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Title: THE EFFECT OF PRECIPITATION VARIATION ON SOIL MOISTURE, SOIL NITROGEN, NITROGEN RESPONSE AND WINTER WHEAT YIELDS IN EASTERN OREGON

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The semi-arid regions of the Pacific Northwest are characterized by a high degree of annual temperature and precipitation variation. As a result of this climatic variation, dryland nitrogen fertilizer trials on fallow-wheat rotations typically demonstrate a variable response. Wheat growers in the area must not only cope with this climatic variation and its sundry effects upon their livelihood, they must also make decisions regarding the future level of anticipated climatic variation.

The specific objectives were to: 1) develop a climatically responsive yield potential prediction model for soft white winter wheat from historical data at the Sherman Branch Experiment Station (Moro, OR); 2) modify this model for use on commercial fields; 3) field simulate five fallow-crop precipitation patterns characteristic of the variation found in the Sherman county area of eastern Oregon in order to test the yield potential model: 4) examine the effects of precipitation variation on nitrogen fertilizer responses,

moisture storage and depletion and nitrogen mineralization; and 5) establish a quantitative relationship between precipitation/soil moisture and nitrate accumulation in both the fallow and crop seasons.

Two interacting regression models were developed to estimate grain yield levels in the 250-350 mm precipitation zone of eastern Oregon. The first model estimates yield potential from monthly precipitation and temperature values. The second model estimates the percent grain reduction due to delayed crop emergence. The grain yield model was adapted to commercial fields using a Productivity Index factor (PI). The PI is a measure of the productivity of other locations in relation to the Sherman Branch Experiment Station, using water-use-efficiency (WUE) as the basis of comparison.

The field simulation of five fallow-crop precipitation patterns demonstrated that the maximum grain yield response occurred at 40 kg N (soil + fertilizer)/metric ton.

The grain yield model demonstrated a 15% level of accuracy on a commercial field basis in both field trials and a survey of past production levels (1972-1980).

It was hypothesized that the distribution of precipitation in the fallow and crop periods had an effect on both the amount and distribution of stored soil moisture. The field simulation demonstrated that more soil moisture was stored at the 90-240 cm depths by the patterns with more fallow season precipitation when measured in March of the crop year.

Soil moisture storage and storage efficiencies fluctuated throughout the fallow and crop periods. At the cessation of the winter precipitation season in both the fallow and crop periods (March), the storage efficiency was highest when low levels of precipitation occurred. At this point in time, the mean crop period storage efficiency was 10% below the mean fallow period storage efficiency (34 and 44%, respectively) in both simulation studies.

Soil moisture, temperature and immobilization requirements of crop residues interact to affect the net amount of nitrogen mineralization. The mineralization model proposed by Stanford and Smith (1972) was tested under field conditions. When the nitrogen immobilization requirement of the crop residues was included, the actual and predicted values were in agreement at the close of the 1978 fallow period. A nitrogen deficit was predicted at the 0-30 cm depth at the close of the 1980 fallow; however, the actual levels indicated a net accumulation of nitrate-nitrogen.

Crop season mineralization, inferred from Mitscherlick and a-value extrapolations, in 1979 demonstrated that there was a decreasing amount of net mineralization during the crop season with increasing amounts of both fallow and crop season precipitation. Crop season mineralization in 1980 indicated that there was no net accumulation of nitrogen, rather a tie-up of 14 kg N/ha. This result reflects both the unsatisfied immobilization requirement predicted for the 1979 fallow season and crop season denitrification.

THE EFFECT OF PRECIPITATION VARIATION ON SOIL MOISTURE, SOIL NITROGEN, NITROGEN RESPONSE AND WINTER WHEAT YIELDS IN EASTERN OREGON

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This thesis is dedicated to my parents who loved me and taught me to strive to the best of my ability in every aspect of my life.

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THE EFFECT OF PRECIPITATION VARIATION ON SOIL MOISTURE, SOIL NITROGEN, NITROGEN RESPONSE AND WINTER WHEAT YIELDS IN EASTERN OREGON

INTRODUCTION

The Pacific Northwest is a diverse climatic area. The semi-arid regions of the Columbia Basin and Plateau in the Pacific Northwest are characterized by a predominantly winter rainfall pattern but, because this region lies to the east of the Cascade Range, it incurs the predominantly continental climate of the Intermountain Region. The Columbia River Gorge moderates the temperature extremes in both the winter and summer by providing a natural eastward migration route for the Pacific air masses moving inland. As a result, extremely long cold or hot periods do not generally persist for more than a few days at a time. The environmental factors of precipitation and temperature are highly variable in this region as is characteristic of semi-arid areas. It is generally assumed that the seasonal weather variation follows a relatively normal distribution so that in the long-term, very wet seasons occur with approximately the same frequency as very dry seasons. This generalization is approximately true for all but the driest areas of the region.

The major soils of the area (Walla Walla, Ritzville and Condon) are primarily loess derived and generally well suited for agriculture where suitable soil depth occurs.

In general, the climatic and edaphic conditions occurring in the Columbia Basin and Plateau are seldom unfavorable for successful farming. In the absence of irrigation facilities, the primary crops grown are winter cereals with soft white winter wheat predominating. Wheat is generally grown in a fallow-wheat rotation. The fallow period begins after harvest (July and August) and continues 14 months until the crop is planted in September and October. The crop is harvested about 10 months later.

Fallowing is an essential component in this cropping system. Precipitation is highly variable and if an annual cropping system were used, the production level and farmer income would also be highly variable. Fallowing stores a portion of the received precipitation in the soil profile during the 14-month period thereby buffering the subsequent crop against an insufficient level of crop season precipitation. Fallowing tends to stabilize yields and farmer income.

Fallowing is also an attempt to insure that a moist seedbed will be available for fall planting. Because of the variable winter precipitation pattern of the area, significant amounts of precipitation may not occur until October or November. If an annual cropping system were used, the seedbed could remain dry until the fall rains would wet-up the seed-zone and initiate germination. Seeding would either be into a dry seedbed or delayed until sufficient moisture was received. Research has demonstrated that the establishment of an early, vigorous stand is essential to achieving potential yields. The system of fallowing attempts to keep the seed-zone moist so that the crop can be planted into moist soil during the optimal period of time.

In the fallow-wheat rotation, crop residues are incorporated into the upper 15 cm of the soil through tillage. By maintaining residual soil moisture in this zone, fallowing can increase the rate of biological decomposition of the incorporated organic matter. This increased rate of decomposition in conjunction with an extended period of activity results in an increased level of nitrate accumulation at the end of the fallow period as compared with an annual cropping system. This biological activity, like the other aspects of the environment, is seasonally variable.

Significant increases in the level of wheat production are usually obtained by the addition of N fertilizer to the soils of eastern Oregon. Previous research has demonstrated that this response is, to a large degree, influenced by varietal characteristics, seasonal variation in precipitation and temperature and soil depth. Hunter et al. (1957) concluded from more than 200 sites of N fertilizer trials over a 3-year period of time that nitrogen fertilizer recommendations for specific farms within any county cannot be made on the basis of the average fertilizer response in that county due to the wide variation in yield responses found on individual farms.

The general purpose of this research was to measure the effects of seasonal variation in precipitation and soil and fertilizer nitrogen levels on grain yields of soft white winter wheat. The quantitative relationships among these factors are to be integrated into a moisture-nitrogen-yield management model whose purpose is to more accurately predict the response to applied nitrogen fertilizer for a specific farm or field. It is assumed that precipitation is the factor most limiting yield and nitrogen fertilizer response. Management decisions regarding nitrogen fertilizer additions must be implemented in this cropping system before the actual level of precipitation is fully known. These decisions can occur during the fallow period, at planting and in the spring of the crop season. The use of anticipated precipitation probability values in conjunction with recorded monthly levels of previous rainfall, however, can be used to reduce the risk of anticipating future levels of precipitation.

The objectives of this research were:

1) The development of a climatically responsive yield potential prediction model for soft white winter wheat using historical data from the Sherman Branch Experiment Station (Moro, OR). The intent is to modify this model for use on commercial fields in order to estimate their seasonal yield potential and N requirements. Such a model would be verified using both commercial field and experimental plot responses to climatic inputs.

2) The field simulation of five fallow-crop precipitation patterns characteristic of the variation found in the Sherman County area of eastern Oregon. This simulation serves as a variable site to test the yield potential model and also to examine the effect of precipitation variation on fertilizer responses, moisture storage, and depletion and nitrogen mineralization in the fallow and crop season.

3) Investigate the effect of seasonal precipitation variation on soil nitrogen mineralization in the fallow and crop periods. It was hypothesized that since soil temperatures vary considerably less than precipitation that moisture was the factor most strongly influencing the N mineralization rates. The objective was to establish a quantitative relationship between precipitation/soil moisture and nitrate accumulation in both the fallow and crop seasons.

The thesis is presented in four sections: a literature review of the subjects discussed, a manuscript detailing the moisture-nitrogen-yield management model, a manuscript detailing the effects of seasonal precipitation variation on moisture and nitrate-nitrogen accumulation, and an appendix of information and data not presented in the two manuscripts.

LITERATURE REVIEW

Climatic and Soil Moisture Effects on Wheat Production

The majority of the world's small grain production occurs in the mid-latitudes where summer temperatures average 21-24°C. This area of production is limited at the lower latitudes by high summer temperatures and by the length of the growing season at high latitudes (Thompson, 1975). Thompson (1975) studied the historical weather effects on wheat production in the Great Plains and Mid West. He found that the highest yields for an area occur when the weather is near normal or slightly cooler than normal. When weather variables deviate sharply from the norm, yields are lowest. More specifically, he demonstrated that the highest yields of grain occur in summers with lower than normal summer temperatures for a particular area. This is due to two major weather factors: 1) higher rainfall amounts are generally associated with cooler weather and 2) cooler weather permits greater storage of photosynthate. The temperature effect on wheat physiology is most adverse when higher than normal temperatures occur during the period of flowering to ripening.

Nuttonson (1953) studied the thermal requirements of Kharkof winter wheat in the Pacific Northwest. He found that the length of time from planting to emergence was inversely related to temperature. However, if rapid emergence did not occur, the seed remained dormant an unpredictable period of time. The length of time from planting to emergence had no effect on the heading or ripening date. Emergence to heading required approximately 510 degree-days (4.44°C base) and heading to ripening required approximately 532 degree-days. Nuttonson also demonstrated that the winter temperatures had little effect on heading or ripening dates.

The climate of an area, in general, limits the production level for each year. Since the climate, i.e., precipitation and temperature, is composed of uncontrollable factors, then it can only be managed, in a sense, by using long-term weather records to estimate probabilities of future climatic events. Pengra (1952) attempted to estimate wheat yields at seeding time in the Northern Great Plains. He found that above normal precipitation seldom occurred following a fallow season with a marked deficit in stored soil moisture. However, a majority of the years with adequate stored soil moisture at seeding time had above average growing season precipitation. Army et al. (1959) quantitated this idea of estimating future climatic events by generating cumulative probability tables for both precipitation and yield levels. They found from long-term weather and yield records that a wheat-fallow or wheat-sorghum-fallow cropping system produced 0.67 MT/ha or more approximately 80% of the time whereas annual cropping produced 0.67 MT/ha or more approximately 50% of the time. Regression analysis demonstrated that the precipitation level and associated weather factors from October to June accounted for 55-66% of the grain yield variation. They then developed a cumulative probability curve for the precipitation levels of October-June of the crop year and used it for selecting a cropping system on both a regional basis and a yearly basis within a region.

The use of precipitation probabilities has been utilized more recently in nitrogen fertilizer-crop management models for winter wheat in Montana (Jackson and Sims, 1977) and for corn in Romania (Isfan, 1979). Both of these management models rely on a strong correlation between yield and moisture (as either stored or received) during the period preceding the application of nitrogen fertilizer.

Whittlesey and Colyar (1968), using an economic perspective for nitrogen-wheat yield responses, concluded that if knowledge regarding moisture were perfect, a farmer could maximize his income by applying N fertilizer in balance with the known level of moisture. However, as weather in the short-run is certain, the knowledge of long-run probabilities of weather occurrence can help one counter the effects of uncertainty.

Smika (1970) compared yield level, yield stability, water-use-efficiency (WUE) and N-content of the grain for fallow-wheat and annual wheat in the semi-arid Great Plains using a 27-year record. He found that a fallow-wheat system was more stable and had 80% greater water-use efficiency when the annual precipitation level was between 246 and 430 mm. Within this precipitation range annual cropping had a failure rate of 30%. Smika found that 580 mm or more of annual precipitation was required before annual cropping with N fertilization used water as efficiently as fallow-wheat without fertilization. He concluded that in all aspects of the study, a fallow-winter wheat system was superior to annual cropping in the Great Plains and was necessary for stable production in the variable semi-arid climate.

The practice of fallowing land is common to the semi-arid regions of the United States. It is used to store additional moisture in the soil profile prior to planting the crop. Fallowing serves to reduce N fertilizer requirements through the natural accumulation of mineralized nitrogen via the decomposition of soil organic matter and residues. It is also practiced to control weeds. From an economic standpoint, fallowing is utilized to maximize crop production (Bauer and Conlon, 1974; Michalyna and Hedlin, 1961; Olson and Rhodes 1953). As a moisture storage practice, fallowing is inefficient. Published fallow storage efficiencies in the Great Plains range from 8.6 to 42% (Mathews and Army, 1960; Bracken and Cardon, 1935; Greb et al., 1967; Smika and Wicks, 1968) and 40 to 64% in the Pacific Northwest (Lindstrom et al., 1974). However, its importance in stabilizing production has been demonstrated by many researchers (Bracken and Cardon, 1935; Greb et al., 1967; Smika, 1970; Smika and Wicks, 1968). Yield stability results from fallowing because sufficient additional moisture is stored to bring the wheat crop to the point where it can begin producing an economic crop. This threshold value of production has been intensively studied across a wide range of environmental conditions. Johnson (1964) conducted an exhaustive study of the literature for the Great Plains and found threshold values ranging from 178-203 mm. Army et al. (1959) also reported a threshold value of 127 mm. Johnson determined that the grain yield contribution from a millimeter of soil moisture ranged from 2.6 to 9.3 kg/ha/mm. He also demonstrated that management factors (i.e. time of plowing and fertilizing) could reduce this value 0.69 to 1.99 kg/ha/mm of stored soil moisture. According to Johnson, stored soil moisture was the most important measurable factor affecting the success of a wheat crop. Olson et al. (1964) studying fertilizer responses in dry and wet locations found that with proper fertilization of wheat, each additional millimeter of soil moisture resulted in a yield increase of 15.9 kg/ha. DeJong and Rennie (1969) in Canada found that 120-150 mm of soil moisture were required before grain production of spring wheat began and, thereafter, the yield increased 80-110 kg/ha for each additional cm of soil moisture.

Johnson and Davis (1980) conducted a 10-year study of moisture accumulation, tillage effects and water use on winter wheat yields. They found a high correlation (r = 0.97) between total water use and yield. The average grain yield increase was 162 kg/ha for each millimeter of water use. The average grain yield increase was 182 kg/ha per millimeter of soil water used and 149 kg/ha per millimeter of growing season precipitation. Statistical analysis indicated that the level of growing season precipitation had the greatest overall importance in determining the level of wheat production.

In the Pacific Northwest, Leggett (1959) demonstrated that approximately 102 millimeters of soil moisture were required to grow a wheat crop to the point where grain production begins. Each additional millimeter of moisture resulted in a 390 kg/ha increase in yield.

Brown (1971) demonstrated that this threshold value is not static but is related to the fertility status of the crop. He found that the amount of soil moisture required to reach the point of initial grain production increased with an increase in N fertility and ranged from 80 to 110 mm of soil moisture.

Eck and Tucker (1968) were unable to relate wheat yields and N responses to stored soil moisture, growing season precipitation levels and six other climatic and agronomic variables. While grain yield and N responses were correlated to total precipitation, it was a weak association. Apparently, precipitation distribution rather than the total amount is most important in this region because comparable yields were attained over a wide range of precipitation totals. Po chop et al. (1975) also concluded from a principal component analysis of wheat yield and weather factors in Wyoming that in semi-arid regions, the timing of rainfall is often as influential as the total amount of precipitation. They found that additional moisture in the mid-portion of the growing season produced the greatest yield response. Additional moisture early in the growing season had a negligible effect and there was a negative effect late in the growing season. Russell (1968) in Australia similarily found that rainfall near harvest reduced yields. However, he found that pre-heading precipitation increased grain yield in a linear fashion. In conjunction with this finding, he stated that winter rainfall in the growing season was more important to the crop than spring rainfall.

Greb (1979) examined the relative value of stored soil moisture and crop season precipitation using historical data from research plots in Akron, Colorado. His analysis demonstrated that the relative value of moisture, whether stored or occurring as precipitation is highly related to the evaporation exposure. Stored soil moisture at seeding was not subject to a high evaporative demand and was found to be several times more efficient than crop season rainfall and approximately 1.7 times more efficient than captured snowmelt, captured runoff water or sprinkler irrigation.

