = end of rains and rainy season
d = end of growing season
P = precipitation
PET = potential evapotranspiration

Figure 29. Procedure for determining the growing season in the tropics.

the potential rate. This amount of moisture meets the average crop demand in normal field conditions (Oldeman 1980).

The planting dates for the first crop were chosen beginning with the first week of the growing season and at three weeks interval thereafter for each location. The dates for planting of sequence crops was set at ten days after harvest of the first crop, which was also referred to as turn-around period. The cropping pattern used was for a rainfed rice-based production area and the alternative crops considered for second planting are rice, corn, sorghum, pearl millet and proso millet.

For simplicity of plotting, all the daily normals were summarized into weekly means with week no. 1 corresponding to March 1-7 and so forth. Week no. 52 therefore referred to the period February 21-27 and week no. 53 covered the days of February 28-29. The growing degree-day summation (50 ^{o}F base) was used to determine the length of ontogenesis in selected crops using three major phenological periods: vegetative (germination to panicle differentiation), reproductive (panicle differentiation to anthesis) and grain-filling or maturation (anthesis to maturity). The various phases of development in rice have been discussed in detailed by Nuttonson (1965), Tanaka (1976) and Stansel (1975). Stansel and Fries (1980) summarized the effects of meteorological factors on different stages of rice

development in warm-temperature cultivars (Appendix Figure 1). Pre-season precipitation refers to the accumulated rainfall from the end of the growing season to the scheduled planting date. Conversely, the season precipitation is the accumulated rainfall from planting to the end of the growing season (Logan 1981).

From the range of GDD given for each crop in Table 7, a sample GDD summary between phenological periods for early to medium early varieties of crops was selected based on past experiments. Table 8 shows the degree-day summation requirement of an early (110-day) rice variety, early corn hybrid, medium early sorghum hybrid, and early pearl and proso millet varieties. These values were utilized to determine the expected dates of occurrences of the phenological periods after planting. The choice of corn and sorghum hybrids were from a listing of varieties commonly grown in the Midwestern United States. There was no information immediately available (if any) on the GDD requirements of traditionally adapted tropical corn or sorghum hybrids.

From a selected planting date, degree-day units equal to the required GDD units for completion of a phenological event were accumulated. The estimates of expected dates of occurrence of a phenological event were obtained by calculating the value (Tm - To) for each day from some starting date (usually the planting date) and accumulating these values until the sum was equal to or

Table 8. Accumulated degree-day requirement[1] of different grain crops to complete each phenological periods as used in this assessment.

Phenological Periods	Rice[2]	Corn[3]	Sorghum[3]	Pearl millet[3]	Proso millet[3]
Vegetative	1925	788	837	769	432
Reproductive	629	476	860	654	665
Maturation	934	1191	859	654	666
TOTAL	3488	2455	2556	2077	1763

[1]Based on a temperature treshold of 50 F.

[2]The vegetative period in rice includes the time from seeding to lag-tillering (1561 GDD), and lag-tillering to panicle differentiation (364 GDD). This is on the basis of a 110 day direct-seeded rice variety. Transplanted rice will have different GDD requirements.

[3]Commonly planted hybrids in the Midwestern parts of the United States.

exceeded the K or TRIS value (see Eq. 4) for the crop variety used. For example, supposing that rice is to be planted on May 19;

Julian date	Calendar date	Accumulated GDD	Required GDD	Phenological events
139	May 19	4280	0	Seeding
193	July 12	6205	1925	Vegetative
211	July 30	6834	629	Reproductive
239	August 27	7768	934	Maturation

Then the dates listed corresponded to the expected date that a certain phenological period will be completed. This is an attempt to assess the use of degree-day summations in evaluating the possibility of success for a certain set of cropping patterns.

7.1 Fundamental Assumptions

In assessing the feasibility of different rice-based cropping patterns, several assumptions were made. First, planting can be done when rainfall is greater than one-half PET. Secondly, there are three critical periods when the plants are sensitive to water stress and lead to crop failure; (a) a dry period of more than 5 days after germination will require replanting, (b) a deficit during the period after panicle differentiation will cause considerable yield reduction, and (c) a moisture deficit

during flowering will seriously reduce final yields. Third, the GDD summation between phenological periods of each crop holds true for the same maturity class regardless of variety. In locations having the rainy seasons, the GDD unit requirements of the same variety during its total growth period remain consistent. Fourth, the base 50 F is an appropriate threshold temperature limit for all the selected crops. And fifth, rainfed rice requires a minimum of 3 consecutive wet months (greater than 200 mm/mo) to grow a single crop, at least 5 months for 2 successive croppings provided the first rice is direct-seeded prior to the start of the rainy season, or at least 7 months for 2 crops of transplanted rice in succession, or at least 10 continuous wet months for year round cultivation (Oldeman 1980). Heavy rainfall during the rice ripening period could damage the crop.

VIII. RESULTS AND DISCUSSION

8.1 Comparative Temperature And Rainfall Profiles

One major characteristic of the temperature patterns in the tropics is the seasonal uniformity. Slight variation can be accounted for by altitudinal gradients and some by proximity to maritime ecosystems or mountain ranges. The seasonal temperature profile showed more variability over a whole year in Tuguegarao than in Iloilo and General Santos. High maximum temperature occurs in May (week nos. 10-12) and the minimum in January (week nos. 44-47) over the Tuguegarao area than at other times (Appendix Figure 2 and Appendix Table 5). The seasonal and diurnal temperature variations in Iloilo is relatively uniform throughout the year at an average of 81 ^{o}F with less departure from the mean values than in Tuguegarao (Appendix Figure 3 and Appendix Table 6). Except for a slightly wider band separating the maximum and minimum temperature values the pattern for General Santos is similar to Iloilo (Appendix Figure 4 and Appendix Table 7).

Mean weekly temperature profiles for all locations are presented in Figure 30. Tuguegarao has warmer conditions during the months of April through September (week nos. 5-31) than during the rest of the year. Iloilo and General Santos have almost identical trends but the latter is 2-3 ^{o}F cooler than the former during the humid

MEAN WEEKLY TEMPERATURE BY STATION

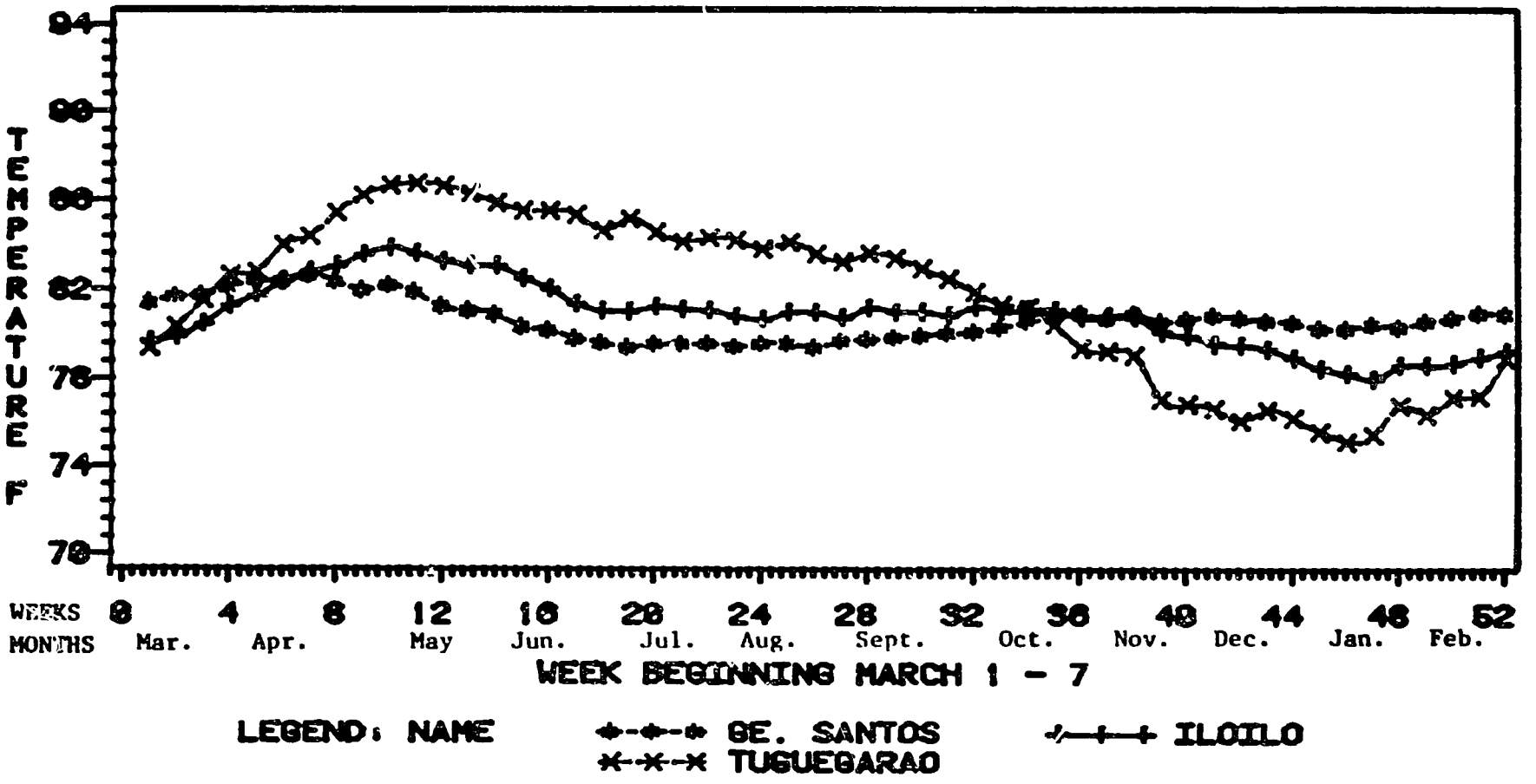


Figure 30. Mean weekly temperature profile for General Santos (south), Iloilo (central) and Tuguegarao (north), Philippines from 1951-1980.

season. These two locations are closer to mean sea level elevation and both are within proximal distance from a water system which has a high specific heat and serves as a buffer to minimize temperature fluctuations. In spite of the wider variability in mean temperature for Tuguegarao, all three locations have a yearly average of 81 °F.

Since the estimates of potential evapotranspiration (PET) for all three locations were based on their temperature normals, the plot of half-PET (Fig. 31) followed a pattern similar to the mean temperature plot in Figure 30. On the contrary, the precipitation pattern showed two types: (1) a unimodal distribution (Tuguegarao and Iloilo) and (2) a uniform distribution (General Santos). At Iloilo and Tuguegarao, the peak weekly rainfall reaches approximately 3.6 in. (91.4 mm) during the middle of the rainy season compared with only about 1.2 in. (30.5 mm) for General Santos (Fig. 32). The uniform rainfall distribution in the latter allows the planting of an annual crop over a wider time frame or two crops during the growing season with very little risk of moisture deficit plus the possibility of establishing a dryland crop before the summer months.

8.2 Onset And Termination Of The Growing Season

The growing season at Tuguegarao begins on May 19 (Fig. 33), while at Iloilo it is expected to begin on May

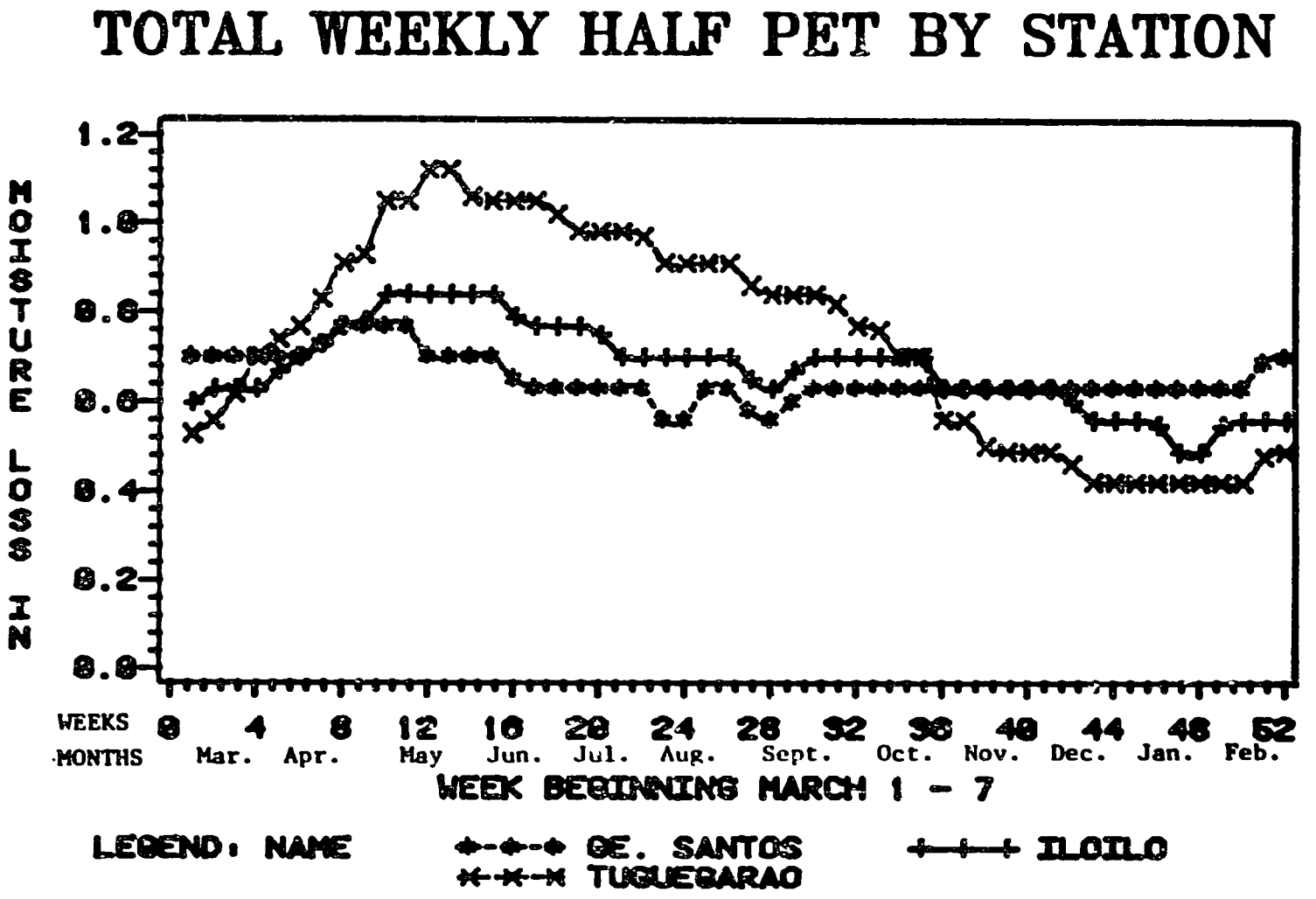


Figure 31. Total weekly half-potential evapotranspiration for Generál Santos (south), Iloilo (central) and Tuguegarao (north), Philippines from 1951-1980.

TOTAL WEEKLY RAINFALL BY STATION

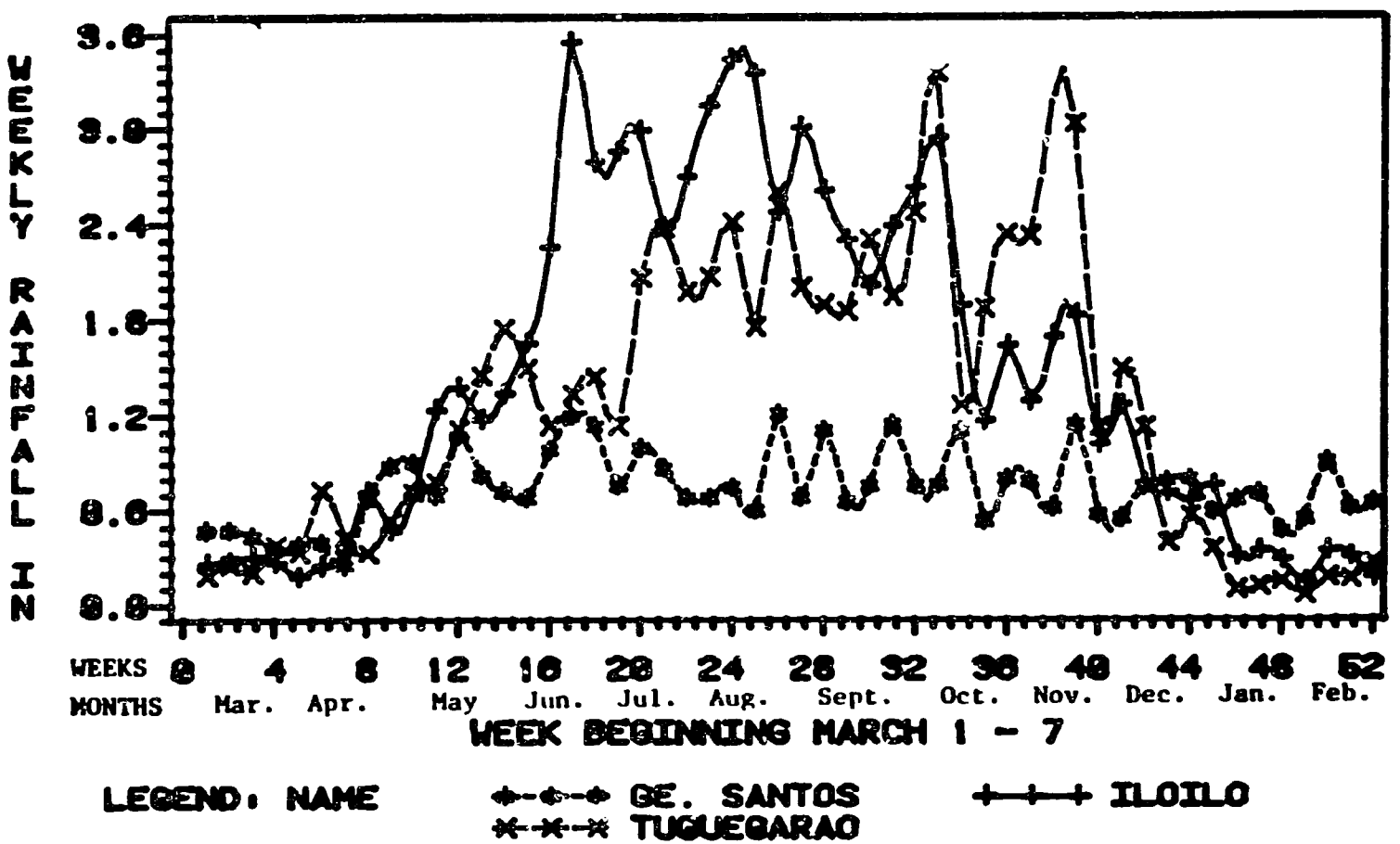


Figure 32. Total weekly precipitation for General Santos (south), Iloilo (central) and Tuguegarao (north), Philippines from 1951-1980.

11 (Fig. 34) and around April 30 for General Santos (Fig. 35). It ends on February 6 at Tuguegarao, February 3 at Iloilo and March 20 at General Santos. This is in close agreement with observations by Zandstra et al (1980) who identified the onset of the growing season based on an accumulated rainfall criteria of more than 2.95 in. (75 mm) after April at a 70 percent probability. The mean start of the growing season occurs early from the southern to the northern regions of the Philippines. From this information, a series of planting schedules for a first crop of an early maturing variety of rainfed rice was chosen for each of the locations, with a 21 day interval between successive plantings.

Table 9 shows the different planting dates, season and pre-season precipitation, number of days and GDD accumulation from respective planting dates to the end of the growing season at each location. The length of the growing season at Tuguegarao and Iloilo differs by only 5 days while General Santos shows a longer duration of 326 days. Iloilo receives the most moisture during the entire growing season. Before accounting for moisture losses in the soil, Iloilo receives 72.28 in. (1836 mm) over the 269 day growing season while Tuguegarao gets about 61.51 in. (1562 mm) during its entire 264 day growing period. General Santos gets only about 50 percent of the total amount falling at Iloilo in spite of its having an obviously longer growing season than the latter.

