SOIL-PLANT-LIVESTOCK-WEATHER RELATIONSHIPS OF A RANGE ECOSYSTEM: INTERACTIVE TIMESHARE REGRESSION AND SIMULATION MODEL APPROACHES

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BY

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"Soil-Plant-Livestock-Weather Relationships of a Range Ecosystem: Interactive Regression and Simulation Model Approaches", a thesis prepared by John William Russell, in partial fulfillment of the requirements for the degree Master of Science, has been approved and accepted by the following:

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ABSTRACT

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Data from Pasture Nine, Jornada Experimental Range, New Mexico, were used in regression and simulation modelling approaches to predicting perennial grass growth for use in management. These approaches served to illustrate the capabilities of timeshare computer facilities and APL (A Programming Language).

Existing data of soil moisture (bars of moisture tension), precipitation (monthly), stocking rate (animal units), and herbage yield and cover of perennial grasses were examined in the regression approach in accord with a subjective and simplistic graphic model of assumed interactive relationships. Soil moisture data were measured intermittently, and this demanded an expression of the data as the number of days above or below some level that theoretically influenced plant growth. Various regression attempts were made to establish the relationships of precipitation, soil moisture, and herbage yield and cover.

Precipitation received during November, February, March and April, and for February, March, and April alone were highly significantly correlated ($p < .01$) with perennial grass herbage yield (R^2=.91 and R^2=.89). Precipitation received in September, November, and March were significantly correlated ($p < .05$) with perennial grass cover (R^2=.72). Days of soil moisture greater than 2 bars moisture tension in July, August, October, December, January and February were highly significantly correlated ($p < .01$) with yield divided by cover (R^2=.99)

Results of various regressions of the relationships of precipitation, days of soil moisture levels, and yield and cover of perennial grasses were used to heuristically develop a simulation model. Plotting the model output against the actual yields, although not statistically significant, gave promising results. The addition of parameters for evapo-transpiration could result in a valid model.

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INTRODUCTION

Over a billion acres of range and pasture land in the United States are not adapted to cultivated crop production or other similar intensive use, but are suitable for grazing by livestock and wildlife. Multiple Use management of this resource is limited by economics, social pressures, and knowledge. The resultant complexities arising from these increasing limitations demand supplementation of traditional procedures with newer approaches to methods of analysis (Thomas and Ronningen, 1965).

Successional ecology has long been the base of approach to resource management. With the advent of the digital computer to handle tedious and complicated mathematics and statistics, quantitative ecology and systems ecology have bolstered successional ecology as tools in studying ecosystems for management (Jameson, 1970).

Implicit in the concept of an ecosystem, dealing with interrelationships of organisms and environment, is the use of interdisciplinary knowledge. There is such a wide array of subject matter that no one person can adequately encompass it in his mind in its entirety; however the real world may be simulated in an abstraction or model, and if the information is quantified, a computer can store and manipulate it in response to the dictates and needs of man (Bledsoe, 1968).

A model is that which resembles something, or a representation of a thing. A quantified model can be developed from a verbal, graphical, pictorial, or mechanical model. One has no choice as to whether to model but merely the choice of how satisfactory the model is, since every individual consciously or unconsciously uses one or perhaps all of these four models in decision processes every day. A model must be descriptive of the real situation, or ecosystem, in order to be applied in a practical management situation (Clymer, 1969; Clymer and Bledsoe, 1970).

The model may provide an overall view of the primary functions of a system in use in systems ecology. It is a method of logic for predicting the consequences of certain assumptions about, and actions of, a set of variables within the constraints of the model. The interaction of man's judgement, his developed realistic assumptions and the actions obtained may then be used for resource management.

Systematic analysis of grasslands demands definition of the structure and function of the system. General functional processes such as biomass dynamics, energy flow, and nutrient cycling are of primary importance for understanding or manipulating the overall system. At present, most ecosystems analysis approaches are based on such concepts and are based on an objective of total or near-total understanding of all or most of the basic functions (Watt, 1968); Van Dyne, 1966, 1969).

One deterrent to practical applications of systems ecology in management is the lack of data. Basic data -- such as specific plant response to regimes of soil temperature and moisture conditions are mostly unavailable for species on "wildlands." Ecological simulation

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models have, in general, indicated this inadequacy and indicated areas of needed research.

An immediate application to resource management requires a model based on existent data, without waiting for the results of research designed to fill the obvious voids. This approach might appear inadequate for complete understanding, since it represents the real world imperfectly.

From the vantage of a resource manager, if such a model predicted consequences better than those obtained from his current methods, it would be desirable for immediate application. It would also be superior to existent techniques if he interacted with such a model, giving the benefit of personal judgement and experience in its application. Continuity of management would be assured with interaction, since current updating of the model would incorporate a manager's judgement and experience, bequeathing his knowledge to a successor.

The purpose of the analysis expressed here is to examine existing data from a range ecosystem, develop predictive models from this data, and illustrate the use of computer terminals in heuristically developing predictive models using APL (A Programming Language), a conversational language.

Regression and stochastic simulation approaches were used to examine forage yield, cover, and stocking data from Pasture Nine of the Jornada Experimental Range, in conjunction with soil moisture and rainfall data from West Well, which is on the north side of Pasture

Nine.

Annual yield of perennial grasses relative to stocking rates was a basic managerial consideration so this variable was selected as the current output goal. The study was confined to those variables commonly and easily measured (except for soil moisture).

The underlying philosophy of the regression and simulation approaches used in this study is simplistic, allowing eventual practical application and ultimate expansion and incorporation into a larger model for a ranch or resource unit.

The results are recognized to be incomplete, but they are ex-ploratory in nature and represent "opportunity seizures" in contrast to planned, preconceived experimental design. There is a tendency to stray from the stated objective by examining more basic relationships,

e. g., the pursual of optimum soil moisture conditions for a particular species of perennial grasses. Such basic understandings are needed, but that specificity is outside the scope and intent of this study.

LITERATURE REVIEW

Early investigators recognized the need for quantification of knowledge in order to understand and study plant-soil-water relation-ships. An example of this is found in a statement by Livingstone and Hawkins (1915) in a study to measure the resistance offered by the soil to root absorption: "Sooner or later it may be realized that the behavior of an organism is not to be adequately studied without quantitative knowledge of its surroundings...."

Tansley (1935) introduced the term "ecosystem" which may be now taken to mean a functional unit consisting of organisms, includ-ing man, and the environmental variables of a given area. Resource management can be studied as manipulations of ecosystems, with systems ecology as outlined by Watt (1968), Van Dyne (1969), Goodall (1970b), and others.

Systems analysis, simulation models, and computers have solved complex problems in business, commerce, and industrial fields (Emshoff and Sisson, 1970); moreover Naylor et al. (1968) and McMillan and Gonzalez (1968) outlined some methods and procedures from that viewpoint.

An understanding of the basic ideas and concepts underlying systems ecology may be best gained by examining selected examples in a chronological fashion. A real impetus came with the increasing awareness that computers could readily handle the complicated mathe-matics which previously stifled efforts to quantify biological and environmental processes and relationships.

Garfinkel (1962) used the digital computer in a simplistic approach to ecology. He considered the simple relationships of grasses, rabbits, and foxes in differential equations that he compared to chemical equations in order to convey his concepts to less mathe-matically oriented individuals. He concluded the method of using computers to handle calculations was no substitute for detailed knowledge of the system under study.

Ecologists had a reticence or conservatism in early applications of computers and systems analysis; their use was limited to a "niche" or small portion of an ecosystem. The tedius use of pencil and paper and mechanical calculators to handle complex ecological relationships would produce a tendency to shy away from mathematics and statistics.

Watt (1961) considered a mathematical model for insect pest control to estimate which factors regulated the insect population and to determine the relative importance of the attributes of the regu-lating agent that made the factors significant. He reported that there were criticisms to such an approach. Some scientists had said that the aims were too ambitious and unattainable--that no method could manage the complexities and reduce them to mathematical form. It was stated that it is difficult or impossible to determine which model best explains a process, and there may be two explanations, or models, for the same process. Watt defended the approach by saying that it was too early to tell whether the aims were unattainable and that there is a large payoff in "optimum control," plus a payoff for each step in research or "improvement in control." The usefulness of the approach will depend on the objective. If the methods cannot be used for prediction, they may be useful for explanation of a system. Any conflicts between models can be resolved by collecting more and different kinds of data. A final model may be a synthesis of many preceding models.

Woo, et al. (1966) used a set of differential equations and transfer functions in expressing terms of water suction variables or transpiration in the balance of atmosphere water demand and water availability to plant roots. These workers used an analog computer, and the major problem was the lack of data, which made it difficult to compare the results generated from the model with actual field experiments. It was concluded that a dynamic integrated model provides a method for a physical-mathematical analysis of a complete living system.

There appeared to be a definite chronological expansion of the application of modeling techniques and computers to ecology, as might be expected. More consideration was being given to what are now considered to be "compartments" or submodels of ecosystems, rather than to simple "niches."

Patten and Witkamp (1967) used an analog computer to describe radio-cesium activity curves in microcosms of soil. These scientists used five compartments of cesium-134-labelled oak leaves, mineral soil, microflora, millipedes, and an aqueous leachate, and adjusted their analog computer model to fit the data. This gave a description of radio-cesium kinetics for each microcosm in terms of a system of differential equations, which specified and quantified transfer pathways. This permitted additional information to be derived by computer simulations. These authors concluded that the multiplicity of material transfers and interactions that are con-ceivable in macrocosms, together with the effects of intrasystem coupling in this study, made it apparent that to understand eco-systems, it is necessary to understand networks and their functioning.

Duncan et al. (1967) studied photosynthesis in plants. An immense number of calculations were required to predict the amounts of photosynthate produced by the illumination of each leaf at a particular time of day when the quantities were used mathematically. An IBM 7044-type computer performed the needed calculations in about six seconds and gave solutions to real and hypothetical problems.

An epidemic marching through a population of plants, animals, or men reflects the integration of a very large number of factors in the environment and characteristics in the pathogen and host.

In a study of early blight (Alternaria solani) of tomato and potato, the complete system of weather, pathogen, and host was examined and this led to conducting some missing critical experiments. A computer simulation model was then completed, and verified. It pro-vided a guide to the importance of influence of the characteristics of the fungus, the weather, and the host, and provided a predictor for the outcome of modified weather (Waggoner and Horsfall, 1969).

Growth of populations and the interaction of two populations was simulated by Pennycuick et al. (1968). A computer program was designed to follow changes in number and age distribution in a model population through many generations. The information incorporated in the program was difficult to obtain for real populations and was limited in scope when applied to real populations, but it was easily modified, and presented no difficulty in using empirical data when they became available. The consequences of complicated and mathe-matically intractable hypothesis are easily determined by this approach.

A program for precipitation probabilities was written and com-piled in PDQ Fortran (1620 General Program Library 2.0.031) by Weaver and Miller (1967). The program was developed on the IBM 1620 and assumes that precipitation follows the incomplete gamma distri-bution. Input is the number of years of record of precipitation, operating on monthly and annual precipitation.

The ultimate product of variables--such as precipitation, photo-synthesis, and soil--operating in the constraints of such factors as population growth and diseases is vegetation. Simulation models and computer programs of vegetational responses are exemplified by estimating site quality for trees (Brickell, 1970), and estimating the growth of pasture grasses (McAlpine, 1970). Once vegetation is produced, consideration of man's understanding, modification and management of that vegetation and its use begins. The complexities increase along with the need for better techniques to study and under-stand these relationships systematically.

There have been several attempts to simulate grazing of pastures or grasslands. One such model used SIMSCRIPT and a CDC-3600 computer for sheep grazing a summer pasture. Preliminary tests indicated that the predicted responses of sheep weight were similar to those observed. The weight response predictions were based on changes in grazing subdivision, stocking rate, growth rate of herbage, and grazing efficiency (Freer et al. 1970). A similar grazing simulation (Goodall, 1967; 1970a; 1970b) had some oversimplifications that created problems in obtaining a high predictibility in meeting management goals.

A systems approach was used by Davidson et al. (1970) to predict scarab populations based on pasture, soil, and animal relationships. One pertinent application of simulation models to resource manage-ment does not involve ecology, per se, but is so significant that it must be included. As reported by Hufschmidt and Fiering (1966), this deals with the study of hydrologic structures of the LeHigh River Basin in New Jersey, which was later extended to the Delaware River. A simulation model specified the objectives of design, and translated them into criteria which were used to formulate specific designs for the development and management of a water resource system. The model fulfilled its objectives in the highest degree and enabled the modelers to evaluate the consequences of various designs.

Water resource simulation can be constructed to take advantage of operational hydrology for any desired period and treat dynamic in-vestment programs. It is possible to analyze economic performance of a selected water resource system in a way best suited to the nature of the system and to the physical and economic data available. It is extremely significant that the LeHigh River Basin model was highly successful, in terms of resource management.

In corollary to this theme, Odum (1966) discussed the use of systems analysis as one approach to solving the question, "How do we know when we are getting too much of a good thing?" Although this does not involve computer models, it presents a compartment model derived by systems analysis pertinent to the basic theme of ecology.

Two major efforts in modelling and simulating entire ecosystems within the United States are the Desert Biome and the Grassland Biome studies, both part of the International Biological Program, funded by the National Science Foundation. These investigations of desert and grassland ecosystems are among six that will study the major eco-systems in this country. A major goal of the International Biological Program is to develop an understanding of the dynamics and functioning of these ecosystems.

A discussion of the development of a whole ecosystem mathe-matical model, as used by personnel of the Grassland Biome, is given by Bledsoe and Jameson (1969). A section of that report is designed for the nonmathematically-inclined scientist and is devoted to the explanation of notational and mathematical conventions. The abiotic variables are divided into extrinsic or driving variables, and in-trinsic variables such as environmental temperatures and soil moisture mathematically related to the driving variables.

A major point that is stressed is the need for communication between the modeller and biologist. It is necessary for one or both to learn something of the other discipline since there are few commun-icators adept in both.

The systems approaches have large implications on the training of grassland scientists and managers, on the design of grassland re-searches, and on the modification of management concepts, practices and tools. As resource management is forced to become more intensive because of population increases, managers must be able to make more accurate forecasts of responses of a system to management input variables. There must be an interface between the manager and re-source biologist, as well as with the modeller, data collectors, etc. There will be increasing needs for training students, researchers, and resource managers to take advantage of systems analysis procedures (Van Dyne, 1969).

Other techniques that have been developed, such as time-sharing (Davis and Nickey, 1970), and specific techniques such as PERT (Davis, 1968), emphasize the need for more training of managers to utilize such techniques fully and to implement them for maximum benefit.

There are models in use with a high degree of success and efficiency for farms and farm firms, using a generally accepted theory of firm behavior incorporated into an abstract computerized simulation model. The model described by Hinman and Hutton (1970) provides a means of studying management problems, using the simulation approach, by entering, in most instances, only data needed to describe the problem situation. The basic logic of the model can be modified at link points for situations that are different from the general logic of the model. It is not unreasonable to expect that "wildland" resource management models of equal sophistication will also become fact.

The foregoing overview of the development in recent years of quantitative ecology epitomizes some of the problems and advantages of systems ecology. It has also confirmed the foresight of Lindeman (1941) when he first advanced the principles of trophic-dynamics in ecology, which now underlie most current approaches to systems ecology.

DESCRIPTION OF AREA

General Area

The Jornada Experimental Range, approximately twenty-five miles north-east of Las Cruces, New Mexico, is included in the area described by Merriam (1898) as the Lower Sonoran Life Zone, and is classified as Desert Plains Grassland by Clements (1934). It is included in the grama-tobosa shrub-steppe of Kuchler (1964). The experimental range is located on the Jornada del Muerto Plain, which is bounded by the Rio Grande Valley and the Fra Cristobal-Caballo Mountain complex on the west and by the San Andres Mountains on the east. The area ranges in elevation from 1,100 to 1,400 m.

The climate of the Jornada Range is typical of the arid phase of the semidesert grassland. Winters are mild, summers are hot, and both exhibit wide ranges between day and night temperatures. The temperatures favor plant growth for approximately 200 days, but plant growth occurs for only 90 to 100 days per year due to lack of moisture. The average maximum temperature in June is 36^{o}C, and the average maximum in January is 13^{o}C (Buffington and Herbel, 1965). The mean daily average for July is 26^{o}C. Temperatures above 38^{o}C are not uncommon in the summer, and there are occasionally temperatures of -18^{o}C in the winter. The annual mean temperature is 15^{o}C.

The annual average precipitation is 228 mm (1915-1967). The July 1 to September 30 growing season receives about 52% of the annual average. This growing season precipitation comes from erratic, high intensity convectional storms. Rainfall is often poorly distributed.

Wind velocities are highest in March through June, averaging more than 1610 km per month. The average annual wind movement is about 17,000 km. The months of May and June have the highest rates of evaporation. The average annual evaporation is nearly ten times the average annual precipitation, or approximately 225 cm per year.