Greb constructed an arbitrary index of water use efficiency for various periods of moisture reception:

Source of Water for Plants	WUE Index
Stored soil water	100
Captured snow melt in soil	89
Sprinkler irrigation plus evaporation	62
Captured runoff plus evaporation	57
Cool season rainfall plus evaporation	25
Warm season rainfall plus evaporation	22

While the WUE index may not be specifically applied to all crops, it does serve to demonstrate in a general way the plant-water-climate relations for the west-central Great Plains. According to Greb, the value of crop season rainfall varies widely in relation to the stages of plant development, intensity and frequency of rainfall events.

Isfan (1979) found that in Romania, two periods of time (winter and summer) were highly correlated with yield and N-fertilizer responses. For the same total amount of precipitation (winter + summer) the N rate and yield increased with the level of winter precipitation. The enhanced effect of winter precipitation on yield and N response is probably due to greater infiltration during this time, reduced evaporative losses and greater leaching of mineral N than during the summer months. Isfan demonstrated that summer precipitation directly influenced the efficiency of the N fertilizers and the optimum N rate when a reserve of soil moisture had been accumulated during the winter months. Consequently, during less rainy winters, the optimum N rate depends primarily on winter precipitation.

Bracken and Cardon (1935) found that a larger percentage of precipitation (57-69%) was found in the upper

180 cm profile after the first winter in a fallow-crop rotation in Utah than in any other portion of the entire fallow-crop cycle. The second winter period of the fallow-crop cycle stored only 45% of the rainfall on the average. They attributed this lower storage efficiency to plant transpiration, reduced infiltration compared with stubble land and a greater tendency for evaporation to occur from crop land. Over the entire fallow-crop cycle, they estimated that only 30% of the precipitation received was stored and later transpired by the wheat crop.

Read and Warder (1974) in Saskatchewan determined that rainfall during the growing season had a greater influence than stored soil moisture on wheat yield and protein content of unfertilized plots. On fertilized plots, though, stored soil moisture had a greater influence on the variation in grain yield and protein content.

Baier and Robertson (1968) attempted to assess the performance of soil moisture estimates vs the direct use of climatological data for estimating crop yields in Australia. They examined 39 sites over five seasons and concluded that wheat yields were more closely related to estimated daily soil moisture than to precipitation, maximum or minimum temperatures. Rainfall on a monthly basis, rather than on a crop development basis had the strongest influence on yield. This unexpected result may be explained by four scenarios: 1) light rains may not penetrate and be effective, 2) heavy rainfall may runoff, 3) a moderate rain at or near the end of a developmental period may have no effect on that growth stage, 4) a moderate rain prior to a developmental period may have a strong effect on that growth stage. They concluded that a soil moisture budget avoided these shortcomings.

Soil moisture was most important to the crop following jointing when growth accelerates. Simple correlations between yield and moisture zones showed a tendency for deeper soil moisture to be more important as growth progresses. Ample moisture at medium depths from jointing to heading were most important for high yields. This is followed in importance by moisture at deeper depths presumably to support filling and ripening. Taylor et al. (1974) in a later Australian study found that the inclusion of a NO_3-N X soil moisture interaction gave a more reliable index of grain yield potential than soil moisture alone.

Moisture X Nitrogen Interactions in Wheat Production

The proper balance of applied nitrogen fertilizer to available soil moisture is a prime concern in dryland winter wheat production, according to Ramig and Rhodes (1963). They studied the interrelationships of pre-plant soil moisture level and nitrogen level on winter wheat production for a three-year period using four levels of soil moisture and eight N rates. A multiple regression of nitrogen fertilizer rate and soil moisture at seeding on grain yield accounted for 70-80% of the variability in yield. Their data demonstrated that there was greater grain yield, nitrogen uptake and efficiency of nitrogen utilization by the wheat crop as the nitrogen rate and pre-plant soil moisture level increased. The water use efficiency (WUE) of the crop increased with the N rate and pre-plant soil moisture level up to 150 mm of added water. There was an interaction in which low moisture levels did reduce WUE when the N rate was above 22.4 kg N/A. Residual soil-N accumulated only when soil moisture levels were low.

The effect of increasing WUE of winter wheat by proper applications of N fertilizer has been well documented (Brown, 1971; Singh et al., 1975; Olson et al., 1964; Hunter et al., 1957; Viets, 1962; Ramig and Rhoades, 1963). However, the effect of N fertilization on water use and soil water depletion remains controversial. Many researchers have found that a wheat crop fertilized with N can extract more moisture from the soil than a non-fertilized crop. Olson et al. (1964) found that fertilized grain crops uniformly removed additional water from the top 90 cm of soil and each millimeter of additional water extracted resulted in a yield increase of 15.9 kg/ha. Singh et al. (1975) demonstrated that water use was enhanced by N fertilization. It resulted in greater water depletion during intermediate growth stages and these differences increased with crop development. Between 25 and 40% more water was extracted by optimally fertilized crops as compared with the control. There was little difference in extraction at the 0-75 cm depths but below 75 cm, 2.4 times more water was extracted.

Bond et al. (1971) examined the effect of a relatively high rate of N on water use during different growth periods of spring wheat. Applied N (151 kg/ha) increased total water use 14-28% due to increased water use between tillering and heading. Less moisture was used by N fertilized plots after heading. In two or three years there was adequate moisture. remaining at heading to greatly increase the yield over the check plot. When moisture was limiting at heading, the yields were comparable for the 0 and the 151 kg N/ha. Soil moisture extraction extended 90-120 cm depending upon the year. The N fertilized plots extracted more moisture and this extraction occurred at the deeper depths late in the growing season. They also found that over-winter soil moisture storage was increased 7-31% by N fertilization of the previous crop. This was attributed to the lower water content of the profile increasing the infiltration rate.

According to Brown (1971) soil water depletion by winter wheat increased with increasing amounts of N fertilizer. Net depletion began at the booting stage and differential effects were most significant between 90 and 120 cm. There were no differences below 120 cm.

Koehler (1960) found that both fertilized and unfertilized wheat used all the available moisture to a depth of 152 cm, but the fertilized wheat did extract significantly more at the 183-244 cm depth indicating a deeper penetration of the soil by roots. Kmoch et al. (1957) found similar responses when they studied wheat root weight and distribution in relation to available soil moisture content and N fertilization. They found 50 percent greater root weight due to N fertilization regardless of the depth sampled and the N fertilized wheat did extract more water from the 300 cm soil profile. Nitrogen fertilization did not appear to have any effect on rooting depth.

Holbrook and Welsh (1980) evaluated the soil water extraction patterns of two tall varieties and 3 semi-dwarfs in eastern Colorado. They found that there was no significant difference in total water use or extraction pattern over time and profile depths.

Several studies have found that both nitrogen and phosphorous fertilization do not affect soil moisture extraction and water use. Viets (1962) cites studies of Zubriski and Norum working in North Dakota that demonstrated while there was a phosphorous response in wheat there was no different in water use. However, they measured only to a 150 cm depth. Power et al. (as cited by Viets, 1962) found that phosphorous fertilization of spring wheat in Montana had no consistent effect on cumulative soil moisture use or total moisture use from seeding to tillering, to heading, to dough stage or to harvest. Alessi and Powers (1977) further studied the residual effects of N fertilization on spring wheat in Montana and found a wide range of consumptive water use values (26-34 cm). They argue that water use is generally controlled by the amount available in a given season rather than by soil fertility or management factors. DeJong and Rennie (1969) found similar results with spring wheat grown in Canada.

Papendick et al. (1971) examined the effect of N fertilization and soil moisture content on water extraction by following the changes in soil water potential. They used soil water potential measurements because they felt water content data did not adequately reflect the soil depth-extraction pattern. They found that winter wheat grown in the dryland areas of eastern Washington could extract moisture to a range of 30 to 33 atm without N fertilization. Nitrogen fertilizer further stimulated moisture extraction to potentials of 35 to 40 atm. Nitrogen fertilization increased root density in the upper 150 cm profile. The increased root density increases the absorbing surface area of the root system. As soil moisture is depleted, the unsaturated hydraulic conductivity and rate of water flow rapidly decrease; the density of rooting then becomes important in reducing the distance moisture must move under unsaturated conditions. They concluded that N fertilization increased the extent of moisture removal by its effect on root density.

Papendick et al. also found that the consumptive water use between spring and harvest was lower than expected. They determined that this anomoly was due to upward water flow from beyond the rooting dpeth. Therefore, crop available water may exist outside the zone of root penetration and as long as upward flow can keep pace with the evapotranspiration rate, the water content or water potential of the soil may change very little with time. Rickman et al. (1978) also noted that in eastern Oregon there was upward moisture flow into the root zone from beneath a cemented layer at 150-180 cm.

Sharma and Ghildyal (1977) studied the development of winter wheat roots under dry and moist conditions in a pot experiment. They demonstrated that root systems developed under relatively dry soil conditions (15 bar) were capable of extracting a greater amount of soil moisture on a unit root volume basis than root systems developed under moist conditions (0.33 bar).

However, Singh et al. (1975) found that the higher the initial soil-water storage level, the greater was the amount of water extraction from the profile. They did not measure root density, but Aldrich et al. (1935) has demonstrated that soil-water loss is positively correlated with root density. According to Holbrook and Welsh (1980) this correlation indicates that soil-water loss can be accepted as an indicator of root density providing the soil water content is such that water movement is slow and not the result of surface evaporation.

Bole and Pitman (unpublished data) modeled grain yield and protein content of spring barley as a function of stored moisture, crop season precipitation and the level of N fertilization. This model demonstrated that stored soil moisture was the most influential and nitrogen level was the least influential single factor variable. The interaction of stored soil moisture and N level had more effect on yield than any other interaction variable.

Environmental Effects on Soil-Nitrogen Fertility

Early climate-yield relationships attempted to explain the yearly differences in crop yields through the variations in atmospheric conditions prevailing during the growing season of the crop. Such relationships have never fully accounted for yield variations. Van der Paauw (1966) concluded that the omission of soil aspects in investigations concerning relationships of weather to crop yield has limited the value of these studies.

Van der Paauw (1963) investigated the periodic trends of soil fertility components and found that they were the result of the fairly regular alternation of periods of different amounts of precipitation. He demonstrated that cyclic crop yields and crop responses to fertilizer could be related to the periodicity of soil fertility. The fertility status of the soil then is an intermediary between climatic fluctuations and crop yields. He further states that the total soil fertility complex is affected and fluctuates under the cumulative influences of alternating precipitation periods. He demonstrated that available soil N displayed gradual fluctuations corresponding to those of precipitation periods and that crop responses to N were largely controlled by relatively small differences in the total amount of winter precipitation in northern Europe. He also suggested that the N status of the soil could be affected in the long-run by the cumulative effects of alternating precipitation periods. His research demonstrated that the winter precipitation regime had an effect on N, P, and K response as well as soil pH changes. He speculated that fluctuations in N availability may also be due in part to changes in the physical condition of the soil. The microbial behavior of the soil may also be a function of the soil's physical and chemical changes which in turn would affect fertility status and crop growth.

Van der Paauw (1962) examined the relationship between winter precipitation and yield at varying nitrogen rates. Moisture was added and excluded each year. He found that in the wet years and in plots receiving additional moisture there was a reduction in yield because nitrogen was leached below the root zone. The dry years and the plots with excluded moisture had slightly higher yields of winter wheat because more N was available.

A fallow period in a cropping system is generally utilized to store additional moisture and to accumulate forms of inorganic nitrogen mineralized through the decomposition of soil organic matter and residues. Bauer (1968) sampled 69 fallowed and non-fallowed sites over a four-year period in North Dakota. He found that the difference in water storage between fallowed and non-fallowed fields decreased from west to east within the state while available nitrogen generally increased from west to east. The range of precipitation during this study was from 362 to 533 mm. Precipitation generally increased from west to east within the state. It appeared that the amount of N accumulation increased with a decrease in precipitation and water storage in the soil.

Bracken and Greaves (1941) studied nitrate accumulation in a fallow-wheat rotation at different locations, all with the same mean annual temperature. They found that the amount of soil nitrate and organic matter increased with precipitation, probably as a logrithmic function.

Gogulwar (1973) established different levels of preplanting moisture in a fallow wheat system in Nebraska. He found that total soil nitrate did not change due to the moisture level at planting but its distribution was altered by the moisture treatments. Increased amounts of moisture leached N deeper into the profile. Aktan (1976) found that the level of fallow season moisture in eastern Oregon did have a significant effect on soil nitrate accumulation and distribution. He demonstrated that the highest level of nitrate accumulation occurred under normal and wet fallow moisture levels. Dry fallow moisture levels resulted in a lower level of nitrate accumulation.

Swenson et al. (1979) conducted a three-year study of fallow season nitrate accumulation on 13 representative soils in North Dakota. They determined that during dry years the amount of nitrate accumulation from mineralization will be less during fallow because conditions are not optimum for nitrification. Nitrate accumulation between fall and early spring was not great and they concluded that soil samples collected in the fall were good indicators of the nitrate level. For the North Dakota environment, leaching of nitrate was not a source of N loss in the years with normal and below normal levels of precipitation.

Leggett (1959) sampled the soil nitrate and moisture content at the end of the fallow period of 57 fields over a 5-year period of time. These study areas were located in three precipitation zones: less than 254, 254-381 and greater than 381 mm of annual precipitation. He found no correlation between moisture storage at the end of the fallow period and **nitrate** accumulation level either within each zone or in the total association of zones. Since most of the moisture is stored during the winter when the temperature is low, the moisture supply apparently does not greatly influence the amount of N mineralized.

Bauer and Conlon (1974) studied the effect of tillage on nitrate accumulation in North Dakota over a 5-year period. They found that tillage intervals of 4, 5, 6 or 7 weeks did not affect nitrate accumulation or stored soil moisture. They noted that there was essentially no change in soil nitrate content at depths greater than 60 cm during the fallow period. This suggested that there was no downward movement of nitrate nitrogen.

Wiese and Lavake (1979) studied the influence of weed growth and tillage interval on nitrate and soil water accumulation in the southern Great Plains. The tillage intervals ranged from every 2 weeks to 24 days after weed emergence. Increasing the frequency of tillage increased the level of nitrate accumulation in an almost proportional manner. Approximately 20 kg N/ha were released for each tillage operation. Delaying tillage 17-24 days after weed emergence did reduce the amount of stored soil moisture and wheat yields.

In their seven-year study there was a 3.9-fold difference in annual soil nitrate accumulation. This variation demonstrated a weak correlation with the amount of available soil moisture to a 120 cm depth at the end of the fallow period.

Birch (1960) studied nitrification in tropical soils after different periods of dryness. He found that after moistening a dry soil, two stages of organic matter decomposition could occur: 1) there would be no nitrification and 2) there would be nitrification. Drying would have a more transient effect on 2) than 1). He showed that the rate of N mineralization after moistening decreased more rapidly than carbon mineralization, therefore, the C:N ratio increased as organic matter decomposition preceded unless a drying period intervened. The drying introduced a new flush of nitrate once re-wetted.

In field studies, Birch demonstrated that high temperatures during the dry season enhanced the intensity of the nitrate flush upon re-wetting. The effect of unseasonal rains during a normally dry period would be to shorten the length of the dry period prior to the rainy season when growth occurs. The unseasonable rains tended to reduce the total amount of mineral N produced and available to the crop. He was also able to demonstrate that the increase in crop yield/mm of precipitation during the early growth period was twice that for rainfall received later in the growing season. This was due in part to a more intense nitrate flush early in the season following the dry season.

Storrier (1962) noted a similar response in wheat from southern New South Wales. Rains of greater than 25 mm following a dry period in the spring did stimulate mineralization of organic nitrogen and increase yield. The additional moisture influenced the final yield in two ways. First it provided additional available soil moisture and, secondly, it increased the concentration of available soil nitrate.

Campbell et al. (1973) investigated the short-term effects of rainfall and subsequent drying on changes in soil N and P. They related these changes to microbially mediated and physical processes. They determined that nitrate moved up and down the soil profile with the flow of fallow moisture. ^{36}Cl would accumulate in the upper 15 cm of the profile even when the soil was at the permanent wilting percentage in late August and September. Rainfall amounts greater than 1.75 cm leached soil nitrate at least

30 cm.

Their research demonstrated that as the soil water content at 0-2.5 cm increased, the concentration of soil nitrate decreased. If the soil water content decreased rapidly, as in air drying, then the soil nitrate concentration would increase. If the soil water content decreased slowly, then there was no accumulation of soil nitrate. They pointed out that these results could be due to mineralization and/or upward movement. The favorable conditions for both processes are the same. They concluded from similar work done on phosphorus mineralization, phosphorous being non-mobile, that the accumulation of soil nitrate in the upper soil profile was due more to upward movement than N mineralization.

Russell (1968) stated that the climate has an effect on N transformations and movement through its effect on temperature, wetting and drying cycles and leaching. Winter conditions other than precipitation have not been previously considered important in determining N response. However, he demonstrated that it is possible for low evaporation in association with cold, wet soil conditions to inhibit mineralization of soil N and produce a greater crop response to applied N.

Stanford and Epstein (1974) studied the relationship between soil nitrogen mineralization and soil water content/ matric suction in 9 different soils. They found that the highest mineralization rates occurred between 1/3 and 1/10 bar i.e. when 80-90% of the pore space was filled with water. From the optimum soil matric suction (1/3 to 1/10 bar) to 15 bar, there was a linear, negative relationship between mineralized N and soil matric suction. Soil water contents above optimum reduced nitrate accumulation due to denitrification.