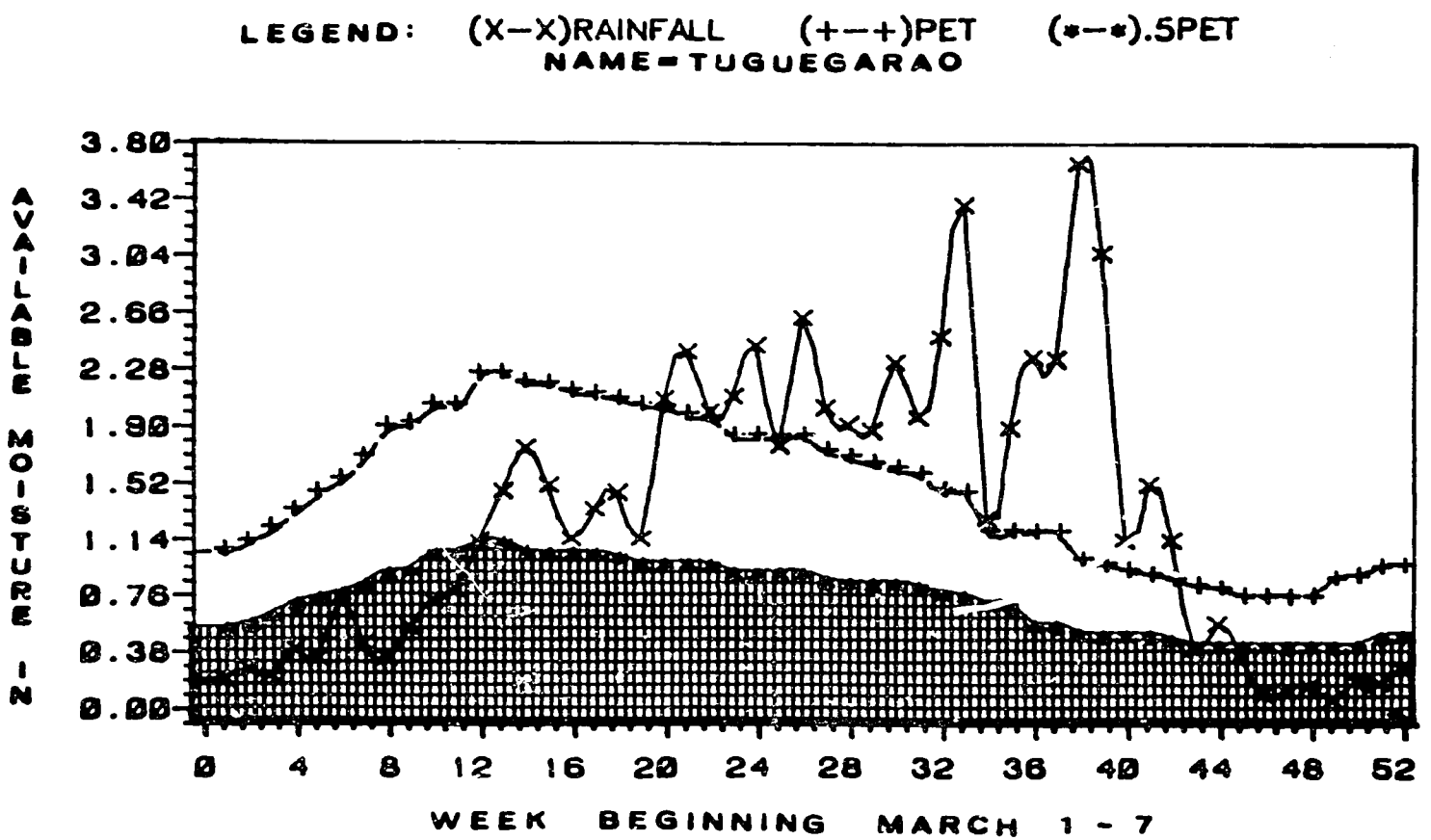


Figure 33. Total weekly precipitation, PET and half-PET for Tuguegarao, 1951-1979. Area above the half-PET curve denotes available moisture from precipitation.

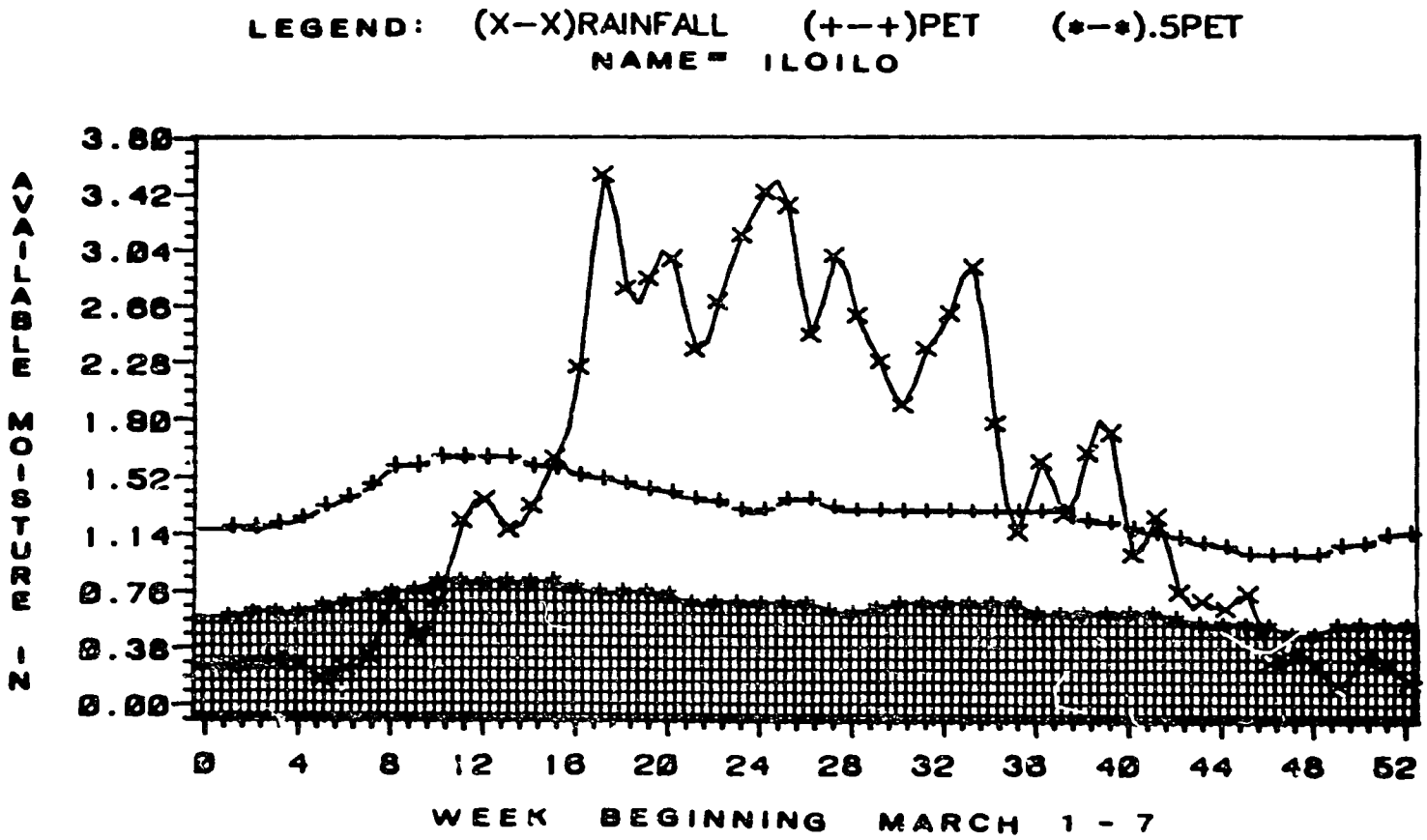


Figure 34 . Total weekly precipitation, PET and half-PET for Iloilo, 1951-1980. Area above the half-PET curve denotes available moisture from precipitation.

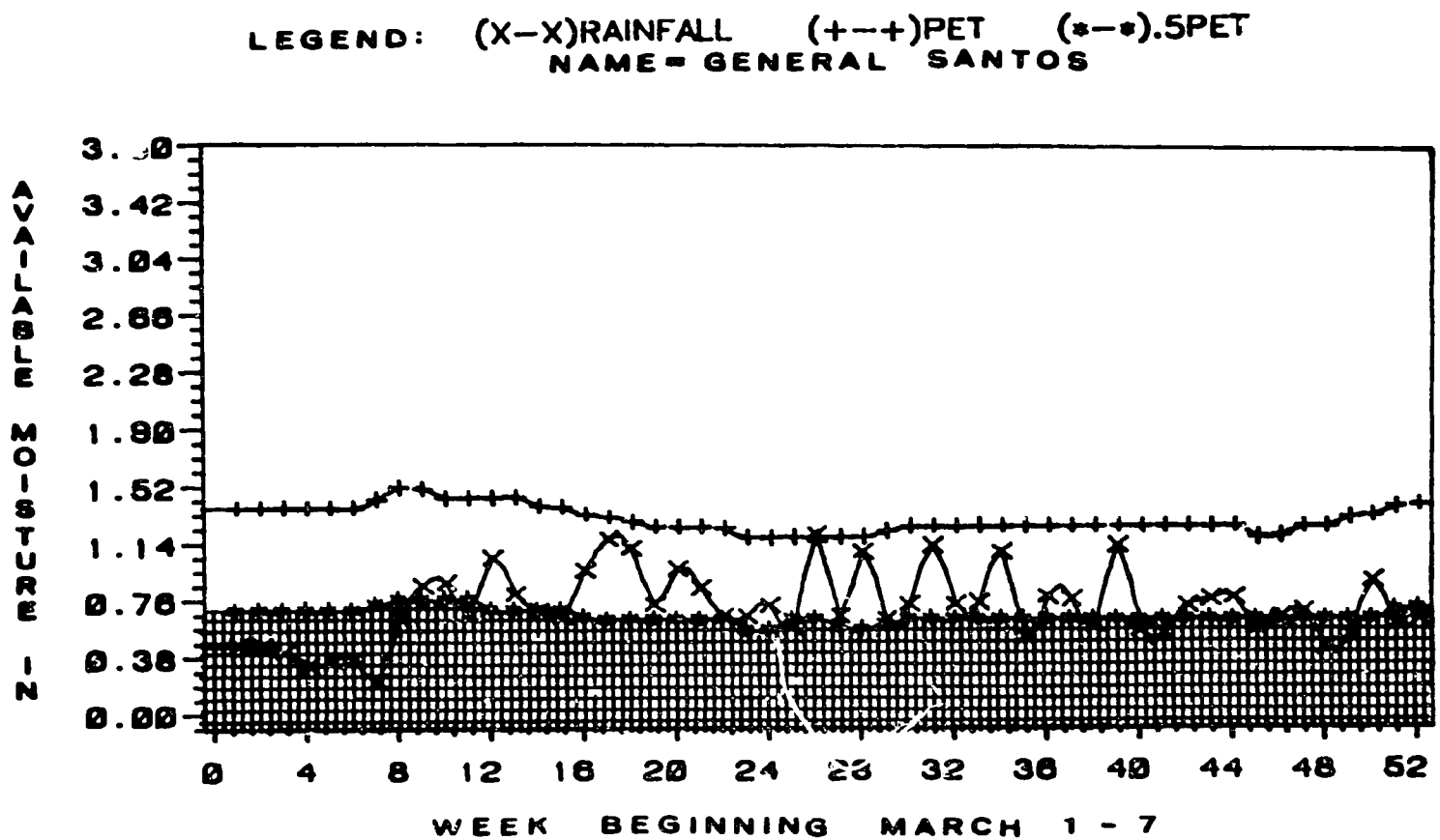


Figure 35. Total weekly precipitation, PET and half-PET for General Santos, 1951-1977. Area above the half-PET curve denotes available moisture from precipitation.

Table 9. Planting dates, season and pre-season precipitation, number of days and accumulated GDD from planting to the end of the growing season in three locations in the Philippines.

Locations	Selected Plantings	Season Precipitation (in.)	Pre-season Precipitation (in.)	No. of days	Growing degree-days
Tuguegarao	May 19 *	61.51	5.60	264	8279
	June 9	57.18	9.93	243	7519
	June 30	52.82	14.29	222	6775
	July 21	47.72	19.38	201	6045
Iloilo	May 11 *	72.28	4.79	269	8296
	June 1	68.43	8.64	248	7596
	June 22	62.88	14.19	227	6913
	July 13	53.97	23.10	206	6258
General Santos	April 30 *	35.55	2.54	326	9907
	May 21	32.88	5.21	305	9238
	June 11	30.51	7.58	284	8589
	July 2	27.38	10.71	263	7959

* Denotes the beginning of the growing season.

Accumulated season precipitation decreases progressively with later plantings in each location. The pre-season precipitation in Tuguegarao and Iloilo are almost equal although differing in dates of coverage.

8.3 Cropping Pattern Assessment For Tuguegarao

Table 10 shows the expected dates of phenological periods for an early maturing (110 day) rice variety seeded on different dates in Tuguegarao. Sowing the first rice on puddled soil generally allows earlier harvest than if the rice is transplanted. Sowing in dry soil allows a gain of 3 to 4 weeks (Zandstra et al 1980). Transplanting older rice seedlings (about 35-40 days old) can reduce the field duration to near 75 days. If planting is done at the start of the season (May 19) the ripening stage is expected to be complete in about 100 days or by mid-August. Moving the planting date 21 days later will extend the duration from planting to maturity by one day. Succeeding delays in the planting date will add another 2 to 3 days to the length of maturity. This is the result of decreasing temperature towards December-January. The growth duration is lengthened and more rainfall is available (25.1 in. to 32.2 in. from May 19 to July 21 plantings) with later plantings.

Early plantings of rice on May 19 and June 9 may be risky to the basic vegetative phase (Yoshida 1981) of rice due to a period of drying prior to the completion of

Table 10. Expected dates of completion and days from planting of different phenological events for rice planted on different dates in Tuguegarao, Philippines using accumulated GDD (base 50) concept.

Alternatives	Planting dates	EXPECTED DATES AND DAYS FROM PLANTING TO:			Accumulated rainfall (in)
		Panicle differentiation	50% floret pollination	Maturity	
Alternative 1	May 19*	July 12 (54)	July 30 (72)	August 27 (100)	25.09
Alternative 2	June 9	August 3 (55)	August 22 (74)	September 18 (101)	27.13
Alternative 3	June 30	August 25 (56)	September 13 (75)	October 11 (103)	30.23
Alternative 4	July 21	September 16 (57)	October 5 (76)	November 4 (106)	32.17

*Start of the growing season.

( ) Indicates number of days from planting to each phenological period.

the panicle differentiation stage (Fig. 36). This could be true in the event of a "false-start" in the growing season. Localized showers of short duration rather than long periods of drizzle-type rain common in the middle latitudes may occur frequently during this time. Late (July) plantings present a favorable time for rice production since moisture will be abundant to maintain flooded conditions. In tropical Asia, rice plants are often submerged during most of the rainy season due to heavy rains. It should not be surprising that the yield may be below the variety's potential yield because of lower sunshine periods during the ripening phase, since this is coincidental with the time of high rainfall occurrence. Cloudy and rainy days are detrimental to rice especially from flowering to maturity (Yoshida 1981).

Lodging problems and diseases may be encountered when too much rainfall occurs at critical stages of rice. Flooding at anthesis can severely reduce yields. Harvesting during the peak of the rainy season may likewise be a hindrance rather than a benefit to late planting. Other considerations must therefore be kept in mind, such as land topography, soil characteristics, and local production practices, before we can make a sound decision on the time of growing rice in Tuguegarao.

Figure 37 shows the phenological development of crops in a cropping sequence in relation to available moisture and shifts in planting dates. The graph suggests that

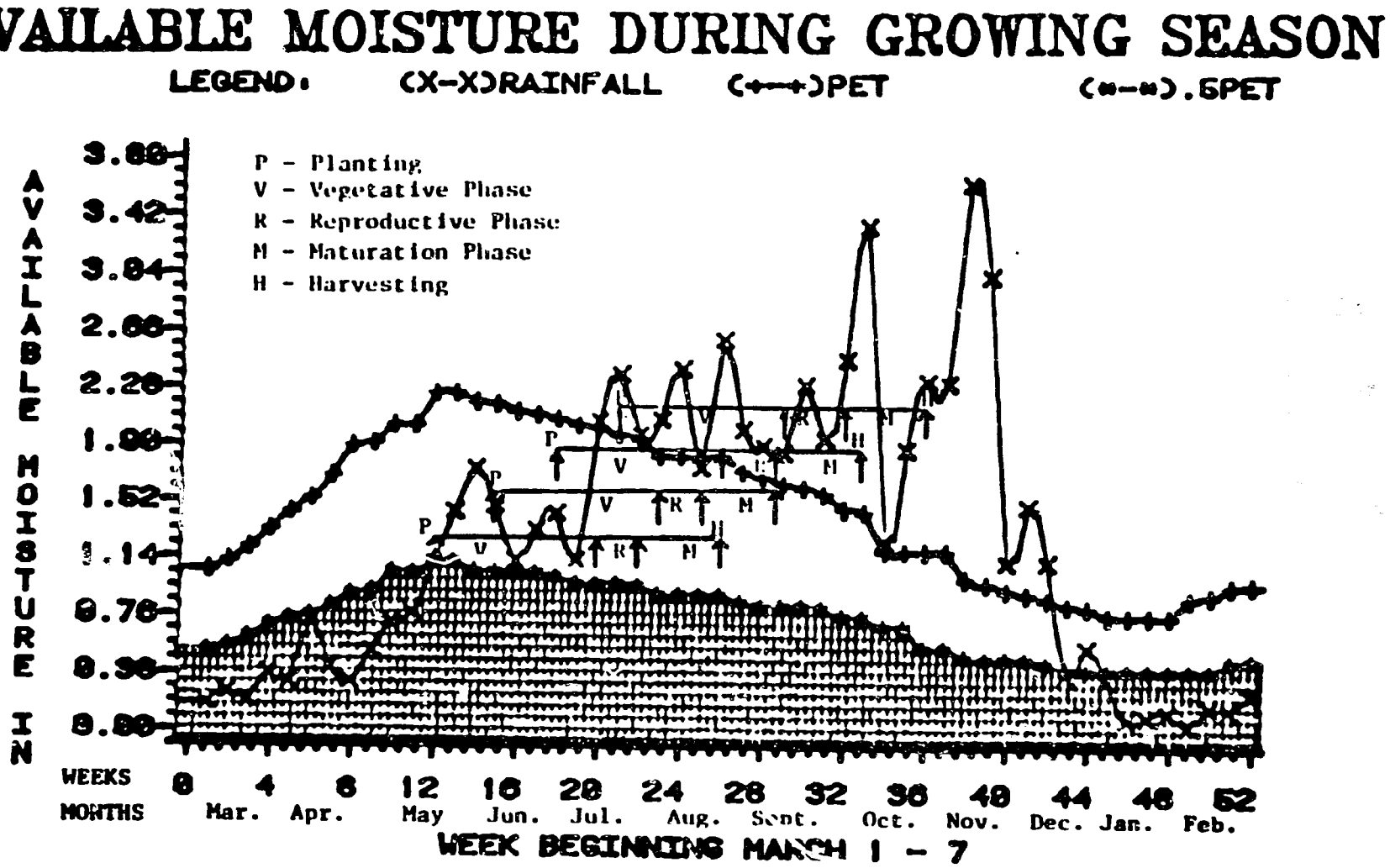


Figure 36. Summary of the phenological events in rice planted on four different dates in relation to rainfall distribution in Tuguegarao, Philippines.