Some of the major plant species found on the Jornada Experimental Range are black grama (*Bouteloua eriopoda* (Torr.) Torr.), dropseeds (*Sporobolus* sp.), threeawns (*Aristida* sp.), muhlys (*Muhlenbergia* sp.), burrograss (*Scleropogon brevifolius* Phil.), soapweed yucca (*Yucca elata* Engelm.), witchgrasses (*Panicum* sp.), mormontea (*Ephedra* sp.), honey mexquite (*Prosopis Juliflora* (Swartz) DC.var. *glandulosa* (Torr.) Cockerell), tarbush (*Flourensia cernua*), creosotebush (*Larrea tri-dentata* (DC) Coville), broom snakeweed (*Gutierrezia sarothrae* (Pursh.) Britt. and Rusby).

Study Area

The area selected for this study was Pasture Nine, located in the south-western portion of the experimental range. Precipitation and soil moisture data used are from measurements at West Well, located on the northern boundary of Pasture Nine. The average annual precipitation at West Well is 217 mm (1918-1972) with an average growing season precipitation (July 1 to September 30) of 126 mm.

Pasture Nine is characterized by rolling topography, an occasional draw, and mostly flat open areas. Perennial grasses are primarily black grama, threeawns, and are quite commonly interspersed with shrubby plants such as honey mesquite, mormontea, soapweed yucca and broom snakeweed.

The soils in the study area were described by the Soil Conservation Service (1963). The bulk of the area studied is characterized by two soil types:

1. Cacique loamy fine sand, 1 to 3% slopes. ---Mostly moderately deep soils with moderately sandy textured surfaces with permeable subsoils that take water well. The soils are underlain with discontinuous layers of indurated caliche. In many places, due to rodent activity, caliche fragments have been mixed throughout the soil profile. The present vegetation is black grama and yucca with broom snakeweed and honey mesquite on deteriorated areas.
2. Simona-Palma complex, 0 to 3% slopes. ---Soils with sandy surfaces over weak to moderate lime zones that may be discontinuously indurated. The principal soils are calcareous to very near the surface and are underlain with fractured, indurated caliche at depths of 25 to 61 cm (10 to 24 inches). These soils comprise about 50 to 60% of the mapping unit. The other soils are moderately deep to deep, usually non-calcareous to about 38 cm (15 inches), with weakly developed, rapidly permeable subsoils over weak to moderate accumulations of lime.

Caliche gravels and fragments have been mixed throughout the soil profile by rodents in most areas. The present vegetation is black grama and yucca with some honey mesquite.

METHODS AND PROCEDURES

Regression Approach

The regression model used in this approach may be expressed as:

$$Y = B_0 + B_1X_1 + ...B_nX_n + E$$

where Y is the dependent variable, and n is the number of independent variables. B_0 is the constant or intercept and B_{1-n} are the partial regression coefficients of Y on X_{1-n}, where X_{1-n} are the independent variables or causal factors. E is symbolic of variation attributable to sampling error or other unknown sources of variation.

B_0 may be visualized, conceptually, as the height of a plane on the Y axis, and B_{1-n} the angles or slope of the plane. If the plane is parallel to the X_{1-n} axis, then there is no predictability possible in the model. Restated, if $B_1=B_2.....B_n=0$, then there is no predictability, and if we are considering X_{1-n} for this population, we know nothing about its mean.

Without exploring the underlying basis and rationale here, we may associate a large value of the F-statistic with $B_{1-n} \neq 0$ (This establishes the Null Hypothesis as $B_{1-n} = 0$). The larger the derived F-statistic, the less probability that the relationship or slope is due to chance alone, i.e., the greater the probability that it is representative of the actual population and the predictability associated with it.

Statistical significance levels, such as $p < .01$ or $p < .05$ (where p is probability) are well established and understood. We can also use the probability level associated with a derived F-statistic at less than these accepted levels to lead us toward improvement of the model for predictability.

The t-statistic for individual independent variables may also be used to determine whether the inclusion of these variables in the model increases or lessens the predictability (as in stepwise re-gressions). This rationale was used for the examinations in this approach and is briefly stated here for an understanding of the pro-cedures throughout.

A general regression analysis model was first prepared graphi-cally (FIGURE 1). It was based on data available from Pasture Nine, Jornada Experimental Range, and prepared in a cause and effect model similar to a flow chart. Juxtaposition of the variables was based on a general understanding and assumed dependency or interaction as indicated by the arrows.

Vegetation data were collected at the end of the growing season in close proximity to the soil moisture station (at West Well, on the north boundary of Pasture Nine). Perennial grasses were clipped at ground level, old growth was separated from current year's production, and the old growth was discarded. The herbage was air-dried and weighed. Beginning about 1939 the perennial grasses were clipped on 10 cm (4-inch) by 15.4 m (50-foot) long belt transects as described by Canfield (1941). Perennial grass basal cover data were collected from 15.4 m (50-foot) line-transects.

The vegetation and soil moisture data collection since 1957

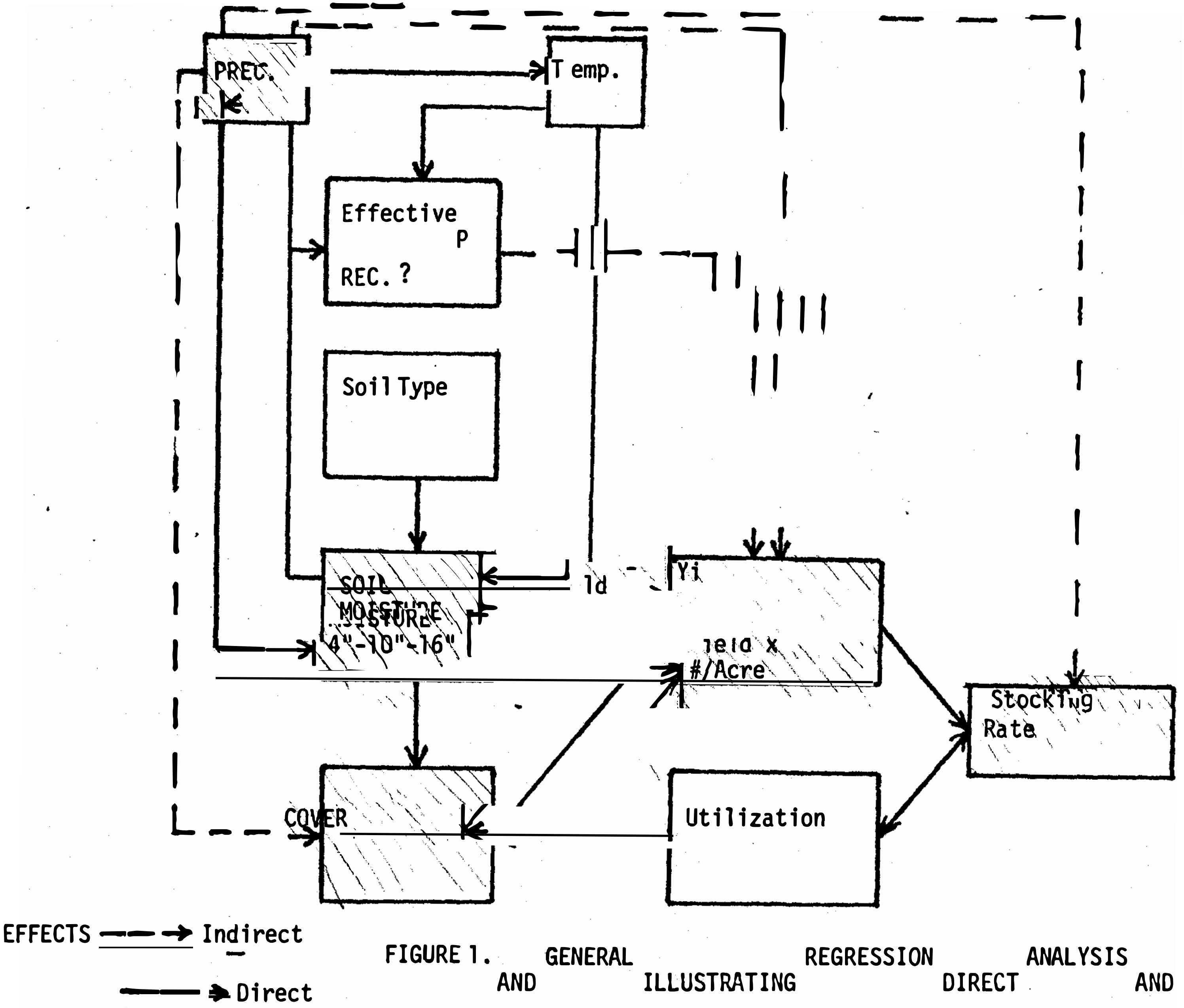


FIGURE 1. GENERAL REGRESSION ANALYSIS
AND ILLUSTRATING DIRECT AND
BASED ON DATA AVAILABLE
MODEL INDIRECT EFFECTS

were described by Herbel and Gile (1971). The procedure for vege-tation was the same as described above, but clipped on 5.1 cm (2-inch) by 30.8 m (100-foot) transects, and cover estimated on 30.8 m (100-foot) line-transects.

Soil moisture data were collected by emplacing gypsum electrical resistance blocks at varying depths in the soil within a livestock exclosure near West Well. Water potential was measured with an ohmmeter and recorded two or three times per week when there was moisture during the summer. It was recorded monthly during the re-mainder of the year when there were fewer changes in moisture status.

The blocks used gave similar readings at the same moisture potential for light and medium textured soils. Only blocks with similar response curves were used. Rainfall data were recorded at a rain gauge within the same livestock exclosure near West Well, con-current with the soil moisture readings.

Stocking records were available, so stocking rate per year was initially included to confirm or deny the use of forage yield as the variable to be considered for determining management. Stocking rate is presumably determined by man, with management based on forage yield.

The assumption of direct relationships was based only on available data for the variables, i.e., there may be intermediary relationships between direct relationships as they are shown, but no observations or measurements were available. The indirect relationships were to be tested first with the premise that if a high degree of predictability were possible, no further analysis of variables would be required, and the simplistic concept would be satisfied.

The block, "Effective Precipitation", has a question mark in it since it is a composite of relationships and is indeterminate in the model as initially prepared. "Effective Precipitation" could, for example, reflect the effects of temperature, wind, insolation, soil moisture retention ability, and transpiration (i.e., evapo-transpiration). Since evapo-transpiration was not measured or simulated, it is reflected by variables that were measured, e.g., soil moisture expressed through time.

Temperature and utilization records were available but were not fully analyzed or included in this study since they are peripheral to the main objective at this point. Soil type is shown in the graphic model, but was assumed to be homogenous.

Following preparation of the graphic model, the data (Appendix I) were entered into the IBM 360/50 computer on the IBM 2741 remote terminal in APL (A Programming Language, Gilman and Rose, 1970). Data were stored in a computer workspace (on magnetic tape) for immediate access as needed for analysis.

The primary program used was MREG, a conversational multiple regression analysis, developed by K.W. Smillie (1969) and commonly available through IBM. Minor programs to manipulate the data were programmed by the author. They are shown in the Appendices, as developed, without refinement. The program PLOTFORMAT was used for plotting variables of interest, to examine visually their relationships.

The first relationships examined were precipitation, stocking rate, and yield. Amounts of precipitation by month and by annual totals were entered into a matrix with yield and stocking rate data, all for a 26 year period (1941 through 1967, excluding 1947, for which no data were available).

Annual precipitation was compared with stocking rate and yield individually. Monthly precipitation was also compared, first, against stocking rate, and then against yield, in multiple regressions. This was to determine which months accounted for the greatest variation in each of the two dependent variables, stocking and yield.

A regression was also computed using yield as an independent variable and stocking rate as a dependent variable.

Using the interactive properties of the terminal, monthly precipitation columns in the matrix were quickly added in various combinations, based on the results from the monthly multiple regression. Every reasonable possibility was explored in this manner, to determine if any combinations of monthly precipitation were significantly correlated with stocking rate and/or yield.

A regression was computed between cover and precipitation by one-month intervals and then various monthly combinations. Cover and yield were also examined in a linear regression analysis.

In plotting the annual precipitation totals, to see how they related to forage yield, two fairly distinct populations were confirmed by closer examination of the data (Figure 2). These were arbitrarily defined as 1941 through 1959 (excluding 1947), and 1960 through 1969.

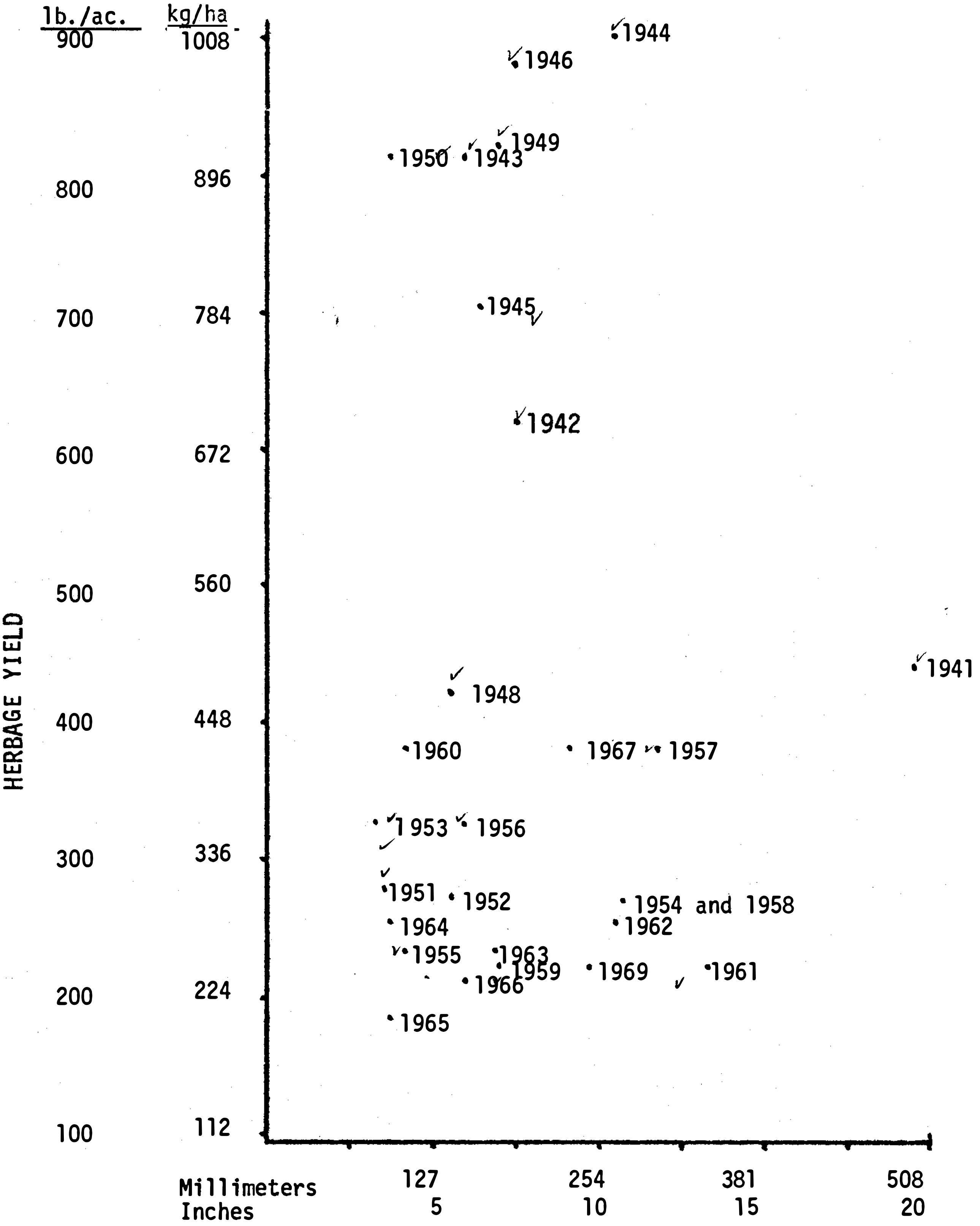


FIGURE 2. RELATIONSHIP OF ANNUAL PRECIPITATION AND FORAGE YIELD FOR PASTURE NINE (1941 TO 1969, EXCLUDING 1947)

The data were separated and the two periods were examined in-dependently in the same manner as before using all possible combinations of months, etc.

The regression analysis method used exclusively to this point in the examination may be considered analogous to the "All Possible Regressions" method in Draper and Smith (1966). Other less-cumbersome methods could be employed, depending on the background and knowledge of the investigator (Morris, 1967).

It was necessary, because of a lack of significant relationships, to attempt to define the indeterminate block, "Effective Precipitation", in terms of a composite of precipitation and soil moisture.