Miller and Johnson (1964) also found similar results when they studied ammonium and nitrate production over a wide range of soil moisture tensions. Nitrification was maximized at 0.15-0.50 bar. It was limited by moisture at higher tensions and by aeration at lower tensions. Nitrification did occur very slowly at tensions above 15 bars.

Parker and Larson (1962) examined the effects of soil temperature on nitrification. Between 16 and 20°C, each 2° decrease in temperature had a measurably negative effect on nitrate accumulation. Above 25°C there was no measurable temperature effect. Mulched soils were 1-2°C lower than bare soils and this reduced nitrate accumulation. Mulched soils generally had a higher moisture content and this retarded nitrification when it approached saturation. At low soil temperatures, ammonification rather than nitrification was the avenue most limiting nitrate accumulation.

According to Harmsen and Kolenbrander (1965), ammonification continues over a wide range of soil temperatures but nitrification ceases at 45°C. In the mineralization process, the rate limiting step is ammonification because over the range of normally occurring soil temperatures

(0-35°C) almost complete conversion of ammonium to nitrate-N occurs in aerated soils.

Stanford and Smith (1972) determined from laboratory incubations that mineralization was optimized at 35°C. They determined that cumulative N mineralization over time conformed to a first order equation:

$$\log (N_o - N_t) = \log N_o - K/2.303(t)$$

where

N_o = potentially mineralizable N
N_t = amount of N mineralized in time (t)
K = mineralization rate constant for a specific temperature ($^{\circ}$C)

Stanford, et al. (1973) determined the K values for 11 different soils at 5, 15, 25 and 35°C. They found no difference among the soils and determined that the Q_{10} for the mineralization rate constant was approximately 2.0.

Smith, et al. (1977) integrated this knowledge of moisture and temperature effects on N mineralization to examine soil nitrogen mineralization potentials under modified field conditions. Two procedures were used. Firstly, soil was placed in filter tubes (50 ml capacity) at optimum moisture content and the top sealed; the stem was left open. These tubes were installed in an upright position at a 7 cm depth in field microplots. They were leached monthly to determine the amount of N mineralized and then they were replaced in the microplots. This procedure represented the case where soil water was always at field capacity and, therefore, never limiting to mineralization. The second procedure required that soil from the microplots be placed in plastic bags and then buried at a 7 cm depth. In this case, soil moisture varied with each monthly sampling but remained essentially constant in the bag. Net accumulation of N was calculated according to the following equation:

$$N_t = N_o \cdot K \cdot Y$$

where

N_t = net accumulation of N

N_o = N mineralization potential for the soil

K = rate constant for a specific mean temperature

Y = soil water content expressed as a percentage of field capacity

In general, the calculated amounts were strongly correlated ($r=0.88$) with the actual field amounts. The differences were frequently less than 10 ppm N. The calculated amounts correlated as well or better with the field amounts than did six other nitrogen availability indices.

Herlihy (1979) substantiated these findings to a limited degree in Ireland. He found that there was agreement between experimental and calculated values of mineralized N only when moisture was held relatively constant and when mean temperatures were not rising rapidly. The fluctuation of soil moisture stimulated greater N mineralization than calculated. This result was apparently due to the increase in energy sources and the partial sterilization effects of the wet-dry cycles reported by Birch (1960). Herlihy speculated that this concept may not be applicable under arable cropping systems where drying and re-wetting are commonly associated with the periodic exposure of new suffaces during spring cultivation and with wetting and rapid drying cycles later in the season.

Kowalenko (1978) studied N transformations and movement over a 17-month fallow period in field microplots using N^{15} in Canada. He demonstrated that denitrification was quantitatively most significant (19%) during the late spring and summer when anaerobic conditions induced by high water content would be expected to be minimal in relation to other seasons. During the wet fall, denitrification was much less (4%) even though there were significant amounts of nitrate present. His data suggested that during the fall significant denitrification occurred in the upper horizons, where organic matter is higher, and proceeded almost simultaneously with high rates of nitrification. This resulted in little net change. Mineralization rates were also high during the summer months (2.3 kg/ha/day) but they could not be calculated from the fall to early spring because of high rates of leaching. Overall, 65% of the N fertilizer was lost due to denitrification and leaching, more than 40% was attributed to denitrification.

Olson et al. (1979) monitored the fate of tagged fertilizer N applied to winter wheat in both the fall and the spring. Losses did not differ between application times, however, with the spring application more fertilizer

N was removed compared with fall applications. Approximately 20% of the labeled N was unaccounted and assumed to be denitrified. It was noted that fall applications of N had no priming effect on mineralization of soil N. Olson et al. cite Hauck and Bremner as reporting a priming effect from early applications of N fertilizer, i.e. inorganic N stimulated microbial growth resulting in an increased rate of mineralization.

Broadbent and Clark (1965) reviewed the literature relating to denitrification and found a range of values from 1-50% in a wide variety of soils. Denitrification losses fell into two major categories -- rapid losses and continuing small losses over an extended period of time. Rapid losses occur when soils containing nitrate-nitrogen and readily decomposable organic matter are concurrently exposed to warm temperatures and excessive wetness that reduces the partial pressure of oxygen. These conditions can occur for brief periods in arable lands. The continuing small losses of N occur within small pockets of high microbial activity and within large soil aggregates where loci of anaerobic conditions can exist. These small losses can account for 10-15% of the yearly mineral N input. In areas where winter precipitation leaches nitrate into the subsoil, the combination of low soil temperatures and the lack of decomposable organic matter do not create a high biochemical demand for oxygen and so there is little denitrification under these conditions.

Rasmussen et al. (1980) maintained long-term trials to examine the effects of crop residues on soil nitrogen in a fallow-wheat rotation in eastern Oregon. When there was a net input of N from residues, regression analysis of net N input vs the change in soil N infered that 75% of added N is retained in the soil system and 25% lost via deep leaching and denitrification.

Bracken and Greaves (1941) concluded that in the predominantly winter precipitation areas of Utah, soil nitrate is leached out of the root zone only when annual precipitation exceeds 500 mm.

Burns (1974) developed a mathematical model to predict nitrate leaching losses on fallowed soils. Nitrate movement is calculated from the amount of water movement on a proportional basis:

$$\% \text{ N loss due to leaching} = \frac{100\ P^x}{100\ P + V_m}$$

where

V_m = soil volumetric percentage at field capacity
P = cm of water moving through the profile
x = factor for the uniformity of nitrate distribution within the profile

In field trials this model accurately predicted nitrate leaching in a wide range of soils during the predominantly wet periods of the year.

The topic of crop season mineralization is poorly represented in the literature. This is apparently due to the N uptake interference of the crop. Goring and Clark (1948) cite historical literature demonstrating that the accumulation of nitrate under wheat, oats and maize was approximately half that occurring in corresponding fallow soil even after allowance had been made for N uptake by the crop. Two causes of this depression have been proposed. Either there is an actual depression of mineralization or an apparent one caused by denitrification. Goring and Clark (1948) studied N mineralization in fallow and cropped soils using pot experiments. They determined that there were more total bacteria in the cropped soil, however, *Nitrosomonas* and *Nitrobacter* populations were not stimulated by crop roots and showed no difference between cropped or fallowed soils. Nitrogen mineralization over time was the same for 0 to 5 weeks and then the cropped soil mineralization rate began to decline. This decline was correlated with an increase in microbial numbers in the presence of growing roots. Apparently, the greater the amount of organic material sloughed off and exuded by the roots and the lower the N content of these materials, the less mineral N will accumulate in the soil. Goring and Clark concluded that there was an actual depression of mineralization due to immobilization by increasing microbial populations.

Ferguson and Gorby (1964) conducted a 7-year study to examine the effects of incorporated straw on the availability of N to cereal crops in Manitoba. They concluded that the cool moist conditions occurring during a large portion of the growing season reduced mineralization and that the well adapted cereal varieties could successfully compete with microbial populations for mineralized nitrogen.

Hart et al. (1979) in New Zealand found that there was enhanced net soil N mineralization in both field and pot experiments as compared with fallow. They attribute this stimulation to the biotic effect of wheat on microbial populations, together with the continuous removal of mineralized N from the soil pool by the roots. This continuous removal depletes the equilibrium level of the soil inorganic N pool and may have stimulated greater release of N from the soil organic matter.

Crop season mineralization has been indirectly determined from fertilizer response curves using the Mitscherlick equation and a-values. The Mitscherlick equation states that the increase in yield of a crop under the influence of a increasing amount of any growth factor (x) is proportional to the difference between a partial yield (y) obtained at any stage and a certain maximum yield (A) (Balba and Bray, 1957). This relationship has the following form:

$$\log(A-y) = \log A - c(x+b)$$

where

c = a constant that depends on the nature of the growth factor and determines the slope of the yield curve.

b = the amount of growth factor (x) originally present in the soil

Balba and Haley (1956) and Balba and Bray (1957) determined that the uptake values of P calculated by the Mitscherlick equation and from radioactive techniques using labeled P were approximately equal. They determined that the percentage of P uptake increased with an increase in P rate and that the proportion of fertilizer P uptake decreased with an increase in the amount of available nutrient in the soil.

Engelstad and Khasawneh (1969) mathematically modified the Mitscherlick equation in such a way that a family of response curves could be determined via multiple regression. This application was used to evaluate the response of corn forage yield to rate, source and granule size of fertilizer N.

Dean (1954) designated the extrapolated value of fertilizer responses to the X-axis as a-values. A-values require the measurement of total nutrient uptake within the plant while the Mitscherlick equation requires only yield data. Dean states that either method has two major assumptions: 1) the amount of nutrient absorbed from the soil is independent of the fertilizer rate and 2) the utilization percentage of a growth factor is the same for all rates of fertilizer applied.

Ramig and Rhodes (1963) used a-values to estimate the effect of preplant soil moisture level on crop season mineralization. They determined that the Holdrege very fine sandy loam produced 45 kg N/ha independent of the preplant soil moisture level.

Stanford, Legg and Smith (1973) used N^{15} fertilizer to compare a-values with nitrogen availability indices. They found that the a-values were very close to the amounts of

N mineralized before and during crop growth in pot experiments.

Wheat Yield Responses to Soil Moisture and Nitrogen Fertilization in the Pacific Northwest

In field and pot trials, Stephens et al. (1943) determined that the average dryland soils of the Columbia River Basin were low in total nitrogen and would not produce a heavy crop, even when adequate moisture was available, unless the land were fallowed to accumulate soil nitrate or N fertilizer were added. They surmised that the amount and distribution of precipitation in the Columbia River Plateau, more than any other climatic factor, explained the yearly variation in winter wheat grain yields. However, high temperatures during the growing season could adversely affect the yield.

Leggett (1959) demonstrated that the maximum wheat yields in eastern Washington were directly related to the amount of available water, the efficiency with which it was used, and the supply of all the available and essential plant nutrients. Nitrogen was the limiting plant nutrient for the soils in the area. The amount of nitrogen required for maximum wheat production was related to the amount of available water.

Using a linear regression of wheat yield on available soil water, Leggett calculated that approximately 102 mm of soil moisture were required to grow a wheat crop to the point where grain production begins. Each additional millimeter of moisture resulted in a 390 kg/ha increase in yield.

Multiple regression of stored moisture in the fallow and crop season precipitation on maximum grain yield indicated that crop season precipitation was more effective in increasing yields; however, it was less closely related ($r = 0.53$) to the final yield than was the amount of moisture stored in the fallow ($r = 0.77$).

Linear regression of mineralized nitrogen plus fertilizer nitrogen on maximum wheat yield demonstrated that 1.0 kg of N was required to produce 20 kg/ha of wheat when nitrogen was limiting.

Leggett's experimental work demonstrated that the soil moisture supply can be evaluated most accurately in the spring of the crop year and the amount of fallow nitrogen most accurately evaluated just prior to planting.

Hunter et al. (1961) conducted fertilizer trials on 173 sites over a four-year period in the Columbia Basin Dryland areas. They also stated that available soil moisture and N were the most important factors limiting wheat yields for the area. Overall, they found that yield and protein contents were increased with increasing rates of nitrogen fertilization. The protein content of the wheat was not raised to objectionably high levels until more nitrogen was applied than was required to produce maximum yield. As long as increasing nitrogen rates increased the yields significantly, the yields would increase more rapidly than protein content. Above the point of maximum yield, further additions of nitrogen fertilizer increased the protein content more rapidly than yield. The amount of N fertilizer required to produce optimum yields of high quality wheat varied from field to field and year to year depending upon the amount of available soil moisture and nitrogen, climatic conditions, management factors and other factors affecting production. Hunter et al. stated in their work that because of the wide variations in yield responses on individual farms in a given year, nitrogen fertilizer recommendations for specific farms within any county could not be made on the basis of the average yield response in that county.

Rhode (1963) conducted nitrogen fertilization trials with 10 wheat varieties over a nine-year period in eastern Oregon. He found that yield varied from year to year, as expected, but that yield increases with nitrogen application were similar each year. The addition of N increased the number of culms/plot but had no effect on the number of kernels/head. Nitrogen application did reduce the kernel weight in some varieties but overall it increased the test weight 11.7 kg/MT. In general, fertilizer N had variable effects on the yield components each year and individual yield components were not correlated with yield.

Koehler (1960) studied nitrogen uptake and moisture use of wheat in eastern Washington during a very favorable year with above-average yields. He found that the N percentage in the heads increased with increasing nitrogen fertilizer rates (0-179 kg N/ha). The total uptake of nitrogen and the rate of uptake were also directly related to the N fertilizer rate. At 90 and 179 kg of N, the crop matured much earlier than at the lower rates and the wheat plants receiving 179 kg N/ha extracted an additional 18 mm of soil water from the 180-210 and 240 cm depths.

Halvorson et al. (1972) conducted 20 fertilizer trials in 1968 throughout the 200-500 mm annual rainfall area of eastern Washington. The optimum fertilizer rate varied with location but they demonstrated that the lowest nitrogen rate required to produce the maximum yield had no residual nitrate at harvest. They also showed that when the optimum fertilizer rate was exceeded by 22 kg of N, there was no residual nitrate; however, with 44 or more kg of N above the optimum there was residual nitrate after harvest. 1968 was characterized by above normal precipitation and yields. They also determined that soil nitrate did not leach below a 300 cm depth during the growing season at the high precipitation sites.

Gardner et al. (1975) conducted 44 soil fertility trials over a seven-year period (1968-74) in the Columbia Plateau of Oregon. They divided the sites into high, medium and low yielding locations. Low yielding sites had no N response and were generally on shallow soils (mean depth of 81.3 cm) with limited water storing ability. The medium and high yielding sites had a N response at 86% of the locations and were situated on deeper soils (mean depth of 122 cm). The mean soil nitrate concentration at the responding sites was 18 ppm nitrate-nitrogen. It was 37 ppm at the non-responding sites. The greatest frequency of response occurred when the soil nitrate concentration was 4-13 ppm nitrate-nitrogen. They noted that the total soil nitrate concentration increased with increasing soil depth presumably because deeper soils have a greater nitrate storage capacity.

Their research generated a linear regression model to estimate the nitrogen requirement for a given year:

$$F = 0.037\,Y - 4.5\,S$$

where

F = rate of nitrogen application (kg/ha)
Y = estimated yield potential (kg/ha)
S = soil test value (ppm nitrate-nitrogen)

They indicated that the coefficient of Y varies with variety and may range from 0.035-0.042.

Halvorson et al. (1972) surveyed eastern Washington dryland wheat producers and found only 25% of them soil tested their fields and of these many did not sample adequately.

The current 1976 Oregon State Fertilizer Guide for non-irrigated wheat in the Columbia Plateau uses a modified Leggett (1959) yield-water-nitrogen relationship with slight modification. It assumes that water is the primary limiting factor and that N can be added to the soil to permit optimum utilization of the available soil water. The following equations are used to determine the amount of N that should be added:

Potential yield (kg/ha) = (18.54) X (expected crop season precipitation + available soil water from the fallow (mm) - 102 mm)

The amount of Nitrogen required (kg/ha) = (Potential yield kg/ha) X (0.042) for soft white wheat

or X (0.050) for white club or hard winter wheat

The amount of available soil N = soil test N + expected N release from the crop season

The amount of required N fertilizer = @ of N required - available soil N

To date N fertilizer recommendations are based only on environmental conditions i.e., moisture and soil test values. They do not include any agronomic inputs other than the class of wheat to be grown. Eck and Stewart (1959) and Jackson and Sims (1977) suggest that other agronomic variables be considered together with environmental factors in predicting responses to applied fertilizer inputs. These agronomic factors include date of seeding, achieved stand density, variety differences and farming methods.

<u>The Modeling Approach to Estimating Wheat Production</u>

A model is a simplified, mathematical description of a system. It is constructed from numerical values given to the components of the system and the interrelationships among the components (Allaby, 1977). Models are testable, although complicated, hypotheses that provide a vehicle for further understanding of a complex system. Modeling clearly demonstrates gaps in our knowledge and so generates new hypotheses (Passioura, 1973). Modeling, then, has two major objectives. One, it is used to aid in understanding a system. Two, if the model is sufficiently accurate to be approximately true, it can be used to predict the effect of changes within the system, i.e., production level of the final product.