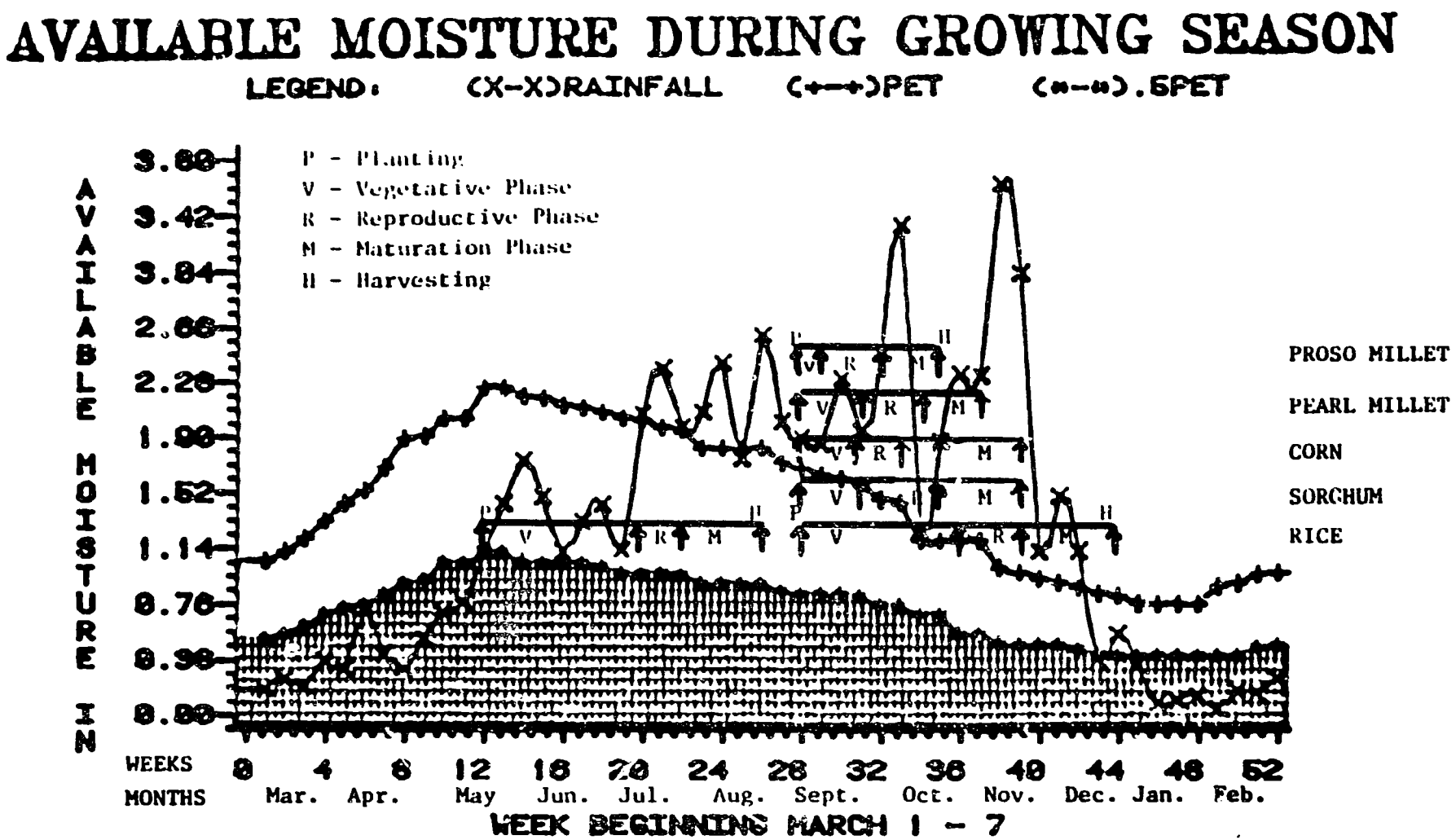


Figure 37. Summary of the phenological events in rice and other upland crops planted after rice in relation to rainfall distribution in Tuguegarao, Philippines. (Alternative 1)

harvesting of the first crop will coincide with high rainfall periods. The second crop can be planted as early as September 6 and the choice of crop would depend on a number of considerations. Selecting rice for a second crop could be an option for a September planting. Decisions on whether to employ a direct-seeding or transplanting method will have to be made early in the season, particularly so, if the moisture in the field remains high. Considering a direct-seeded second rice, the remaining moisture regime appears to be excellent to maintain good rice cultivation until harvest in early January when ripening coincides with the cessation of the rainy season.

Flooded field conditions in bunded (with levees) paddies can well be maintained by occurrences of peak rainfall in September to November. However, risk of too much moisture during this time may be complicated further by the onslaught of typhoons which pass the region 31-40 percent of the time each year. Seeding rice in early September will bring it to maturity in 118 days. This leaves 36 days before the end of the growing season on February 6 for a rice-rice pattern (Table 11). Planting any of the upland crops like corn, sorghum, pearl millet or proso millet may not be as successful as growing rice, although they would mature early in the season when the prevalence of high rainfall may cause injury rather than increase productivity. These types of crops are shallow

Table 11. Projected timetable of phenological events for different cereal grains planted on four different dates after rice, Tuguegarao.

Planting dates	Choice of second crop	EXPECTED DATES FROM PLANTING TO:			Accumulated rainfall (in)	Days ahead (+) or beyond (-) growing season
		Panicle differentiation	Anthesis	Maturity		
September 6 (Alternative 1)	Corn	September 30 (24)	October 15 (39)	November 24 (79)	27.10	75
	Sorghum	October 2 (26)	October 29 (53)	November 28 (83)	28.22	71
	Pearl millet	September 29 (23)	October 20 (44)	November 11 (66)	20.44	88
	Proso millet	September 19 (13)	October 9 (33)	October 31 (55)	16.93	99
	Rice	November 6 (61)	November 28 (83)	January 2 (118)	32.89	36
September 28 (Alternative 2)	Corn	October 23 (25)	November 8 (41)	December 21 (84)	25.63	48
	Sorghum	October 25 (27)	November 23 (56)	December 25 (88)	25.77	44
	Pearl millet	October 22 (24)	November 13 (46)	December 7 (70)	23.22	62
	Proso millet	October 12 (14)	November 2 (35)	November 25 (58)	20.96	74
	Rice	December 1 (64)	December 25 (88)	January 30 (124)	27.10	8
October 21 (Alternative 3)	Corn	November 16 (26)	December 4 (44)	January 19 (90)	18.98	19
	Sorghum	November 18 (28)	December 20 (60)	January 22 (93)	19.05	16
	Pearl millet	November 16 (26)	December 10 (50)	January 4 (75)	18.60	34
	Proso millet	November 5 (15)	November 28 (38)	December 23 (63)	17.83	46
	Rice	December 29 (69)	January 22 (93)	February 26 (128)	19.79	-19
November 14 (Alternative 4)	Corn	December 13 (29)	December 31 (47)	February 14 (92)	12.64	- 7
	Sorghum	December 15 (31)	January 17 (64)	February 18 (96)	12.73	-11
	Pearl millet	December 12 (28)	January 6 (53)	January 31 (78)	12.39	7
	Proso millet	November 30 (16)	December 25 (41)	January 20 (67)	12.17	18
	Rice	January 26 (73)	February 18 (96)	March 20 (126)	13.63	-41

( ) Indicates number of days to each phenological period from planting.

rooted and are sensitive to conditions of too much moisture in the soil surface over extended periods. The stalks become succulent and tend to be more susceptible to diseases.

Nevertheless, corn planted on September 6 will be at stage 10 by November 24, about 75 days ahead of the last date of the growing season. Sorghum will be at stage 9 or physiologic maturity by November 28 which should be 71 days to the end of the season. Pearl and proso millets should be ready for harvest on November 11 and October 31, respectively. The remainder of the season following a rice-pearl or rice-proso sequence should allow an extra catch crop to produce some yield. Lodging of proso millet is highly probable especially when grown during the peak months of excessive rainfall or typhoon passes.

Figure 38 shows the pattern of phenological development for the same crops except for a change in planting date. Rice seeded on June 9 will reach maturity on September 18. The most critical stage for this planting is the period when drying occurs after a time of false-start. This may cause partial injury to a young rice plant which is in the tillering stage. Otherwise, the plant should be growing in good moisture condition. The second rice planting on September 28 would be ripe on January 30. This is about 124 days from seeding to maturity, or 14 days longer than normal (110-days). The lengthened duration could be attributed to decreasing

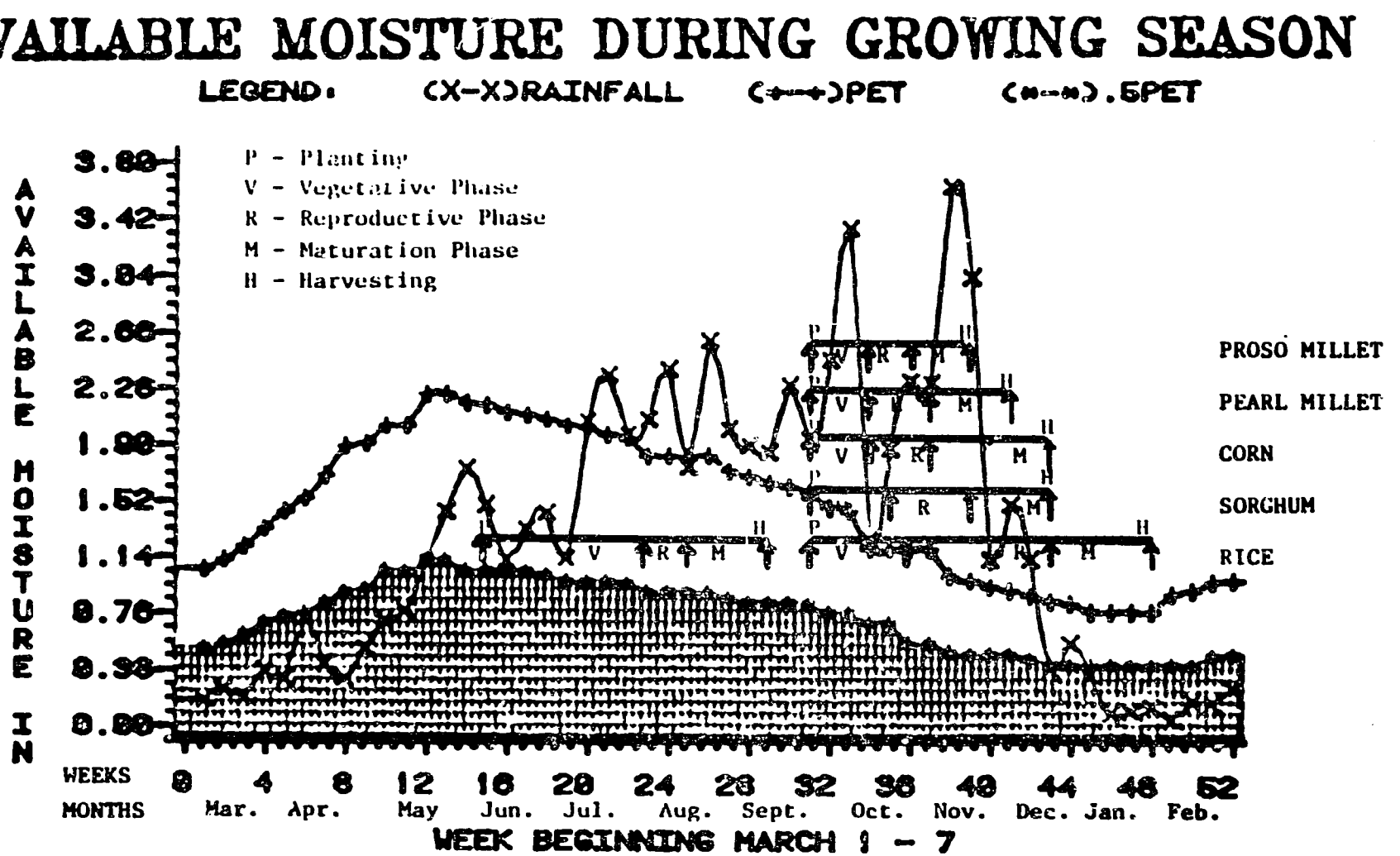


Figure 38. Summary of the phenological events in rice and other upland crops planted after rice in relation to rainfall distribution in Tuguegarao, Philippines. (Alternative 2).

temperature towards December and January.

Rainfall during ripening would be very low since the rainy season would cease during the reproductive period. This is somehow an advantage for a ripening crop in the sense that more sunshine could be expected to improve the total photosynthesis and some soil moisture would still be present even after harvest. The rice-rice cropping pattern should be completed 8 days prior to the end of the growing season. Corn and sorghum are good alternatives if rice cannot be seeded by September. The only risk is peak rainfall occurrence from planting to anthesis. Ripening should be aided by declining rainfall towards the end of the rainy season. Sorghum and corn planted on September 28 may ripen by late December (Table 11). That would be 44-48 days before the end of the growing season.

Pearl millet or proso millet would not appear promising for planting at this time. Heavy rainfall may cause extensive damage to either crop by saturating the soil profile for long periods. The roots would be prone to experience "wet-feet" injury or prolonged exposure to wet ground and this hampers gas exchange in the root system. Although these crops mature early, they would be more suited for much later plantings, like the end of the rainy season in late November or early December. There would still be sufficient time to reach maturity before the end of the growing season.

Delaying the first planting of rice by another 21 days, on June 30, will bring it to maturity on October 11. This time of the year seems to be the best time to grow rice (Fig. 39). The risk of a false-start is eliminated and the rice can grow throughout the rainy season provided that no dramatic change in rainfall distribution or heavy typhoon passage occurs during that time. The second crop can be seeded by late October, weather permitting of course. Rice can no longer be cultivated at this time because of lower temperatures during the last quarter of the year that will extend its growth duration to 128 days from planting. This exceeds the end of the growing season by 19 days. There may be an overestimation since drying conditions of the soil may hasten the ripening phase as well.

Corn, sorghum and pearl millets have better chances of producing good yields than rice for later planting. Proso may still be subject to excessive moisture problems when planted in October. Some risk of damage to the young plants of any of these dryland crops may still occur as a result of a high rainfall incidence from October to late December. The corn and sorghum crops should be mature in mid-January while the pearl and proso millets should be expected to complete grain-filling by late-December, with still ample time before the growing season terminates in February.

A further postponement of the first rice planting

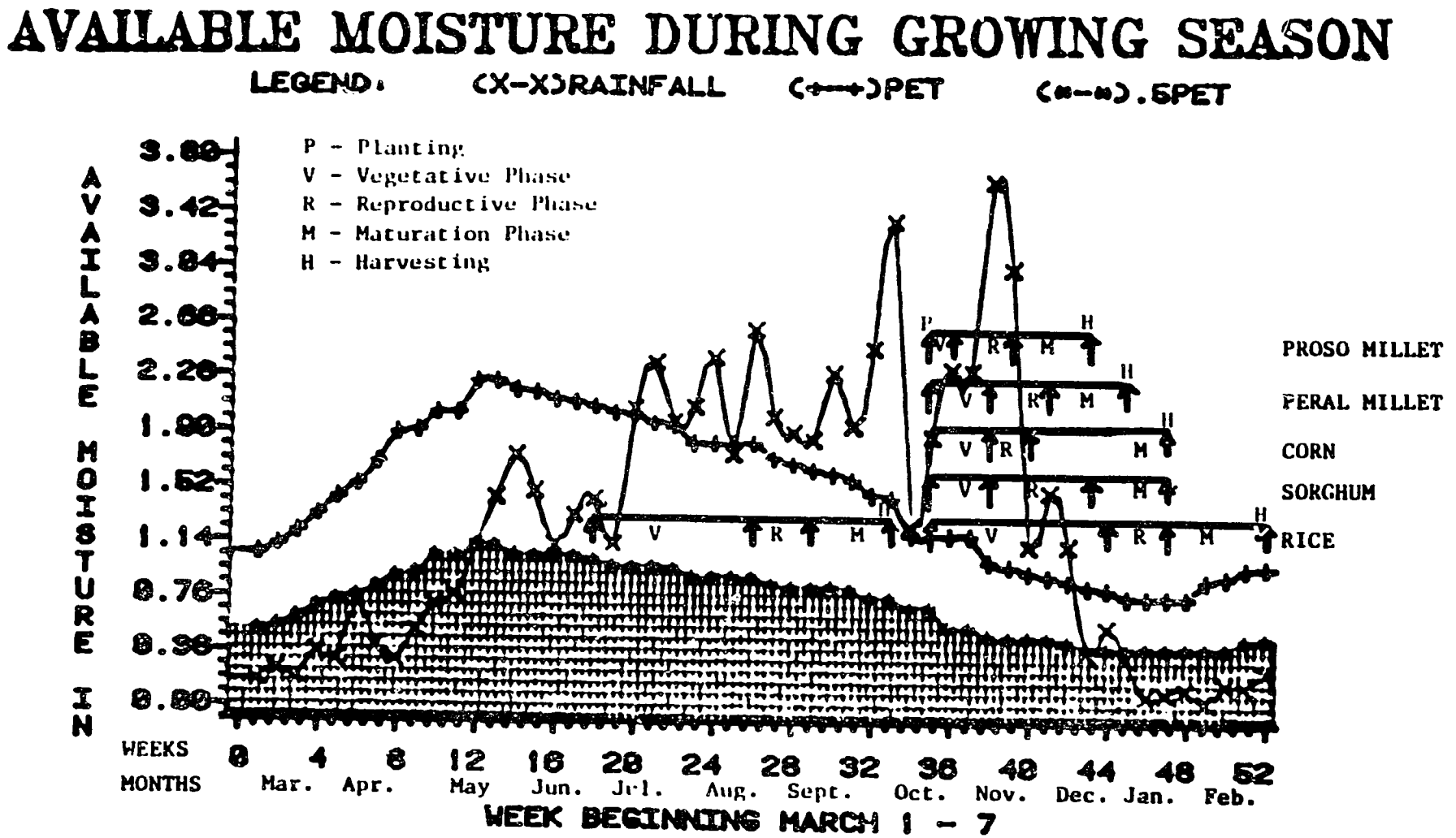


Figure 39. Summary of the phenological events in rice and other upland crops planted after rice in relation to rainfall distribution in Tuguegarao, Philippines. (Alternative 3)

until July 21 will take about 106 days to grow the rice from seeding to maturity. Rainfed-lowland rice culture or the maintenance of flooded fields for several weeks can be done since rainfall would be abundant during this time of the year (Fig. 40). A rice crop requires about 39 in. (1000 mm) to 118 in. (3000 mm) of rain during the wet-season cultivation. Harvesting during the peak of the rainy season would be a problem because of wet fields and a high moisture content of the ripening grains. Threshing and drying the wet grains would increase post-harvest operations and cost. The rice-rice cropping sequence would not be profitable due to possible failure of the second crop.

Seeding the second rice crop on November 14 will bring it to maturity by March 20, a total of 126 days from seeding (Table 11). This is 41 days after the growing season. Only 13.25 in. (337 mm) of rainfall would be available to raise the crop. Even transplanted rice would not have much chance to succeed without considerable yield losses. Similarly, a second crop of corn or sorghum may fail when planted in place of rice since either one would exceed the growing season by 7-11 days. Soil moisture was calculated to be adequate to meet an average crop requirement until February 6. The only feasible alternative for a second crop would be to grow pearl or proso millet since this would reach full maturity in late January. This is several days ahead of

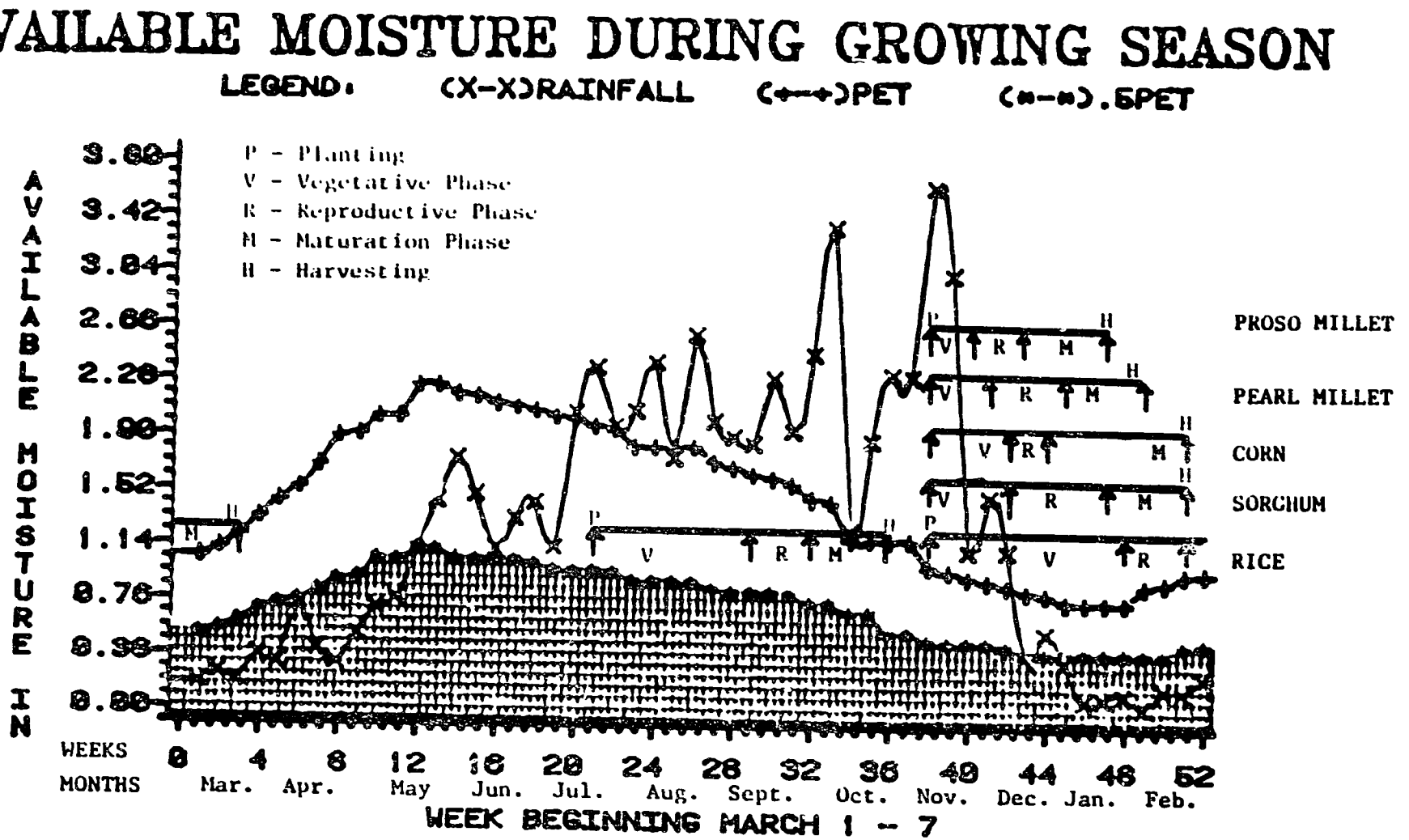


Figure 40. Summary of the phenological events in rice and other upland crops planted after rice in relation to rainfall distribution in Tuguegarao, Philippines. (Alternative 4)

the date when the growing season ends in Tuguegarao.