The primary question that arose concerned the definition of the response values for soil moisture. Observations were taken at re-latively consistent intervals only during the growing season because of manpower limitations. Comparisons with monthly or other equal time increments of precipitation or similar variables would not be valid unless soil moisture data were somehow represented on the same basis. This was not possible with the data available.

This was resolved by using graphs that had been kept annually, where observations of soil moisture recorded as bars of atmospheric pressure were plotted through days of the year. The number of days that soil moisture exceeded specific levels was determined by interpolation between connected observation points. Initially, cate-gories of the days that soil water tension was less than 2, 5, 10 or 15 bars were used, to determine which soil moisture levels, if any, were significantly different from any other. The 0-2 bar was selected as a criterion of "wet", 2-15 bars as "moist", and greater than 15 bars was labelled " dry", as a result. Using these criteria, the number of wet, moist, or dry days for any selected time increment were obtainable.

The total number of "wet" (0-2 bars) days per year, was compared with concurrent annual rainfall (Figure 3) by plotting the two variables in a graph using the PLOTFORMAT program. In spite of the lack of statistical significance, there appeared to be a relationship and an attempt was made to further analyze it, in much the same manner as comparing precipitation with yield.

Using equal increments of time for days of "wet" soil moisture, and equal increments of time for precipitation, ignores frequency of occurrence, amounts of rainfall at occurrence, and existing conditions of soil moisture at the event of rainfall. Recognizing this to be of importance, it was decided to separate each rainfall event into one of 5 categories based on soil moisture conditions by depths at the time of the event:

1. "Dry" (Greater than 2 bars, in this case) at all depths for less than 30 days prior to rain.
2. "Dry" at all depths for 30 days or more, prior to rain."
3. Wet" (Less than 2 bars) at all depths at rain event.
4. ''Wet"- at the 10-centimeter depth at rain event, but not "wet" somewhere in the lower depths.
5. "Wet" at any or all depths below 10-centimers, but not "wet" at the 10-centimeter depth.

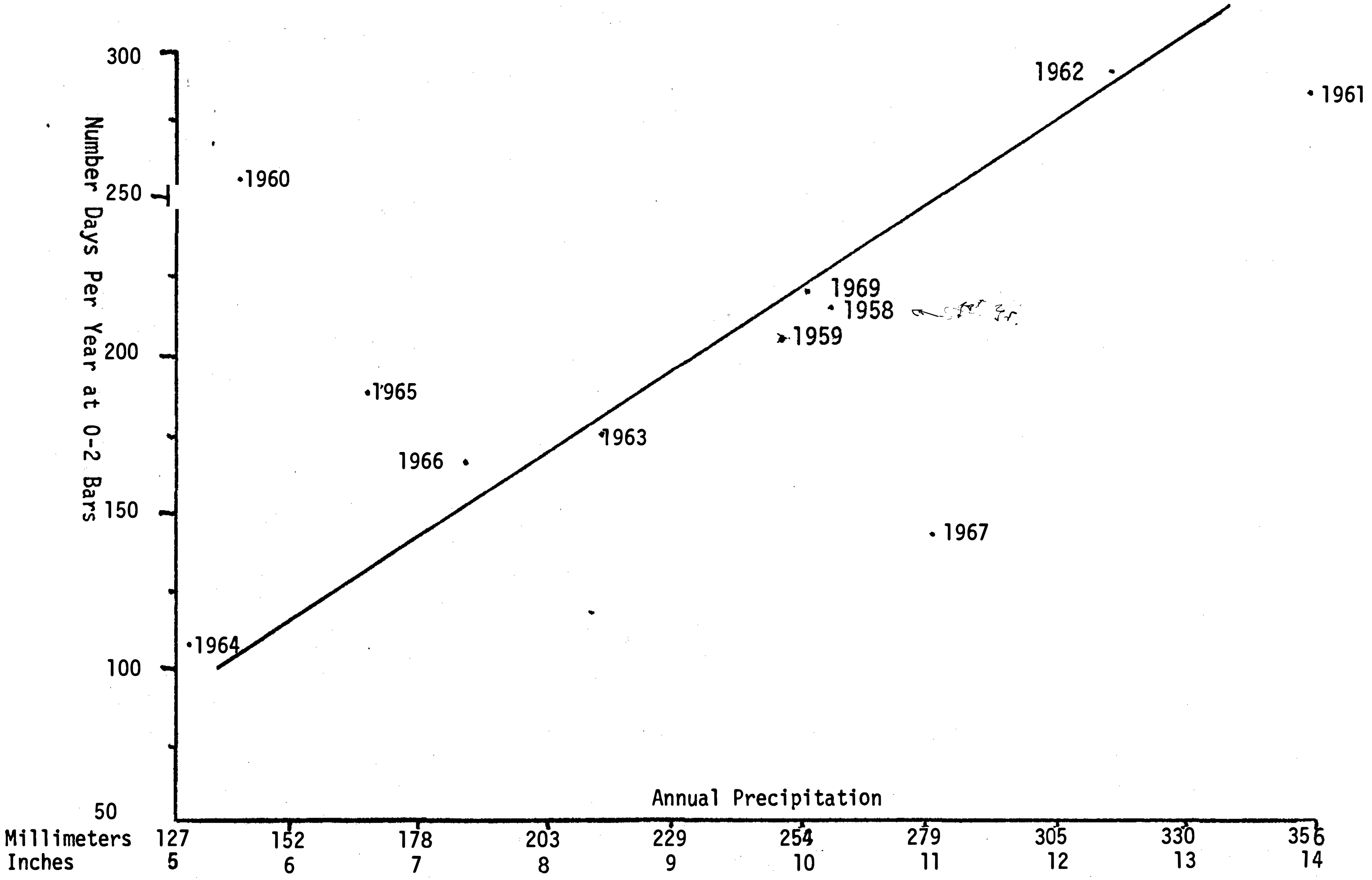


FIGURE 3. RELATIONSHIP OF ANNUAL PRECIPITATION AND TOTAL NUMBER OF "WET" (0-2 BARS) DAYS PER YEAR AT WEST WELL (1959-1969)

A program, EXPAND (Appendix II), was written to expand basic data of soil moisture categories for all depths and precipitation into a matrix that represented daily conditions for each year. The data were entered as a vector of 2 number sets; the first number, soil moisture condition, and the second, the number of days from the graphs, e.g., 3, 180, 2, 91, 1, 94. In this example the first 180 days of the year for that depth were "dry" (3), the next 91 days were "moist" (2), and the last 94 days were "wet" (1).

Rainfall was entered similarly, e.g., 0 180 25 1 0 32, etc., represents 180 days of no rain, 1 day of 25 "points" (6.35 mm or .25 inches), and 32 days of no rain, etc., for 365 days each year. Each vector entered, filled a column in the matrix, so each day could be compared independently, by examining individual rows of the matrix.

Another program, CONDITION (Appendix III; a, b), separated these conditions into the 5 categories on a rainfall event basis by examining each row (day) for all full years (12, therefore, 12 columns)that data were available. Rainfall events, with the corresponding conditions, within the 5 categories, were arranged (using the interactive properties of APL) in order of ascending amounts of precipitation, and then by season of the year that rainfall occurred. All categories were also combined into one overall compari-son, and listed by ascending amounts of rainfall, and by season of the year rainfall occurred. No definite pattern was subjectively discernible for any trials, so this procedure was terminated.

Investigation to this point was based on annual observations, i.e., those inclusive within a calendar year, the premise being that any interactions from previous years regarding precipitation and soil moisture would be minimized by normally occurring dry months in the spring and early summer. This assumed that current perennial grass growth was based primarily on current rainfall and soil moisture during each growing season.

A program, WORK (Appendix IVa, with an accumulating and output subroutine CUM, Appendix IVb) was written to examine "dry" days for any length period within a year, by entering a "beginning point" and "ending point". The optimum increment of time was judged to be 30 days. In order to reduce the number of variables involved, the 10-centimeter depth of soil moisture was finally selected to work with.

Herbage yield figures for the north portion of Pasture Nine (North Ridge) were separately recorded, and it seemed these might reflect the true situation better than the average herbage yield figures for the entire pasture. In order to reduce the source of variation from differences in annual cover of perennial grasses, these figures were divided by corresponding cover data, to put the yield figures on a unit of cover basis. (Appendix V)

There were sources of variation in relation to dependent forage observations, other than from the independent variables used, so the data were further modified. The length of time was extended back into the previous year, using "dry" days per 30-day increments, in a multiple regression with herbage yield.

The "best" relationship of "dry" days was sought, by adding or deleting 30-day periods and obtaining multiple correlations of the different regressions when compared to herbage yield (North Ridge data).

July through April values gave the highest correlation for the number of "dry" days per 30-day intervals with yields, so the same period was compared with cover of perennial grasses, corresponding to yield observations.

Precipitation and yield, and precipitation and cover were compared in regressions as a consequence of the results obtained from the "dry" days comparison.

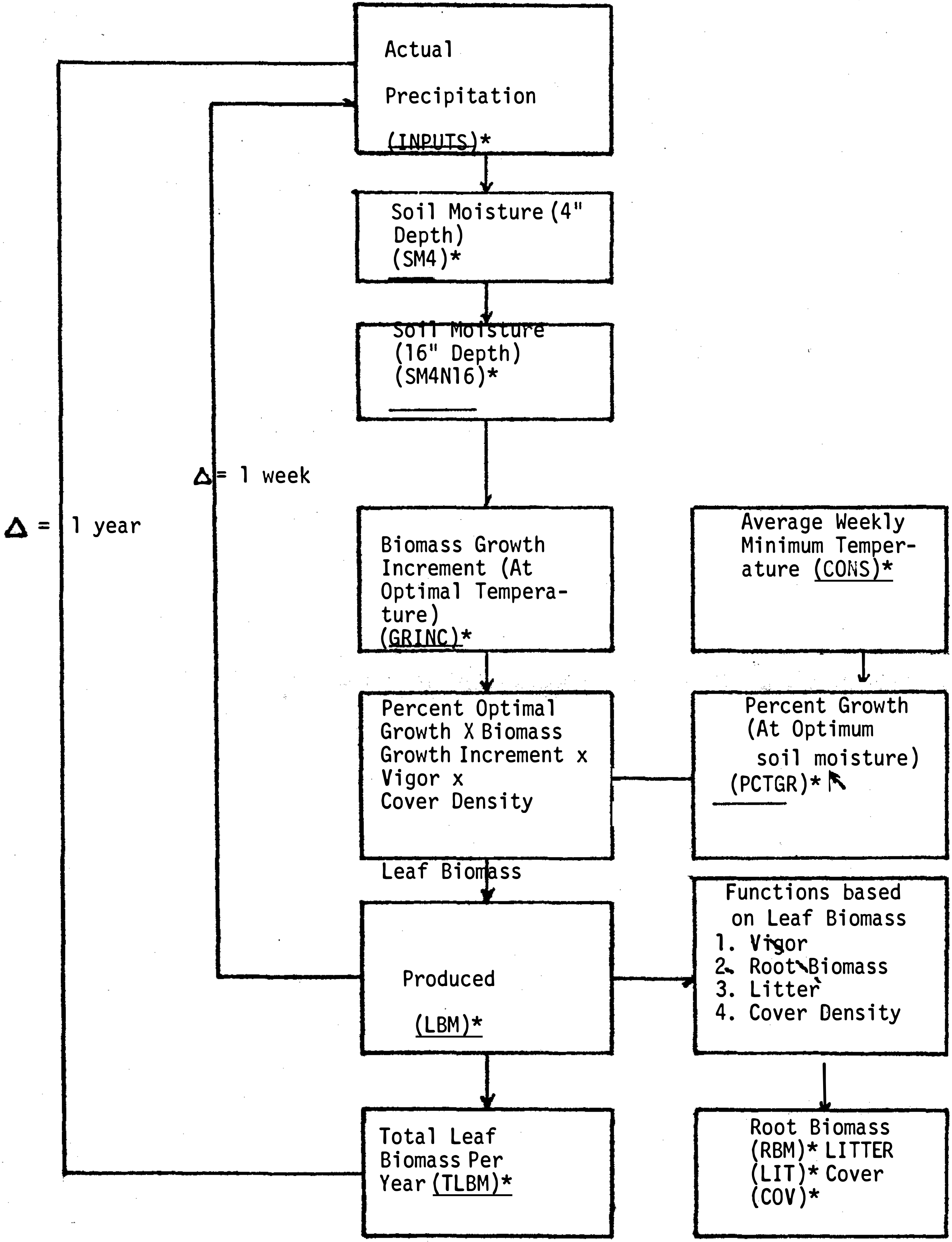
Simulation Approach

A graphic "flow chart" model was prepared in a general overview of some basic relationships involved in the growth of perennial grasses (Figure 4).

The variable input used was weekly precipitation (INPUTS, Appendix VI). The total time length was from July 1 to September 30, of the following year, or 65 weeks.

Thirty-five year average weekly values were used for minimum temperature. A table of percent of growth increment (PCTGR, Appendix VII) based on minimum temperature and optimum soil moisture for growth was developed. It was based on a subjective assessment of some available growth curves.

A similar approach was used to estimate weekly growth increments at various soil moisture levels (GRINC, Appendix VIII), and assumed



*Variable Names of Model (MDL)

FIGURE 4. GRAPHIC "FLOW CHART" MODEL OF SOME BASIC RELATIONSHIPS INVOLVED IN THE GROWTH OF PERENNIAL GRASSES

optimum temperature for perennial grass growth. An intensive literature search revealed no specific work or studies yielding in-formation pertinent to either of the above assumed sets of values, or for soil moisture relations and values that were also needed.

Only two soil depths were considered in the model for initial simplicity, i.e., the 10-centimeter (4-inch) depth (SM4, Appendix IX), and the 40-centimeter (16-inch) depth (SM4N16, Appendix X).

The 10-centimeter depth is more directly affected by precipitation,

and the 40-centimeter depth is just below the greatest portion of the perennial grass root system.

These were set up in tables with previous weekly inputs in the first column and current weekly inputs in the first row, with the resultant output values coming from the body of the table at the corresponding junction.

The values for these tables were obtained by examining the soil moisture graphs derived from observations of gypsum blocks at West Well.

The output was expressed first as above ground biomass (LBM) in kilograms per hectare, and each loop in the computer simulation model MDL (Appendix XI), represented one week, terminating at a pseudo-date of September 30. Average precipitation inputs were used until the model was programmed, and in debugging the program.

Tentative root biomass, standing dead biomass, litter and cover were tentatively added as mere mathematical functions of above ground biomass, to illustrate their consideration. A great deal more work on transfer functions would be required to simulate them adequately and this must be left to later study.

The output value of above-ground biomass derived from the average values appeared reasonable after debugging, so actual inputs were then incorporated. An overall iterative loop was used in the program to give yearly biomass output from the 12 years of actual precipi-tation (INPUTS). Data from West Well, and herbage yield data from the north part of Pasture Nine were used in an attempt to verify the model, MDL.

The resultant output of biomass values was then plotted against the actual observed values, using the program PLOTFORMAT, and a regression computed, using MREG, to determine how well they were correlated.

The temperature/percent growth table (PCTGR), and the soil moisture/growth table (GRINC) were modified independently to observe the resultant changes in output of subsequent runs of the model.

The tables SM4 and SM4N16 were modified to a lesser extent after a more intensive examination and analysis of the soil moisture graphs.

Each time a modification was made, the twelve years of weekly precipitation (INPUTS) were rerun in the model and the outputs (LBM) were plotted against the actual yield figures. In this manner,

it was possible to assess the modification results visually.

A program (MDL2, Appendix XII) was written to evaluate the weekly growth increments by using actual soil moisture data. Data from the 25-centimeter (10-inch) depth was selected as a compromise between the 10-centimeter (4-inch) and 40-centimeter (16-inch) depths (SM10, Appendix XIII). Use of actual soil moisture conditions obviated the need for precipitation (INPUTS) as the driving force.

The need for estimating percent growth for temperature (PCTGR) was eliminated by normalizing the mean weekly minimum temperatures (expressed in the model in Fahrenheit), i.e., dividing each weekly mean by 65. Temperatures lower than 3.33°C (40°F) were considered to be 0. This assumed a linear function of temperature.

A coefficient vector (COEFF) was derived by multiplying temperature (TEMP), by the soil moisture (SM10). A "wet" day was expressed as 2, a "moist" day by 1 and "dry" by 0, and then weekly averages derived for SM10.

Growth increment (GRINC) was initialized as 25, and then optimized by comparing the estimated forage yield (TLBM) with the actual forage yield. The computer modified the growth increment for each year until the estimated yield closely matched the actual.

The growth increments thus computed were plotted against the actual yield, seasonal precipitation and total precipitation (65 weeks) for comparison.

A program (SORT, Appendix XIV) was written to compute the number of dry weeks in the 65 week period (INPUTS) by length of dry period. Each time it rained signified the end of a count of dry weeks, thus giving an index of dryness. The number of weeks in each period was squared, thus giving it additional weight, and then it was divided into the concurrent total precipitation for the 65-week period. This gave an index of amount and frequency of precipitation for the period, and was plotted with the estimate of forage yield from the program MDL2.