Two distinctly different approaches to modeling have evolved in the agricultural sciences: systems analysis and statistical modeling. Systems analysis, the more recent approach, attempts to quantify the physical aspects of the crop production system. This approach models or describes individual processes within the system and integrates them into an overall or unified systems model. The general philosophy has been to relate yield to evapotranspiration (ET). Several models pertaining to small grain production have been published (Rasmussen and Hanks, 1978; Baier, 1973; Haun, 1974; deWit, 1958). In general these systems require daily inputs of climatic, edaphic and biotic data to drive the models.

The statistical approach was the first attempt to model crop production. This approach has been used to model production levels under specified conditions. Many such models utilize climatic, edaphic and biotic data. The published models vary in their approach and feasibility in estimating wheat production. Simple linear regression was successfully used by Jackson and Sims (1977) and unsuccessfully by Smika et al. (1969). Leggett (1959) developed a statistical model utilizing soil nitrate-nitrogen and stored available water to estimate winter wheat production. Young et al. (1967) used growing season precipitation and air temperature, in addition to soil water and nitrate-nitrogen to predict spring wheat production. Po chop et al. (1975) estimated winter wheat yields using short-term weather factors in principal component and regression analysis. Eck and Tucker (1968), however, had little success estimating yield or fertilizer response using soil and climatic variables in multiple regression analysis.

More recent statistical models of yield have begun to include a stochastic element in order to more accurately predict yields in the future based on incomplete data at the time a management decision is required. Jackson and Sims (1977) developed a multiple regression model to predict optimum wheat yield and protein percentage at optimal fertilizer rates. The required inputs were: initial soil N level, soil organic matter level, pan evaporation rate, soil temperature, available soil water and growing season precipitation. The growing season precipitation level can be estimated from either long-term precipitation summaries or by using precipitation probability publications.

Woodruff (1975) constructed a management model for winter wheat that included a risk factor for each major decision. This model was based on 200 field trials conducted over a 25-year period. The model was adjusted for regional and farm differences using indices based on soil type, cropping history and past production levels. Crop yield and fertilizer need (N and P) were determined on a probabilistic basis as a function of stored soil water and farm site index.

Isfan (1979) developed a corn yield-N rate management model that would predict the most probable spring optimum N rate in Romania. Isfan found that the level of winter precipitation could be used to predict the optimum N rate for the subsequent growing season by assuming a normal level of summer precipitation. If the early summer were wetter than normal a second estimation of N requirements could be calculated based on the increased level of precipitation. He then compared two fertilizer strategies over 14 years of production. In one strategy, the amount of N fertilizer for an "average year" is annually applied without variance. In the second, the optimal N rate was estimated both in the spring and in the early summer if above normal conditions warrant. In the 14 years, the same total amount of N was applied under both strategies. However, by estimating the N need, the economic loss was reduced by applying less fertilizer in dry years and profit was increased during wet years by applying a higher rate.

MANUSCRIPT I

A Nitrogen Fertilizer Management Model for Soft White Winter Wheat in the 250-350 mm Precipitation Zone of Eastern Oregon

ABSTRACT

Dryland nitrogen fertilizer trials on fallow-wheat rotations in the semi-arid regions of the Pacific Northwest typically demonstrate a variable response due to the high degree of annual temperature and precipitation variation. Current fertilizer management models for eastern Oregon attempt to balance the nitrogen fertilizer requirements with the available moisture supply. However, they neglect the effect of stand establishment on fertilizer requirements and they provide no basis for anticipating future levels of precipitation. The purpose of this study was to develop a nitrogen fertilizer management model for the 250-350 mm rainfall zone of eastern Oregon utilizing monthly precipitation and temperature inputs, planting and emergence dates and nitrogen soil testing.

Historical precipitation, temperature and yield data (1912-76) were utilized to develop precipitation probability tables, a grain yield model and a model relating the percentage grain yield reduction to the days to emergence. Three types of model verification studies were conducted: 1) Independent historical data (1956-1963) indicated that the proposed model deviated less from the actual yields (r = 0.46) than did the current soil moisture model (r = 0.37) and had a lower mean percentage deviation (28 <u>vs</u> 117%). A survey study of 19 growers and 35 fields from 1972-1978 indicated that the proposed model, when

adjusted to the productivity of other locations by a Productivity Index, had an accuracy level of 15% of the potential yield. 2) Five fallow-crop precipitation patterns characteristic of the area were field simulated at six fertilizer levels (0, 15, 45, 60, 75, 105 kg N/ha). The maximum grain yield response occurred at 40 kg N (soil + fertilizer)/metric ton. In 1979 the estimations using the proposed model were all within 15% of the actual yield level except for two potentially high yielding treatments in which winter-kill apparently had a differential effect in comparison with the other treatments. The proposed and current soil moisture model were significantly correlated with the actual yield (r = 0.69 and 0.78, respectively). However, the current soil moisture model consistently overestimated the actual yield level by a margin greater than 15%. In 1980, both models underestimated the potential as a result of cool, moist conditions from heading to ripening that helped to produce the highest yields on record. 3) Off-station spring nitrogen fertilizer trials in 1980 demonstrated that in six of ten commercial fields, production levels were within 15% and eight of ten were within 20% of the predicted potential yield adjusted by the Productivity Index.

A reliable estimate of grain yield potential is essential to determine the nitrogen requirements of a winter wheat crop. The proposed nitrogen management model requires a tabulation of monthly precipitation, crop planting and emergence data and nitrogen soil testing to estimate yield potential and nitrogen fertilizer requirements. The yield potential and nitrogen fertilizer requirements can be estimated at any point in the fallow-crop rotation by utilizing known data at the time of estimation and anticipating future levels of precipitation based on the current conditions.

Additional index words: emergence, grain yield prediction, precipitation-nitrogen-yield relationships, soft white winter wheat.

A NITROGEN FERTILIZER MANAGEMENT MODEL FOR SOFT WHITE WINTER WHEAT IN THE 250-350 MM PRECIPITATION ZONE OF EASTERN OREGON

INTRODUCTION

Fertilizer application practices based on long-term average weather conditions have long been criticized as an ineffective and uneconomical management strategy for commercial crop production in areas of variable climate (Hunter, et al. (1957) and Isfan (1979)). The long-term average rate is excessive under dry conditions and is deficient under wet conditions.

In the dryland areas of eastern Oregon, a nitrogen fertilizer management model developed by Leggett (1959) for eastern Washington is utilized with modifications for regional and varietal differences. In this model, common soft white winter varieties require 50 kg nitrogen/metric ton of potential yield and white club varieties require 50 kg nitrogen/metric ton of potential yield. The potential yield level is estimated according to the following equation:

$$Y = 18.54\ (SM + R - 102) \qquad \text{Equation (A)}$$

where: Y = Potential yield (kg/ha)
SM = Available soil water (mm) for the rooting depth using a spring sampling
R = Expected rainfall for the remainder of the growing season (mm) (Gardner et al. (1975))

The nitrogen fertilizer requirement is estimated in the following manner:

$$N = 40Y - (F + C) \qquad \text{Equation (B)}$$

where: N = Nitrogen fertilizer requirement (kg/ha)

Y = Potential yield (kg/ha)
F = Soil test N at the end of the fallow period (kg/ha)
C = Net crop period mineralization (kg/ha), generally assumed to be 34 kg N/ha (Gardner et al. (1975))

This approach has gained acceptance in the more productive and higher rainfall areas of eastern Oregon. However, its acceptance is reduced in the drier and less productive areas of eastern Oregon where climatic and soil depth variations are greater. This approach cannot determine N fertilizer requirements prior to planting when the most inexpensive form of N, anhydrous ammonia, can be applied, because it is based on a crop season sampling of soil moisture.

Workers have suggested that agronomic characteristics be included in fertilizer management models (Jackson and Sims (1977); Eck and Stewart (1959)). These factors may include date of planting, date of emergence, tiller number and final stand density as well as varietal type. Investigators have demonstrated that the establishment of an adequate stand at the optimum time in the fall is an important factor in achieving the potential grain yield of winter cereals (Beutler and Foote (1963); Stickler and Pauli (1964)).

This study describes an alternate nitrogen fertilizer management model for the 250-350 mm rainfall zone of eastern Oregon that utilizes monthly precipitation and temperature inputs, planting and emergence dates and nitrogen soil testing. The relationship and interactions of precipitation, temperature, planting and emergence dates, nitrogen response and field to field yield variation are discussed. Methods for estimating grain yield and nitrogen requirements utilizing stochastic precipitation tables are presented. The effectiveness of this model is compared with the current management model.

METHODS AND MATERIALS

Yield and emergence data from the Regional Soft White Winter Wheat Nursery (1957-76; Moro, OR) were used for multiple regression analysis of precipitation, temperature and emergence effects on grain yield. The nursery yield of the predominant variety under commercial production each year was chosen as the dependent variable. The years 1965 and 1966 were excluded due to an unprecedented high level of December rainfall in 1965 that resulted in flooding. This event also influenced the 1966 crop. The 1973 nursery yield was also excluded from the data set because of station field management problems resulting in yield levels atypical of the potential for that season.

Climatic data were gathered from the Sherman Branch Experiment Station (Moro, OR) where the nursery was located. Monthly precipitation totals and mean air temperatures were collected from a standard U.S. weather service station. The long-term weather record from the Sherman Branch Station (1912-1976) was analyzed according to Aktan (1976) to categorize the seasonal precipitation level for the fallow and crop periods. This method is illustrated (Figure 1) for the 14-month fallow period. The same method is used for categorizing the 10-month crop period.

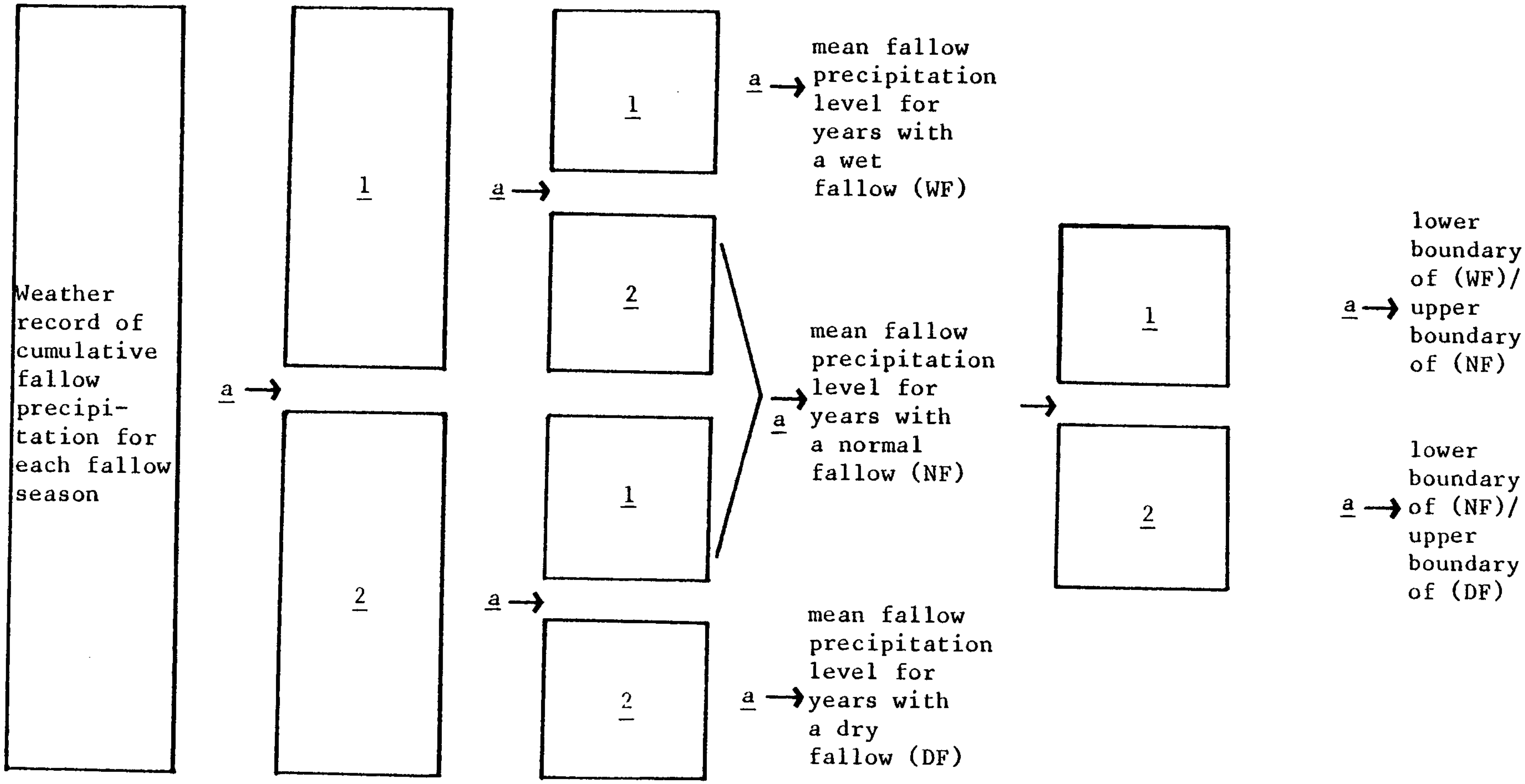
Off-station precipitation amounts were collected by local growers using small rain gauges provided by the OSU Extension Service (1972-present).

Three types of model verification studies were conducted; all on a Walla Walla silt loam (coarse-silty, mixed, mesic Typic Haploxeroll) typical of the area:

I) Historical. Yield, precipitation and soil moisture data from replicated tillage trials at the Sherman Branch Station (1956-1963) were used to compare the current soil moisture model, equation A, and the proposed precipitation model. Soil moisture was gravimetrically measured to a 180 cm depth in these trials. Emergence data, when not specified, were estimated from comments supplied in annual reports.

Replicated planting date trials (1953-1963) were used to validate the model relating emergence time with grain yield reduction. When not specified, the date of emergence was calculated using degree days according to Russelle and Bolton (1980). Grain yield reduction due to delayed emergence was calculated as the percentage decrease in yield of a late planting in comparison with the yield at the optimum date of planting.

A Productivity Index was developed to compensate for



a = determine the fallow season precipitation level mean

1 = years whose fallow precipitation exceeds the mean

2 = years whose fallow precipitation is less than the mean

Figure 1. Methodology for characterizing fallow season precipitation.

the productivity of other locations in relation to the Sherman Branch Experiment Station. Production levels of 19 growers and 35 fields (1972-1978) submitted to the Agricultural Stabilization and Conservation Service (ASCS) were collected to develop the Productivity Index (P.I.) concept and values for commercial fields. Growers from five different areas, as designated by the ASCS, were sampled.

II) Field Simulation. Five fallow-crop precipitation levels (Table 1: DFNC, NFDC, NFNC, NFWC, WFNC) plus a non-treated control were simulated on a commercial dryland farm near Moro, OR, from 1977-1980. These five patterns encompass approximately 80% of the recorded fallow-crop precipitation levels. In each period (fallow or crop) rainfall was excluded using 6 x 15 m plastic tarps that were rolled over the plots at the onset of a precipitation event and removed at the conclusion of each event. A PVC support grid was used to hold the tarps above the crop. Moisture was applied to the crop using a solid set irrigation grid with low-pressure, low-angle nozzles that provided 200% overlap. Moisture was regulated on a monthly basis, primarily during the winter months. A split-plot design was established with four blocks. The main plots were the precipitation patterns. Nitrogen fertilizer (Solution 32; 32% N) was injected into the subplots (2.4 x 6 m) prior to seeding at six levels (0, 15, 45, 60, 75, 105 kg N/ha). In the 1978-80 simulation, the NFWC treatment was duplicated and split applications of Solution 32 and ammonium nitrate were applied (0, 15, 45, 45+15, 45+30, 45+60 kg N/ha). All tillage and planting operations were conducted by the grower as part of his normal farm operations. Stephens winter wheat was planted in late September 1978 and 1979. It emerged within 10 days in both years. This location had a Productivity Index of 1.27.

Soil nitrate-nitrogen was sampled to a 180 cm depth in 30 cm increments in September, prior to fertilizing. Triplicate samples per main plot were collected. Each increment was air dried and ground to pass a 2 mm screen. Soil nitrate-nitrogen was extracted using a water-based extracting solution containing 0.3 g CaO/100 ml and 0.2 g $MgCO_3$/100 ml. Ten grams of soil were shaken with 100 ml of extracting solution for 30 minutes. The extract was filtered through a No. 40 Whatman filter and the nitrate content determined colorimetrically (600 nm) using the Szechrome NB reagent (Szekely, 1976).

Soil moisture was measured with a neutron probe in 15 cm increments to a depth of 270 cm at the beginning of the fallow period (August), at planting (September) and in the spring of the crop period (March). The upper 0-15 and 15-30 cm were measured gravimetrically. Access tube installation was according to Glenn et al. (1980). Available soil moisture was estimated by subtracting the initial, post-harvest soil moisture content for each access tube from each subsequent sampling date.

Grain was harvested from the center of the 2.4 x 6 m subplots with a self-propelled combine.

III) Off-station nitrogen fertilizer trials. Nine nitrogen fertilizer trials were established in commercial fields having a wide range in calculated Productivity Indices. These trials were established on land planted to Stephens winter wheat. The selected sites had uniform stands. Planting, emergence and nitrogen application data were gathered from the grower. Four rates (0, 10, 20, 30 kg N/ha) and two sources of nitrogen (ammonium nitrate and liquid Solution 32) were applied in a randomized block with 4 blocks. Plot size was 3 x 6 m.