8.4 Cropping Pattern Assessment For Iloilo

In Iloilo, rice seeded at the start of the growing season will complete panicle differentiation on July 10, 50 percent anthesis on July 30 and be mature on August 29 or after 110 days (Table 12). A twenty-one day delay in planting beyond May 11 would require an extra day to complete each phenological period. Further delay in planting beyond the onset of the growing season will need 2 days more to complete each phenological event. Whatever date is chosen between May to July can be ideal for rainfed rice production since flooded conditions can be maintained in bunded paddies or adequate moisture can support upland rice (Fig. 41). No "false-start" was observed for Iloilo as compared to Tuguegarao. However, similar harvesting problems can be expected when planting is done in May to mid-July. A survey by the National Food and Agriculture Council (NFAC) in 1975 revealed that the traditional schedule of growing rice in Iloilo was in May-December (Pantastico and San Valentin 1977), which supports the findings of this evaluation.

Table 13 and Figures 42-45 show the projected timetable of phenological events for different cereal grains that may be planted after harvest of the first rice crop in Iloilo. If rice is planted on May 11 and harvested on August 29, a second crop can be planted on

Table 12. Expected dates of completion and days from planting of different phenological events for rice planted on different dates in Iloilo, Philippines using accumulated GDD (base 50) concept.

Alternatives	Planting dates	EXPECTED DATES AND DAYS FROM PLANTING TO:			Accumulated rainfall (in)
		Panicle differentiation	50% floret pollination	Maturity	
Alternative 1	May 11*	July 10 (60)	July 30 (80)	August 29 (110)	38.63
Alternative 2	June 1	August 1 (61)	August 21 (81)	September 20 (111)	43.04
Alternative 3	June 22	August 23 (62)	September 12 (82)	October 12 (112)	44.94
Alternative 4	July 13	September 13 (62)	October 3 (82)	November 2 (112)	41.78

*Start of the growing season.

( ) Indicates number of days from planting to each phenological period.

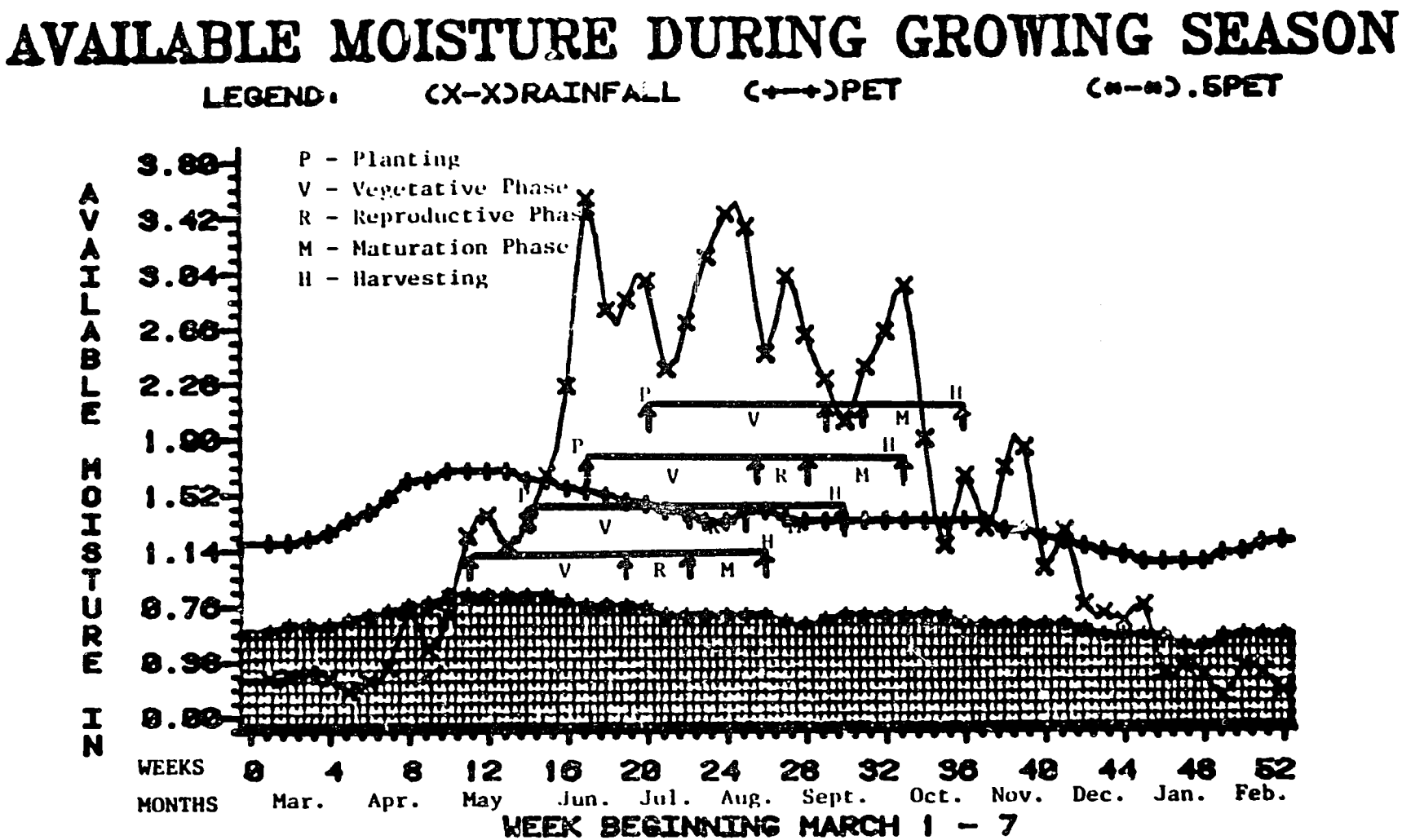


Figure 41. Summary of the phenological events in rice planted on four different dates in relation to rainfall distribution in Iloilo, Philippines.

Table 13. Projected timetable of phenological periods for different cereal grains planted on four different dates after rice, Iloilo.

Planting dates	Choice of second crop	EXPECTED DATES FROM PLANTING TO:			Accumulated rainfall (in)	Days ahead (+) or beyond (-) growing season
		Panicle differentiation	Anthesis	Maturity		
September 8 (Alternative 1)	Corn	October 3 (25)	October 19 (41)	November 27 (80)	23.46	69
	Sorghum	October 5 (27)	November 2 (55)	November 30 (83)	24.19	66
	Pearl millet	October 3 (25)	October 24 (46)	November 14 (67)	20.30	82
	Proco millet	September 22 (14)	October 14 (36)	November 4 (57)	18.28	92
	Rice	November 9 (62)	November 30 (83)	December 31 (114)	28.18	35
September 30 (Alternative 2)	Corn	October 25 (25)	November 10 (41)	December 19 (80)	19.68	47
	Sorghum	October 27 (27)	November 24 (55)	December 23 (84)	19.92	43
	Pearl millet	October 25 (25)	November 15 (46)	December 7 (68)	17.95	59
	Proso millet	October 14 (14)	November 4 (35)	November 26 (57)	16.01	70
	Rice	December 2 (63)	December 23 (84)	January 24 (116)	22.60	11
October 22 (Alternative 3)	Corn	November 16 (25)	December 2 (41)	January 12 (82)	13.77	23
	Sorghum	November 18 (27)	December 17 (56)	January 16 (86)	13.90	19
	Pearl millet	November 16 (25)	December 8 (47)	December 30 (69)	12.72	36
	Proso millet	November 5 (14)	November 27 (36)	December 19 (58)	11.46	47
	Rice	December 25 (64)	January 16 (86)	February 17 (118)	15.22	-13
November 12 (Alternative 4)	Corn	December 8 (26)	December 24 (42)	February 4 (84)	10.27	0
	Sorghum	December 10 (28)	January 8 (57)	February 8 (88)	10.33	- 4
	Pearl millet	December 7 (25)	December 30 (48)	January 22 (71)	9.85	13
	Proso millet	November 26 (14)	December 19 (37)	January 11 (60)	9.31	24
	Rice	January 16 (65)	February 7 (87)	March 20 (118)	11.52	-34

( ) Indicates number of days to each phenological period from planting.

September 8 and still be assured of adequate moisture to support a good crop (Fig. 42). When a rice-rice pattern is selected, the second rice crop will be at panicle differentiation on November 9, anthesis on November 30 and ready for harvest on December 31, 114 days after seeding. Transplanting the second crop will allow earlier harvest than direct-seeded rice.

A rice-corn or rice-sorghum cropping sequence will allow harvest of the second crop in late November. The ripening period of corn is longer than sorghum but either one will ripen during a period of decreasing rainfall towards the end of the growing season. Pearl millet planted after rice will complete anthesis after 46 days or on October 24 and will reach physiologic maturity on November 14, 67 days from planting. Proso millet when planted on September 8 will ripen within 57 days (November 4). Selecting a second crop of rice may be a good choice since adequate rainfall may be expected to produce an appreciable yield. Ripening of rice will occur at a period of decreasing rainfall and increasing sunshine suitable for high photosynthesis. Good yields from corn and sorghum may also be obtained but too much rainfall during the early stages (planting to anthesis) may create problems with the crop development. The same problem will be true for pearl and proso millets. Lodging or diseases may become prevalent for any grain crops other than rice due to the humid conditions.

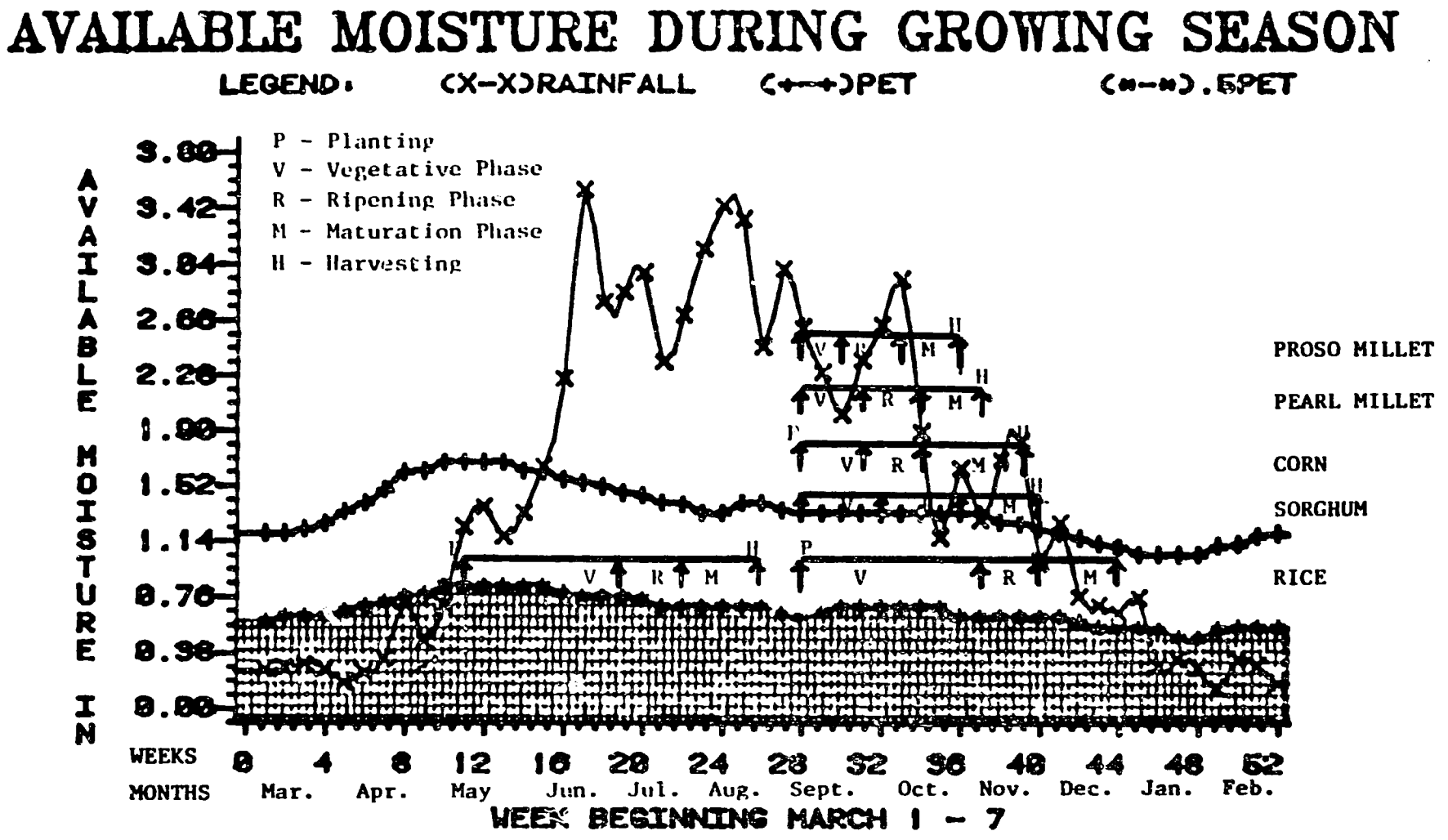


Figure 42. Summary of the phenological events in rice and other upland crops planted after rice in relation to rainfall distribution in Iloilo, Philippines. (Alternative 1)

Planting a second crop on September 30 will still be good for any of the early maturing rice varieties, sorghum, corn, pearl or proso millet (Fig. 43). If rice is selected and seeded rather than transplanted, panicle differentiation and anthesis may be expected after December 2 and December 23, 63 days and 84 days after planting, respectively. There would still be enough rainfall from planting to anthesis to produce a good crop and ripening would coincide with the end of the rainy season which is an advantage for improving photosynthesis and grain-filling. Rice will take about 116 days to mature, 2 days longer than when planted early (September 8).

Corn, sorghum, pearl or proso millet will show good production potentials when planted September 30 after the first crop of rice. The vegetative phase would have sufficient moisture and the anthesis to ripening phases will be completed over a period of decreasing rainfall when there is less danger of too much or too little moisture at critical stages. Maturation will also be improved by greater sunshine towards the tail-end of the growing season. An early corn hybrid that requires 2455 GDD will mature by December 19 after 80 days, while a sorghum hybrid that matures in 2556 GDD will be ready for harvest by December 23, 84 days after planting. Pearl and proso millets will likely mature on December 7 and November 26 if planted on September 30, respectively.

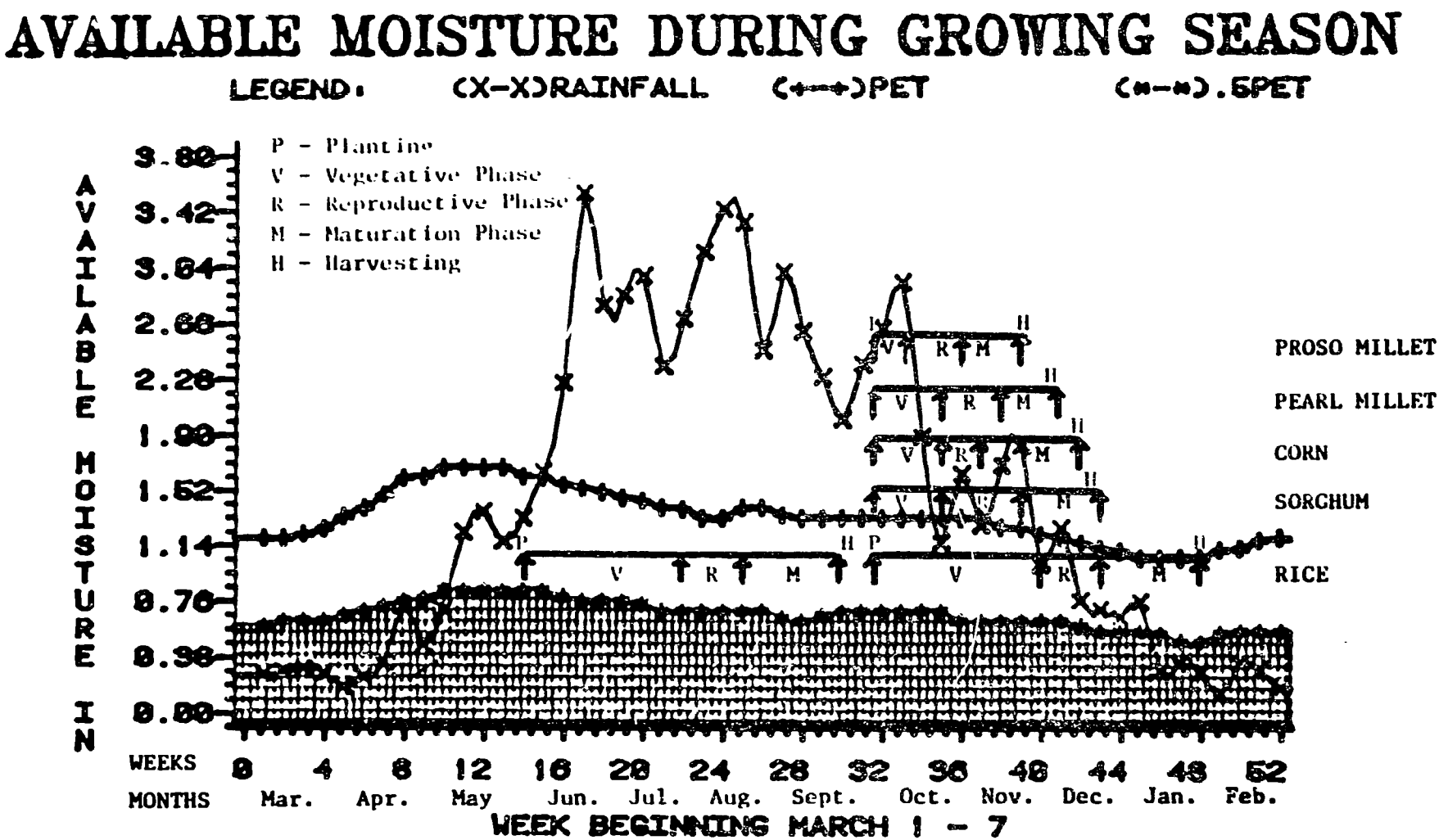


Figure 43. Summary of the phenolopical events in rice and other upland crops planted after rice in relation to rainfall distribution in Iloilo, Philippines. (Alternative 2).

The third alternative to planting rice on June 21 will make possible the planting of a second crop on October 22 (Table 13 and Fig. 44). If rice is seeded after harvest of the first rice crop it could be expected to reach panicle differentiation on December 25, anthesis on January 16 and maturity on February 17, a duration of 118 days from planting. This is about 6 days longer than the time required by the first planted rice to complete maturation. Rainfall distribution at this time will not be very favorable for maintaining flooded field conditions for long periods to sustain good rice production. There will be a high risk of moisture deficit for rice during the grain-fill period because rainfall is less than .5 PET and the total duration for a sequence of rice-rice will exceed the length of the remaining growing season because of delayed planting of the first crop. Advancing the planting time for the first crop earlier than June 21 and transplanting the second rice crop (under certain conditions of moisture availability and local practices) may appear to be more favorable.