The original program (MDL) was modified slightly to give the same weekly coefficients for soil moisture and temperature as in MDL, and used the computed growth increment factors for each year as optimized.

The modified program MODEL (Appendix XV) was then intended to be run and the total leaf biomass (TLBM) compared to actual yield to verify the soil moisture inputs (SM4 and SM4N16) in MDL. No time was available for completion so the study was terminated.

RESULTS AND DISCUSSION

Regression Approach

Graphic Model

The value of the graphic model, or regression layout, in approach-ing a multivariate ecological situation, is inestimable. Sheer mental conceptualization of numerous relationships is possible, to a certain degree, but as the number of variates increases, it becomes almost impossible.

The graphic model provides a focal point for the amalgamation of several disciplines, e.g., in this case, ecological relationships, and definitive constraints and steps for statistical analysis. It provides a vehicle for interface between the ecologist or biologist, and the statistician, or perhaps even the computer programmer. It is an essential for the individual that attempts to combine multidisciplinary measurements or observations as in the case under consideration.

The model shown (Figure 1) is obviously not the only one, and certainly not the best one. It meets the objective of illustration, and, hopefully, provides a foundation for further study and future students. The most vital and important function it served, was to prevent the investigator from straying too far from the original objective and becoming enmeshed in the maze of trivia extraneous to that objective.

Analysis of Relationships.

In order to express succinctly the actual results, only those analyses of considered significance will be presented, in toto, relegating the numerous discarded examinations (i.e., failures), to near obscurity, without minimizing their importance. Without them those of significance might not have occurred, for these last are "opportunities of seizure" among the many examined.

Precipitation-yield. Tables 1, 2, and 3 are the results and examples of regressions of the original date for 26 years (excluding 1947), for the period 1941 through 1967, for Pasture Nine, Jornada Experimental Range (Appendix II). Table 1 illustrates the more mean-ingful regressions for the 26-year period, which, in spite of their lack of statistical significance, pointed the way for other analyses. Table 2 shows some of the initial regressions for the 9-year period (1941 through 1950, excluding 1947) and Table 3 is the results of some regressions for 1951 through 1967.

Tables 4 and 5 show the results of the regressions of monthly precipitation (using the period July 1 through June 30 for the years 1957 through 1969) and the corresponding herbage yield of perennial grasses for North Ridge (Pasture Nine) from the following growing season (Appendix V).

TABLE 1. SOME RESULTS OF REGRESSIONS USING 26 YEARS DATA FROM PASTURE NINE, JORNADA EXPERIMENTAL RANGE.

VARIABLES

Monthly Precipitation $(X_1+X_2...+X_n)$												Yield J F M	Stocking Rate	R^2	F-Value
A	M	J	J	A	S	O	N	D							
X	X											Y		.07	1.
	X	X										Y		.01	70 .2
		X	X									Y		.06	1.66 2
			X	X								Y		.01	.28
				X	X							Y		.01	.13
					X	X						Y		.06	1.43
						X	X					Y			.09
							X	X				Y		.04	.90
								X	X			Y			.01
									X	X		Y		.05	1.
										X	X	Y		.02	15
X	X	X										Y			.41
	X	X	X									Y		.02	.02 .37
		X	X	X								Y		.04	1.08
			X	X	X							Y		.02	.38
				X	X	X						Y		.05	1.38
					X	X	X					Y		.01	.17
						X	X	X				Y			.08
							X	X	X			Y		.02	.50
								X	X	X		Y		.01	.14
									X	X	X	Y		.04	.91
		X				X					X	Y		.03	.71
			X	X	X	X	X	X							

Months $(X_1, X_2,....X_n)$

J	F	M	A	M	J	J	A	S	O	N	D				
X	X	X	X	X	X	X	X	X	X	X	X	Y		.48	1.02
X	X	X	X	X	X	X	X	X	X	X	X		Y	.56	1.38
												X	Y	.22	6.93(p <.05)

TABLE 2. SOME EXAMPLES OF REGRESSIONS USING 9 YEARS (1941-1950, EXCLUDING 1947) OF DATA FROM PASTURE NINE, JORNADA EXPERIMENTAL RANGE.

VARIABLES												
Monthly Precipitation Months (X_1+X_2)												
J	F	M	A	M	J	J	A	S	O	N	D	Yield
X	X											Y
	X	X										Y
		X	X									Y
			X	X								Y
				X	X							Y
					X	X						Y
						X	X					Y
							X	X				Y
								X	X			Y
									X	X		Y
										X	X	Y
X												Y
	X											Y
		X										Y
			X									Y
				X								Y
					X							Y
						X						Y
							X					Y
								X				Y
									X			Y
										X		Y
											X	Y
Months (X_1+ X_2+....X M_n)												
J	F	M	A	M	J	J	A	S	O	N	D	
X	X	X	X	X	X							Y
						X	X	X	X	X	X	Y

TABLE 3. RESULTS OF REGRESSION USING 17 YEARS (1951-1967) OF DATA FROM PASTURE NINE, JORNADA EXPERIMENTAL RANGE.

VARIABLES														
Monthly Precipitation Months (X_1+ X_2...X n)														
J	F	M	A	M	J	J	A	S	O	N	D	Yield	R^2	F-Value
X	X	X	X	X	X	X	X	X	X	X	X	Y	.76	1.08

TABLE 4. RESULTS OF REGRESSION OF PRECIPITATION FOR NOVEMBER, FEBRUARY, MARCH AND APRIL WITH HERBAGE YIELD. DATA FROM NORTHRIDGE, PASTURE NINE, JORNADA EXPERIMENTAL RANGE (1957-1969)

Dependent Variable = Yield

Independent Variables	Coefficient	St. Error	t-Value	R^2
		1.9	. 12	
February	238.02	125.49	.14	
March	167.42	98.88	1.69	
April	1114.58	229.57	4.85	.62
November	60.74	46.32	1.31	.02

Intercept 279.53

F-Value 17. 94 ($p < .01$)

Multiple R-Squared . 91

TABLE 5. RESULTS OF REGRESSION OF PRECIPITATION FOR FEBRUARY, MARCH, AND APRIL WITH HERBAGE YIELD DATA FROM NORTHRIDGE, PASTURE NINE, JORNADA EXPERIMENTAL RANGE (1957-1969)

Dependent Variable = Yield 102.87 192.42 . 12

Independent Variables	Coefficient	St. Error	t-Value	R^2
February	235.63	131.00	1.8	
March	178.39		1.73	.14
April	1294.04		6.72	.62

Intercept 285.50

F-Value 21.42 ($p < .01$) Multiple

R-Squared .89

The November variable shows a low t-value (Table 4) and accounts for only 2.18% (R^2=.0218) of the variability, so it was eliminated in the regression in Table 5. Eliminating it raised the overall F-value from 17.94 ($p < .01$) to 214.2 ($p < .01$), increasing the predictability by a minor amount, and increasing the degrees of freedom in the denominator.

Selection of the variables used came from the correlation table (Table 6), and initially, February, March, April, June, September, and November variables were used to compute a stepwise regression. Those variables with a low t-value were dropped in successive regressions, to obtain those illustrated in Tables 4 and 5.

<u>Precipitation-cover relationships.</u> Cover density and forage yield had a correlation coefficient (r) of .75 (Table 6), and this led to the results of the regression in Table 7. The variables selected by a similar process of elimination, were September, November, and March with an R^2 of .73 and an F-value of 7.22 ($p < .05$). Although not as significant as the yield regressions, there is a close relationship between these monthly precipitations and cover.

Regressions for the same period and time intervals of precipitation revealed no significant correlations with forage yield or for forage yield divided by cover, however.

<u>Precipitation-soil moisture.</u> An initial examination of precipitation and soil moisture was included here in spite of its failure to attain statistical significance (Figure 3). It is tantalizing to recognize that the lack of significance probably resulted from the

TABLE 6. PARTIAL CORRELATION COEFFICIENTS (r) FOR PRECIPITATION WITH BOTH COVER AND YIELD AND CORRELATION COEFFICIENT (r) OF COVER AND YIELD USING DATA FROM NORTHRIDGE, PASTURE NINE (1957-1969)

Precipitation/Yield	
Month	r
July	.05
August	.20
September	.61
October	.09
November	.66
December	.10
January	.31
February	.36
March	.49
April	.87
May	.19
June	.36

Precipitation/Cover	
Month	r
July	.05
August	.25
September	.48
October	.06
November	.60
December	.15
January	.02
February	.41
March	.67
April	.63
May	.25
June	.34

Cover/Yield

r = .75

TABLE 7. RESULTS OF REGRESSION USING PRECIPITATION FOR SEPTEMBER, NOVEMBER AND MARCH IN RELATION TO COVER. DATA FROM NORTHRIDGE, PASTURE NINE, JORNADA EXPERIMENTAL RANGE (1957-1969)

Dependent Variable = Cover

T-Value 1.33 St. Error 2.12

Variable	Coefficient			R^2
September	.08	0.06		.22
November	.33	0.15		.23
March	1.02	0.35	2.91	.29

Intercept 0.62

F-Value 7.22 (p < .05)

Multiple R-Squared .73

extreme variation exhibited by the years 1960 and 1967. In spite of rather intense examination, there is no other recourse but to assume that the variation is due to some source other than soil moisture or precipitation such as evapo-transpiration.

This "almost significant" correlation has a distinct bearing on the attempt to simulate the processes involved in growth of perennial grasses as outlined later in the study.

Other initial examinations of precipitation and soil moisture are shown in Table 8, along with similar analyses involving yield as a dependent variable. The variable shown as "significant storms" are those storms that appeared to affect soil moisture at the 10-centimeter (4-inch) depth because of their magnitude and amount.

Soil moisture-yield. Soil moisture was expressed as days or periods that measurements (bars of moisture potential) were within selected ranges such as 0-2 bars, 0-5 bars, 0-10 bars, etc. Table 9 shows the results of examinations of days that soil moisture was

2-16+ bars within the period July 1 through April 30 (300 days) as compared to herbage yield following that period. The period was reduced by 30 day increments beginning with July 1, e.g., the number of days at 2-16+ bars for July 30 to April 30 (270 days) was the second variable, and the number of days at 2-16+ bars for August 28 to April 30 (240 days) was the third variable, etc. These results provided a basis for formulating a more precise hypothesis that current yield is dependent upon previous fall, winter and current

TABLE 8. RESULTS OF COMPARISONS OF SOIL MOISTURE (DAYS PER YEAR AT VARIOUS LEVELS), YIELD, SIGNIFICANT STORMS, STORMS GREATER THAN 12.7 mm (.5 inches), AND ANNUAL PRECIPI-TATION (1958-1970).

VARIABLES																Multiple		
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	R^2		F-Value
X				X				X							Y	.39		1.47
	X				X				X						Y	.33		1.13
		X				X				X					Y	.29		.95
X		X		X		X		X		X			Y			.55		.81
X		X		X		X		X		X		Y				.81		2.79
X	X	X	X	X	X	X	X					Y				.95		5.63
X	X			X	X		X	X						Y		.45		.54
X				X				X						Y		.30		.98
	X				X				X					Y		.23		.69
												X		Y	X	.23		1.21
X	X			X	X			X	X						Y	.89		5.43
		X	X			X	X			X	X				Y	.91		7.03 (p <.05)
X	X	X	X												.71 Y	.84		7.70 (p <.05)
X	X			X	X			X	X					Y		.45		.54
		X	X			X	X			X	X			Y				1.59
X	X	X	X											Y		.68	.79	3.15
				X	X	X	X							Y		.61		2.31
				X	X	X	X								Y	.48		1.35
X	X			X	X			X	X				Y			.54		
X	X	X	X					Y								.41		1.03
X	X	X	X						Y							.42		1.08

TABLE 8. (Cont.)

VARIABLES																Multiple	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	R^2	F-Value
X	X	X	X	Y												.45	1.28
X	X	X	X				Y									.58	2.04
Y								X	X	X	X					.44	1.19
	Y							X	X	X	X					.44	1.16
			Y					X	X	X	X					.44	1.16
X	X	X	X								Y					.53	1.72
X	X	X	X		Y											.48	1.38

Description of Variables:

1. 10 cm depth, days per year at 0-2 bars.
2. 10 cm depth, days per year at 0-5 bars.
3. 10 cm depth, days per year at 0-10 bars.
4. 10 cm depth, days per year at 0-15 bars.
5. 25 cm depth, days per year at 0-2 bars.
6. 25 cm depth, days per year at 0-5 bars.
7. 25 cm depth, days per year at 0-10 bars.
8. 25 cm depth, days per year at 0-15 bars.
9. 40 cm depth, days per year at 0-2 bars.
10. 40 cm depth, days per year at 0-5 bars.
11. 40 cm depth, days per year at 0-10 bars.
12. 40 cm depth, days per year at 0-15 bars.
13. Number storms per year greater than 12.7 mm (.5 inches).
14. Number "significant" (affecting soil moisture at the 10 cm (4 inches) depth, apparently) storms per year.
15. Herbage yield per year, kg/ha, Pasture Nine.
16. Annual precipitation.

TABLE 9. DAYS OF SOIL MOISTURE GREATER THAN 2 BARS (2-16+) AT THE 10-CENTIMETER (4-INCH) DEPTH IN THIRTY-DAY INCREMENTS, BEGINNING JULY 1 AND ENDING ON APRIL 1. SOIL MOISTURE FROM WEST WELL (1957-1970), YIELD AND COVER DATA FROM NORTHRIDGE, PASTURE NINE (1958-1970)

Variables												
1	2	3	4	5	6	7	8	9	10	11	R^2	F-Value
X	X	X	X	X	X	X	X	X	X	Y	.95	4.17
	X		X		X	X	X			Y	.76	4.41 ($p <.05$)
					X					Y	.52	5.33 ($p <.05$)
X				X	X			X	X	Y	.92	15.09 ($p <.01$)
X					X			X	X	Y	.90	18.78 ($p <.01$)

<u>Description of Variables:</u>

1. July 1 - April 30, Days Soil Moisture 2-16+ bars, 10 cm.
2. August 1 - April 30, "
3. September 1 - April 30, "
4. October 1 - April 30, "
5. November 1 - April 30, "
6. December 1 - April 30, "
7. January 1 - April 30, "
8. February 1 - April 30, "
9. March 1 - April 30, "
10. April 1 - April 30, "
11. Yield in kg/ha divided by cover (%)

year's spring moisture.

The number of days at 2-16+ bars for 30-day increments, i.e., July 1 to July 30, etc., were then determined for the period 1958 through 1969, and compared with yields for the period 1959 through 1969. The results of these computations and the data are shown in Table 10. These results prompted an effort to expand the period covered and the results for the period 1957-1970 were an R^2 of .996 and an F-value of 22.86 ($p < .01$). It should be noted that Tables 9 and 10 express the dependent variable as yield divided by cover (to put yield on a per unit of cover basis). This apparently decreased the variation, and increased the statistical significance.

TABLE 10. DAYS OF SOIL MOISTURE GREATER THAN 2 BARS, i.e., (2-16+) AT THE 10 cm (4-INCH) DEPTH, IN THIRTY-DAY INCREMENTS, BEGINNING JULY 1 AND ENDING ON APRIL 1. SOIL MOISTURE FROM WEST WELL, YIELD AND COVER DATA FROM NORTHRIDGE AND PASTURE NINE.

Forage	Yield ÷ Cover	Data	Soil Moisture							
Year	kg/ha	lbs./acre	Days/month greater than 2 Bars							
			JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR
1960	300	268	7	7	17	31	0	0	0	0	22
1961	199	178	31	6	0	0	0	0	0	0	19
1962	423	378	5	0	0	0	0	0	0	0	0
1963	416	372	9	16	8	0	0	0	0	0	14
1964	640	572	21	5	9	20	0	0	0	0	11
1965	274	245	23	10	15	31	30	31	31	7	13
1966	814	727	24	21	10	15	29	9	0	0	13
1967	557	498	11	5	18	31	30	31	31	28	31
1968	910	812	20	8	0	17	28	0	0	0	0
1969	1343	1199	14	20	30	31	14	0	0	0	0

Results

Multiple R-Squared - .99

F-Value - 52.57 ($p < .01$)

Independent Variables - July, August, October, December, January, and February periods.

Simulation Approach

The graphic model (Figure 3) and the APL program MDL (Appendix XI) appeared to contian the essential elements for representation of the actual processes of growth of perennial grass. Unfortunately, various parameters driving the model were not available, and a great deal of speculation and sheer guess work were necessary to provide some subjective inputs. These subjectively derived parameters, are, therefore, results of the art and science of the modelling itself.

Weekly precipitation (INPUTS). The results of the regression exam-inations of precipitation-soil moisture herbage yield, etc., seemed to indicate that the period from July 1 to September 30 is most influential in simulating actual conditions and processes. The information was available in the computer workspace from having previously used it in the regressions and it was quickly rearranged by weeks for the required input (Appendix VI).