The sites were characterized by a single sampling of soil moisture and nitrogen in March of the crop period. Soil moisture was measured to a 240 cm depth or bedrock in 15 cm increments with a neutron probe. The upper 0-15 and 15-30 cm increments were measured gravimetrically. Soil nitrogen samples were collected to a 180 cm depth or bedrock in 30 cm increments. They were analyzed for nitrate-nitrogen colorimetrically. Grain was harvested from the center of each plot using a self-propelled combine. Overall field production levels were supplied by the grower.

RESULTS AND DISCUSSION

The 250-350 mm precipitation zone of eastern Oregon exhibits a high degree of temporal variation and a wide range of expected precipitation amounts in both the fallow and crop periods (Figure 2). In this area, the precipitation

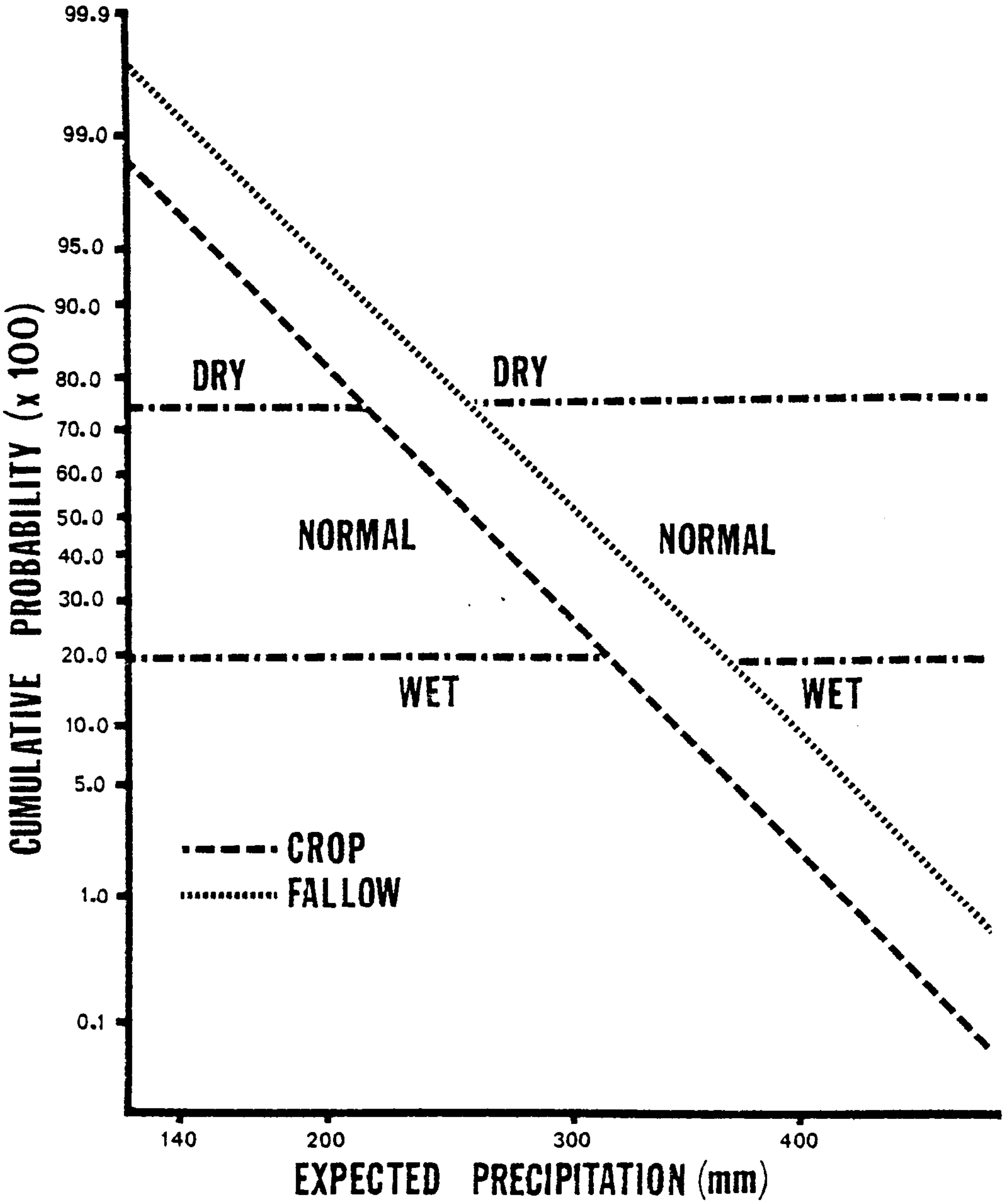


Figure 2. Cumulative probability levels of fallow and crop season precipitation at the Sherman Branch Experiment Station (Moro, OR), 1912-76.

level of the fallow period has a conditional effect on the subsequent level of crop period precipitation (Figure 3). Following a dry fallow period (DF), the probability is greater for a normal (NC) or wet (WC) crop period to occur than a normal or dry (DC) crop period. Similarly, following a wet fallow period, the probability is greater for a normal or dry crop period to occur than a normal or wet crop period. This conditional effect can be further illustrated by examples of the effect of the previous fallow condition on future levels of anticipated crop period precipitation in seasonal increments (Figure 4). Following a dry fallow period, the mean level of winter season precipitation (November + December + January) is approximately 25 mm greater than following a wet fallow period. Similarly, the mean level of spring season precipitation (February + March + April) is approximately 10 mm greater following a dry fallow compared with a wet fallow period. These deviations from the long-term mean are potentially useful in making management decisions regarding yield expectations and fertilizer requirements based on incomplete data.

Two interacting regression models are proposed to estimate the potential grain yield level for commercial winter wheat production in the 250-350 mm precipitation zone of eastern Oregon. Monthly precipitation and temperature values and the length of time between planting and emergence are the required input variables (Table 1).

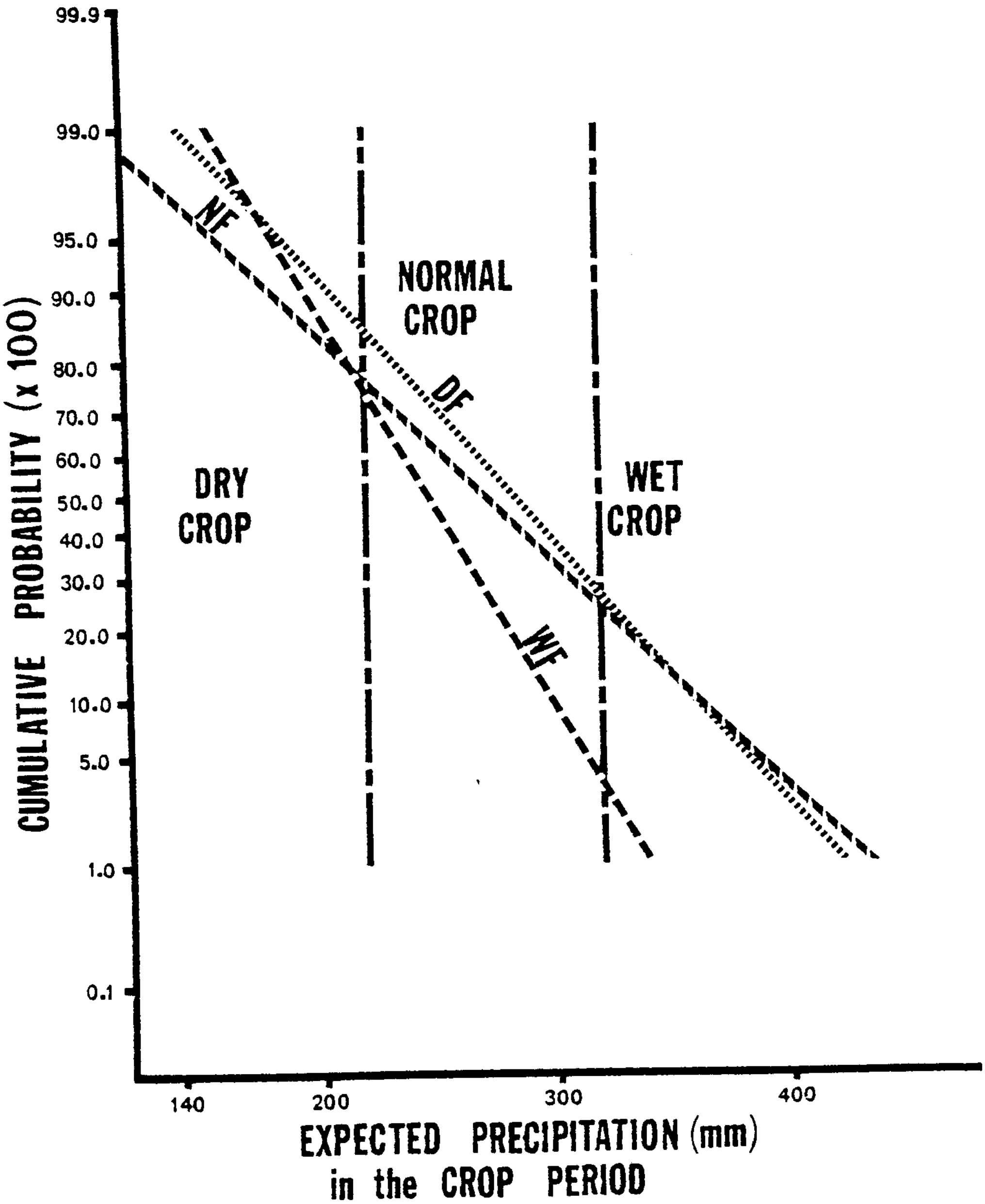


Figure 3. Cumulative probability levels of crop period precipitation following a dry (DF), normal (NF) and wet (WF) fallow period (Moro, OR), 1912-76.

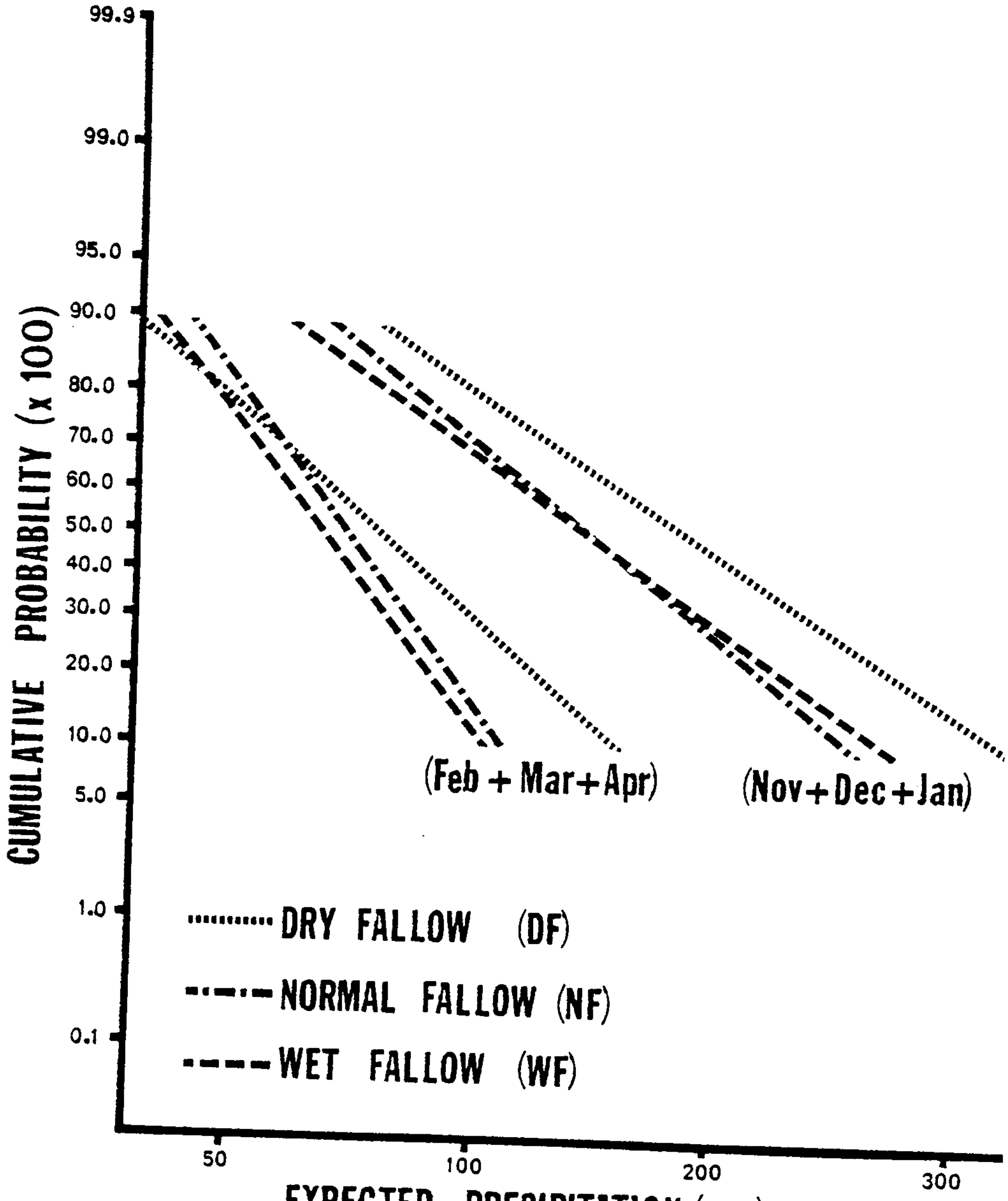


Figure 4. Cumulative probability level of the (Nov + Dec + Jan) and (Feb + Mar + Apr) crop periods following a dry/normal/wet fallow period (Moro, OR), 1912-76.

Table 1. Regression models for estimating grain yield potential and grain yield reduction due to delayed emergence.

Potential yield (metric ton/ha)

$$
\begin{aligned}
= & -0.0161\,(\text{Aug} + \text{Sept} + \text{Oct}) \\
& + 0.0129\,(\text{Nov} + \text{Dec} + \text{Jan}) \\
& + 0.0148\,(\text{Feb} + \text{Mar} + \text{Apr}) \\
& + 0.0195\,(\text{Sept})
\end{aligned}
\quad \text{Fallow period (mm)} \quad R^2=0.82 \quad \text{equation (1)}
$$

$$
\begin{aligned}
& + 0.0074\,(\text{Nov} + \text{Dec} + \text{Jan}) \\
& + 0.0032\,(\text{Feb} + \text{Mar} + \text{Apr}) \\
& - 0.1938\,(\text{May temp } (^{\circ}\text{C}) - 12.70^{*})
\end{aligned}
\quad \text{Crop period (mm)}
$$

$$- 0.6355$$

*Long-term mean May temperature = 12.70°C

Yield reduction due to delayed emergence (%)

$$= 0.7269\,(\text{days to initial emergence from planting}) - 8.1364 \quad \text{equation (2)}$$

Actual yield (metric ton/ha)

$$
\begin{aligned}
= & -0.0123\,(\text{Aug} + \text{Sept} + \text{Oct}) \\
& + 0.0125\,(\text{Nov} + \text{Dec} + \text{Jan}) \\
& + 0.0135\,(\text{Feb} + \text{Mar} + \text{Apr}) \\
& + 0.0173\,(\text{Sept})
\end{aligned}
\quad \text{Fallow period (mm)} \quad R^2=0.80 \quad \text{equation (3)}
$$

$$
\begin{aligned}
& + 0.0065\,(\text{Nov} + \text{Dec} + \text{Jan}) \\
& + 0.0037\,(\text{Feb} + \text{Mar} + \text{Apr}) \\
& - 0.1750\,(\text{May temp } ^{\circ}\text{C})
\end{aligned}
\quad \text{Crop period (mm)}
$$

$$- 0.3710 \times 10^{-3}\,(\text{days to initial emergence from planting})^2 + 1.6902$$

The negative regression coefficient (equation 1) for (August + September + October) of the fallow period indicates that increased rainfall reduces yield potential. This is the result of fall weed and volunteer growth that progresses uncontrolled into the spring. This growth consumes moisture and, if extreme, can potentailly create a weed control problem that continues throughout the summer fallow months and into the crop period. Rydrych (1979) has demonstrated that an effective post-harvest weed control program in the dryland areas of the Pacific Northwest can increase water storage by as much as three cm of moisture. The positive regression coefficients of (November + December + January) and (February + March + April), (12.9 and 14.8 kg yield/ha/mm, respectively) indicate that moisture in this time period is 2-3 times more effective than moisture received during the same months in the crop period (7.4 and 3.2 kg yield/ha/mm, respectively). In general, these relationships can be explained by the more efficient water intake rate of the drier soils of the fallow period that leave less water near the soil surface to be evaporated or runoff. Rainfall in September is extremely useful in providing additional seed zone moisture that promotes rapid emergence. The deviation of May temperatures about the long-term mean (12.70°C) indicate that cool temperatures during the heading and filling stages decrease plant stress and increase grain yield.