Although planting rice on October 22 may not be a very good practice, planting either corn, sorghum, pearl millet or proso millet on that date is appropriate. This seems to be the best time to grow an upland crop particularly when rice planting is delayed. Corn and sorghum planted at this time will be almost mature by mid-January while pearl millet will be ready for harvest

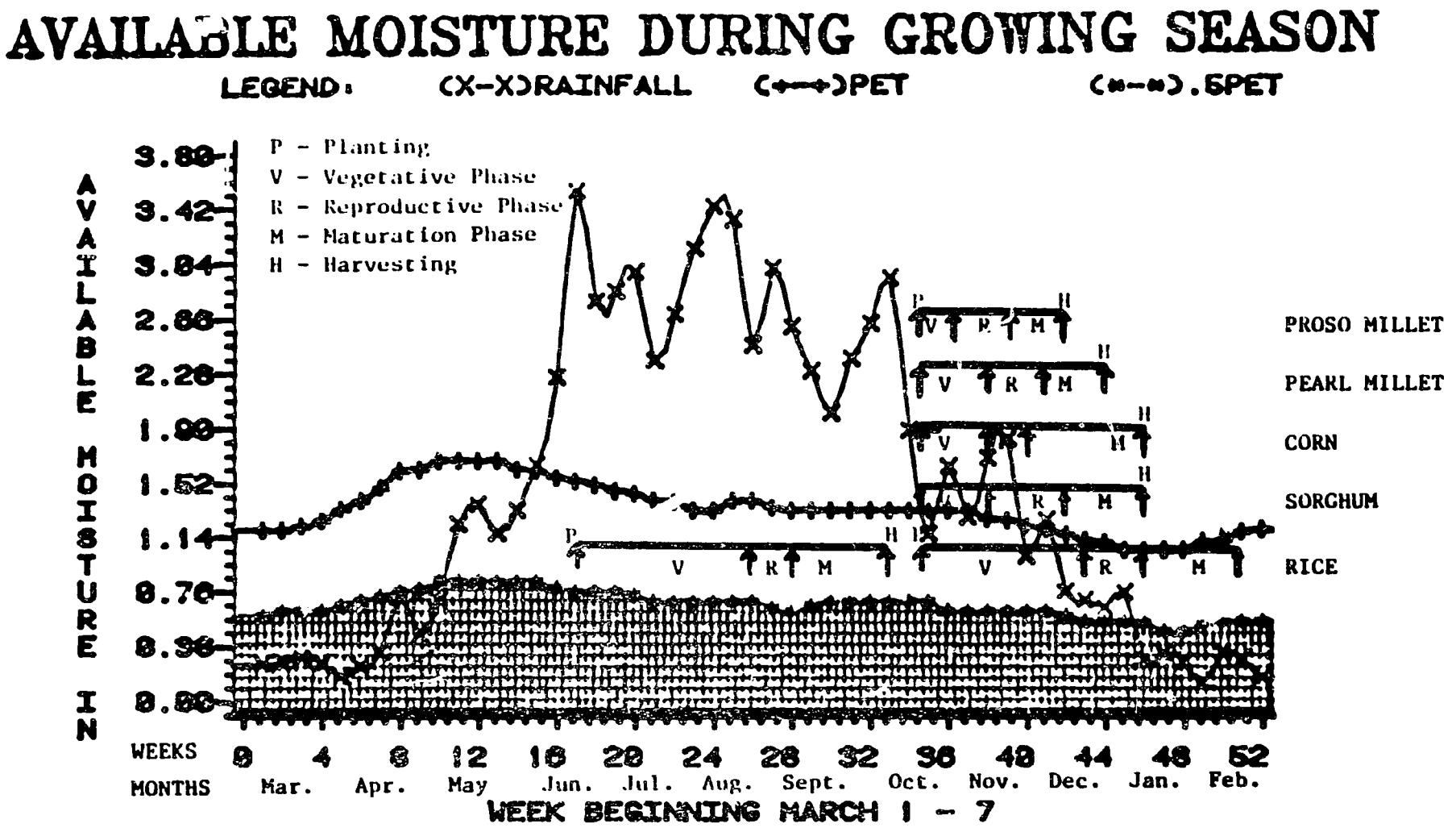


Figure 44. Summary of the phenological events in rice and other upland crops planted after rice in relation to rainfall distribution in Iloilo, Philippines. (Alternative 3)

by the end of December and proso millet should be mature by December 19, 58 days after planting (Table 13).

A delay in planting the first rice crop until about mid-July will create problems in growing a second crop. If rice is planted in mid-July it should be ready for harvest by early November assuming no environmental complications cause a delay in its normal development. This will leave only a short period to grow a second crop before the growing season ends in early February. Planting rice as a second crop would extend the maturity 34 days beyond the end of the growing season. This would put the plants under prolonged moisture stress with expected severe reductions in yields. Chances are that failure of the rice will predominate and large losses will be incurred. There would only be enough rainfall to sustain a good crop stand until about anthesis following which moisture stress would be a big problem (Fig. 45).

Corn or sorghum may be grown instead of rice during this late planting but the yields would also be low because of a moisture deficit during the grain-filling phase. However, the risk of crop failure with a corn or sorghum crop after rice is much lower than a rice-rice sequence late in the season. A better selection would be to plant pearl or proso millet after rice. Pearl millet will reach maturity on January 22 after 71 days from planting or 13 days before the end of the growing season (Table 13). Proso millet would be expected to ripen on

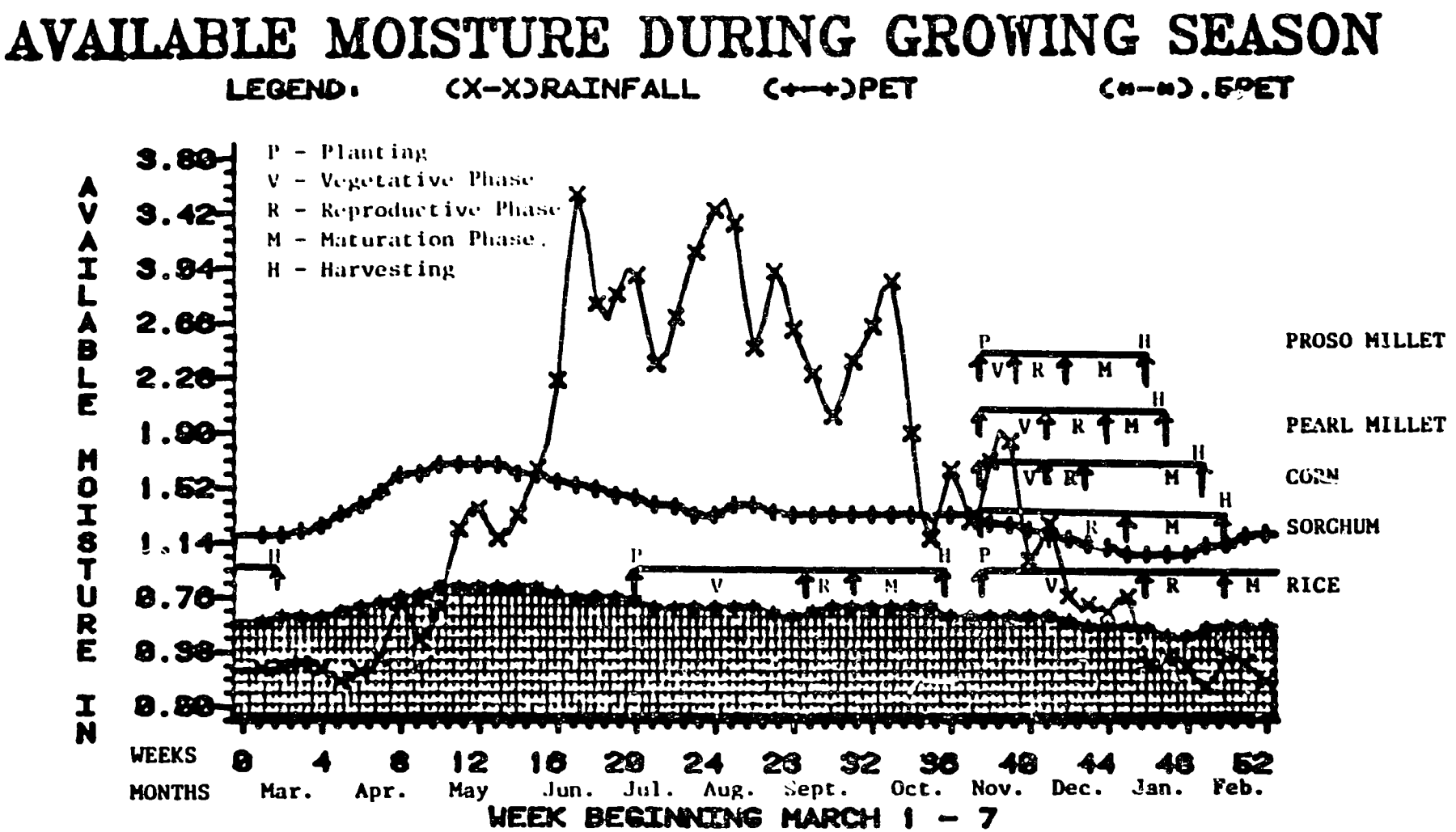


Figure 45. Summary of the phenological events in rice and other upland crops planted after rice in relation to rainfall distribution in Iloilo, Philippines. (Alternative 4)

January 11, about 60 days after planting and 24 days before the growing season terminates.

8.5 Cropping Pattern Assessment For General Santos

Table 14 summarizes the expected dates when different phenological events in rice will occur with different planting dates. Planting rice at the start of the growing season (April 30) will bring the crop to panicle differentiation by July 1, anthesis on July 23 and to maturity by August 23. This will take about 115 days from seeding to maturity. Plants planted later will require more days to reach certain phenological stages than when planted on April 30. Mid-May to early July plantings require an extra two days to reach maturity.

Regardless of planting date the amount of rainfall accumulated from planting should be somewhat uniform. This is expected due to a broad precipitation pattern and more or less uniform distribution throughout the season (Fig. 46). Although the amount of rainfall falling at a given time is low, the time between occurrences is short. This is more favorable than having large amounts of rain followed by long dry periods. De Datta (1981) reported a preference to having a 3.94 in. (100 mm) rainfall per month that is uniformly distributed rather than 7.87 in. (200 mm) per month that falls in 2-3 days. Hence rice can be grown over an extended period from the start of the growing season, or any date thereafter, with minimum risk

Table 14. Expected dates of completion and days from planting of different phenological events for rice planted on different dates in General Santos, Philippines using accumulated GDD (base 50) concept.

Alternatives	Planting dates	EXPECTED DATES AND DAYS FROM PLANTING TO:			Accumulated rainfall (in)
		Panicle differentiation	Anthesis	Maturity	
Alternative 1	April 30*	July 1 (62)	July 23 (84)	August 23 (115)	14.05
Alternative 2	May 21	July 24 (64)	August 11 (82)	September 15 (117)	14.38
Alternative 3	June 11	August 15 (65)	September 5 (86)	October 6 (117)	14.65
Alternative 4	July 2	September 5 (65)	September 26 (86)	October 27 (117)	14.04

*Start of the growing season.

( ) Indicates number of days from planting to each phenological period.

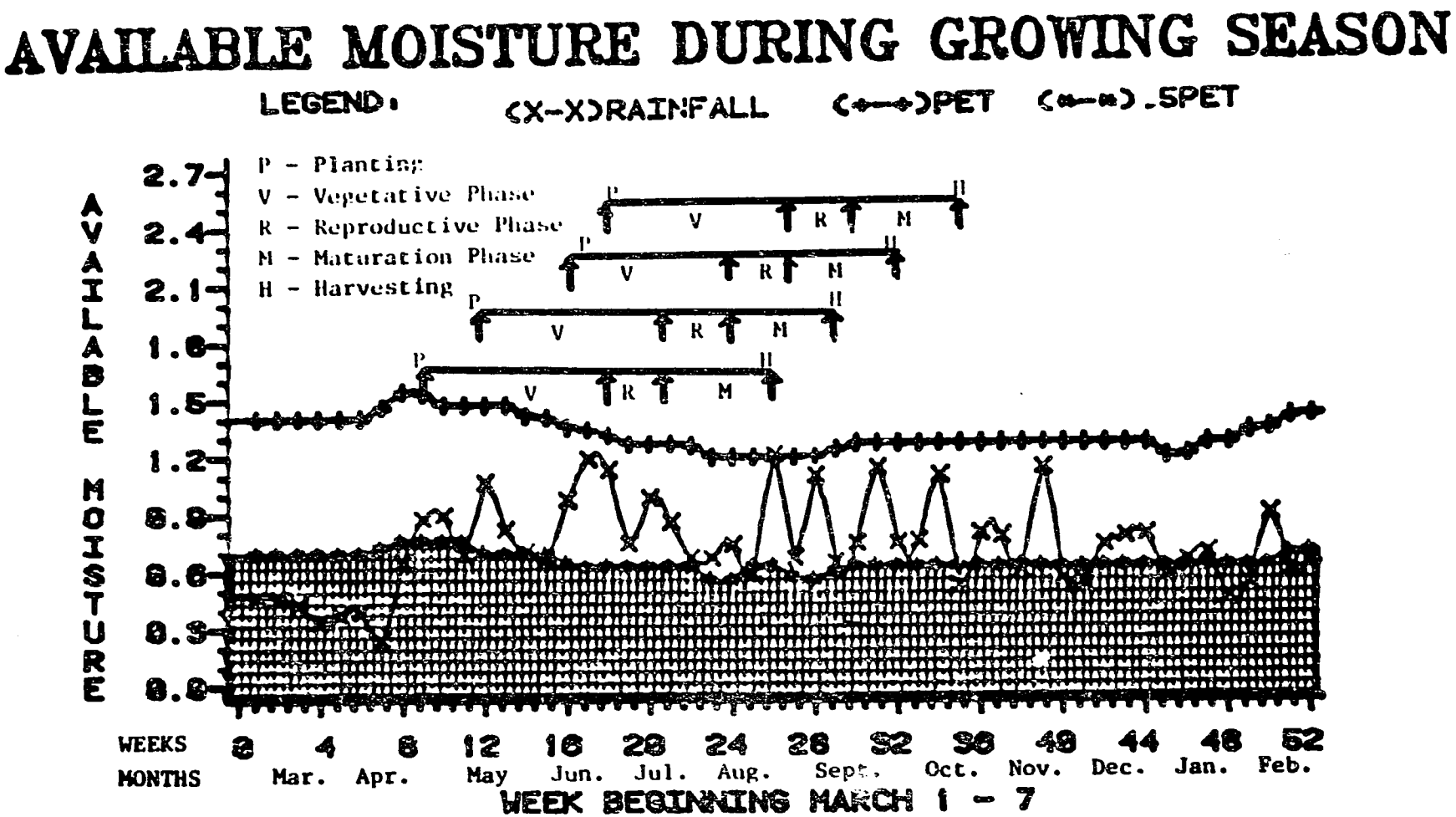


Figure 46. Summary of the phenological events in rice planted on four different dates in relation to rainfall distribution in General Santos, Philippines.

of danger due to moisture deficiency. It was interesting to find that total weekly precipitation was always below total weekly PET, yet the location has a very short dry season. This serves as an ideal case for increasing the cropping intensity from one to two or perhaps three crops in some areas depending on local conditions.

Table 15 and Figures 47-50 show the possible completion dates of phenological stages of different cereals planted after rice. Using a rice-rice sequence shortens the time remaining in the growing season to accomodate a third crop. If the second rice crop is direct-seeded on September 2 it will reach panicle differentiation stage in 64 days (November 5), anthesis in 84 days (November 25) and maturity in 115 days (December 26) after seeding. It will only receive 13.05 in. (332 mm) of rainfall during the whole period. This is a rather small amount to maintain flooded conditions for a long time, but when rainfall is such that it occurs at critical times of the rice development cycle this would be compensatory rather than a limitation.

The first crop of rice will be developing vegetatively at a time when rainfall is not abundant (Fig. 47). From panicle differentiation to anthesis rainfall seems to be sufficiently high. Ripening coincides with a period of scanty rainfall which with higher incidence of sunshine allows greater photosynthesis during grain-filling. This would also be a

Table 15. Projected timetable of phenological periods for different cereal grains planted on four different dates after rice, General Santos.

Planting dates	Choice of second crop	EXPECTED DATES FROM PLANTING TO: Panicle differentiation	Anthesis	Maturity	Accumulated rainfall (in)	Days ahead (+) or beyond (-) growing season
September 2 (Alternative 1)	Corn	September 29 (27)	October 14 (42)	November 22 (81)	9.52	120
	Sorghum	September 30 (28)	October 29 (57)	November 25 (84)	10.05	117
	Pearl millet	September 28 (26)	October 20 (48)	November 10 (69)	8.26	132
	Proso millet	September 17 (15)	October 9 (37)	October 31 (59)	7.08	142
	Rice	November 5 (64)	November 25 (84)	December 26 (115)	13.05	86
September 25 (Alternative 2)	Corn	October 21 (26)	November 6 (42)	December 14 (80)	9.28	98
	Sorghum	October 23 (28)	November 20 (56)	December 18 (84)	9.56	94
	Pearl millet	October 21 (26)	November 11 (47)	December 2 (68)	8.24	110
	Proso millet	October 10 (15)	November 1 (37)	November 22 (58)	6.93	120
	Rice	November 27 (62)	December 17 (83)	January 17 (114)	12.67	64
October 16 (Alternative 3)	Corn	November 11 (26)	November 26 (41)	January 4 (80)	8.79	77
	Sorghum	November 13 (28)	December 11 (56)	January 8 (84)	9.13	73
	Pearl millet	November 10 (25)	December 2 (47)	December 23 (68)	7.51	89
	Proso millet	October 31 (15)	November 21 (36)	December 13 (58)	6.51	99
	Rice	December 18 (63)	January 7 (83)	February 7 (114)	11.72	43
November 6 (Alternative 4)	Corn	December 2 (26)	December 18 (42)	January 26 (81)	8.35	55
	Sorghum	December 4 (28)	December 31 (55)	January 29 (84)	8.48	52
	Pearl millet	December 1 (25)	December 23 (47)	January 13 (68)	7.11	68
	Proso millet	November 20 (14)	December 12 (36)	January 3 (58)	6.28	78
	Rice	January 8 (63)	January 29 (84)	February 28 (114)	11.44	22

( ) Indicates number of days to each phenological period from planting.