Soil moisture at the 10 cm (4-inch) soil depth (SM4). SM4 is a tabulation of a family of curves with precipitation in the first row and existing (or current iteration) soil moisture (bars) in the first column. The -1 is used because the program looks only at positive values in the first row and column (which are analogous to X and Y axis, thus -1 equals 0 essentially). It is obvious that 0 amounts of precipitation (2nd column) cause an increase in bars of moisture tension, or a decrease in soil moisture (in a weekly time interval, or in an iteration of the model, MDL). For example, if there is no rainfall and soil moisture is at .05 bars, then soil moisture will be expressed as 17 bars at the 18th iteration or week. Nothing greater than 17 was considered and is analogous to 16+ bars soil moisture. Seventeen is also the initial value for a yearly iteration (i.e., on July 1).

Soil moisture at the 40 cm (16-inch) depth (SM4N16). The derived value from the body of SM4 is compared to the first row of SM4N16, and the first column is the current value of soil moisture at the 40 cm (16-inch) depth. SM4N16 is also a tabulation of family of curves derived subjectively from the graphs of soil moisture measured at West Well, Pasture Nine. Both SM4 and SM4N16 were modified to their given con-figurations when it became apparent that early versions did not respond with sufficient sensitivity, and resulted in negligible differences in production of biomass from year to year.

Growth increment per week or iteration (GRINC). GRINC is a tabu-lation of a curve (Figure 5) of the amount of biomass (specifically perennial herbage) produced under optimum temperature at various levels of soil moisture in bars of atmospheric pressure (as determined at the 40 cm (16-inch) depth in this case). The basis for establishing the initial values was the data derived from ongoing measurements at the Jornada Comprehensive Site (1 mile south of West Well in Pasture Nine), established for the International Bio logical Program.

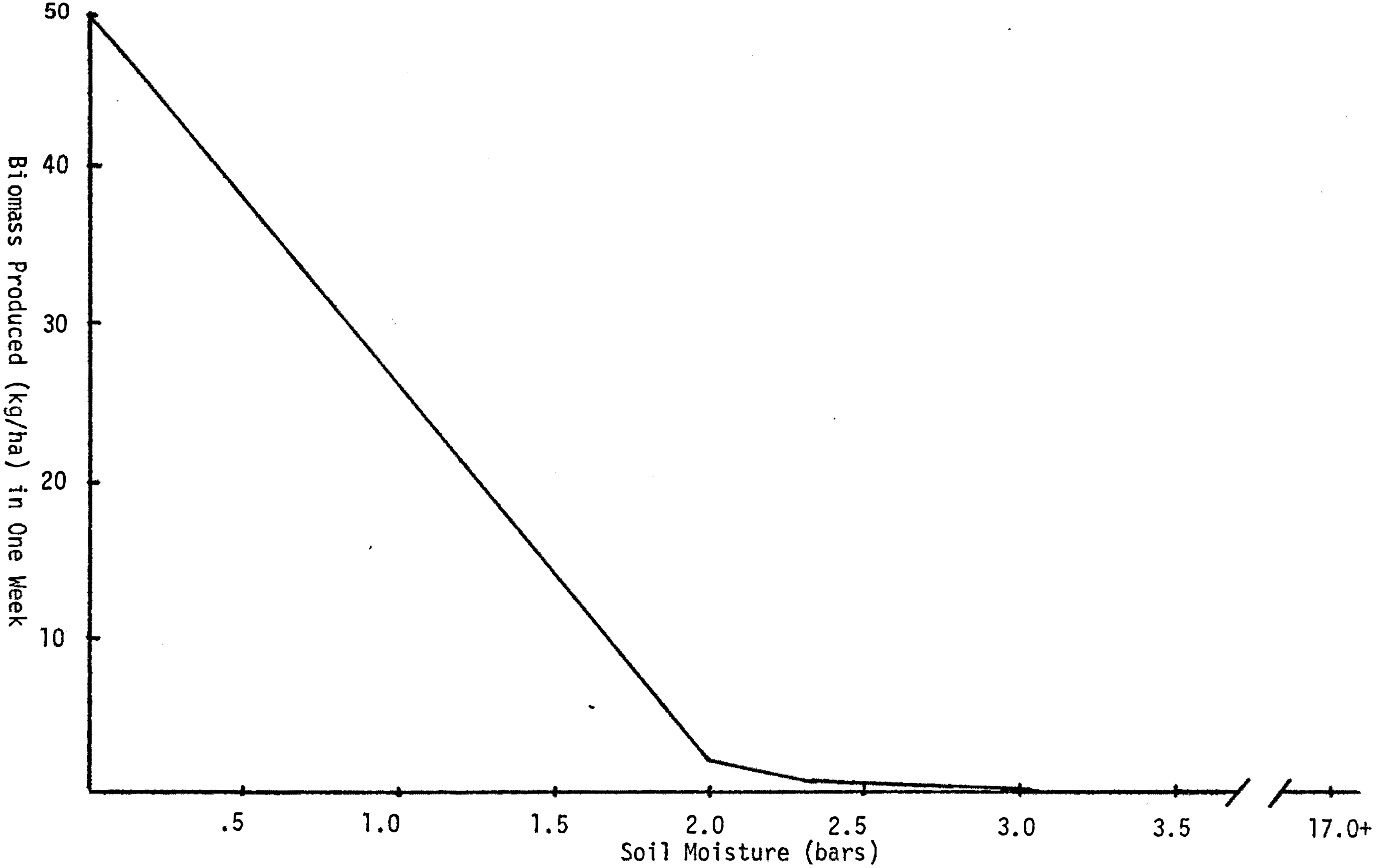


FIGURE 5. INITIAL CURVE OF ESTIMATED BIOMASS PRODUCED UNDER OPTIMUM TEMPERATURE AT LEVELS OF SOIL MOISTURE IN ONE WEEK.

This was tempered with judgment based on information from Idso(1968), Bailey (1967), Aspinall, et al. (1964), Briggs and Shantz (1912), Gates (1964), Lehane and Staple (1962), Livingstone (1906), Livingstone and Hawkins (1915), Maximov (1931), Mueller and Weaver (1942), Russell (1959 and 1961), Stanhill (1957), Stoeckler (1961), Veihmeyer (1950), and Veihmeyer and Hendrikson (1949). Lack of specific data demanded the final arbitrary result, however, which was within the constraint of optimum temperature. The maximum biomass production was set at 50 to 60 kg/ha/week and the curve was heuristically modified between that and the minimum of 0.

Average minimum temperature (CONS). These are weekly averages of data for the previous 35 years as measured at Jornada Experimental headquarters six miles east of West Well. They were interpolated from monthly averages (Figure 6). It is probable that the use of averages constitutes a major and basic deficiency in the results of the model.

Percent growth (PCTGR). This curve (Figure 7) is an estimate of the rate of growth of perennial grasses expressed in percent as determined by minimum temperature, and assumes that soil moisture is for plant growth. It also assumes that maximum temperatures of approximately 37.8+°C (100°+F) delimit growth. The curve is based primarily on information by Lehenbaur (1914), and Livingstone (1906) and also required some basic assumptions and arbitrary subjectivity.

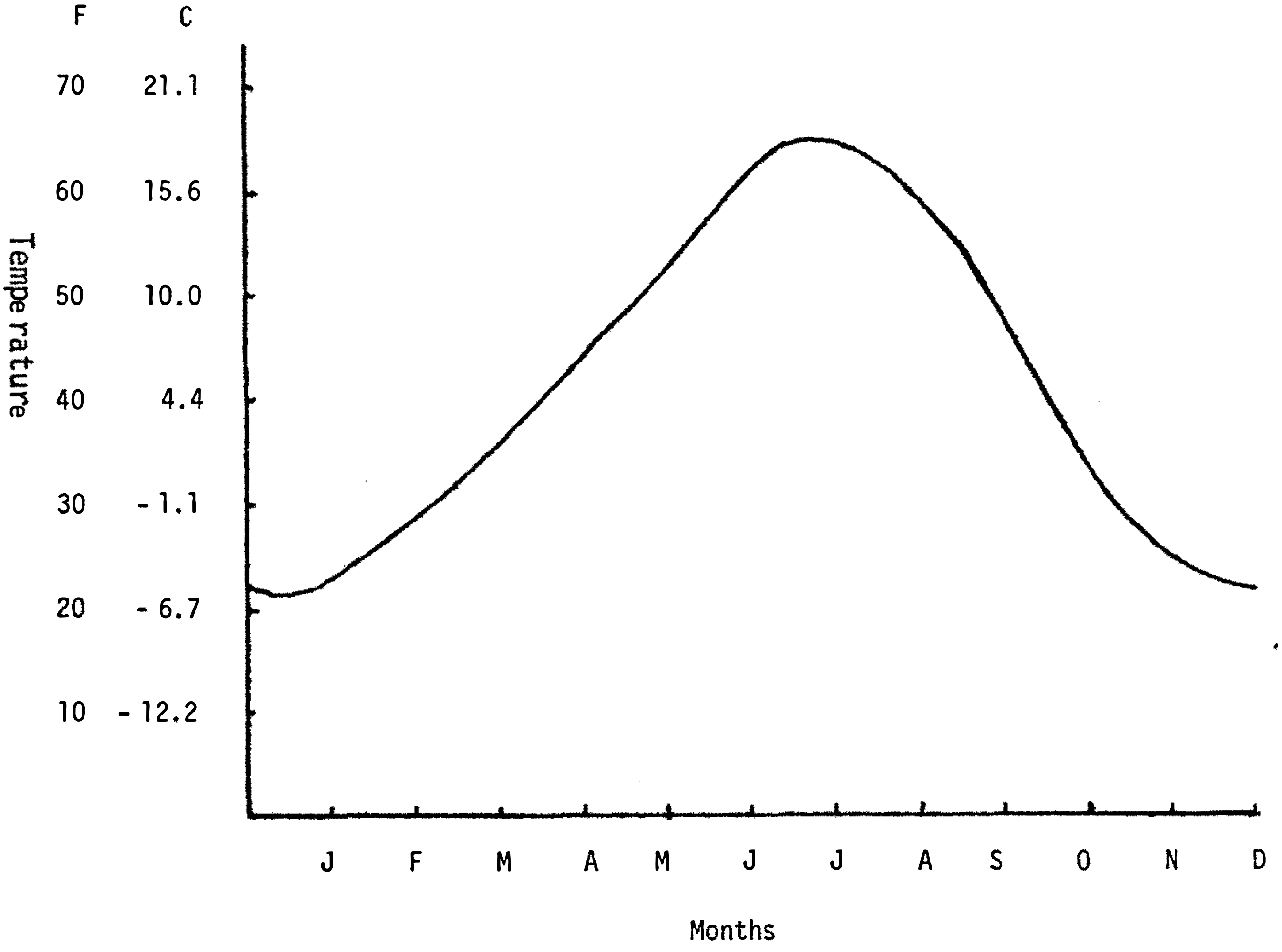


FIGURE 6. WEEKLY AVERAGES OF MINIMUM TEMPERATURE (CONS) FROM JORNADA EXPERIMENTAL HEADQUARTERS. (INTERPOLATED FROM MONTHLY AVERAGES FOR 35 YEARS)

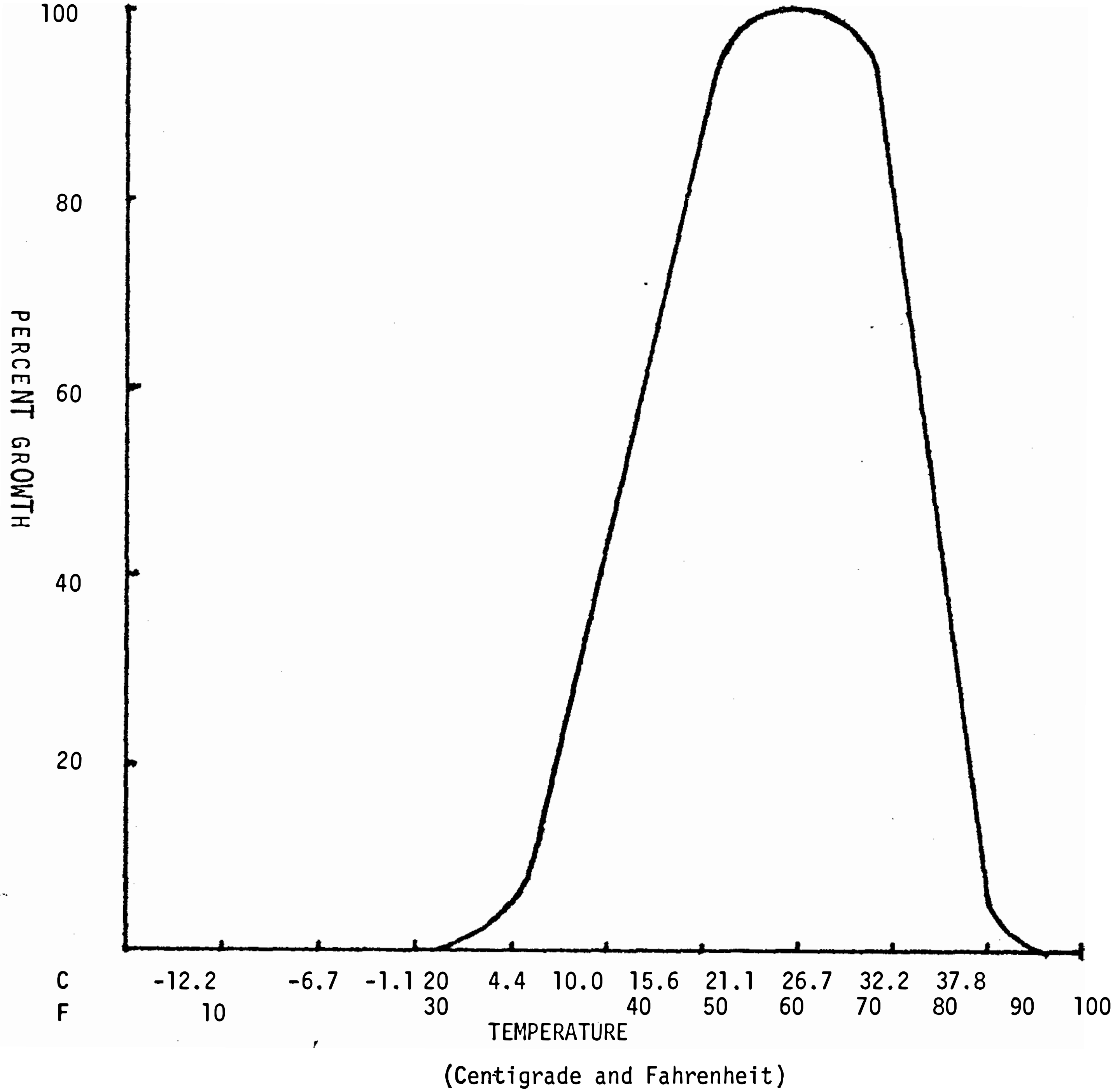


FIGURE 7. ESTIMATED PERCENT GROWTH OF PERENNIAL GRASS AT OPTIMUM SOIL MOISTURE AND MINIMUM WEEKLY TEMPERATURE

Leaf biomass produced (LBM and TLBM). Weekly production of leaf biomass of perennial grasses is a function of PCTGR x GRINC x VIG where VIG is vigor based on the previous weekly production of leaf biomass.
It was initially based on the previous year's total production. Table 11 illustrates various outputs of total leaf biomass using the initial variable SM4 (which was not responsive enough to changes in precipi-tation, as illustrated by the 0 values for 1960). The differences in results in Table 11 are due to changes in the slope and maximum value
of the growth increment curve GRINC.

Table 12 shows the results of various curves of GRINC using the given family of curves for soil moisture at the 10-centimeter (4-inch) depth SM4. No results of the regressions of derived yield and actual yield are given, since they were inconclusive, however, examples of these comparisons are given in Figures 8 and 9. Examination and com-parison of Tables 11 and 12 indicate that as mentioned previously under Precipitation-soil moisture, there are apparently undetermined factors as particularly evidenced by years 1960, 1962, and 1967. Attempts to modify some of the parameters of the model to "force" those years to fit, resulted in disparities of greater magnitude in other years.