In the dryland areas of the Pacific Northwest, stand establishment is a limiting factor to achieving yield potentials. The effect of delayed emergence on yield reduction was initially described by the (Days to initial emergence from planting)^2 variable in equation 3 (Table 2). The response described in this manner, however, was not felt to be applicable over a wide range of yield potential in the area. This specific response variable was altered to describe the percentage grain yield reduction as a function of days to initial emergence by regressing the (predicted actual yield)/(predicted actual yield if (days to initial emergence)^2 = 0) x 100 with the days to initial emergence (equation 2). This relationship generally agreed ($r = 0.59$) with replicated date of planting trials conducted at the Sherman Branch Experiment Station (1953-1963)(Figure 5).

Replicated tillage trials (1956-63) provide a comparison of the proposed yield prediction model (equation 1 and equation 2) and the current soil moisture model (equation A)(Table 2). The yield potential is calculated by multiplying equation 1 by equation 2. While the only year independent of the equation 2 data set is 1956, it is observed that equation A overestimates actual yield levels in the small plots more than the product of equations 1 and 2. This can be attributed to two general factors. First, no compensation for stand development is included in equation A. The inclusion of equation 2 with a soil moisture model should improve the accuracy of fertilizer recommendations

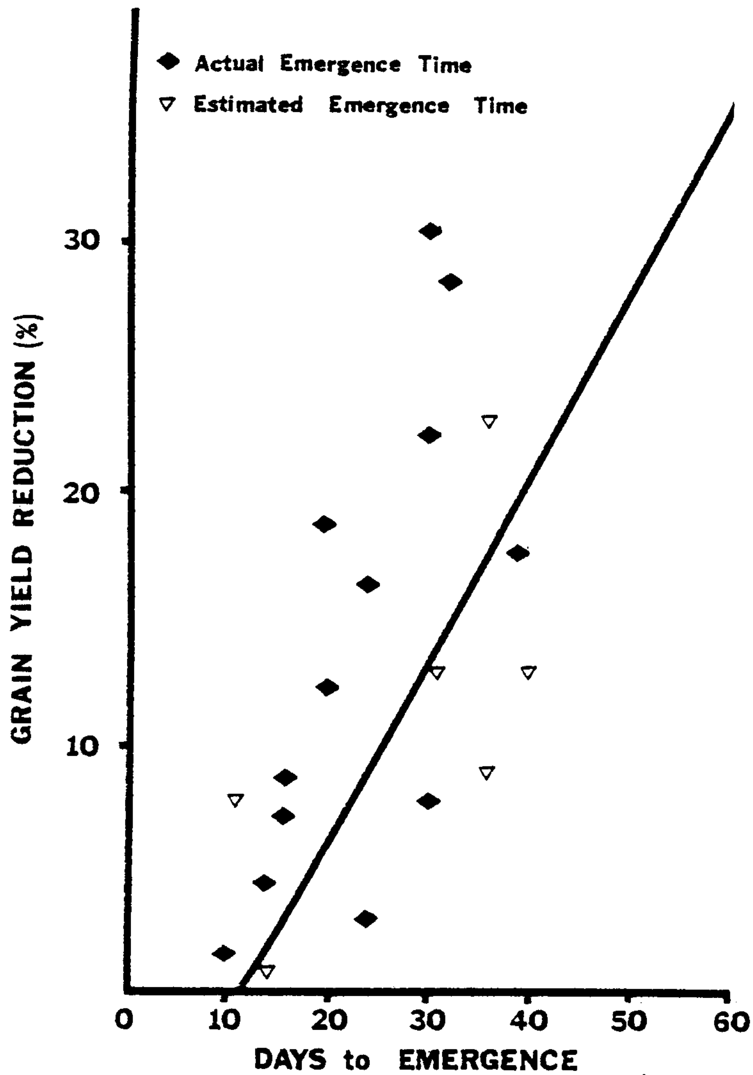


Figure 5. The effect of delayed emergence on percentage grain yield reduction (Moro, OR).

Table 2. A comparison of the current soil moisture model (eq(A)) and the proposed precipitation model (eq(1) X eq(2)) using historical data from replicated tillage trials (1956-63). Moro, OR.

Year	Actual plot yield (metric ton/ha)	Calculated yield potential (metric ton/ha) eq (A) 180 cm sampling depth	Deviation from actual (%)	Calculated yield potential (metric ton/ha) eq(1) X eq(2)	Deviation from actual (%)
1956	1.86	4.20	126	2.65	43
1957	2.76	6.55	137	2.85	3
1958	2.35	4.68	99	2.19	-7
1959	2.43	3.97	63	2.51	3
1960	2.31	4.05	75	3.40	47
1961	1.28	4.72	269	2.11	65
1962	2.02	3.81	89	2.69	33
1963	2.21	3.96	79	2.68	21
		r = 0.37		r = 0.46	

since they are based upon spring sampling when emergence time is known. Secondly, equation A assumes that rainfall received beyond the soil moisture sampling date in the spring is equally as effective as stored soil moisture.

Leggett's (1959) multiple regression of winter wheat yields in eastern Washington with stored soil moisture and growing season rainfall indicated that the amount of growing season rainfall had a greater influence on yield than did stored soil moisture (18.5 vs 14.3 kg yield/ha/mm, respectively). However, the amount of growing season rainfall was less closely related to the final yield ($r = 0.53$) than the amount of stored soil moisture ($r = 0.77$). Leggett did not include a growing season temperature component in his analysis. Cool temperatures are generally associated with precipitation events. In equation 1, the deviation of May temperature from the long-term mean May temperature (12.70°C) was a more effective variable than May precipitation, which was not significantly related.

Historical evidence from the Sherman Branch Experiment Station further demonstrates that precipitation in the fallow period has a greater influence on grain yield than does crop period precipitation (Table 3). A comparison of the long-term average yields for the WFNC with the NFWC and the DFNC with the NFDC patterns indicates that for the same range of total precipitation in the fallow + crop period, the pattern with the lesser amount of crop period precipitation does not have the lower yield. Rather, the pattern with the

Table 3. Fallow-crop precipitation patterns at the Sherman Branch Experiment Station (Moro, OR) based on 65 years (1912-1976) of monthly precipitation data.

Fallow (14 month, Aug-Sept) Cumulative precipitation (mm)	Fallow Probability (%)	Crop (10 month, Oct-July)	Cumulative precipitation (mm)	Probability based on previous fallow (%)	Probability for the fallow-crop sequence (%)	Mean wheat grain yield (metric ton/ha)
206-261 Dry Fallow (DF)	21.5	Dry crop (DC)	179-218	14.4	3.1	1.75
		Normal crop (NC)	219-320	64.3	13.9	1.59
		Wet crop (WC)	321-403	21.3	4.6	2.62
262-370 Normal Fallow (NF)	60.0	Dry crop (DC)	179-218	28.2	16.9	1.79
		Normal crop (NC)	219-320	56.5	33.9	2.03
		Wet crop (WC)	321-403	15.3	9.2	2.27
371-429 Wet Fallow (WF)	18.5	Dry crop (DC)	179-218	16.8	3.1	2.33
		Normal crop (NC)	219-320	75.1	13.9	2.54
		Wet crop (WC)	321-403	8.1	1.5	2.56

greater amount of fallow period precipitation has the higher yield.

Greb (1979) has determined that growing season rainfall in the Great Plains during cool periods is 25% as efficient as stored soil water and is 22% as efficient during the warm season. The coefficient of the crop period's spring season (February + March + April) in equation 1 is 17% of the regression coefficient in equation A (3.2 and 18.54 kg yield/ha/mm of moisture, respectively).

An advantage of equation A is when shallow soils are sampled for soil moisture, the apparent rooting depth is determined by the depth that can be physically sampled. Equation 2 does not consider soil depth. For this reason, a Productivity Index (P.I.) was developed to relate both soil depth and management practices to yield potential estimates. The (P.I.) is a measure of the productivity of other locations in relation to the Sherman Branch Experiment Station, using Water-Use-Efficiency (WUE) as the basis of comparison. It is assumed, and approximately true, that the Regional White Wheat Winter Nursery had adequate nitrogen fertilization and minimal disease incidence for the varietal yields used in developing equation 1.

The Productivity Index is calculated as:

$$\text{P.I.} = \frac{\text{A location's historical WUE in which the difference between the location and Sherman Station's WUE is minimal}}{\text{Sherman Station's WUE for the same year}} \times 100$$

$$\text{Where WUE} = \frac{\text{yield (metric ton/ha)}}{\text{total fallow + crop period precipitation (mm)}}$$

A single year rather than a mean of several years is chosen in calculating the P.I. in order to identify as closely as possible the productive potential of a commercial field. Woodruff (1975) used average production levels as the basis for his farm site indices in Queensland. This approach seemingly reduces the actual potential by averaging the best production with lesser levels.

The derivation of the Productivity Index indicated that the most efficient production of grain, i.e. highest WUE in relation to the Sherman Branch Experiment Station, generally occurred in 1972 and 1976. Both harvest years experienced average rainfall amounts and generally had good seeding conditions with no significant disease problems. Neither year, however, was the highest nor the lowest yielding in the 1972-78 period.

The yield potential of a specific field is calculated as the products of the (P.I.), equations 1 and 2.

A production survey of 35 fields managed by 19 growers over a five-year period of time was used to test the applicability of equation 1 and the Productivity Index to commercial production (Table 4). No specific information was available on stand establishment, fertilizer practices or disease incidence. The actual production levels were 30% below the potential, on the average, in 75% of the surveyed fields. The remaining 25% were within approximately 10% of the predicted potential on the average. Production data from years within the data set for equation 1, (1972, 74-76), and

Table 4. Percentage deviation of estimated yield ($\hat{Y}$) from recorded production levels (Y).*

Area	Mean area Yield (metric ton/ha)	Mean area Productivity Index (PI)	Years 1972, 1974-76						Years 1973, 1977, 1978					
			$\hat{Y} > Y$			$\hat{Y} < Y$			$\hat{Y} > Y$			$\hat{Y} < Y$		
			$\bar{x}$	s	n	$\bar{x}$	s	n	$\bar{x}$	s	n	$\bar{x}$	s	n
A	3.27	1.15	31.3	13.9	30	0	0	0	34.9	17.2	7	8.0	8.2	6
B	2.26	0.93	55.5	38.1	30	7.5	7.2	4	47.0	31.7	15	18.8	13.4	6
C	2.46	0.99	18.8	15.8	21	2.5	2.1	2	4.0	4.4	3	14.7	8.4	9
D	1.63	0.64	25.5	19.7	25	11.3	4.4	6	0	0	0	27.5	13.7	14
E	1.43	0.51	18.9	8.0	9	15.0	8.5	2	49.0	44.0	3	0	0	0
Grand mean	2.21	0.84	30.0	19.1	115 (total)	7.3	4.4	14 (total)	27.0	19.5	28 (total)	13.8	8.7	35 (total)

*Assumes optimum fertilization, no disease, stand reduction or delayed emergence.

from independent years, (1973, 77, 78), indicate similar levels of accuracy and variation. It is felt that if stand establishment and fertilizer practices were reliably known for these fields, at least 15% of the under-production could be explained as a result of under-fertilization and delayed stand establishment. It appears that the product of equations 1 and 2, in conjunction with the Productivity Index, can be applied to commercial production with an accuracy level of 15% of the potential yield.

The field simulation of five fallow-crop precipitation patterns (DFNC, NFDC, NFNC, NFWC, WFNC, Control) provided a replicated test of the proposed equation 1 x equation 2 and current (equation A) yield estimation models. The inclusion of six nitrogen fertilizer levels (0, 15, 45, 60, 75, 105 kg N/ha) quantitated the nitrogen fertilizer requirement at varying yield levels under similar environmental conditions. Maximum grain yield response (slope equal to zero) occurred at 40 kg N (soil + fertilizer)/ha at all yield levels in 1979 (Figure 6). In 1980 extremely cool, moist summer conditions allowed yield levels to rise to unexpected levels, making treatment differences and demonstrating fertilizer responses that apparently had not maximized at 165 kg N/ha.

The comparison of actual and estimated yields by equations 1 and A (Figure 7) demonstrated that in 1980 both models underestimated the potential. This result is expected in light of the cool, moist conditions during

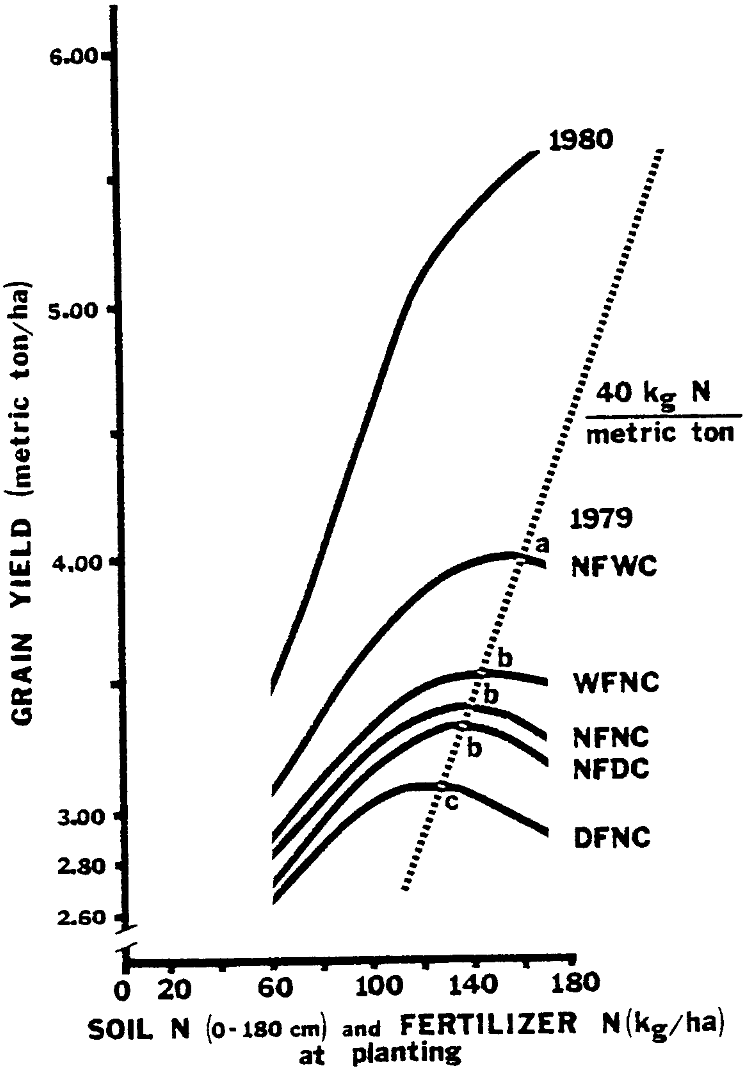


Figure 6. Nitrogen response of winter wheat

Letters (a,b,c) indicate significant differences between treatments with dissimilar letters (1979).

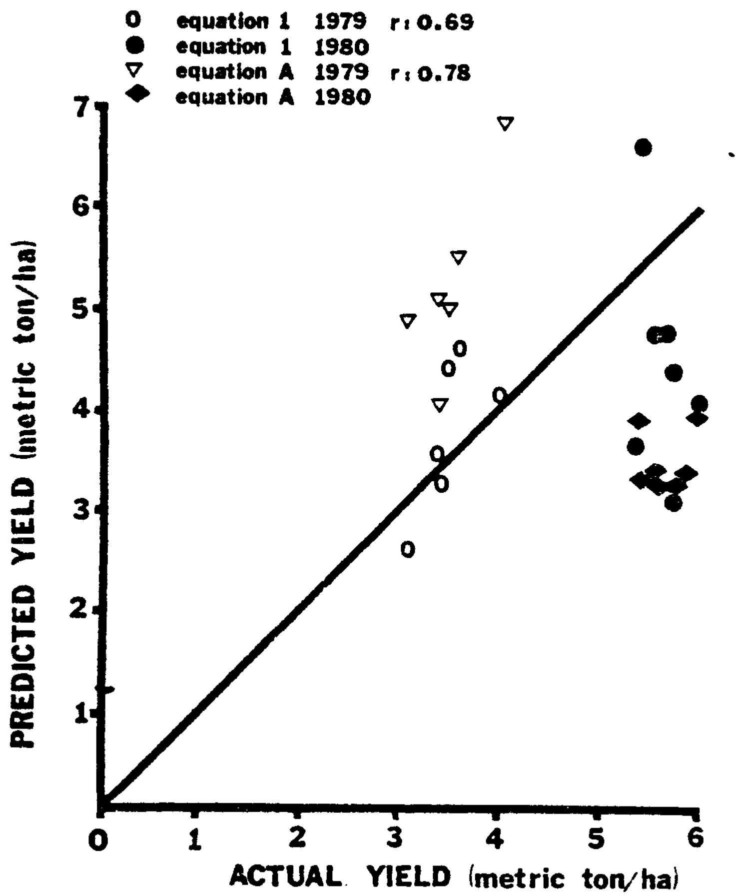


Figure 7. A comparison of actual and estimated yields by equations (1) and (A) from a field simulation (1979, 1980) of five fallow-crop precipitation patterns. (PI = 1.27)

heading and ripening. In 1979 both models were significantly correlated with the actual yields; however, equation 1 deviated less from the actual than equation A. Equation 1 estimations were within 15% of the actual except for the Wet Fallow-Normal Crop (WFNC) and control treatments (26 and 28%, respectively). The control treatment was categorized as WFNC in 1979. Entering the 1979 winter period, these two treatments had more vegetative and tiller growth. The winter-kill in 1979 had a more drastic effect on these treatments than on the other less developed plants. This, in part, explains the larger deviation from the estimated yield level.