AVAILABLE MOISTURE DURING GROWING SEASON

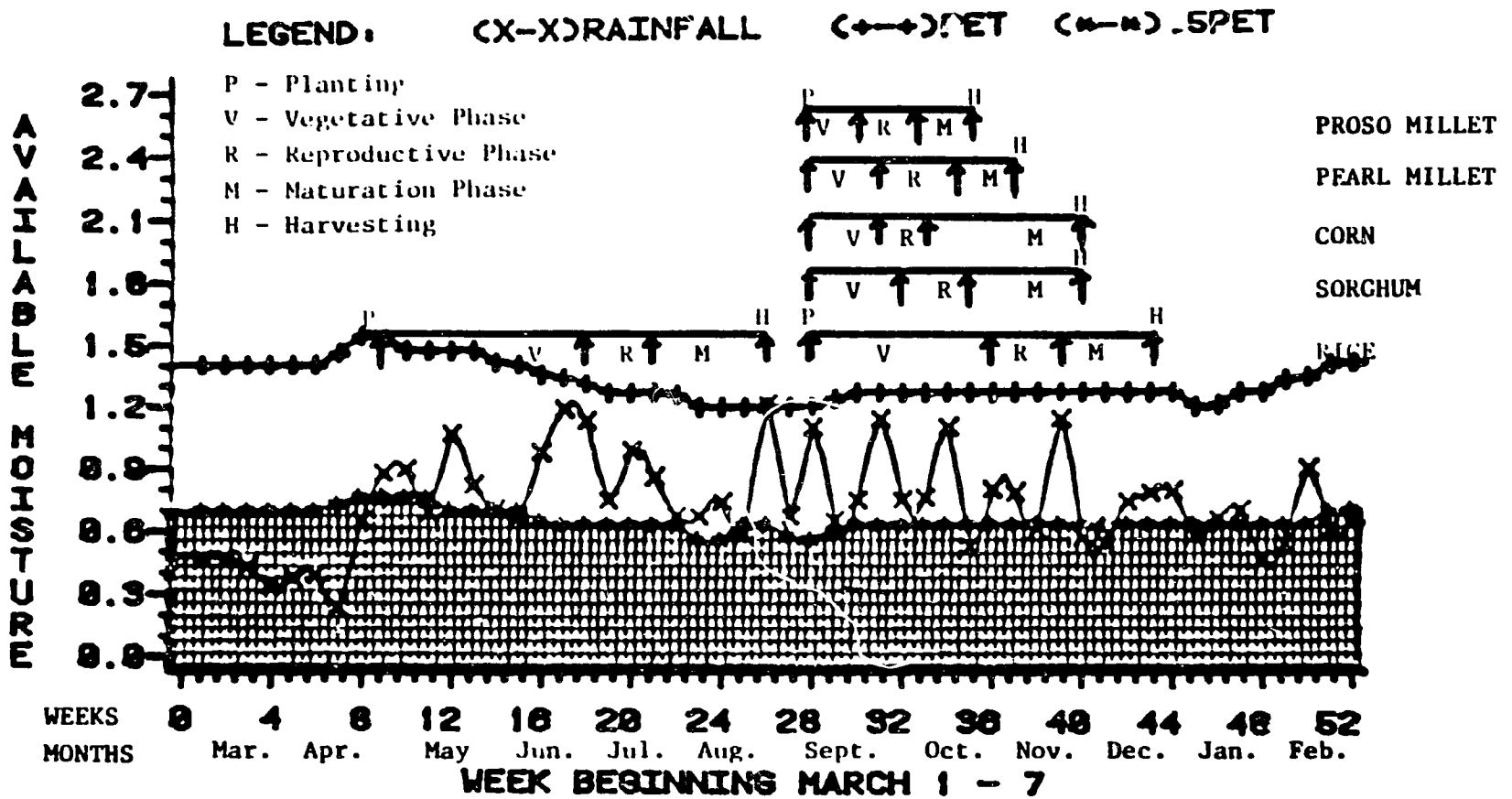


Figure 47. Summary of the phenological events in rice and other upland crops planted after rice in relation to rainfall distribution in General Santos, Philippines. (Alternative 1)

good condition for harvesting since the field would not be so wet. The second rice crop will most likely be as productive as the first since rainfall distribution during this time of the year is better for rainfed rice production.

Other than rice, corn, sorghum, pearl millet or proso millet could be grown with a high probability for success. Except for other environmental constraints, rainfall and temperature favor crop production from June to December. Corn planted on September 2 should be at physiologic maturity by November 22 while sorghum planted on the same date should be ripen on November 25 (Table 15). Either choice of a second crop will allow plenty of time, about 120 days, before the end of the growing season. This is sufficient to plant a third crop. Pearl millet or proso millet will be ready for harvest in about 60-70 days after planting, well before the growing season terminates on March 19.

The same cropping patterns and the expected dates of each phenological period for a first crop planted on May 21 are shown in Figure 48. With this much delay in planting, the first crop would likely have adequately good climatological conditions to succeed and produce economic yields. A small possible problem during the tillering stage and anthesis may be encountered due to reduced moisture conditions because of declining rainfall. This will likely reduce yields significantly

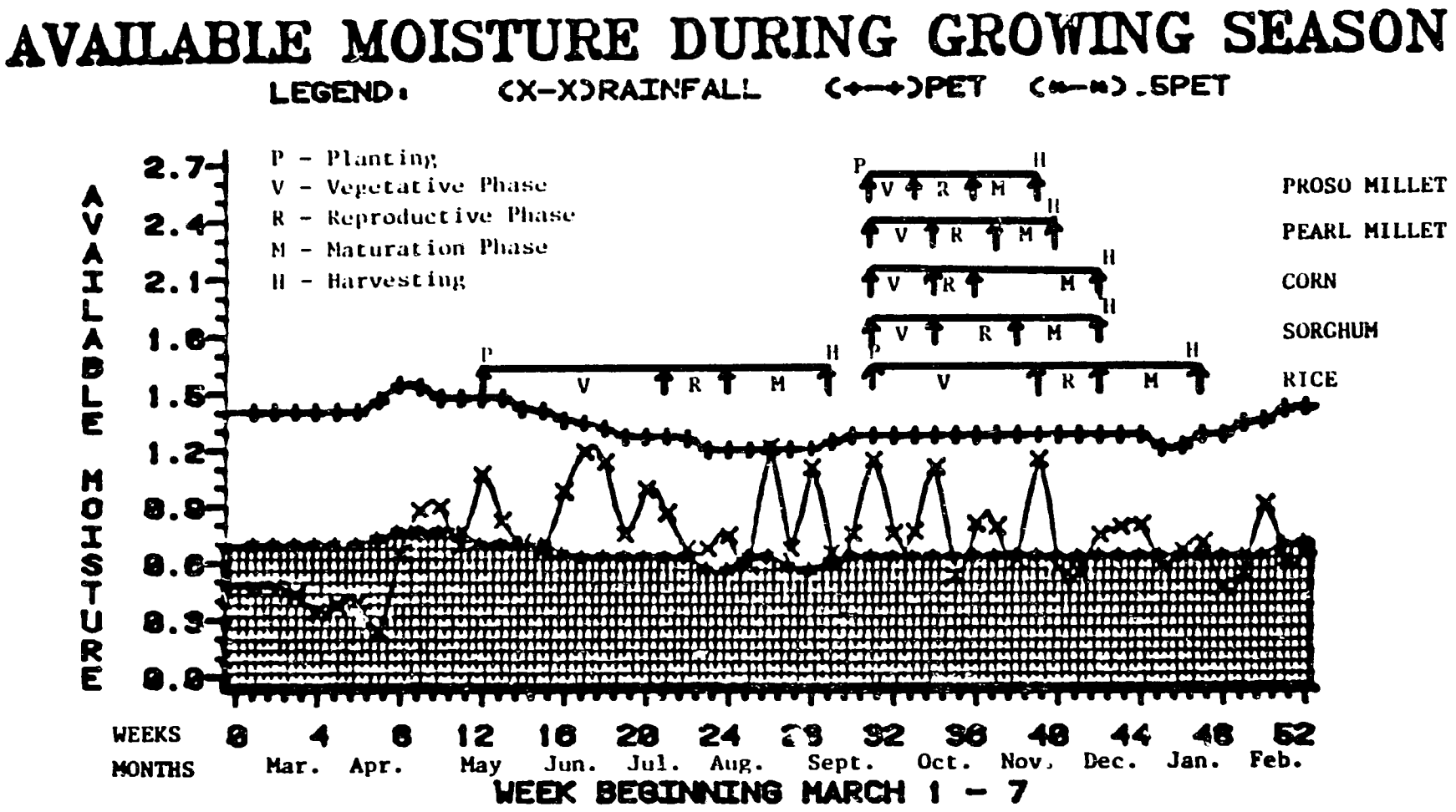


Figure 48. Summary of the phenological events in rice and other upland crops planted after rice in relation to rainfall distribution in General Santos, Philippines. (Alternative 2)

because of reduced tiller number and grain number per panicle. A sequence of rice-rice may still give good production results but the yield will probably be below the variety's genetic potential because of possible moisture deficit at some point during the development of both crops. The risk of crop failure is, however, not great during these times except when other environmental factors impose limiting circumstances while the rice crops are growing. Transplanting the second rice crop may improve the success of its cultural productivity.

Rice seeded on September 25 should be mature in 114 days or about January 17 (Table 15). The amount of accumulated rainfall is slightly lower than a September 2 planting. With a rice-rice pattern, about 64 days would remain in the growing season. A choice of either corn, sorghum, pearl or proso millet after rice would be a good option. Either combination will have the potential to produce an economic yield. Corn and sorghum will ripen by December 14 and December 18, respectively when planted on September 25. This shortens the remaining growing season to around 94-98 days. Proso and pearl millet should be at maturity in late November to early December leaving more than 110 days in the growing season to raise a third dryland crop.

A delay in planting the first crop until June 11 will still be fine since the chances of climatological failure do not seem evident (Fig. 49). However, growing a second

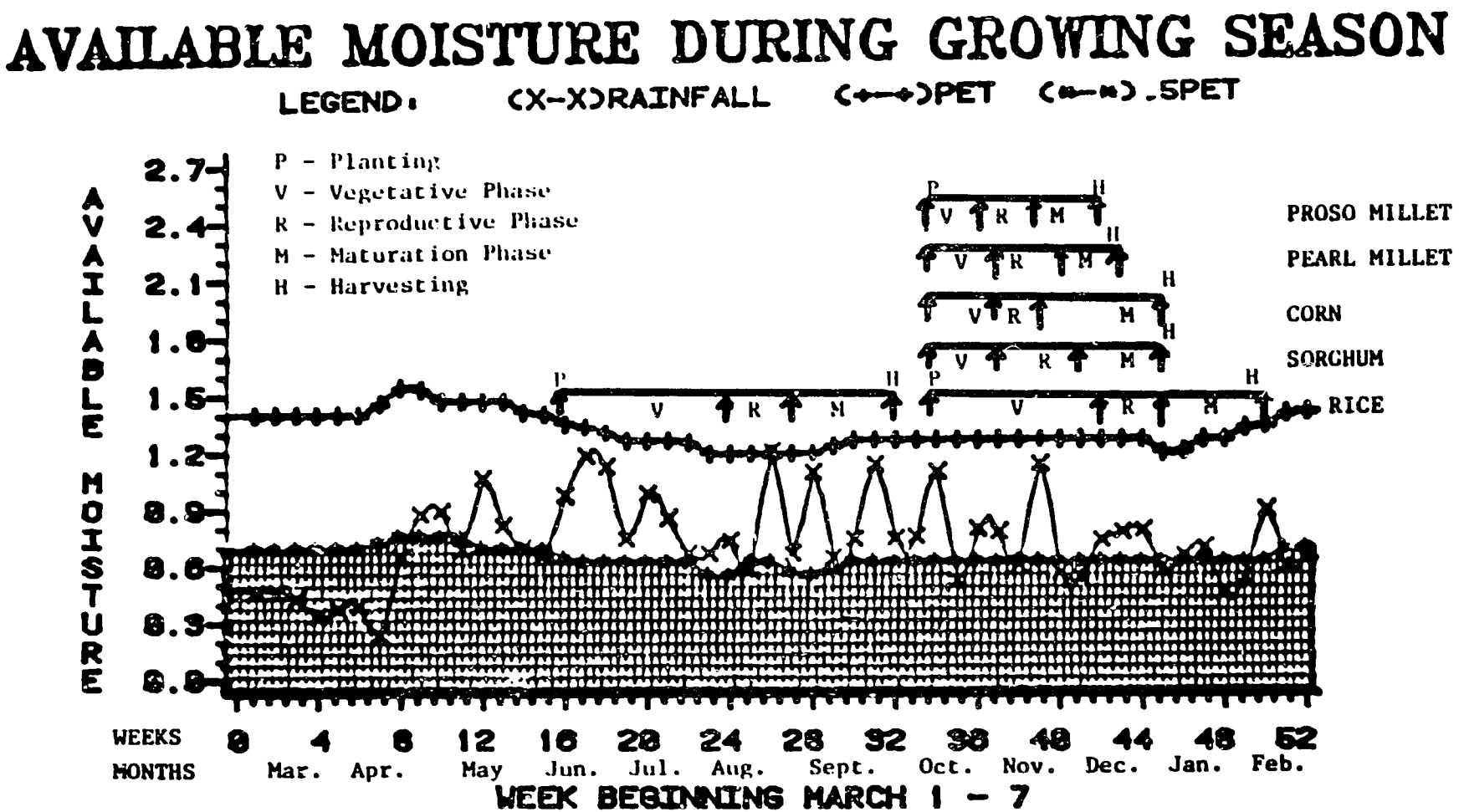


Figure 49.Summary of the phenological events in rice and other upland crops planted after rice in relation to rainfall distribution in General Santos, Philippines. (Alternative3)

rice crop may be prone to moisture deficit late in the season. If instances dictate success in the cultivation of a second crop, there is a likelihood that the yield would be well below potential because of diminishing rainfall towards the latter part of the year. A good alternative cropping pattern for late season planting would be a rice-corn, rice-sorghum, rice-pearl millet or rice-proso millet sequence. Based on rainfall, there would be a greater likelihood of success in either alternative other than a rice-rice pattern.

Data in Table 15 supports these observations on the basis that the accumulated rainfall from planting to maturity of any crop is lower than when planted early. Rice planted on October 16 may be expected to mature on February 7 while an early corn hybrid would be ripe on January 4. Sorghum and pearl millet would be at physiologic maturity on January 8 and December 23, respectively. A full-season proso millet will be at anthesis within 36 days or on November 21 and be ready for harvest on December 13, 99 days prior to the end of the growing season. The remaining period before the growing season terminates on March 19 ranges from 43-99 days depending on the choice for a second crop.

If rice is planted as late as July 2, it becomes ready for harvest by October 27. Rainfall distribution appears to be non-restricting for this period of rice culture (Fig. 50). Planting the second rice crop on

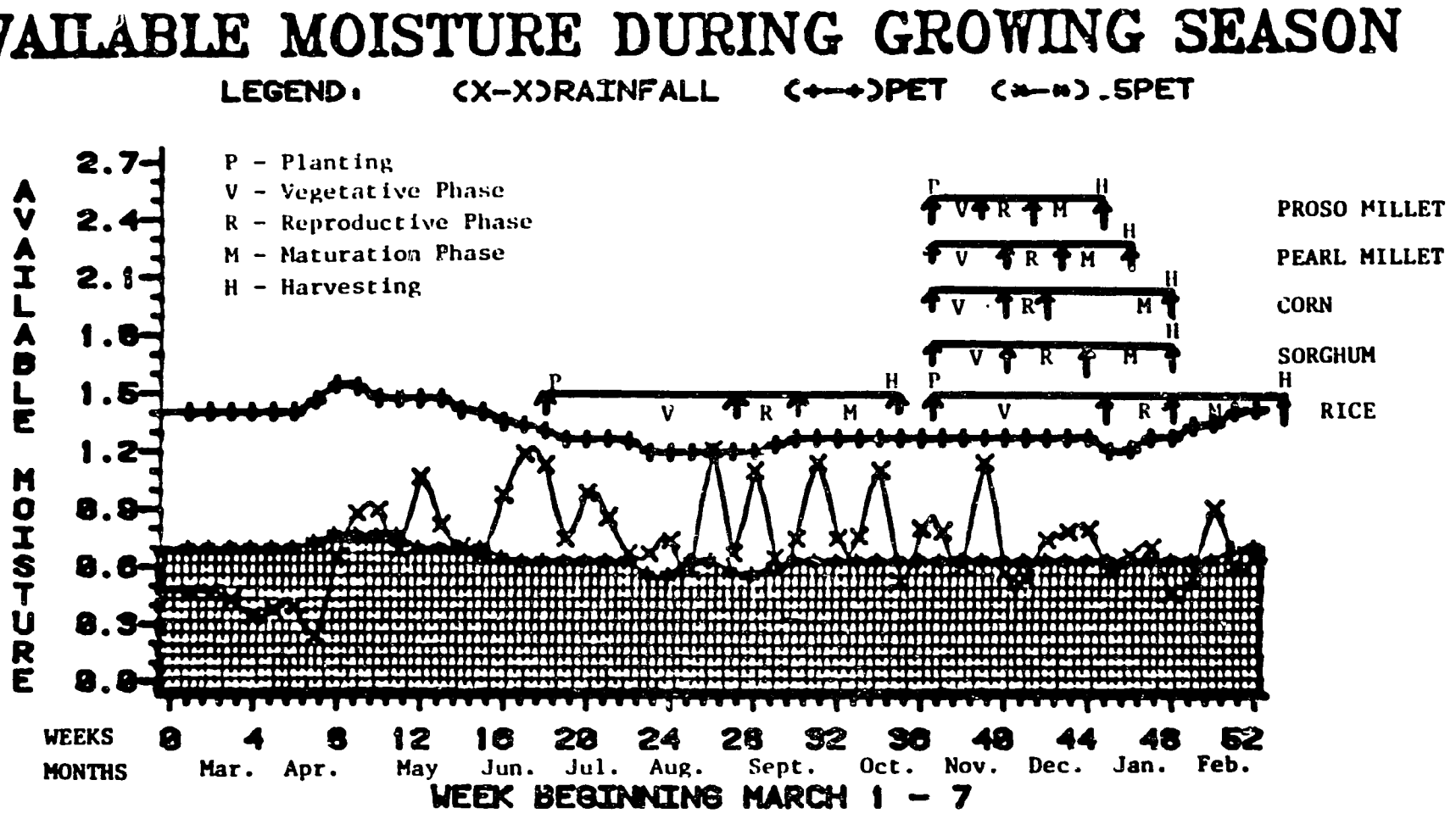


Figure 50. Summary of the phenological events in rice and other upland crops planted after rice in relation to rainfall distribution in General Santos, Philippines. (Alternative 4)

November 6 would not be ideal because of declining precipitation and possible moisture deficit during the flowering period. This is critical and may ultimately influence the yielding ability of the crop. Corn, sorghum, pearl or proso millet may be better crops to plant following harvest of the first rice crop. There would be a minimum tendency towards crop injury since these upland crops are better adapted to lower moisture conditions than rice.

Rice seeded on November 6 should approach maturation within 114 days or on February 28. This would be approximately 22 days before the growing season ends. Only 11.44 in. (291 mm) of rainfall would be available during this period. Sorghum and corn should be at physiologic maturity by late January, more than 50 days before the end of the growing season. Proso and pearl millets should be ripe by early to mid-January, respectively. This is 68-78 days prior to the last date of the growing season. It may be possible to plant a dryland crop that matures in less than 70 days following proso millet, but a high risk of drought may prevail especially from late January to March.

8.6 Monthly Summaries Of Selected Meteorological Components

Based on the monthly summaries of rainfall, potential evapotranspiration (PET), mean temperature, daily solar

radiation and percent sunshine, the three locations are climatologically heterogenous (Table 16). General Santos had lower monthly rainfall, less PET loss, and more uniform seasonal temperatures and percent sunshine than Tuguegarao or Iloilo. The mean daily solar radiation record showed more seasonal variability in Tuguegarao and Iloilo than in General Santos. This can be explained by the lower rainfall occurrences in General Santos, even during the rainy season. On days of high rainfall the sky would generally be cloudy and reduce the solar radiation received at the ground. Also General Santos is almost not affected by passing tropical cyclones compared to Iloilo which has a frequency of 7 percent or Tuguegarao with the highest frequency of 32 percent.

Tuguegarao and Iloilo are relatively dry from January to April, while rainfall is sufficient and often times in excess from July to November. In Tuguegarao the rainy season is noted for high risk that coincides with the prevalence of typhoon passing. These climatic hazards can be of sufficient consideration to say that a two cropping scheme is possible, but there is an occassional risk to the second crop at this location (PCARR 1981). However, Iloilo is suitable for double cropping with very moderate risk of typhoon onslaught. These tropical cyclones are accompanied by high winds and excessive rainfall that produce flooding and could result in destruction of a whole cropping season. Therefore, General Santos, which is located further south, is more climatologically stable

Table 16. Monthly summaries of (a) rainfall (in.), (b) potential evapotranspiration (in.), (c) mean temperature (F), (d) solar radiation (cal/cm^2 per day) and (e) percent sunshine for three stations in the Philippines.

Months	Tuguegarao					Iloilo					General Santos				
	a[1]	b[1]	c[1]	d[2]	e[2]	a[1]	b[1]	c[1]	d[2]	e[2]	a[1]	b[1]	c[1]	d[2]	e[2]
January	0.81	3.41	75.9	338	51	1.80	4.65	78.5	380	51	2.60	5.43	80.40	382	44
February	0.64	3.78	77.6	382	51	0.97	4.62	79.0	414	51	2.76	5.46	80.90	407	44
March	1.25	5.29	81.2	454	58	1.15	5.40	80.5	471	58	1.85	6.20	81.80	452	51
April	1.88	7.35	84.7	513	65	1.78	6.45	82.8	485	58	2.12	6.30	82.40	453	51
May	4.37	9.42	86.6	525	65	4.81	7.43	83.5	428	44	3.80	6.52	81.60	415	44
June	6.38	9.15	85.5	471	51	10.15	6.75	82.2	392	36	4.06	5.85	80.30	405	44
July	8.01	8.85	84.6	468	51	11.92	6.36	81.2	393	36	3.78	5.59	79.60	408	44
August	9.53	8.06	84.0	434	44	13.41	5.85	81.0	370	29	3.51	5.27	79.60	418	44
September	8.62	7.05	83.3	413	44	10.32	5.70	81.1	391	36	3.45	5.25	79.90	423	44
October	9.74	6.23	81.4	398	51	9.94	5.89	81.2	371	36	3.76	5.58	80.40	412	44
November	11.84	4.65	78.6	332	44	6.81	5.55	80.7	368	44	3.49	5.40	80.80	389	44
December	4.01	3.89	76.5	307	44	3.99	5.13	79.5	349	44	3.11	5.58	80.80	374	44

Source: Philippine Atmospheric, Geophysic and Astronomic Services Administration (PAGASA)

[1]Based on daily normals computed from 27-30 years of records.