Optimization of growth increment (MDL2). The preparation of MDL2 was an initial step in the systematic investigation to determine the source(s) for the obvious discrepancies in the model and parameters. Using the vector and matrix multiplication capabilities of APL, the intent was to merge several parameters into vector(s) of coefficients,

TABLE 11. RESULTS (TOTAL LEAF BIOMASS, KG/HA) OF RUNS OF MDL (INITIAL PROGRAM), USING THE ORIGINAL VARIABLE SM4 (SOIL MOISTURE AT 10 CM) AND MODIFYING THE GROWTH INCREMENT CURVE (GRINC)

YEAR	ACTUAL	GRINC1	GRINC2	GRINC3	GRINC4
	kg/ha				
1959	547	532	407	488	383
1960	198	225	-0-	-0-2	-0-
1961	187	353	212	54	180
1962	796	429	235	282	189
1963	336	357	246	295	240
1964	302	409	348	418	306
1965	182	380	60	72	58
1966	477	390	313	376	276
1967	145	541	504	605	500
1968	181	409	354	426	348
1969	372	415	366	439	338
1970	232	368	66	79	60

GRINC1	GRINC2	GRINC3	GRINC4	Output SM4N16
50	50	50	50	0.0
48	46	42	44	.05
46	42	35	38	.25
44	38	,29	32	.5
41	34	24	26	.75
38	30	20	20	1.0
34	26	17	14	1.5
31	22	15	8	2.0
28	18	14	2	2.5
26	14	13	1	3.
23	10	12	0	3.5
21	6	11	0	4
19	4	10	0	4.5
16	2	9	0	5
13	1	8	0	6
10	0	7	0	7
8	0	6	0	8
6	0	4	0	9
5	0	4	0	10
4	0	3	0	11
3.0	0	2.5	0	12
2.	0	2.0	0	13
52.0	0	1.5	0	14
1.5	0	1.0	0	15
1.0	0	.5	0	16
0	0	0	0	17

TABLE 12. RESULTS (TOTAL LEAF BIOMASS, KG/HA) OF RUNS OF MDL (INITIAL PROGRAM), USING THE MODIFIED VARIABLE SM4 (AS GIVEN IN APPENDIX IX) AND MODIFYING THE GROWTH INCREMENT CURVE (GRINC)

YEAR	ACTUAL	GRINC4	GRINC1 k 7ha	GRINC5	GRINC6
1959	547	493	389	391	476
1960	198	276	104	160	217
1961	187	436	303	306	391
1962	796	482	373	376	460
1963	336	242	130	166	230
1964	302	422	313	313	399
1965	182	161	68	138	168
1966	477	458	184	260	345
1967	145	604	500	500	600
1968	181	430	355	355	464
1969	372	462	373	373	463
1970	232	178	57	130	162

GRINC4	GRINC1	GRINC5	GRINC6	Output of SM4N16
50	50	60	72	0.0
44	48	52.8	63.4	.05
38	46	45.6	54.7	.25
32	44	38.4	46.1	.5
26	41	31.2	37.4	.75
20	38	24	28.8	1.0
14	34	16.8	20.2	1.5
8	31	9.6	11.5	2.0
2	28	2.4	2.9	2.5
1	26	1.2	1.4	3.0
0	23	0	0	3.5
0	21	0	0	4.0
0	19	0	0	4.5
0	16	0	0	5
0	13	0	0	6
0	10	0	0	7
0	8	0	0	8
0	6	0	0	9
0	5	0	0	10
0	4	0	0	11
0	3	0	0	12
0	2.5	0	0	13
0	2.0	0	0	14
0	1.5	0	0	15
0	1.0	0	0	16
0	0	0	0	17

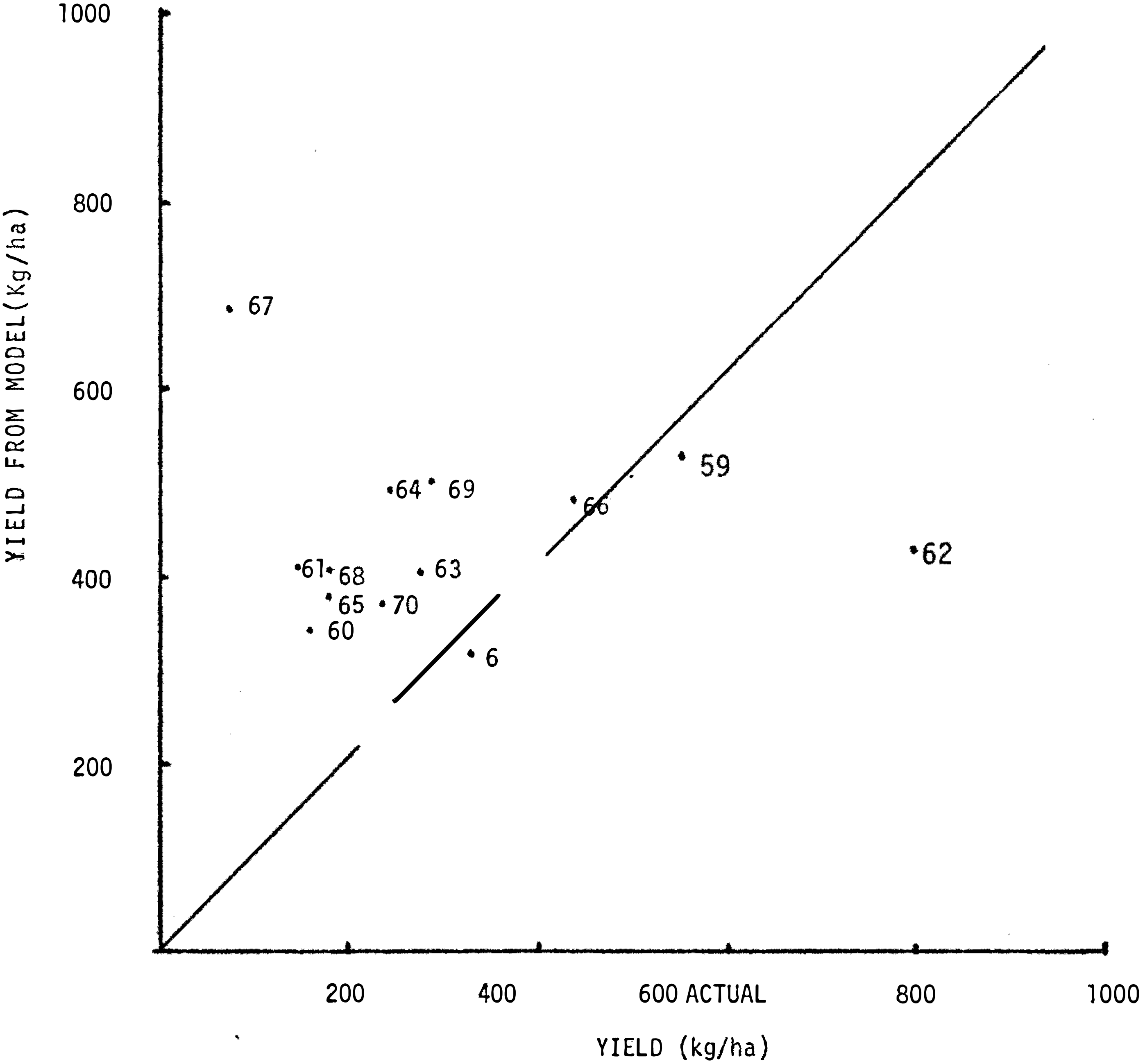


FIGURE 8. EXAMPLE OF COMPARISONS OF ACTUAL YIELD AND MODEL YIELD USING ORIGINAL SM4 GRINC1

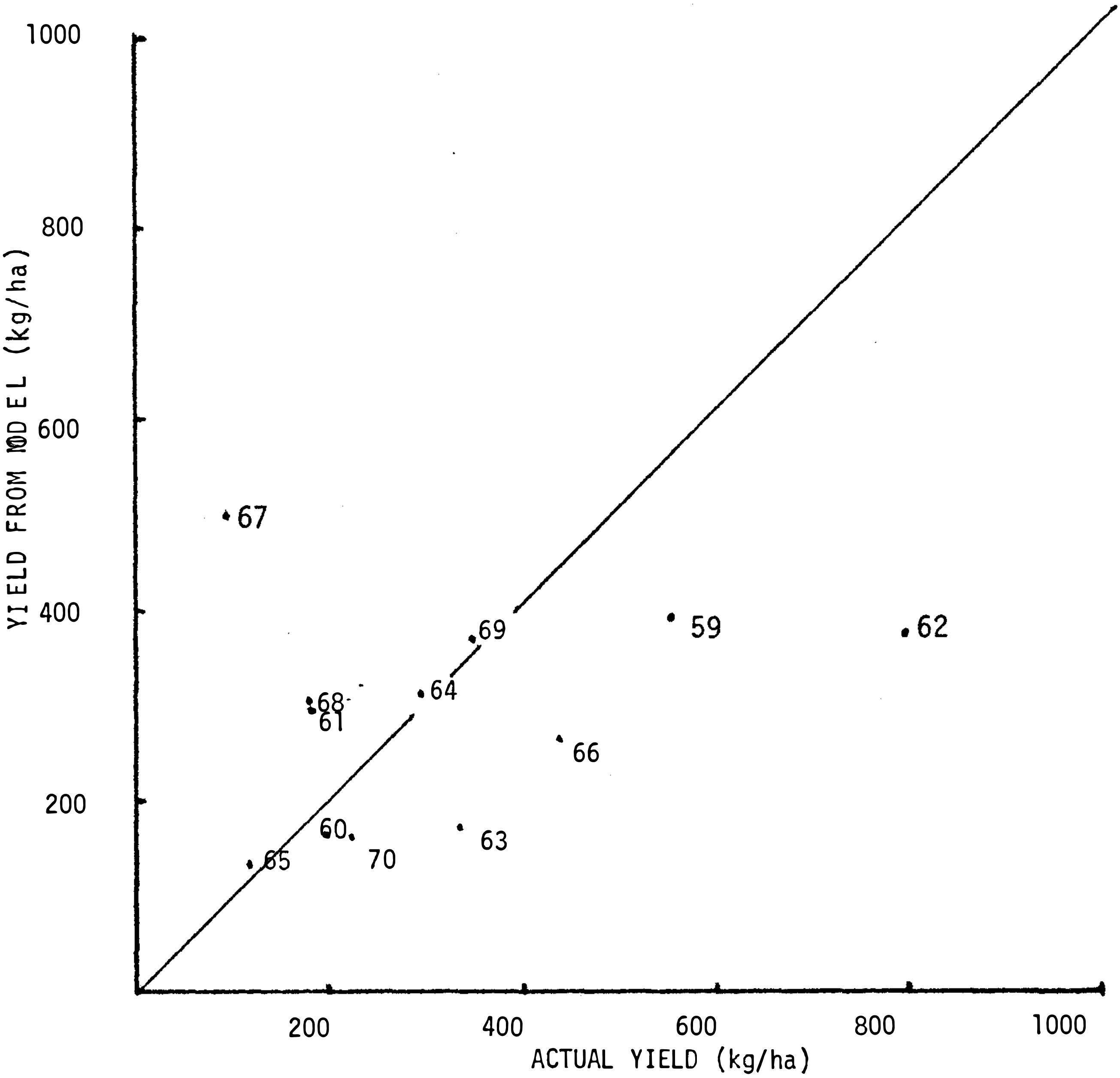


FIGURE 9. EXAMPLE OF COMPARISONS OF ACTUAL YIELD AND MODEL YIELD USING GIVEN SM4 AND GRINC6

optimize selected factors one by one using the actual forage yields, and arrive at a growth increment curve that appeared reasonable for use in the original model. Using actual soil moisture at the 25 cm (10-inch) depth and optimizing GRINC would permit the determination of how well SM4 and SM4N16 closely simulated real processes. These were then intended to be run in MODEL (Appendix XV) which is a refined modification of MDL. Investigations were terminated at this point.

CONCLUSIONS AND SUMMARY

Computer and Terminal

Any attempt to evaluate the use of the computer with a remote terminal in the regression approach used here, seems almost anticli-mactic, since without them, such an approach would be impractical,

if not impossible. Over 50 multiple or linear regressions, alone, were computed in the investigations of monthly and annual precipitation combinations in relation to herbage yield.

This in itself would be a monumental task for a desk calculator, but appears almost trivial when one considers manipulation and prepar-ation of the basic data for combinations, etc., prior to regression computation. The 14 column and 26 row matrix for precipitation/yield is relatively minor when considered in light of a 7-column, 365-row matrix for daily soil moisture conditions (one for each of 12 years), or a vector for daily moisture conditions for 14 years (5110 digits). Manipulations such as these are almost a matter of course, using the terminal and APL, and are limited in a practical sense, only by imagination, need, and available funds.

This must not be construed as obviating the need for "batch pro-cessing" in Fortran IV with card decks, or similar setups, or delimiting their use in similar studies. Once relationships are validly estab-lished as being highly correlated, and techniques of data manuipulation and extraction perfected, such methods become imperatively useful, particularly for voluminous data. For initial investigation, as illustrated here, the interactive, manipulative, and heuristic use of the terminal APL are extremely proficient.

Regression Approach

There is evidence (Tables 4 and 5) to indicate that perennial grass production or yield is dependent upon precipitation that occurs during the previous November, February, March, and April. Cover density of perennial grasses appears to be dependent upon precipitation received from July through April (Table 7). These latter conclusions are based on the yield and cover data from Northridge, and were statistically significant both before and after including data from an additional year. This, in itself, is confirmation that this relation-ship is valid.

The lack of significance between precipitation and days of soil moisture at the 2-bar level at 10cm (4-inches) depth, on an annual basis (Figure 3), is somewhat startling. Future study should probably be directed at the determination of the relationship of the monthly precipitation and days per month of soil mositure, e.g., at either greater than or less than 2 bars. There is apparently another influencing factor other than precipitation amounts in determining days of soil moisture, at least on an annual basis. It is probable that this variation is due to evaporation rate, duration, frequency and intensity of storms. Attempts to isolate this were unsuccessful, however, as discussed previously. An indication of this relationship is shown in the two significant relationships in Table 8, particularly the days at four levels of soil moisture at 10-centimeters (4-inches) depth for January, February, March, and April. These significant relationships in

Table 10 also helped direct interest towards the more significant relationships involving prior months.

The July through April period appears to be a consistent influence in the growth of perennial grass, whether expressed as yield or cover and whether the causative factor is expressed as monthly precipitation or days of soil moisture at 0-2 bars per month. This indicates that regression models using these causal factors have considerable merit and provide opportunities for predicting perennial grass growth for Pasture Nine, and other areas with similar soils and climate.

Simulation Approach

The use of precipitation and soil moisture at both the 10-centi-meter (4-inch) and the 40-centimeter (16-inch) depths may be entirely redundant in the model (MDL). The use of precipitation alone or perhaps soil moisture measurements at the 25-centimeter (10-inch) depth would reduce the amount of considerations and study for validation of the model. This might require consideration of other parameters, however, as discussed later.

A primary difficulty in obtaining model values of perennial grass biomass that correlated with actual measured values seemed to center around the years 1960, 1962, and 1967. When parameters of the model were altered to obtain comparable values for those years, predicted values from other years were uncorrelated with actual measured values. The earlier regressions using yield as dependent variables exhibited similar problems. It is possible that there was sampling error or other unknown sources of variation as discussed previously. One indicated action for future study might be to eliminate those years and/or use data from similar soil(s) in a different area.

The failure to properly introduce such abiotic factors as wind, temperature, and insolation into a sub-system or compartment of the simulation model (such as an evapo-transpiration subsystem) may be the single greatest factor for lack of correlation between actual yearly yields and the model output yields. At least two factors contributed to this lack of consideration:

1. The earlier results from the regression approach which indicated a high correlation for yield and cover with precipitation and/or soil moisture data from a period preceding the dry spring and early summer period. This latter period is one when the influences of such factors as wind, temperature and insolation are probably great. Use of the time period prior to the spring period apparently permitted circumvention of evapotranspiration effects (and variation attributable to those effects) and their importance was not recognized in the simulation model formulation.
2. The simplistic approach and the use of existing data only, tended to overshadow the need for incorporating the causal factors for, and effects of, evapo-transpiration into the model. The assumption was made that measurement of soil moisture expressed in days at various levels provides adequate consideration of evapo-transpiration and this may

not necessarily be true (soil moisture measurements were available for use, however). In addition, the derivations of families of curves expressed in the tables (model variables SM4 and SM4N16) were essentially linear. This derivation was primarily subjective with considerable inter-polation of the graphs.

The use of actual instead of average temperatures would probably improve the sensitivity and accuracy of the model (actual temperatures were not available for West Well). Incorporating these and other parameters into equations describing the evapo-transpiration function might provide a basic index for plant growth.

Idso (1968) discusses five basic factors having a direct influence upon photosynthesis, i.e., carbon dioxide (CO2) concentration, light intensity, leaf temperature, leaf water availability, and level of essential nutrients in the soil. The indirect effect of wind upon carbon dioxide, leaf temperature, and even more indirectly (by increasing evaporation of soil moisture) upon leaf water availability indicates a probable need for also incorporating this as a parameter in the model.

It was originally assumed, from the simplistic viewpoint, that average temperatures provided some index of day length, and thus accounted for some effects of solar radiation on both photosynthesis and on evapo-transpiration. It is very probable that this is not true, and that some parameters of solar radiation or at least solar time, should be included in the model.