Off-station nitrogen fertilizer trials in 1980 demonstrated no response to N source. With one exception, all fields produced the highest grain production levels on record. Seven of the nine fertilizer trials demonstrated a significant N response indicating that at least five of the fields were under fertilized (Table 5-B). Inferences about under-fertilization cannot be made at locations where the control plot did not refect the field production level.

The control treatment in three of the nine fields (Table 5-A) was not of the same magnitude as the overall field production level. At these locations, equation A generally estimated the yield from the highest yielding treatments and over-estimated the field production levels. The product of equations 1 and 2 underestimated the control

Table 5. A comparison of the current soil moisture model (eq(A)) and the proposed precipitation model (P.I. X eq(1) X eq(2)) using off-station, replicated nitrogen fertilizer trials and commercial production levels (1980).

					(P.I.) X eq(1) X eq(2)				eq(A)			
						Deviation from				Deviation from		
	P.I.	Field production level (metric ton/ha)	Control plot yield (metric ton/ha)	Max plot yield (metric ton/ha)	Calculated potential yield (metric ton/ha)	Field level (%)	Control yield (%)	Max yield (%)	Calculated potential yield (metric ton/ha)	Field level (%)	Control yield (%)	Max yield (%)
A.	1.17	3.77	5.72	5.72	3.53	- 6	-38	-38	5.25	39	- 8	- 8
	1.02	3.30	4.44	5.11*	2.73	-17	-39	-47	4.45	35	1	-13
	0.49	1.75	2.42	4.30*	1.43	-18	-41	-67	3.32	90	37	-23
					mean	14	39	51		55	15	15
B.	1.10	3.89	3.90	4.37*	3.30	-15	-15	-25	4.50	16	15	3
	1.10	2.82	2.69	3.23*	3.10	10	15	- 4	3.51	25	31	9
	0.81	3.16	3.23	3.23	2.17	-31	-33	-33	2.00	-37	-38	-38
	1.02	3.03	3.03	4.17*	2.73	-10	-10	-35	3.13	3	3	-25
	0.57	0.81	0.81	1.34*	1.41	74	74	5	1.55	91	91	16
	1.00	3.70	3.77	5.04*	2.68	-28	-29	-47	4.27	15	13	-15
					mean	28	25	29		31	18	32

*Indicates significant spring nitrogen fertilizer response (p = 0.10).

and yield from the highest yielding treatments but generally estimated the field production level, indicating that the Productivity Index averages field variation. When field conditions, i.e. soil depth, slope and exposure vary within a field and management practices average across this variation, the Productivity Index in conjunction with the product of equations 1 and 2 should be effective in estimating yield potential on an average field basis.

At the six locations where the control was comparable to the field production level (Table 5-B) both models generally under-estimated the yield from the highest yielding treatment as they had in the simulation study (1980). In light of the inflated yield levels in 1980, it appears that the proposed precipitation model can estimate yield potential levels under the normal range of environmental conditions present in the 250-350 mm precipitation zone on a field basis.

A reliable estimate of grain yield potential is essential to determine the nitrogen requirements of a winter wheat crop. The greater relative importance of precipitation in the fallow period as compared with the crop period in the 250-350 mm precipitation zone of eastern Oregon provides a basis for management decisions regarding nitrogen fertilizer application prior to planting. The proposed nitrogen management model requires a tabulation of monthly rainfall, crop planting and emergence data in order to estimate yield potential. The yield potential can be estimated at any point in the fallow-crop rotation by entering known data into equations 1 and 2 at the time of estimation and anticipating both future levels of precipitation and days to emergence based on the current conditions. May temperature is assumed to be the long-term mean when estimates are made during the crop period, long-range temperature forecasts from the U.S. Weather Service can be utilized. May temperatures do not exhibit a correlation with previous levels of crop season precipitation.

Nitrogen fertilizer requirements are calculated according to equation B with fallow soil nitrogen levels determined by soil sampling at planting or estimation (Glenn, unpublished manuscript). Crop season nitrogen levels may either assume a constant value, i.e. 34 kg N/ha or be estimated in relation to crop season conditions (Glenn, unpublished manuscript). In this manner yield potential can be estimated during the fallow period and a major portion of the nitrogen requirement can be applied using the least expensive source, anhydrous ammonia. Further nitrogen additions can be made in the spring if the actual precipitation exceeds the anticipated levels. In general, April is the latest date nitrogen fertilizer can be effectively applied. Unexpected conditions beyond this point can alter the yield potential as demonstrated in 1980.

LITERATURE CITED

1. Aktan, S. 1976. Nitrate-nitrogen accumulation and distribution in the soil profile during a fallow-grain rotation as influenced by different levels of soil profile moisture. M.S. Thesis. Oregon State University.

2. Beutler, L.K., and W.H. Foote. 1963. Influence of date of seeding and nitrogen rates on winter wheat varieties in eastern Oregon. Agron. J. 55:4-6.

3. Eck, H.V., and B.A. Stewart. 1959. Response of winter wheat to phosphate as affected by soil and climatic factors. Agron. J. 51:193-195.

4. Gardner, E.H., T.W. Thompson, H. Kerr, J. Hesketh, F. Hagelstein, M. Zimmerman, and G. Cook. 1975. The nitrogen and sulfur fertilization of dryland winter wheat in Oregon's Columbia Plateau. Proc. 26th Pacific Northwest Fert. Conf., Salt Lake City, Utah. pp. 99-104.

5. Glenn, D.M., R.L. Henderson, and F.E. Bolton. 1980. A retractable neutron-probe access tube. Agron. J. 72:1067-1068.

6. Glenn, D.M. Fallow-crop precipitation effects on moisture storage and soil-nitrate-nitrogen mineralization. Unpublished manuscript.

7. Greb, B.W. 1979. Reducing drought effects on croplands in the West-Central Great Plains. USDA-SEA. Info. Bull. 420. 31 pp.

8. Hunter, A.S., C.J. Gerard, H.N. Waddoups, W.E. Hall, H.E. Cushman, and L.A. Alban. 1957. Progress Report - Wheat fertilization experiments in the Columbia Basin, 1953-1955. Ore. Agr. Expt. Sta. Cir. of Info. 570.

9. Isfan, D. 1979. Nitrogen rate-yield precipitation relationships and N rate forecasting for corn crops. Agron. J. 71:1045-51.

10. Jackson, G.D., and J.R. Sims. 1977. Comprehensive nitrogen fertilizer management model for winter wheat. Agron. J. 69:373-77.

11. Leggett, G.E. 1959. Relationships between wheat yield, available moisture and available nitrogen in eastern Washington dryland areas. Wash. Agri. Exp. Sta. Bull. 609. Wash. State University.

12. Russelle, M.P., and F.E. Bolton. 1980. Soil temperature effects on winter wheat and winter barley emergence in the field. Agron. J. 72:823-827.

13. Rydrych, D.J. 1979. Weed control for minimum tillage systems. Proceedings of the Thirteenth Annual Northwest Fertilizer Conf. Spokane, Wash.

14. Stickler, F.C., and A.W. Pauli. 1964. Yield and winter survival of winter barley varieties as affected by date and rate of planting. Crop Sci. 4:487-489.

15. Szekely, E. 1976. Szechrome analytical reagents. Research and Development Authority. Ben-Gurion Univ. of the Negev.

16. Woodruff, D.R. 1975. Decision making for wheat growers in Queensland. Dept. of Primary Industries. Agriculture Branch Tech. Bull. 10.

MANUSCRIPT II

Fallow-Crop Precipitation Pattern Effects on Moisture Storage and Soil Nitrate-Nitrogen Mineralization

ABSTRACT

Climatic effects on crop production are in many ways mediated through their effects on the soil system. Precipitation variation can influence not only the amount of moisture stored in a soil profile, but also its distribution within the profile. The amount and distribution of precipitation also has a direct effect on the amount and rate of mineralization.

The purpose of this study was to examine the effect of precipitation variation in a 14-month fallow and 10-month crop period on soil moisture storage and fallow-crop season mineralization in the semi-arid region of eastern Oregon. Five different fallow-crop precipitation patterns characteristic of the area were field simulated to demonstrate the effect of precipitation variation on soil water storage and nitrate mineralization in both the fallow and crop season.

The field simulation of five fallow-crop precipitation patterns demonstrated that for a given level of total precipitation (fallow + crop season) more soil moisture was stored at the 90-240 cm depth by the patterns with more fallow season precipitation when measured in March of the crop year. The effect on grain yield, however, was confounded by atypical environmental conditions. Soil moisture storage and storage efficiencies fluctuated throughout the fallow and crop periods. At the cessation

of the winter precipitation season in both the fallow and crop periods (March), the storage efficiency was highest when low levels of precipitation occurred. At this time, the mean crop period storage efficiency was 10% below the mean fallow period storage efficiency (34 and 44%, respectively).

The potential mineralization model (N_o) was tested under fallowed-field conditions. There was agreement between the actual and predicted levels of mineralization at the 30-180 cm depth. However, at the 0-30 cm depth, the predicted values greatly exceeded the actual. When the nitrogen immobilization requirement of the crop residues was included, the actual and predicted values were in agreement at the end of the 1978 fallow period. A nitrogen deficit was predicted at the 0-30 cm depth at the end of the 1979 fallow period. The actual levels, however, indicated a net accumulation of nitrate-nitrogen.

Crop season mineralization, inferred from Mitscherlick and a-value extrapolations, demonstrated in 1979 that there was a decreasing amount of net mineralization during the crop season with increasing amounts of both fallow and crop season precipitation. Crop season mineralization in 1980 indicated that there was no net accumulation of nitrogen, rather a net immobilization of 14 kg N/ha. This result reflects both the unsatisfied immobilization requirement predicted for the 1979 fallow season and crop season denitrification.

Additional index words: a-values, mineralization potential, Mitscherlick equation, storage efficiency.

FALLOW-CROP PRECIPITATION PATTERN EFFECTS ON MOISTURE STORAGE AND SOIL-NITRATE-NITROGEN MINERALIZATION

INTRODUCTION

The semi-arid regions of the Pacific Northwest are characterized by a high degree of annual temperature and precipitation variation. This variation has a pronounced effect upon the level of crop production in the region. Van der Paauw (1963) has pointed out, however, that climatic effects on crop production are in many ways mediated through their effects on the soil system. Precipitation variation can influence not only the amount of water stored in a soil profile, but conceivably, its distribution within the profile as well. In the semi-arid areas of eastern Oregon, a 14-month fallow system is utilized in order to store soil moisture to insure that sufficient water will be available to meet crop demands in the subsequent 10-month crop season. In general, the amount of stored soil moisture varies proportionately with the level of precipitation. Leggett (1959) demonstrated that the yield level of winter wheat is more closely related to the level of fallow season stored soil moisture than to the amount of growing season precipitation. Baier and Robertson (1968) demonstrated that deeper soil moisture becomes more important as growth progresses. Ample moisture at medium depths from jointing to heading is most important for high yields. This is followed in importance by moisture at deeper depths to support filling and ripening.

The amount and distribution of soil moisture in fallowed land also has a direct effect on the amount and rate of mineralization. The model of soil nitrogen mineralization developed by Stanford and Smith (1972) and Stanford et al. (1974) relates soil mineralization rates to soil moisture content and soil temperature. The biologically intrinsic value of the nitrogen mineralization potential (N_o) developed by Stanford and Smith (1972) for this model suggests a direct relevance to studies of climatic effects on soil fertility. Smith et al. (1977) demonstrated the validity of the (N_o) concept under modified field conditions. They speculated that average seasonal soil temperatures and water contents could be effectively utilized in estimating field nitrogen mineralization.

The effect of climatic variation on crop season mineralization has received little attention owing to the dynamic interference by the crop. Crop season mineralization amounts are generally one-half that of fallowed soil. Goring and Clark (1948) concluded that this was due to an actual depression of mineralization related to immobilization by increasing microbial populations. Historically, net crop season mineralization has been determined using yield responses from fertilizer trials in conjunction with the Mitscherlick relationship (Balba and Bray, 1957) and a-values (Dean, 1954). Ramig and Rhodes (1963) used the a-value approach in the Great Plains to demonstrate that the level of pre-plant stored soil moisture had little effect on crop season mineralization.

The purpose of this study was to examine the effect of precipitation variation in a 14-month fallow and 10-month crop period on soil moisture storage and fallow-crop season mineralization in a winter precipitation regime. Five different fallow-crop precipitation patterns were field simulated in order to field test the (N_o) concept, determine the amount of net crop season mineralization and demonstrate the effect of precipitation variation on soil water storage.

METHODS AND MATERIALS

Five fallow-crop precipitation patterns characteristic of the 250-350 mm precipitation zone of eastern Oregon were simulated on a commercial farm near Moro, OR (Table 1). The natural precipitation during this period was considered as a control treatment. In each season (fallow or crop), rainfall was excluded using plastic tarps that were rolled over the plots at the onset of a rainfall event and removed at the conclusion of each event. A PVC support grid was used to keep the tarps above the crop. Moisture was applied to the crop using a solid set irrigation grid with low-pressure, low-angle nozzles that provided 200% overlap. Moisture was regulated on a monthly basis, primarily during the winter months. A split-plot design was established with four blocks. The main plots (6 x 15 m) were the precipitation patterns. Nitrogen fertilizer (Solution 32;

Table 1. Fallow-crop precipitation pattern treatments

	Projected level of precipitation (mm)			Realized level of precipitation (mm)					
				1977-79			1978-80		
Pattern	14 mo. Fallow	May-Sept	10 mo. Crop	Fallow	May-Sept	Crop	Fallow	May-Sept	Crop
Dry fallow Normal crop (DFNC)	230	47	270	306	64	180	237	52	389
Normal fallow Dry crop (NFDC)	310	67	200	371	79	133	301	52	351
Normal fallow Normal crop (NFNC)	310	67	270	371	79	180	301	52	389
Normal fallow Wet crop (NFWC)	310	67	390	371	79	290	301	52	426
Wet fallow Normal crop (WFNC)	415	78	270	488	130	201	418	85	389
Control				422	79	180	263	39	389

32% N) was injected prior to seeding at six levels (0, 15, 45, 60, 75, 105 kg N/ha) into the subplots (6 x 2.5 m). All tillage and planting operations were conducted by the farmer as part of his normal farm operations. Stephens winter wheat was planted in late September 1978 and 1979 and emerged within 10 days in both years.

Soil nitrate-nitrogen was sampled to a 180 cm depth in 30 cm increments. Triplicate samples per main plot were collected at each sampling date. Each increment was air dried and ground to pass a 2 mm screen. Soil nitrate-nitrogen was extracted using a water-based extracting solution containing 0.3 g CaO/100 ml and 0.2 g $MgCO_3$/100 ml. Ten grams of soil was shaken with 100 ml of extracting solution for 30 minutes. The extract was filtered through a No. 40 Whatman filter and the nitrate content determined colorimetrically (600 nm) using the Szechrome NG reagent (Szekely, 1976). In the 1978 fallow season, soil samples were collected in August and September. In the 1979 fallow season, soil samples were collected in May and September.

Soil moisture was measured with a neutron probe in 15 cm increments to a depth of 270 cm. Triplicate readings per main plot were made at each sampling date. The 0-15 and 15-30 cm increments were measured gravimetrically. Access tube installation was according to Glenn et al. (1980). Available soil moisture was estimated by subtracting the initial, post-harvest soil moisture content for each access tube from each subsequent sampling date.

Total nitrogen in the straw and chaff was determined using the Kjeldahl distillation procedure. (A. Carey, unpublished data). Total nitrogen in the grain was determined using a Technicon infra-red analyzer. Straw and chaff dry weight and nitrogen samples were collected from 8.4 m of row in each subplot. Yield and grain samples were harvested with a self-propelled combine.

The nitrogen mineralization potential (N_o) of a Walla Walla silt loam (coarse, silty, mixed, mesic Typic Haploxeroll) was determined using a week pre-incubation and a 2-week incubation at 1/3 atm according to Stanford et al. (1974). The mineralization rate constant ($k = 0.047$ week^{-1} at 35^oC) was taken from the study of Stanford and Smith (1972). The Q_{10} for K was assumed to be 2.0 (Stanford et al., 1973). N_o was calculated according to Stanford et al. (1974) where $N_o = N_t/1-10^{(-kt/2.303)}$ with N_t = the amount of nitrogen mineralized in time t = 2 weeks. For a 2-week incubation, $N_o = 11.15\ N_t$. N_t was measured as nitrate and ammonium-nitrogen using Kjeldahl distillation.

Average soil temperature was measured at 10 and 30 cm depths at the nearby Sherman Branch Experiment Station, Moro, OR. These readings from undisturbed soil were used directly for March soil temperature estimations. The 10 and 30 cm readings were reduced 4^oC for soil temperature estimations at time periods when an insulating stubble mulch existed in the 0-15 cm depth. Soil temperature at depths greater than 30 cm were calculated by assuming a constant temperature of 9.7 ^{o}C, the long-term mean annual temperature (1918-1976), at a 3 m depth and then joining this point to the surface temperatures with a smoothly curving line. Soil temperature was estimated in this manner at each moisture sampling date.