[2]Based on 20 years of record.

for a bountiful harvest than any of the locations in the higher latitudes. A third crop, of an early maturing type can be grown with minimal climatic constraints.

It should be noted that other environmental factors may impose limitations upon the cultivated crop. These would include topographic conditions, internal and external drainage and also nutrient availability. A sloping terrain is conducive to excessive soil erosion and removal of nutrients by high rainfall. Although the mean rainfall distribution can be a useful guide in agricultural planning, one should never completely rely on the normal distribution.

In the traditional rainfed rice-based cropping systems, a single crop of rice per year followed by fallowing the rest of the year, or two crops of rice in succession are common. Various dryland crops can be cultivated during the summer months at pre- or post-harvest periods of rice to augment farm income.

The choice of crops to grow at any one time may not only be decided by their success environmentally but also by the economic implication or benefit associated with the final product. Post harvest operations may require a large proportion of the total investment cost unless steps are taken to rapidly bring the supply to the consumers at minimal cost and high economic returns.

IX. TEMPORAL UNCERTAINTY IN THE GROWING SEASON

Any variability in the onset of the monsoon season may be critical to the intensification of cropping systems. Cessation and interruptions of the monsoon rainfall have been examined for many locations by Kao and Hsu (1962), Huke (1966), Sastry (1976), Morris and Zandstra (1979), and Raj (1979). The advance and retreat of the monsoon rains have provided an insight into the duration of the growing season. The beginning and termination of the growing season are variable within locations for any given year. Thus the difficulty of assessing the extent of variability undoubtedly results in differences in cropping pattern adoptations and agricultural strategies.

For a number of years in Tuguegarao, rainfall exceeded half-PET during the early part of the second quarter (April-June), followed by several dry days. These dry periods are long enough to dry the top soil and retard germination or seedling growth in the field. Such events are termed "false-starts". Rainy days during this transistion period are generally dominated by "showers" as opposed to "rain" (Ramage 1971). This phenomenon has been reported to occur in 40 percent of the years at Samaru (11.11 ^{o}N latitude) and in 60 percent of all years at Kano (12.03 ^{o}N latitude) during the months of April and May for the period 1951 to 1975, both in Nigeria

(Benoit 1977).

The yearly summary of the growing season in Tuguegarao indicating the transistion of dry-wet season with regular occurrences of a false-start are shown in Figure 51 and Appendix Table 9. False-starts occurred in 90 percent of the years from 1951 to 1979. The mean date for a false-start was April 28 and the actual start of the growing season was 42 days later on June 9. This suggests that planting too early during the transistion period will be risky for a developing crop. There was large variability from the mean date for individual years. A false-start occurring prior to the mean date was observed in 52 percent of all years while 58 percent showed an actual start occurring earlier than June 9. In some years (1953, 1954, 1957, 1966 and 1970) the false-start began as early as mid- to late-March, but the safest planting date did not come until late May and early June. The earliest "safe" planting between 1951 to 1979 was in 1970 and the latest was in 1967. Only in three (1963, 1964 and 1965) of 29 years was there no actual false-start. The season began rather early and rainfall increased thereafter.

The growing season ended on a mean date of January 13 for an average season period of 218 days not accounting for the false-start. There was wider variability from the mean date in the retreat of the monsoon rains and the subsequent termination of the growing season. It ended

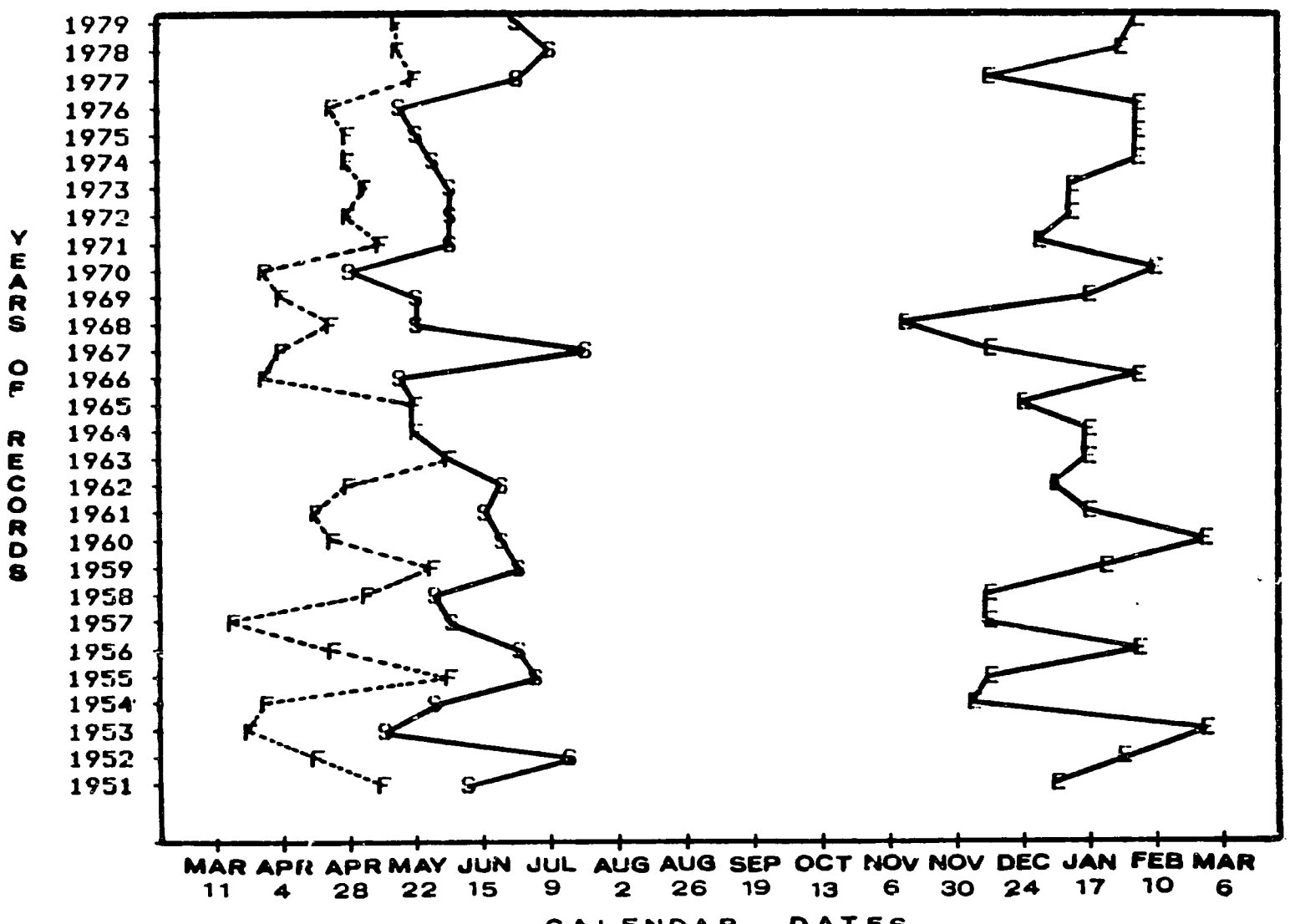


Figure 51. Summary of the occurrences of false-start, actual start and end of the growing season in Tuguegarao, Philippines from 1951-1979.

abruptly in 1968 and was delayed in 1953 and 1960. The only years when the growing season was close to 300 days were in 1953 and 1970. Approximately 41 percent of all years showed a longer growing season than the mean duration of 218 days.

There was no consistent pattern of early, normal or late start and end of the growing season among the individual years. No simple reason could be given to account for the variability in the start or end of the growing season for individual years. Benoit (1977) speculated that in Nigeria, where rainfall and latitude are related, the mean pattern was determined by the Inter-Tropical Discontinuity (ITD) or the boundary between the humid maritime air mass and the dry Saharan air mass. For agricultural planning, a more sound approach would be to ignore any rainfall which would occur more than 30 days before the mean actual start of the growing season. These periods are most likely characterized by early rainfall of light to intermediate amounts for planting followed by several dry days. Planting during the dry-wet season transistion period may lead to crop injury. However, a successful early planting would allow more time for the crop to mature and may contribute to higher yields. A delayed planting will shorten the time before the season ends and the crop may be subject to drought at later stages which could make the difference between partial and total yield loss.

X. SUMMARY AND CONCLUSION

A series of phenological stages for proso millet have been identified. The scales indicated are meant to serve as an arbitrary guide for researchers, extension workers, and farmers working on proso millets. Later modifications may be made as more observations covering a wider range of maturity classes become available.

Results of the regression analyses on phenology and degree-day summations showed variations occurring for different maturity classes and among species. Generally, the rate of development per unit change in GDD summation was homogenous for a given variety regardless of planting dates. For proso millets, the range in GDD summation constants from planting to maturity was from 1400 to 1900, while pearl millets ranged from about 2000 to 2500 units. The sorghum hybrid, RS-671, requires about 2500 GDDs. A family of curves for the regression of calendar days and GDD on phenological stages of each crop have been presented. The actual time sequence of plant height for individual varieties are likewise given.

In the assessment of cropping patterns for three selected locations in the Philippines, meteorological considerations seem to suggest that Tuguegarao can adopt a double cropping scheme but with occassional risk of failure on the second crop. This risk factor may be reduced further by adjustments in planting dates,

appropriate selection of crops and varieties to be grown in sequence, and use of supplementary irrigation. On the other hand, Iloilo is more suitable for double cropping with very minimal risk of crop failure. A third crop can be grown but, with some risk, depending on existing conditions in the field during the remainder of the growing season. General Santos is more agriculturally stable for triple cropping with very few climatic constraints.

Large rainfall variability, uncertainty of the onset and retreat of the rainy season, magnitude of soil moisture holding capacity in combination with other edaphic factors and management practices present some difficulty in assessing crop responses and the internal adjustments necessary to cope with continously changing growing conditions. Even the wetter areas with adequately reliable moisture regimes are frequently plagued by low solar radiation. Moreover, the temporal variability associated with the meteorological factors and the spatial variability related to geographic and hydrologic components lead to changing production potentials. Thus, it is difficult to predict the success of an actual cropping pattern. These environmental factors have to be recognized and judicious agricultural planning must be undertaken if significant improvement in rainfed crop production is to be achieved.

Some common guidelines based on past experiences in

the Philippines, are useful when properly evaluated. Rice grown during an increasing precipitation (start of the rainy season) experiences less risk of drought than one planted late during a declining rainfall pattern. A sequence of a rice-upland crop is less likely to fail than a rice-rice pattern in rainfed areas with light- to medium- textured soils. The identification of superior cropping patterns requires serious thought and interpretation of climatic informations supported by agricultural research for improved technology in the farmer's field. Priorities for different countries will change with prevailing social and economic situations.

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XII. APPENDICES

Appendix Table 1. Number of days from planting and GDD[1] requirements per growth stage of Dawn millet planted in the growth chamber, spring 1982, Lincoln, Nebraska.

Stage	Treatment 1		Treatment 2		Treatment 3	
	Days	GDD	Days	GDD	Days	GDD
1	9	279	9	213	10	241
2	16	467	15	381	17	418
3	22	654	22	550	24	595
4	28	842	29	718	31	771
5	34	1030	36	886	38	948
6	41	1217	42	1055	45	1125
7	47	1405	49	1223	52	1301
8	53	1592	56	1391	59	1478

NOTE:

Treatment 1: Temperature range 85°F - 75°F day/night temperatures with 13 hours light period (C 80/13).

Treatment 2: Temperature range 80°F - 70°F day/night temperatures with 13 hours light period (C 75/13).

Treatment 3: Temperature range 80°F - 70°F day/night temperatures with 15 hours light period (C 75/15).

[1]To convert to metric units: GDD50 X .5556 = GDD10 (base 10°C).

Appendix Table 2. Dates represented by week number beginning with the specified planting dates used in the field experiment, Summer 1982.

Week No.	First Planting	Second Planting	Third Planting	Fourth Planting
1	June 10-16	June 21-27	July 9-15	July 19-25
2	June 17-23	June 28-July 4	July 16-22	July 26-Aug. 1
3	June 24-30	July 5-11	July 23-29	Aug. 2-8
4	July 1-7	July 12-18	July 30-Aug. 5	Aug. 9-15
5	July 8-14	July 19-25	Aug. 6-12	Aug. 16-22
6	July 15-21	July 26-Aug. 1	Aug. 13-19	Aug. 23-29
7	July 21-28	Aug. 2-8	Aug. 20-26	Aug. 30-Sept. 5
8	July 29-Aug. 4	Aug. 9-15	Aug. 27-Sept. 2	Sept. 6-12
9	Aug. 5-11	Aug. 16-22	Sept. 3-9	Sept. 13-19
10	Aug. 12-12	Aug. 23-29	Sept. 10-16	Sept. 20-26
11	Aug. 19-25	Aug. 30-Sept. 5	Sept. 17-23	Sept. 27-Oct. 3
12	Aug. 26-Sept. 1	Sept. 6-12	Sept. 24-30	Oct. 4-10
13	Sept. 2-8	Sept. 13-19	Oct. 1-7	Oct. 11-17
14	Sept. 9-15	Sept. 20-26	Oct. 8-14	Oct. 18-24
15	Sept. 16-22	Sept. 27-Oct. 3	Oct. 15-21	Oct. 25-31
16	Sept. 23-29	Oct. 4-10	Oct. 22-28	***
17	Sept. 30-Oct. 6	Oct. 11-17	Oct. 29-31	
18	Oct. 7-13	Oct. 18-24	***	
19	Oct. 14-20	Oct. 25-31		
20	Oct. 21-27	***		
21	Oct. 28-31			
	***			

Appendix Table 3. Growing degree day[1] requirements per growth stages of three varieties of proso millet planted on two different dates during the summer of 1982, Lincoln Horticulture Farm.

Growth Stages	DAWN			PANHANDLE			COPE		
	June 10	June 21	Composite	June 10	June 21	Composite	June 10	June 21	Composite
1	208	317	254	150	264	210	174	281	227
2	391	493	429	378	481	432	410	510	460
3	574	669	604	605	698	654	646	739	694
4	756	844	778	832	914	876	881	968	928
5	939	1020	953	1059	1311	1097	1117	1197	1161
6	1122	1196	1128	1287	1348	1319	1353	1426	1395
7	1305	1372	1303	1514	1565	1541	1589	1655	1629
8	1488	1548	1477	1714	1781	1763	1825	1884	1863

[1]To convert to metric units: GDD50 X .5556 = GDD10 (base 10°C).

Appendix Table 4. Growing degree day[1] requirements per growth stages of a sorghum hybrid and two pearl of millets planted on four different dates during the summer of 1982, Lincoln Horticulture Farm.

Growth Stages	RS-671					SENEGAL BULK					SERERE-3A				
	June 10	June 21	July 9	July 19	Composite	June 10	June 21	July 9	July 19	Composite	June 10	June 21	July 9	July 19	Composite
1	182	250	307	282	232	290	295	346	401	326	253	305	395	394	334
2	473	537	571	532	513	533	537	572	610	559	491	519	605	596	551
3	764	823	836	781	794	777	780	799	818	792	728	733	816	799	769
4	1055	1110	1101	1031	1075	1020	1023	1026	1027	1025	965	946	1027	1001	987
5	1346	1397	1365	1280	1357	1264	1266	1253	1230	1258	1203	1160	1238	1203	1205
6	1637	1683	1630	1529	1638	1507	1508	1479	1445	1491	1440	1374	1449	1406	1423
7	1928	1970	1894	1779	1919	1751	1751	1706	1653	1723	1677	1587	1660	1608	1641
8	2219	2256	2159	2028	2200	1995	1994	1933	1862	1956	1915	1801	1871	1811	1859
9	2510	2543	2423	2277	2481	2238	2236	2160	2071	2189	2152	2015	2082	2013	2077

[1]To convert to metric units: GDD50 X .5556 = GDD10 (base 10°C).

Appendix Table 5. Mean weekly temperature (°F), total weekly rainfall (in) and ½ potential evapotranspiration (in) for Tuguegarao, Philippines, summarized over 29 years (1951-1979).

Week No.	Period	Temperature	Rainfall	$\frac{PET}{2}$
1	March 1-7	80	0.18	0.53
2	March 8-14	80	0.25	0.56
3	March 15-21	82	0.20	0.62
4	March 22-28	83	0.38	0.70
5	March 29-April 4	83	0.32	0.74
6	April 5-11	84	0.72	0.77
7	April 12-18	85	0.42	0.83
8	April 19-25	86	0.32	0.91
9	April 26-May 2	86	0.53	0.93
10	May 3-9	87	0.71	1.05
11	May 10-16	87	0.78	1.05
12	May 17-23	87	1.11	1.12
13	May 24-30	86	1.45	1.12
14	May 31-June 6	86	1.74	1.06
15	June 7-13	86	1.49	1.05
16	June 14-20	86	1.13	1.05
17	June 21-27	85	1.33	1.05
18	June 28-July 4	85	1.44	1.02
19	July 15-11	85	1.13	0.98
20	July 12-18	85	2.06	0.98
21	July 19-25	84	2.37	0.98
22	July 26-Aug. 1	84	1.97	0.97
23	Aug. 2-8	84	2.07	0.91
24	Aug. 9-15	84	2.41	0.91
25	Aug. 16-22	84	1.75	0.91
26	Aug. 23-29	84	2.60	0.91
27	Aug. 30-Sept. 5	83	2.00	0.86
28	Sept. 6-12	84	1.89	0.84
29	Sept. 13-19	84	1.85	0.84
30	Sept. 20-26	83	2.30	0.84
31	Sept. 27-Oct. 3	83	1.94	0.82
32	Oct. 4-10	82	2.47	0.77
33	Oct. 11-17	81	3.35	0.76
34	Oct. 18-24	81	1.26	0.70
35	Oct. 25-31	81	1.87	0.70
36	Nov. 1-7	80	2.33	0.56
37	Nov. 8-14	79	2.32	0.56
38	Nov. 15-21	79	3.63	0.50
39	Nov. 22-28	77	3.02	0.49
40	Nov. 29-Dec. 5	77	1.12	0.49
41	Dec. 6-12	77	1.49	0.49
42	Dec. 13-19	76	1.12	0.46
43	Dec. 20-26	77	0.39	0.42
44	Dec. 27-Jan. 2	76	0.56	0.42
45	Jan. 3-9	76	0.35	0.42
46	Jan. 10-16	75	0.09	0.42
47	Jan. 17-23	76	0.11	0.42
48	Jan. 24-30	77	0.14	0.42
49	Jan. 31-Feb 6	77	0.05	0.42
50	Feb. 7-13	77	0.17	0.42
51	Feb. 14-20	77	0.16	0.48
52	Feb. 21-27	79	0.26	0.49
53	Feb. 28-29	79	0.01	0.07

Appendix Table 6. Mean weekly temperature (°F), total weekly rainfall (in) and ½ potential evapotranspiration (in) for Iloilo, Philippines, summarized over 30 years (1951-1980).