The difficulties arising from the generalized assumptions taken in the stated simplistic approach indicate the need for more in-depth examination than that portrayed in this study. If the model had been prepared under more strict assumptions, e.g., that transpiration is almost completely controlled by conditions of the atmosphere, and photo-synthesis almost completely controlled by conditions of the soil (Idso, 1968), additional data and information would have been required. The literature search, however, revealed no data or curves for perennial grasses, such as those under consideration here. This indicates a need for basic information describing the photo-synthetic response for these and other grasses to leaf water availability, light intensity, leaf temperature, and carbon dioxide concentration.

From the managerial viewpoint, the difficulty of obtaining the necessary additional data to permit development and use of models in varied areas and situations arises. The relative difficulty and need will remain undefined, of course, until attempts are made to develop a model or models using basic information as exemplified in the pre-ceding paragraph, and the exact determination of needed measurement parameters is made. It is hoped that the approach outlined here will contribute to that definition of need.

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APPENDICES

APPENDIX I

DATA FROM PASTURE NINE, JORNADA EXPERIMENTAL RANGE USED IN THE INITIAL REGRESSIONS (TABLES 1, 2 AND 3)

YEAR	PRECIPITATION BY MONTH (mm)												YIELD	STOCKING
	JAN.	FEB.	MARCH	APRIL	MAY	JUNE	JULY	AUG	SEPT.	OCT.	NOV.	DEC.	Kg/ha.	A. U.
1941	38.8	20.3	34.0	33.2	25.1	15.7	45.2	77.9	132.2	39.3	14.2	23.6	503.6	82.8
1942	6.9	9.4	0.0	12.2	0.0	7.9	24.9	59.9	37.1	16.5	0.0	9.6	699.9	79.3
1943	3.6	0.0	1.8	0.0	0.0	33.2	64.7	19.3	28.9	0.0	24.1	19.5	908.5	120.8
1944	11.4	20.1	1. 3	0.0	2.0	.3	85.5	34.0	29.2	35.5	41.9	10.4	1016.2	80.2
1945	5.6	0.0	3.6	0.0	0.0	0.0	109.1	30.7	0.0	51.8	0.0	0.0	761. 6	77.2
1946	22.1	0.0	0.0	1. 3	6.9	0.0	35.5	23.6	69.8	20.8	2.3	6.1	988.2	127.8
1948	3.0	26.1	2.0	1. 3	2.3	10.9	24.1	1.3	9.9	16.8	0.0	35.5	470.0	102.9
1949	25.6	19.0	0.0	0.0	4.3	3.8	43.7	17.3	32.5	24.6	0.0	9.6	919.7	87.8
1950	0.0	1.8	0.0	0.0	0.0	0.0	52.3	2.5	39.3	25.9	0.0	0.0	888.3	87.3
1951	3.3	2.5	6.3	13.5	0.0	0.0	8.6	22.3	0.0	30.2	0.0	0.0	306.2	110.4
1952	0.0	3.8	12.9	7.4	9.4	23.1	67.3	15.2	10.9	0.0	14.0	8.9	236.7	37.7
1953	0.0	16.0	17.5	4.8	0.0	11.	38.1	10.4	0.0	9.1	0.0	0.0	281.5	30.8
1954	.8	0.0	1.8	0.0	25.4	9	12.4	41.4	35.3	67.3	0.0	1.8	233.3	7.9
1955	29.4	0.0	9.4	0.0	.8	3.	71.6	13.2	0.0	17.5	1.3	0.0	173.9	18.4
1956	0.0	3.0	0.0	0.0	0.0	4807	39.6	20.8	0.0	7.9	0.0	3.8	279.3	17.3
1957	6.1	16.2	2.5	21.8	0.0	030	51.0	130.5	.8	62.7	18.	0.0	346.6	16.4
1958	12.4	16.0	44.4	15.2	14.0	280	14.2	58.9	113.5	44.7	2	0.0	226.6	23.8
1959	0.0	3.0	0.0	6.3	.5	.5	64.2	151.8	0.0	15.7	0.	5.3	241.2	26.2
1960	19.5	.3	0.0	0.0	0.0	12.4	16.8	23.1	12.2	17.0	0	37.8	350.0	72. 1
1961	17.5	0.0	2.5	0.0	0.0	3.0	45.2	108.1	103.0	0.0	5108	23. 1	256.9	52.8
1962	4.8	0.0	0.0	8.9	0.0	1.5	103.6	19.0	108.4	38.1	609	24.9	201.9	102.7
1963	.8	7.6	.3	2.0	2.5	2.0	14.7	78.7	70.6	31.	32	0.0	188.4	86.7
1964	0.0	.8	9.9	3.3	6.9	0.0	47.0	20.1	34.5	0	530	4.8	213.1	123.3
1965	13.7	8.4	6.3	0.0	0.0	10.9	18.5	38.6	33.2	3.	2.8	27.2	121. 1	97.9
1966	10.2	5.3	7.4	5.3	1.0	8.4	33.5	70.1	46.2	130	0.0	0.0	158.2	36.2
1967	0.0	8.9	12.2	0.0	5.8	65.0	15.7	75.6	53.3	090 6	21.3	20.8	363.4	43.3

APPENDIX II

APL PROGRAM EXPAND, FOR EXPANDING VECTORS OF TWO NUMBER SETS

```
                          ∇EXPAND[⎕]∇
     ∇EXPAND
[1]     'SET VARIABLE A TO A←ρ0 IF DESIRED.'
[2]   LOP:'ENTER 0 IF  NO MORE ENTRIES, 1 IF THERE ARE MORE:'
[3]     END←⎕
[4]     →(0=END)/0
[ SJ    'ENTER ITEM TO BE EXPANDED:
[6]     VAR←⎕
[7]     I←0
[8]     B←ρVAR
[9]     LP:→((B+1)≤I←I+2)/OV
(10]  EA←A,(VAR[I]ρ,VAR[I-1])
[11]    →LP
[12]  OVER:→LOP
     ∇
```

APPENDIX III a

APL PROGRAM CONDITION, FOR EXAMINING DAILY CONDITIONS OF MOISTURE

```
[1]CAT←P←1
[ 2    CHK←I←0
] [    DUM← 30 5 ρ,0
[4]    TCOND← 1 7 ρ,0CO
[5]
[6]    ND← 5 30 7 ρ,0
[7]    K3←K4←K5←K6←K7←0
       K8←1
[8]   LOOP:→(366≤I←I+1)/PRNT
[9]    →(25≤MAT[I;2])/LO
[10]   OP2→(2<MAT[I; 3] )/S
[11]   IP1TCOND[1;3]←(K3←K
[12]  SIP1:→(2<MAT[I;4])/S P2
   [13]TCOND[1;4]←(K4←K4+1) S
[14    SIP2:→(2<MAT[I;5])/SIP3
[15]   TCOND[1;5]←(K5←K5+1 )
[16]  SIP3:→(2<MAT[I;6])/SIP4
[17]   TCOND[1;6]←(K6←K6+1)
[18]  SIP4:→(2<MAT[I;7])/SIP5
[19]   TCOND[1;7]←K7←K7+1
[20]  SIP5:DUM[K8;ι5]←MAT[I; 3 4 5 6 7]
[21]   CHK←+/(+⌿DUM)
[22]   K8←K8+1
[23]   →(31 ≤K8)
[24]   /RESET
[25]  RESET:K8←1
[26]   →LOOP
[27]  LOOP2:→(1=P)/LOOP3
[28]   COND[CAT;P;]←TCOND[1;]
[29]  LOOP3:→(450≤CHK)/SOP1
[30]   →(0=+/(1 2 ∊MAT[I-2; 3 4 5 6
[31]   7]))/SOP4→(0=+/(3∊MAT[I; 3 4 5 6
[32]   7]))/SOP3
[33]  SOP4:CAT←1
[34]   →SOP5
[35]  SOP1:CAT←2
[36]   →SOP5
[37]  SOP7:→(3=MAT[I;3])/SOP2
[38]   CAT←4
[39]   →SOP5
[40]  SOP3:CAT←5
[41]   →SOP5
[42]  SOP2:CAT←3
[43]  SOP5:K3←K4←K5←K6←K7←0
[44]   TCOND[1; 1 2]←MAT[I; 1 2]
[45]   MAT[I; 1 2]
[46]   P←P+1
[47]   TCOND[1; 3 4 5 6 7]←,0
[ 48]  K8←K8+1
[49]   TCOND[1; 1 2]←MAT[I; 1 2]
[    50]→LOOP
[51]  PRNT:COND[CAT;P;]←TCOND[1;]
```

APPENDIX III (Cont.)

```
[52]  SUMCOND
[53]      DAY  PREC    4    10    16   21-24 27-36'
[54] LP:→(1>+/(+/COND[1;⍳P;]))/PT1
[55]  'DRY AT ALL DEPTHS FOR LESS THAN 30 DAYS: '
[56]  COND[1;⍳P;]
[57]  PT1:→(1>+/(+/COND[2;⍳P;]))/PT2
[58]  'DRY AT ALL DEPTHS FOR MORE THAN 30 DAYS: '
[59]  COND[2;⍳P;]
[60] PT2:→(1>+/(+/COND[3;⍳P;]))/PT3
[61]  'DRY AT 4 INCH DEPTH, WET AT SOME DEPTH IN LOWER
PROFILE:'[62]  COND[3;⍳P;]
[63] PT3:→(1>+/(+/COND[4;⍳P;]))/PT4
[64]  'WET AT 4 INCH DEPTH, DRY AT SOME DEPTH IN LOWER PROFILE:'
[65]  COND[4;⍳P;]ZY:''
[66] PT4:→(1>+/(+/COND[5;⍳P;]))/FUZY
[67]  'WET AT ALL DEPTHS:'
[68]  COND[5;⍳P;]
[ 6 9
]     ''
[70]  'ACCUMULATED DAYS:'
[71]  ''
[72]  ⎕←ACCOND[1;⍳CT1[1;1];]
[74]  ''
[75]  ⎕←ACCOND[2;⍳CT1[2;1];]⎕←ACCOND[4;⍳CT1[4;1];]
[76]  ''
[77]  ⎕←ACCOND[3;⍳CT1[3;1];]
[78]  ''
[7!J]
[80]  ''
[81]  ⎕←ACCOND[5;⍳CT1[5;1];]
```

- APPENDIX
Illb.

SUBROUTINE SUMCONO, FOR ACCUMULATING CONDITIONS INTO_MATRIX

```
[1]   CT1← 5 1 ⍴,CT1
[2]   CT←J←0
[3]  LIB:→(6≤J←J+1)/0
[4]   CT←0
[5]  CK1:→((P+1)≤CT←CT+1)/LIB
[6]   →(1>COND[J;CT;1])/CK1
[7]   ACCOND[J;CT1[J;1];]←COND[J;CT;]
[8]   CT1[J;1]←CT1[J;1]+1
[9]   →CK1
[10]  →LIB
    ∇
```

APPENDIX IVa

APL PROGRAM WORK, FOR DETERMINING "DRY" DAYS BY GIVEN PERIOD

```
[1]    J←0
[2]    BP← 1 10 ρ,BP
[3]    EP← 1 10 ρ,EP
[4]    Z←0
[5]    C← 11 10 ρ,0
[6]   OA:→(11≤Z←Z+1)/PRT
[7]    J←0
[8]    L←BP[1;Z]
[9]    D←EP[1;Z]
[10]   I←D-L
[11]  LP:→(12≤J←J+1)/OA
[12]   M←(D↑A)
[13]   N←(L↓M)
[14]   C[J;Z]←+/B←B←[M[⍳(I)]←N
[15]   D←D+365
[16]   L←L+365
[17]   →LP
[18]  PRT:CUM
     ∇
```

APPENDIX IVb.

SUBROUTINE CUM OF PROGRAM WORK FOR ACCUMULATING DRY DAYS IN PERIOD

```
[1]    RES← 11 10 ρ,0
[2]    TIME← 3 10 ρ,0
[3]    NUM←0
[4]   LOP:→(11<NUM←NUM+1)/PRIT
[5]    TIME[3;NUM]←EP[1;NUM]-BP[1;NUM]
[6]    TIME[2;NUM]←EP[1;NUM]
[7]    TIME[1;NUM]←BP[1;NUM]
[8]    RES←C
[9]    →LOP
[10]  PRIT:'RESULTS: '
[11]   'FIRST ROW = BEGINNING DATE'
[12]   'SECOND ROW = ENDING DATE '
[13]   'THIRD ROW = TOTAL DAYS '
[14]   ''
[15]   TIME
[16]   'RESULTS: '
[17]   RES
     ∇
```

APPENDIX V

DATA FROM NORTHRIDGE, PASTURE NINE, JORNADA EXPERIMENTAL RANGE

YEAR	PERENNIAL GRASS	
	Cover (Percent)	Yield (kg/ha)
1958	1.30	560
1959	.95	547
1960	.66	198
1961	.94	187
1962	1.88	796
1963	.81	336
1964	.47	302
1965	.66	182
1966	.59	477
1967	.26	145
1968	.20	181
1969	.28	372
1970	.21	232

APPENDIX VI

WEEKLY PRECIPITATION (ROWS) FOR YEARS 1959-1970 (COLUMNS)

INPUTS

0	102	0	62	216	0	0	12	0	0	0	0
0	0	52	87	40	29	168	0	82	49	0	113
13	112	0	0	97	29	0	11	84	0	175	28
0	0	0	0	57	0	0	50	43	18	0	84
68	0	0	25	43	125	17	106	11	0	50	3
0	0	48	0	0	34	0	0	0	161	90	0
0	347	0	344	40	13	75	0	0	81	51	0
0	203	39	57	11	138	0	46	0	46	22	46
232	0	0	0	0	162	4	0	0	8	50	0
1	0	27	233	85	101	0	82	81	77	44	178
97	0	0	161	12	10	136	0	75	8	0	0
233	0	0	0	0	5	0	49	0	31	0	14
23	0	0	0	332	0	0	0	118	95	0	0
112	0	0	0	48	0	0	0	0	0	0	16
52	0	0	0	0	0	0	0	23	0	0	0
85	0	42	0	82	122	13	38	91	0	2	0
20	0	0	0	32	0	0	0	71	0	0	92
0	45	0	0	0	0	0	0	0	0	0	0
0	0	0	147	0	0	0	0	5	0	2	0
0	0	0	52	0	0	0	0	0	0	67	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	125	10	0	11	0	83	0	6
0	0	0	0	0	0	2	0	0	0	0	94
0	0	110	77	0	0	0	107	0	0	0	0
0	0	0	0	0	0	17	0	0	81	0	0
0	0	0	0	0	0	0	0	0	0	60	34
0	0	25	0	0	0	0	0	0	0	0	0
0	50	0	0	0	0	54	0	0	0	0	0
0	0	0	0	0	0	0	48	0	0	0	0
0	0	45	5	0	0	0	0	0	52	0	0
0	0	25	0	3	0	0	0	0	0	51	0
0	0	0	0	0	0	33	20	0	55	10	0
0	0	0	0	30	3	0	0	0	0	0	0
0	0	0	0	0	0	0	0	40	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	68	0	0
0	0	0	0	0	0	25	0	0	0	4	52
0	0	0	0	0	39	0	0	50	0	0	13
0	0	0	0	0	0	0	30	0	0	0	0
0	0	0	0	1	13	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	17	0	0

APPENDIX VI (Cont.)