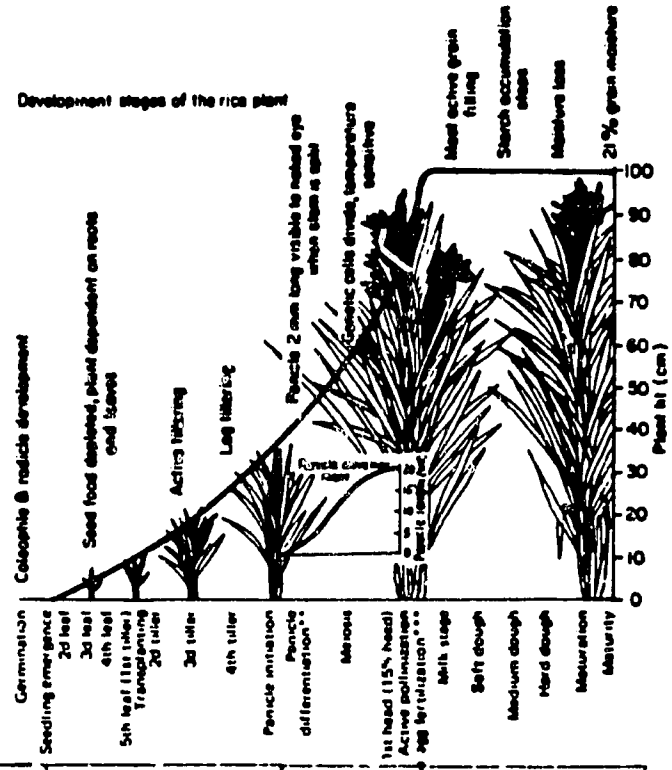
Week No.	Period	Temperature	Rainfall	$\frac{PET}{2}$
1	March 1-7	80	0.27	0.60
2	March 8-14	80	0.28	0.63
3	March 15-21	81	0.31	0.63
4	March 22-28	81	0.27	0.63
5	March 29-April 4	82	0.18	0.67
6	April 5-11	83	0.25	0.70
7	April 12-18	83	0.34	0.73
8	April 19-25	83	0.72	0.77
9	April 26-May 2	84	0.47	0.78
10	May 3-9	84	0.71	0.84
11	May 10-16	84	1.24	0.84
12	May 17-23	83	1.38	0.84
13	May 24-30	83	1.18	0.84
14	May 31-June 6	83	1.34	0.84
15	June 7-13	83	1.66	0.84
16	June 14-20	82	2.26	0.79
17	June 21-27	81	3.55	0.77
18	June 28-July 4	81	2.79	0.77
19	July 5-11	81	2.86	0.77
20	July 12-18	81	2.99	0.75
21	July 19-25	81	2.38	0.70
22	July 26-Aug. 1	81	2.70	0.70
23	August 2-8	81	3.15	0.70
24	August 9-15	81	3.44	0.70
25	August 16-22	81	3.35	0.70
26	August 23-29	81	2.48	0.70
27	Aug. 30-Sept. 5	81	3.01	0.65
28	September 6-12	81	2.61	0.63
29	September 13-19	81	2.30	0.67
30	September 20-26	81	2.01	0.70
31	Sept. 27-Oct. 3	81	2.39	0.70
32	October 4-10	81	2.63	0.70
33	October 11-17	81	2.94	0.70
34	October 18-24	81	1.89	0.70
35	October 25-31	81	1.17	0.70
36	November 1-7	81	1.64	0.63
37	November 8-14	81	1.29	0.63
38	November 15-21	81	1.70	0.63
39	November 22-28	80	1.83	0.63
40	Nov. 29-Dec. 5	80	1.02	0.63
41	December 6-12	80	1.27	0.63
42	December 13-19	80	0.77	0.60
43	December 20-26	79	0.71	0.56
44	Dec. 27-Jan. 2	79	0.66	0.56
45	January 3-9	79	0.76	0.56
46	January 10-16	78	0.30	0.55
47	January 17-23	78	0.34	0.49
48	January 24-30	79	0.28	0.49
49	Jan. 30-Feb. 6	79	0.14	0.55
50	February 7-13	79	0.34	0.56
51	February 14-20	79	0.30	0.56
52	February 21-27	79	0.17	0.56
53	February 28-29	80	0.05	0.08

Appendix Table 7. Mean weekly temperature (°F), total weekly precipitation (in) and ½ potential evapotranspiration (in), for General Santos, summarized over 27 years (1951-1977).

Week No.	Period	Temperature	Rainfall	$\frac{PET}{2}$
1	March 1-7	81	0.47	0.70
2	March 8-14	82	0.47	0.70
3	March 15-21	82	0.43	0.70
4	March 22-28	82	0.34	0.70
5	March 29-April 4	82	0.38	0.70
6	April 5-11	82	0.39	0.70
7	April 12-18	83	0.24	0.73
8	April 19-25	82	0.66	0.77
9	April 26-May 2	82	0.[illegible]	0.77
10	May 3-9	82	0.90	0.77
11	May 10-16	82	0.69	0.77
12	May 17-23	82	1.07	0.70
13	May 24-30	81	0.82	0.70
14	May 31-June 6	81	0.71	0.70
15	June 17-13	80	0.67	0.70
16	June 14-20	80	0.98	0.65
17	June 21-27	80	1.19	0.63
18	June 28-July 4	80	1.13	0.63
19	July 5-11	79	0.75	0.63
20	July 12-18	80	0.99	0.63
21	July 19-25	80	0.86	0.63
22	July 26-Aug. 1	80	0.67	0.63
23	August 2-8	80	0.67	0.56
24	August 9-15	80	0.74	0.56
25	August 16-22	80	0.59	0.63
26	August 23-29	79	1.21	0.63
27	Aug. 30-Sept. 5	80	0.67	0.58
28	September 6-12	80	1.10	0.56
29	September 13-19	80	0.65	0.60
30	September 20-26	80	0.75	0.63
31	Sept. 27-Oct. 3	80	1.14	0.63
32	October 4-10	80	0.75	0.63
33	October 11-17	80	0.76	0.63
34	October 18-24	81	1.10	0.63
35	October 25-31	81	0.53	0.63
36	November 1-7	81	0.80	0.63
37	November 8-14	81	0.78	0.63
38	November 15-21	81	0.61	0.63
39	November 22-28	81	1.14	0.63
40	Nov. 29-Dec. 5	81	0.57	0.63
41	December 6-12	81	0.55	0.63
42	December 13-19	81	0.74	0.63
43	December 20-26	81	0.78	0.63
44	Dec. 27-Jan. 2	81	0.79	0.63
45	January 3-9	80	0.58	0.63
46	January 10-16	80	0.66	0.63
47	January 17-23	81	0.70	0.63
48	January 24-30	80	0.46	0.63
49	Jan. 21-Feb. 6	81	0.54	0.63
50	February 7-13	81	0.90	[illegible]53
51	February 14-20	81	0.61	[illegible].69
52	February 21-27	81	0.64	0.70
53	February 28-29	81	0.12	0.10

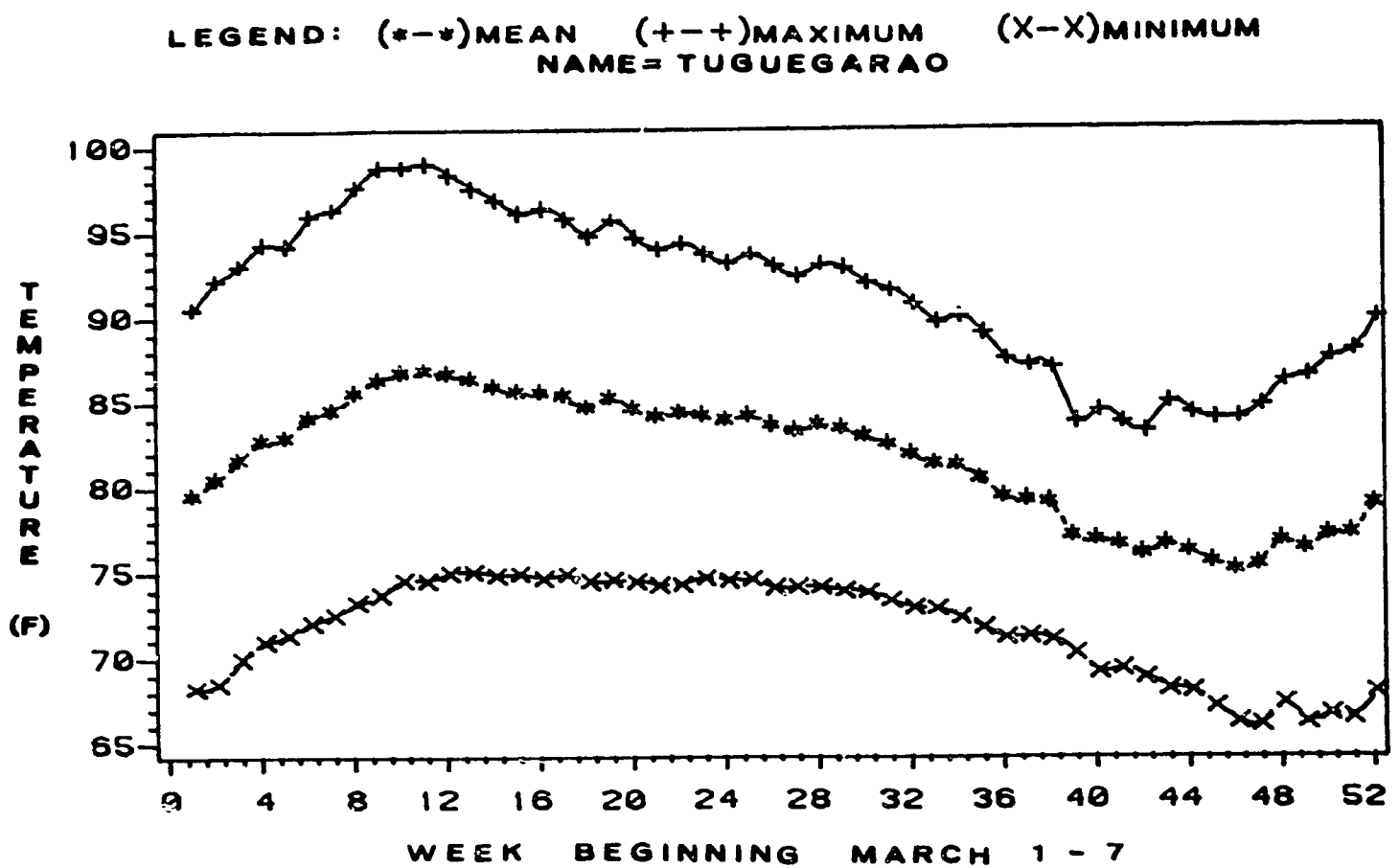
Appendix Table 8. Summary of the beginning and end of the growing season in Tuguegarao, 1951-1979.

Year	False start	Actual start	Days between false and actual	End	Days from actual to end	Year	False start	Actual start	Days between false and actual	End	Days from actual to end
1979	May 17	June 30	44	Feb. 2	217	1964	May 25	May 25	0	Jan. 17	237
1978	May 19	July 11	53	Jan. 30	203	1963	June 5	June 5	0	Jan. 19	228
1977	May 22	June 26	35	Dec. 13	170	1962	April 27	June 21	55	Jan. 3	196
1976	April 25	May 28	33	Feb. 5	263	1961	April 15	June 18	64	Jan. 17	213
1975	April 29	May 20	21	Feb. 7	263	1960	April 24	June 22	59	Feb. 27	250
1974	April 26	May 29	33	Feb. 3	250	1959	May 28	June 27	30	Jan. 26	213
1973	May 7	June 6	30	Jan. 10	218	1958	May 6	May 28	22	Dec. 12	198
1972	April 29	June 1	33	Jan. 14	227	1957	March 16	June 4	80	Dec. 11	190
1971	May 12	June 1	20	Jan. 2	215	1956	April 21	June 27	67	Feb. 5	223
1970	March 27	April 26	30	Feb. 8	288	1955	June 2	July 1	29	Dec. 13	165
1969	April 7	May 22	45	Jan. 15	238	1954	March 29	May 28	60	Dec. 16	192
1968	April 20	May 22	32	Nov. 4	176	1953	March 25	May 13	49	March 3	294
1967	April 7	July 21	105	Dec. 13	145	1952	April 18	July 18	91	Jan. 30	196
1966	March 30	May 19	50	Feb. 4	261	1951	May 10	June 11	32	Jan. 4	207
1965	May 24	May 24	0	Dec. 23	213						
					Mean		April 28	June 9	42	Jan. 13	218
					Standard deviation		22	21		27	

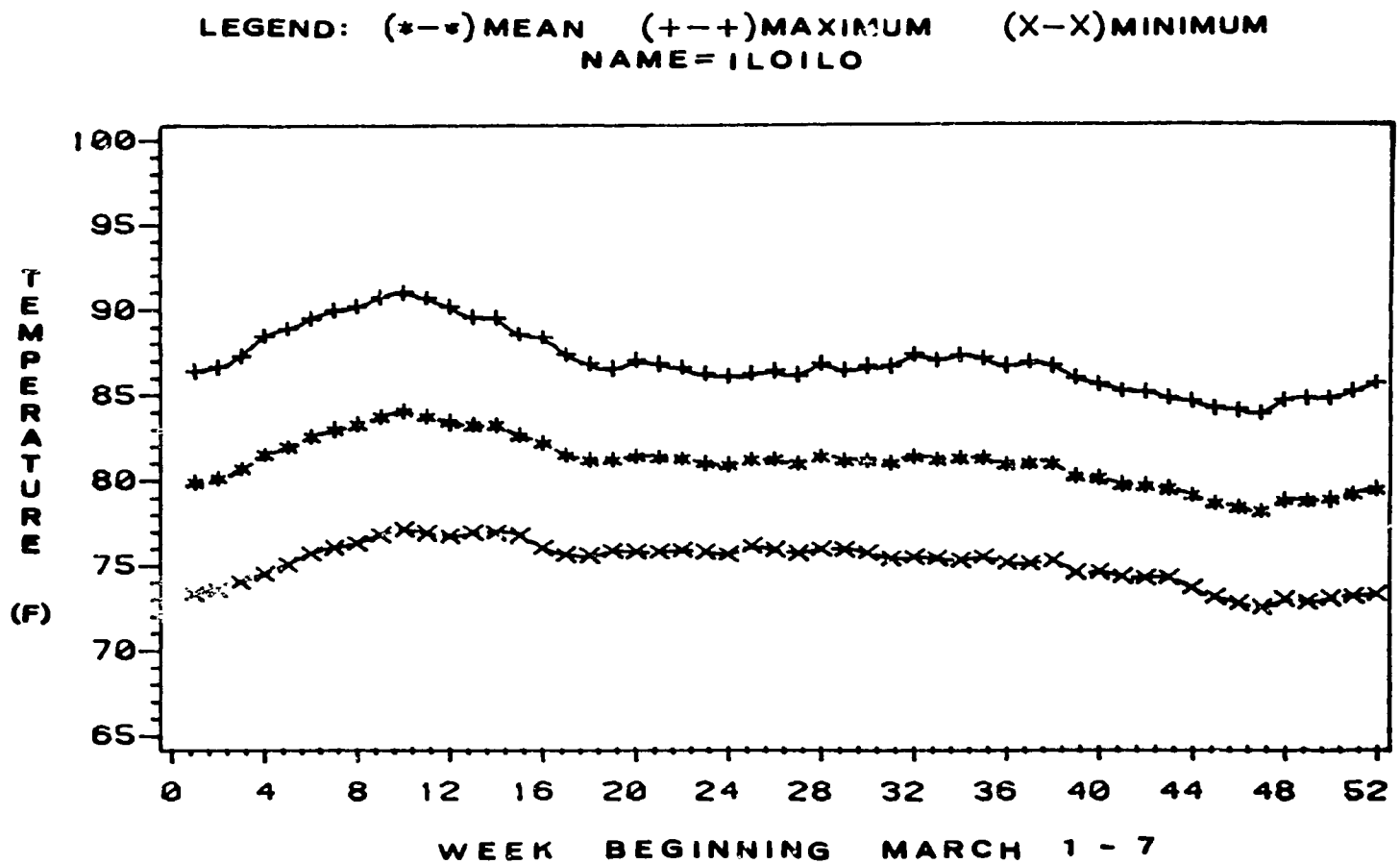


	Stage I Vegetative		Stage II Reproductive	Stage III Grain filling & maturation
100°C units	650°C units	Variable day length	300°C units	500°C units
I. Soil moisture	ET 4.0 mm/day EM 200 mm/mo		ET 6.0 mm/day EM 300 mm/mo	ET 4.0 mm/day EM 200 mm/mo
II. Temperature	15°C–35°C *r (low significance)		22°C–31°C *r (high signif.)	14°C–25°C *r (medium significance)
III. Solar radiation	100-300 cal/cm² per day *r (low significance)		200-500 cal/cm² per day *r (high signif	150-400 cal/cm² per day *r (medium significance)
IV. Catastrophe				
A. Temp	14°C		15°C, 20°C, 35°C, 22°C	
B. Flood	Moderate damage		Moderate dam.	High damage
C. Wind	Low damage		High damage	Moderate damage
D. Diseases & insects	Moderate damage		High damage	Moderate damage

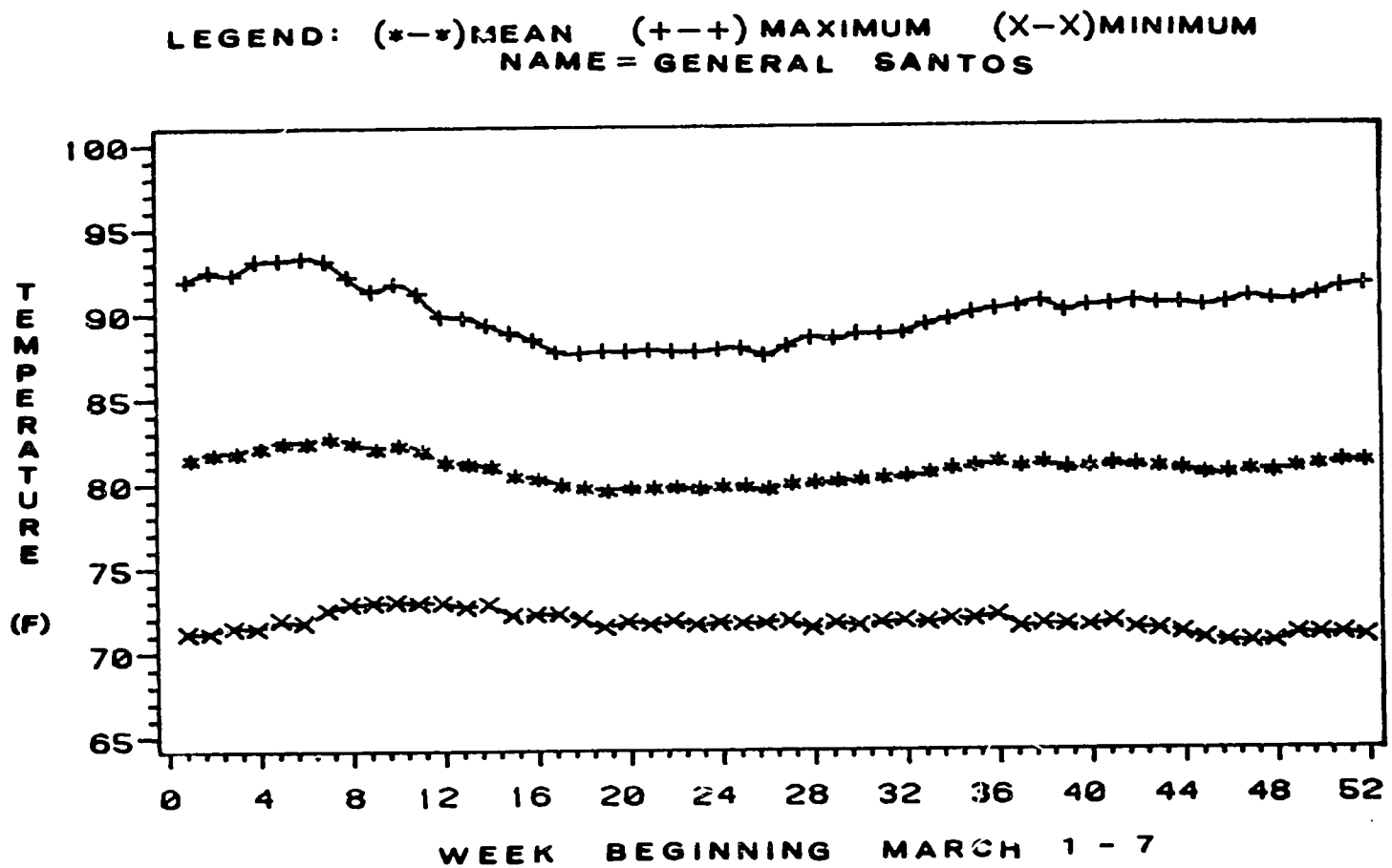
Appendix Figure 1. Meteorological effects on stages of rice development for warm-temperature cultivars (from Stansel and Fries 1980).



Appendix Figure 2 . Mean weekly diurnal temperature profile for Tuguegarao from 1951-19[illegible], Philippines.



Appendix Figure 3. Mean weekly diurnal temperature profile for Iloilo from 1951-1980, Philippines.



Appendix Figure 4. Mean weekly diurnal temperature profile for General Santos from 1951-1977, Philippines.