0	0	0	37	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	30	0	0	0	0
0	0	0	0	8	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	10	27	0	6	23	0	0	0
0	0	0	0	0	0	0	0	0	0	44	25
0	42	0	0	4	0	43	0	4	0	0	0
0	0	0	0	0	0	0	0	136	0	0	0
0	0	0	2	4	0	0	0	0	0	0	0
102	0	62	52	0	0	12	32	122	0	0	36
0	52	87	204	29	168	0	0	43	0	113	0
26	0	0	97	29	0	11	166	6	175	28	28
86	0	0	2	0	0	50	43	12	0	84	180
0	0	25	98	0	17	106	11	6	50	0	46
0	48	0	0	159	0	0	0	161	90	3	16
248	0	344	40	13	75	0	0	81	51	0	0
302	39	57	11	138	0	46	0	46	22	46	0
0	0	0	0	0	4	0	0	8	50	0	12
0	0	233	85	263	0	0	81	77	44	157	0
0	27	161	12	10	136	82	75	8	0	21	0
0	0	0	0	5	0	49	0	31	0	14	68
0	0	0	332	0	0	0	118	95	0	0	0

APPENDIX VII

ESTIMATED PERCENT GROWTH (RIGHT COLUMN) OF BIOMASS BY TEMPERATURE IN DEGREES F (LEFT COLUMN)

PCTGR

20	0
25	0
32	0
40	3
45	10
50	25
55	50
60	80
65	100
70	30

APPENDIX VIII

ESTIMATED GROWTH IN KG/HA (LEFT COLUMN) AT SOIL MOISTURE LEVELS (RIGHT COLUMN) IN BARS

GRINC

50	0.05
46	0.25
42	0.5
38	0.75
34	1
30	1.5
26	2
22	2.5
18	3
14	3.5
10	4
6	4.5
4	5
2	6
1	7
0	8
0	9
0	10
0	11
0	12
0	13
0	14
0	15
0	16
0	17
0	18

APPENDIX IX

SOIL MOISTURE CHANGE (INTERSECTION) IN BARS FOR GIVEN PRECIPITATION (FIRST ROW) AND PREVIOUS WEEKS SOIL MOISTURE (FIRST COLUMN) IN BARS AT 10 CM DEPTH.

```
                        SM4[;ι6]
¯1          0           0.25        0.5         0.75        1
 0.05       0.25        0.25        0.05        0.05        0.05
 0.25       0.5         0.5         0.25        0.25        0.25
 0.5        0.75        0.75        0.25        0.25        0.25
 0.75       1           0.75        0.5         0.25        0.25
 1          1.5         1           0.75        0.25        0.25
 1.5        2           1.5         0.75        0.25        0.25
 2          2.5         2           1           0.5         0.25
 2.5        3           2.5         1.5         0.5         0.25
 3          3.5         2.5         2           0.5         0.5
 3.5        4           3.5         2.5         0.5         0.5
 4          4.5         4           2.5         0.5         0.5
 4.5        5           4.5         3.5         0.5         0.5
 5          7           5           4           0.75        0.5
 6          8           6           4.5         0.75        0.5
 7          9           7           5           1           0.5
 8         11           8           6           1.5         0.5
 9         13           9           7           2           0.5
10         17          10           8           2.5         0.5
11         17          11           9           2.5         0.5
12         17          12          10           3.5         0.5
13         17          13          11           4           0.75
14         17          14          12           4.5         0.75
15         17          15          13           5           1
16         17          16          14           6           1.5
17         17          17          15           7           2
```

APPENDIX IX (Cont.)

```
                  SM4[;6+ι6]
1.25      1.5       1.75      2         2.5       5
0.05      0.05      0.05      0.05      0.05      0.05
0.25      0.25      0.25      0.05      0.05      0.05
0.25      0.25      0.25      0.05      0.05      0.05
0.25      0.25      0.25      0.05      0.05      0.05
0.25      0.25      0.25      0.05      0.05      0.05
0.25      0.25      0.25      0.25      0.05      0.05
0.25      0.25      0.25      0.25      0.05      0.05
0.25      0.25      0.25      0.25      0.05      0.05
0.25      0.25      0.25      0.25      0.05      0.05
0.25      0.25      0.25      0.25      0.05      0.05
0.5       0.25      0.25      0.25      0.25      0.05
0.5       0.25      0.25      0.25      0.25      0.05
0.5       0.5       0.25      0.25      0.25      0.05
0.5       0.5       0.25      0.25      0.25      0.05
0.5       0.5       0.5       0.5       0.25      0.05
0.5       0.5       0.5       0.5       0.25      0.05
0.5       0.5       0.5       0.5       0.25      0.05
0.5       0.5       0.5       0.5       0.25      0.05
0.5       0.5       0.5       0.5       0.5       0.05
0.5       0.5       0.5       0.5       0.5       0.05
0.5       0.5       0.5       0.5       0.5       0.05
0.5       0.5       0.5       0.5       0.5       0.05
0.5       0.5       0.5       0.5       0.5       0.05
0.5       0.5       0.5       0.5       0.5       0.05
0.5       0.5       0.5       0.5       0.5       0.05
```

APPENDIX X

SOIL MOISTURE CHANGE (INTERSECTION) IN BARS FOR SOIL MOISTU
(FIRST ROW) AND FOR PREVIOUS WEEKS SOIL MOISTURE AT 40 CM (
AT 40 CM DEPTH.

```
                      SM4N16[;⍳6]
  0          0.05       0.25       0.5        0.75
  0.05       0.05       0.25       0.5        0.75
  0.25       0.05       0.25       0.5        0.75
  0.5        0.25       0.5        0.5        0.75
  0.75       0.25       0.5        0.75       0.75
  1          0.5        0.75       1          1
  1.5        0.5        0.75       1.5        1.5
  2          1          1.5        1.5        2
  2.5        2          2          2          2
  3          2          2.5        2.5        2.5
  3.5        2.5        2.5        3          3
  4          3          3          3          3.5
  4.5        3.5        3.5        3.5        3.5
  5          3.5        4          4          4
  6          4.5        4.5        4.5        4.5
  7          5          5          5          5
  8          5          6          6          6
  9          6          6          7          7
 10          7          7          7          8
 11          8          8          8          8
 12          8          9          9          9
 13          9         10         10         10
 14         10         10         11         11
 15         11         11         11         12
 16         11         12         12         12
 17         12         12         12         13
```

APPENDIX X (Cont.)

```
                  SM4N16[;6+ι6]
 1.5      2        2.5      3        3.5      4
 1.5      2        2.5      3        3.5      4
 1.5      2        2.5      3        3.5      4
 1.5      2        2.5      3        3.5      4
 1.5      2        2.5      3        3.5      4
 1.5      2        2.5      3        3.5      4
 1.5      2        2.5      3        3.5      4
 2        2        2.5      3        3.5      4
 2.5      2.5      2.5      3        3.5      4
 3        3        3        3        3.5      4
 3        3.5      3.5      3.5      3.5      4
 3.5      3.5      4        4        4        4
 4        4        4        4.5      4.5      4.5
 4        4.5      4.5      5        5        5
 5        5        5        5        6        6
 6        6        6        6        6        7
 6        7        7        7        7        7
 7        7        8        8        8        8
 8        8        8        9        9        9
 9        9        9        9       10       10
10       10       10       10       10       11
10       11       11       11       11       11
11       11       12       12       12       12
12       12       12       13       13       13
12       13       13       13       13       13
13       13       14       14       14       14
```

APPENDIX X (Cont.)

```
                     SM4N16[;12+⍳6]
      4.5          5          6          7          8          9
      4.5          5          6          7          8          9
      4.5          5          6          7          8          9
      4.5          5          6          7          8          9
      4.5          5          6          7          8          9
      4.5          5          6          7          8          9
      4.5          5          6          7          8          9
      4.5          5          6          7          8          9
      4.5          5          6          7          8          9
      4.5          5          6          7          8          9
      4.5          5          6          7          8          9
      4.5          5          6          7          8          9
      4.5          5          6          7          8          9
      5            5          6          7          8          9
      6            6          6          7          8          9
      7            7          7          7          8          9
      8            8          8          8          8          9
      8            9          9          9          9          9
      9            9         10         10         10         10
     10           10         10         11         11         11
     11           11         11         11         12         12
     12           12         12         12         12         13
     12           13         13         13         13         13
     13           13         14         14         14         14
     14           14         14         14         14         15
     14           15         15         15         15         15
```

APPENDIX X (Cont.)

```
                    SM4N16[;18+ι6]
10          11          12          13          14          15
10          11          12          13          14          15
10          11          12          13          14          15
10          11          12          13          14          15
10          11          12          13          14          15
10          11          12          13          14          15
10          11          12          13          14          15
10          11          12          13          14          15
10          11          12          13          14          15
10          11          12          13          14          15
10          11          12          13          14          15
10          11          12          13          14          15
10          11          12          13          14          15
10          11          12          13          14          15
10          11          12          13          14          15
10          11          12          13          14          15
10          11          12          13          14          15
10          11          12          13          14          15
10          11          12          13          14          15
11          11          12          13          14          15
12          12          12          13          14          15
13          13          13          13          14          15
14          14          14          14          14          15
14          15          15          15          15          15
15          15          15          15          16          16
15          16          16          16          16          16
```

APPENDIX X (Cont.)

```
SM4N16[;24+ι2]
    16          17
    16          17
    16          17
    16          17
    16          17
    16          17
    16          17
    16          17
    16          17
    16          17
    16          17
    16          17
    16          17
    16          17
    16          17
    16          17
    16          17
    16          17
    16          17
    16          17
    16          17
    16          17
    16          17
    16          17
    16          17
    16          17
```

APPENDIX XI
ORIGINAL PROGRAM (MDL) FOR SIMULATING GROWTH OF PERENNIAL GRASSES

```
[1]    CT1←INPK←CT2←1
[2]    HEADG←'   INPK   INP4  INP16   LBMI    LBM       SDB       LIT
[3]    RBM← 2000
[4]    COV←0.2
[5]    SDB←100
[6]    LIT←500
[7]    LBM←0
[8]          INPK     INP4     INP16     INPGI    DEG     INPT    LBMI
[9]    CT←0
[10]   INP16←INP4←17
[11]   BG←0
[12]   VIG←13⍴0
[13]   VIG[1]←1
[14]  BGLP:→(13≤BG←BG+1)/0
[15]   CT←0
[16]  LP:→(66≤CT←CT+1)/BGLP
[17]   CT1←0
[18]   INPK←INPUTS[CT;BG]×0.01
[19]  LBL2:CT1←CT1+1
[20]   →((INPK)≤SM4[1;CT1])/LBL
[21]   →LBL2
[22] LBL:CT2←SM4[;1]⍳INP4
[23]  LBL3:INP4←SM4[CT2;CT1]
[24]   CT3←SM4N16[1;]⍳INP4
[25]   CT4←SM4N16[;1]⍳INP16
[26]   INP16←SM4N16[CT4;CT3]
[27]   CT5←GRINC[;2]⍳INP16
[28]   INPGI←GRINC[CT5;1]
[29]   DEG←TEMPT[CT]
[30]   CT6←0
[31]  LOOP:CT6←CT6+1
[32]   →(DEG≤PCTGR[CT6;1])/RND
[33]   →LOOP
[34]  RND:INPT←PCTGR[CT6;2]
[35]   LBMI←((INPT×0.01)×INPGI)
[36]   →(21≥CT)/DEAL
[37]   LBMI←LBMI×VIG[BG]
[38]  DEAL:LBM←LBM+LBMI
[39]   →(65=CT)/PUT
[40]   →(0=LBMI)/JMP
[41]   →LP
[42]  PUT:TLBM[BG]←LBM
[43]   PLBM←LBM
[44]   LBM←0
[45]   →LP
[46]  JMP:→(0=LBM)/LP
[47]   VIG[BG]←VIGOR[⌈(PLBM÷100)]
[48]   LBM←0
[49]   →LP
[50]   →BGLP
[51]   +/ACTUAL
```

APPENDIX XII

PROGRAM(MDL2) FOR OPTIMIZING BIOMASS GROWTH INCREMENT USING ACTUAL SOIL MOISTURE AT 25 CM DEPTH AND NORMALIZING WEEKLY TEMPERATURES

```
                    ∇MDL2[⎕]∇
      ∇ MDL2
[1]     GROWTH←12⍴0
[2]     CT←0
[3]     COMP←(+/ACTUAL)*2
[4]     GRINC←40⍴,25
[5]   LP:→(13≤CT←CT+1)/PRINT
[6]     COEFF←⍉ 12 40 ⍴(NINPUTS×TEMP)
[7]   LOOP:TLBM[CT]←GRINC+.×COEFF[;CT]
[8]     GROWTH[CT]←GRINC[1]
[9]     NUM←+/ACTUAL[CT]-TLBM[CT]
[10]    DEN←+/ACTUAL[CT]+TLBM[CT]
[11]    RES←NUM÷DEN
[12]    COMP←1+RES
[13]    →(0.01>|RES)/LP
[14]    GRINC←GRINC×COMP
[15]    →LOOP
[16]  PRINT:'TOTAL LEAF BIOMASS:      ';TLBM
[17]    'GROWTH INCREMENT ESTIMATE:      ';GROWTH
      ∇
```

APPENDIX XIII

WEEKLY AVERAGES FOR "WET" (2), "MOIST" (1), AND "DRY" (0) DAYS AT 25 CM

SM10

2	2	2	2	2	2	1	2	0	2	2	2
2	2	2	2	2	2	2	2	0	2	2	2
1	2	2	2	2	2	2	2	0	2	2	2
1	2	2	2	2	2	1	2	0	2	2	2
0	2	2	2	2	2	1	2	0	2	2	2
0	2	2	2	2	2	1	2	0	2	2	2
0	2	2	2	1	2	1	2	0	2	1	2
0	2	2	2	1	2	1	2	0	2	1	2
0	2	2	2	1	2	0	1	0	2	0	2
0	2	2	2	0	2	0	1	0	2	0	2
0	2	2	2	0	2	0	1	0	2	0	2
0	1	2	1	0	2	0	1	0	2	0	2
0	1	2	1	0	1	0	0	0	2	0	2
0	1	1	0	0	1	0	0	2	2	0	2
0	1	0	0	0	0	0	0	1	2	0	1
0	0	1	2	0	0	0	0	0	2	1	0
0	1	2	2	0	1	0	0	0	2	1	0
1	1	2	2	0	2	0	0	0	2	0	0
2	1	2	2	0	2	0	1	0	2	0	2
2	0	2	2	1	2	0	1	1	1	0	2
2	0	2	2	1	2	0	0	2	0	0	2
2	0	2	0	2	2	0	0	2	0	1	2
2	1	2	0	2	1	0	0	1	0	2	2
2	1	2	0	2	0	0	0	1	0	2	2
2	1	2	0	2	0	0	0	0	0	2	1
2	1	2	0	2	1	0	1	0	0	1	0
2	1	2	1	2	1	1	0	0	0	0	0
2	1	2	2	2	0	0	0	0	0	0	0
2	1	2	2	1	0	0	0	0	0	0	0
1	1	2	2	0	0	0	0	0	0	0	0
0	1	2	2	2	0	0	0	0	0	0	0
0	1	2	2	2	0	0	0	0	0	0	0
0	1	2	2	2	0	0	0	0	0	0	0
0	1	2	2	2	0	0	0	0	0	0	0
0	1	2	2	2	0	0	0	0	0	0	0
0	1	2	2	2	0	0	0	0	0	0	0
0	1	2	2	2	0	0	0	0	0	0	0
0	1	2	2	2	0	0	0	0	0	0	0
0	2	2	2	2	0	1	0	1	0	2	1
1	2	2	2	2	0	2	0	2	0	2	2

APPENDIX XIV

APL PROGRAM SORT FOR COMPUTING DRY WEEKS PRIOR TO RAINFALL EVENT

```
        ∇SORT[⎕]∇
      ∇ SORT
[1]     CT1←CT
[2]     3←CTT←0 CT2←1
[3]     DRYDAYS←100⍴0
[4]   LOOP:(13≤CT1←CT1+1)/0
[5]     CTT←CT3←0
[6]     CT2←1
[7]     DRYDAYS←100⍴0
[8]   LP:→(66≤CTT←CTT+1)/PRINT
[9]     →(24≥INPUTS[CTT;CT1])/ADD
[10]    →~(25<CHECK)/LP
[11]    DRYDAYS[CT2]←CT3
[12]    CT3←0
[13]    CHECK←INPUTS[CTT;CT1]
[14]    CT2←CT2+1
[15]
[16]  ADD:CT3←CT3+1
[17]    CHECK←INPUTS[CTT;CT1]
[18]    →LP
[19]  PRINT:BIGDRY[⍳CT2;CT1]←DRYDAYS[⍳CT2]
[20].   →LOOP
```

APPENDIX XV

MODIFIED PROGRAM MODEL FOR SIMULATING GROWTH OF PERENNIAL GRASSES

```
                    ∇MODEL[⎕]∇
      ∇ MODEL
[1]     CT1←INPK←CT2←1
[2]     INP16←INP4←17
[3]     CT←LBM←BG←0
[4]    BGLP:→(13≤BG←BG+1)/0
[5]     CT←0
[6]     INP16←INP4←17
[7]    LP:→(66≤CT←CT+1)/BGLP
[8]     CT1←1
[9]    LBL2:CT1←CT1+1
[10]    →((INPUTS[CT;BG]×0.01)≤SM4[1;CT1])/LBL
[11]    →LBL2
[12]   LBL:CT2←SM4[;1]⍳INP4
[13]    INP4←SM4[CT2;CT1]
[14]    CT3←SM4N16[1;]⍳INP4
[15]    CT4←SM4N16[;1]⍳INP16
[16]    INP16←SM4N16[CT4;CT3]
[17]    INPGI←GRINC[CT5←(GRINC[;2]⍳INP16);1]
[18]    CT6←(⌈TEMPT[CT]÷5)-4
[19]    LBMI←(PCTGR[CT6;2]×0.01)×INPGI
[20]    →(17≥CT)/DEAL
[21]   DEAL:LBM←LBM+LBMI
[22]    →(65=CT)/PUT
[23]    →(0=LBMI)/JMP
[24]    →LP
[25]   PUT:TLBM[BG]←LBM
[26]    LBM←0
[27]    →LP
[28]   JMP:→(0=LBM)/LP
[29]    LBM←0
[30]    →LP
[31]    →BGLP
      ∇
```