Field nitrogen mineralization was calculated according to Smith et al. (1977) in which the amount of N mineralized for a given time period is equal to the product of (N_o), (k), and (FC) with (FC) representing the average soil water content of the time period as a percentage of field capacity. The rate constant (k) was calculated for the average soil temperature of the time period. Mineralization was assumed to begin on March 1 of the fallow period.

Straw and chaff levels initially in the experimental plots were estimated from grain yield levels assuming a grain to straw + chaff ratio of 1:1.7. The overall nitrogen percentage and grain to straw + chaff ratio of the crop residues was determined from the experimental plots of 1977-79 to be approximately 0.42% N and 1:1.7, respectively, and these values were assumed for straw and chaff residues initially in the plots in 1978 and 1979.

RESULTS AND DISCUSSION

Soil Moisture Storage

Historical yield data from the Sherman Branch Experiment Station (Moro, OR) indicates that for the same total level of precipitation in the fallow + crop period, the distribution of precipitation between the fallow and crop periods does have an effect on yield (Table 2). A comparison of the DFNC and NFDC or NFWC and WFNC indicates that for a given level of total precipitation, the pattern receiving more fallow season precipitation tends to have the higher yield. This is conceivably due to the distribution of stored soil moisture within the profile. The field simulation of these fallow-crop precipitation patterns demonstrated that more moisture was stored at the 90-120 cm depths by the patterns with more fallow season precipitation when measured in March of the crop year (Table 3). Because each pattern received different total amounts of precipitation by the March sampling, this effect is better illustrated using storage efficiences. In the 1977-79 simulation, there was no difference in storage efficiency. In the 1978-80 simulation, the patterns with the greater amount of fallow season precipitation had significantly higher storage efficiency at the 90-240 cm depth. Winter wheat yields in 1979 were significantly higher in the NFWC as compared with the WFNC. Winter killing was observed to reduce the number of tillers and vegetative material more on the WFNC treatment than on the normal or dry fallow treatments. The WFNC treatments had more tillers and vegetative growth in the fall due to a higher level of seed zone moisture. This damage apparently reduced, in a differential manner, the yield potential of the crop. The NFDC had a significantly higher yield than the DFNC

Table 2. A comparison of fallow-crop precipitation distribution effects on historical grain yield. (Moro, OR) 1912-76

Pattern	Yield (metric ton/ha)	Fallow period (mm)	Crop period (mm)	Probability of occurrance for each pattern	Total mean precipitation (mm)
DFNC	1.59	260	220-320	13.9	514
NFDC	1.79	260-370	220	16.9	520
NFWC	2.27	260-370	320	9.2	685
WFNC	2.54	370	220-320	13.9	676

Table 3. Amount of stored soil moisture at the 90-240 cm depth in the crop season (March) under four precipitation patterns.

Pattern	Available moisture (mm) 1977-79	Available moisture (mm) 1978-80	Storage efficiency $\frac{\text{mm stored water}}{\text{mm precipitation}} \times 100$ 1977-79	Storage efficiency 1978-80	Grain yield (metric ton/ha) 1979	Grain yield (metric ton/ha) 1980
DFNC	91^{a}	76^{a}	19.0^{a}	14.2^{a}	3.07^{a}	5.74^{a}
NFDC	91^{a}	104^{b}	16.8^{a}	18.5^{b}	3.43^{b}	5.97^{a}
NFWC	87^{A}	80^{A}	15.2^{A}	12.7^{A}	4.04^{A}	5.35^{A}
WFNC	100^{A}	106^{B}	15.2^{A}	14.9^{B}	3.63^{B}	5.39^{A}

Means followed by the same letter are not significantly different at the 10% level of probability.

due to significantly more stored moisture in the 0-90 cm depth. In 1980 unseasonably cool, moist conditions from heading through ripening in conjunction with a high level of crop season precipitation masked all treatment differences.

Soil moisture storage and storage efficiencies fluctuated sharply throughout the fallow and crop periods (Figure 1). At the cessation of the winter precipitation season in both the fallow and crop periods (March), the storage efficiency was highest when low levels of precipitation occurred. This is primarily due to the slower infiltration rates of precipitation into a more saturated profile that leaves the soil surface in evaporative stage 1 for a longer period of time. Despite the cool temperatures during the winter months, the windy conditions and clear skies generally following precipitation events promote evaporative losses. No runoff occurred in either simulation study.

Storage efficiencies and soil moisture storage beyond March of the crop year indicate continual moisture loss from the profile until the resumption of fall precipitation in the crop season. Significant differences in water storage and storage efficiency occurred between March and September of the fallow period. In 1978, the normal (NF) and wet fallow (WF) treatments lost significantly more moisture from the profile than the dry fallow (DF). However, they also maintained significantly greater amounts of soil moisture. In 1979, there was no significant difference in the total amount of water lost between treatments and the

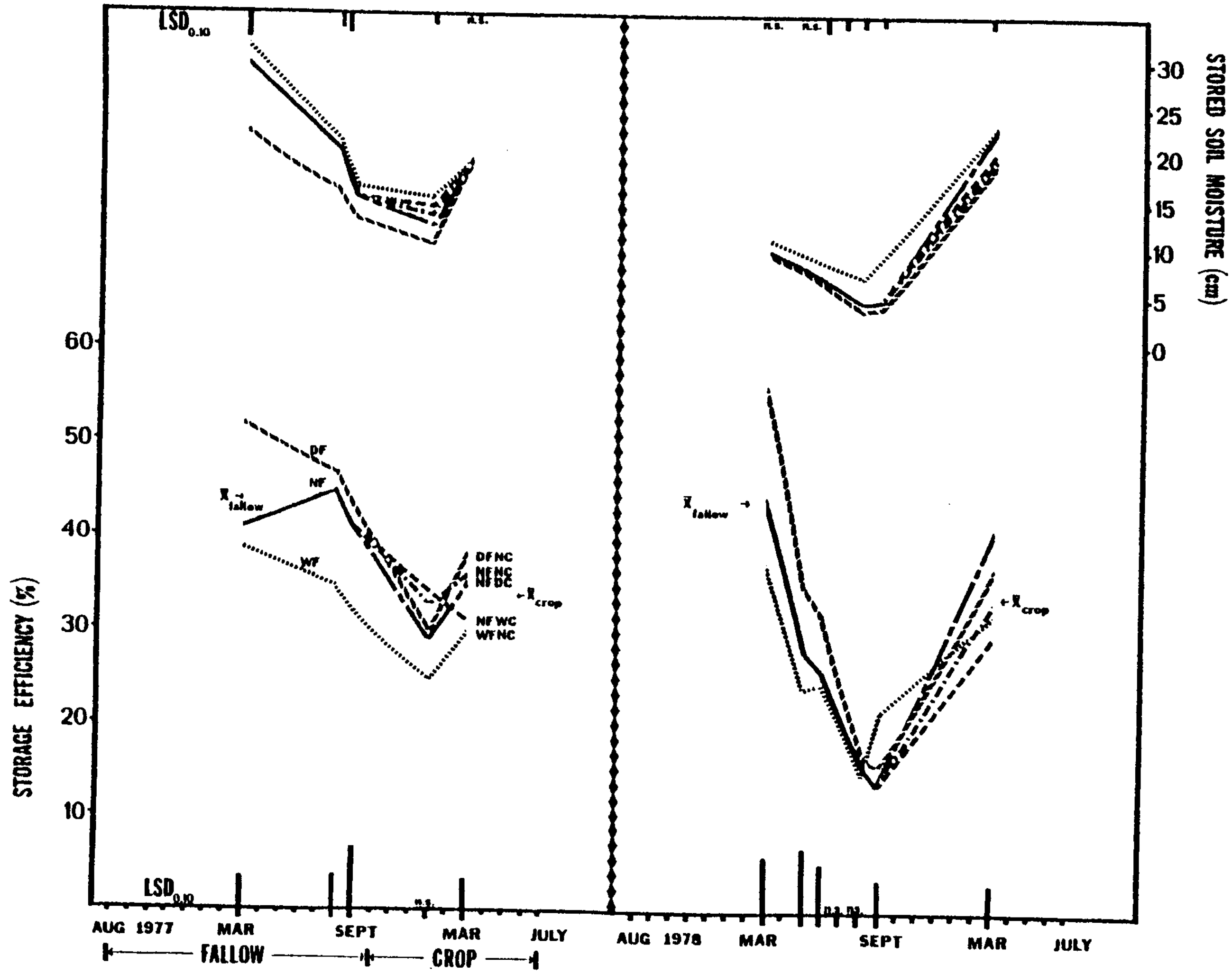


Figure 1. Water storage and storage efficiency in two fallow-crop rotations.

wet fallow treatment maintained a significantly higher amount of stored soil moisture through late September.

Both simulation studies demonstrated that at the close of the winter precipitation period (March), the mean crop storage efficiency was 10% below the mean fallow storage efficiency (34 and 44%, respectively). This 10% decrease in crop season storage efficiency illustrates the reduced overall effectiveness of crop season precipitation to be stored within the profile.

Fallow Season Mineralization

Soil moisture, temperature and immobilization requirements of crop residues interact to affect the net amount of nitrogen mineralized in a fallowed soil. The nitrogen percentage of the straw has a significant effect on the net amount of mineralization. In the 1977-78 fallow period, approximately 3400 kg/ha straw and chaff (dry weight) were incorporated into the upper 15 cm of soil. This crop residue load, at 0.42% N, would require approximately 88 kg N/ha to elevate the residue to 3% N where net mineralization would generally begin (Bremner, 1965; Harmsen and Kolenbrander, 1965). The mean realized mineralization amounts (Table 4) were less than their predicted levels. However, the range of realized values indicates that the maximum level of measured mineralization approximated the predicted potential.

In this cropping system, crop residues are incorporated into the 0-15 cm depth of soil with tillage implements de-

Table 4. Actual and predicted fallow mineralization amounts from March 1 to late September. (0-180 cm)

Fallow pattern	Predicted mineralization at the end of fallow (kg N/ha)	Range	Immobilization Requirement (kg N/ha)	Predicted net mineralization (kg N/ha)	Average realized mineralization (kg N/ha)	Range
1977-78						
Dry	150	140-163	88	62	60[a]	47-70
Normal	161	156-167	88	73	50[a]	39-75
Wet	167	164-172	88	79	66[a]	45-85
1978-79						
Dry	119	113-122	132	-13	62[A]	47-75
Normal	119	114-126	132	-13	61[A]	48-72
Wet	126	124-127	132	- 6	54[A]	42-72
Control	120	118-123	132	-12	62[A]	51-80

Means in a column followed by the same letter are not significantly different at the 10% level of probability.

signed to keep a portion of the stubble on the surface. This stubble mulch is maintained in a relatively dry, loose state to insulate the soil beneath and reduce water vapor loss. Parker et al. (1957) demonstrated that nitrate-nitrogen can move upward in the profile with water vapor and be deposited in crop residues to aid in their decomposition. The amount of mineralization from August-September (Table 5, Figure 2) suggests that immobilization was complete at the close of the fallow period. The mineralization amounts in the 0-30 and 30-180 cm depths generally agreed with the predicted levels. To determine if immobilization was complete, 25 mm of water were applied to the wet fallow treatment in late August. This additional moisture stimulated additional mineralization though not to a significant level.

Mineralization amounts between March and May 1979 indicate close agreement between actual and predicted values at all depths except 0-30 cm (Table 6, Figure 3). During this period, tillage was initiated to incorporate a portion of the residues. This action would stimulate immobilization and result in a decrease in net mineralization in the upper 15 cm.

The 1978-79 fallow period was below normal in both total precipitation and in rainfall from May-September (Table 1). There was also a greater residue load (approximately 5100 kg/ha) which required approximately 132 kg/ha additional nitrogen to elevate the crop residue to 3% N. The dry conditions in the 1978-79 fallow season reduced the predicted

Table 5. Net mineralization amounts between August 9 and September 19. 1977-78 fallow season.

Fallow pattern	Actual (kg N/ha) mean	Actual (kg N/ha) range	Predicted (kg N/ha) mean	Predicted (kg N/ha) range
		0-30 cm		
Dry	8[a]	0-17	11	10-11
Normal	9[a]	1-20	11	10-11
Wet	17[a]	0-32	12	11-12
		30-180 cm		
Dry	3[A]	0-13	16	15-16
Normal	7[A]	0-32	16	16-17
Wet	7[A]	3-14	16	16-17

Means in a column followed by the same letter are not significantly different at the 10% level of probability.

Table 6. Actual and predicted fallow mineralization amounts from March 1 to May 26. 1978-79 fallow.

Fallow pattern	Actual (kg N/ha) mean	Actual (kg N/ha) range	Predicted (kg N/ha) mean	Predicted (kg N/ha) range
		0-180 cm		
Dry	34[a]	27-41	43	42-45
Normal	33[a]	22-57	43	40-46
Wet	34[a]	26-39	45	42-45
Control	36[a]	32-43	44	42-45
		0-30 cm		
Dry	9[a]	6-14	23	22-24
Normal	9[a]	4-14	22	21-23
Wet	6[a]	5-7	22	19-23
Control	10[a]	6-17	23	22-24
		30-180 cm		
Dry	25[a]	21-24	20	20-21
Normal	24[a]	14-43	21	20-23
Wet	28[a]	20-34	23	22-25
Control	26[a]	23-27	21	20-21

Means in a column followed by the same letter are not different at the 10% level of significance.

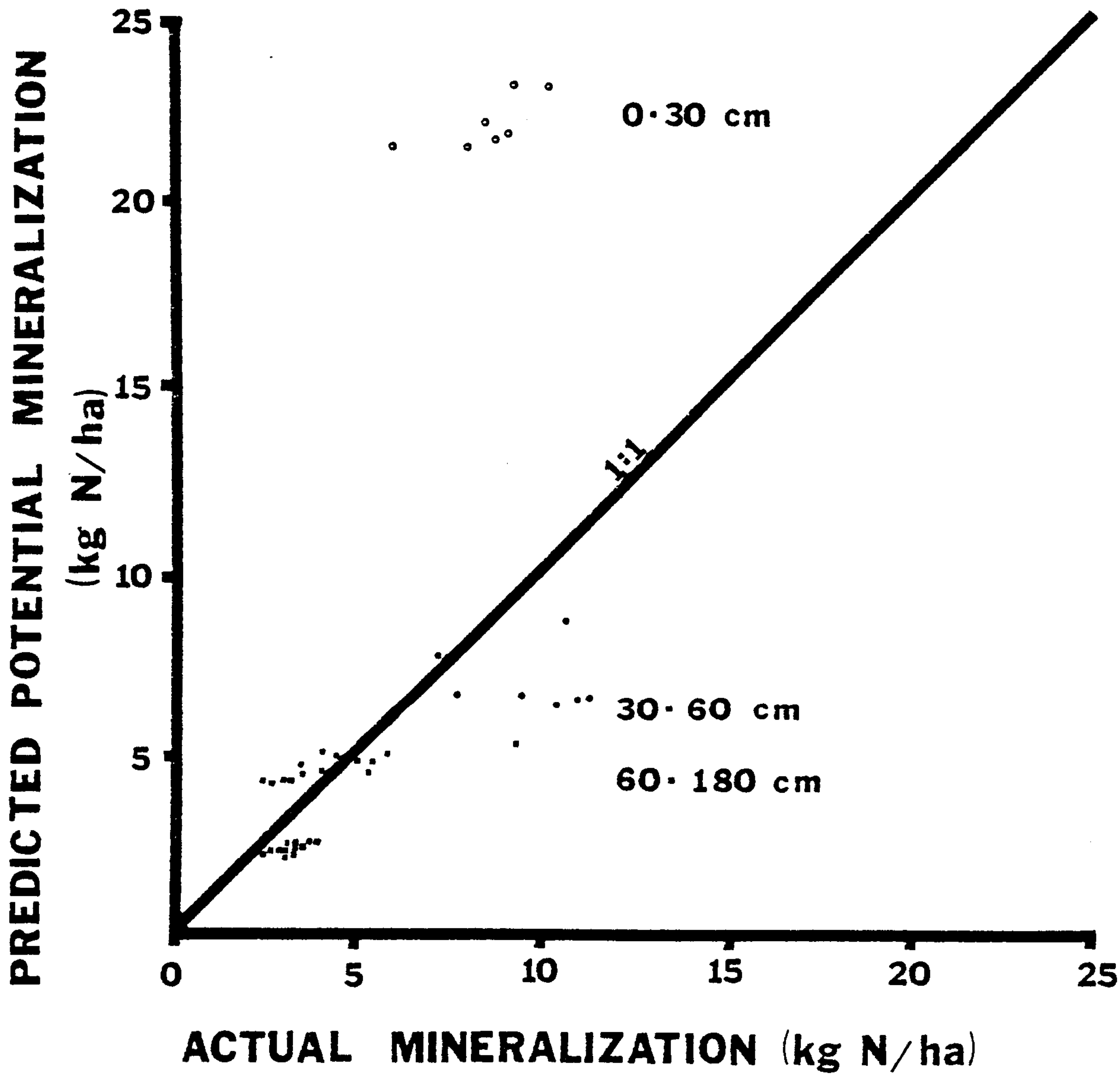


Figure 2. Mean actual and predicted mineralization levels for August 9 - September 19, 1978. 0-180 cm in 30 cm increments for the dry, normal and wet fallow treatments.

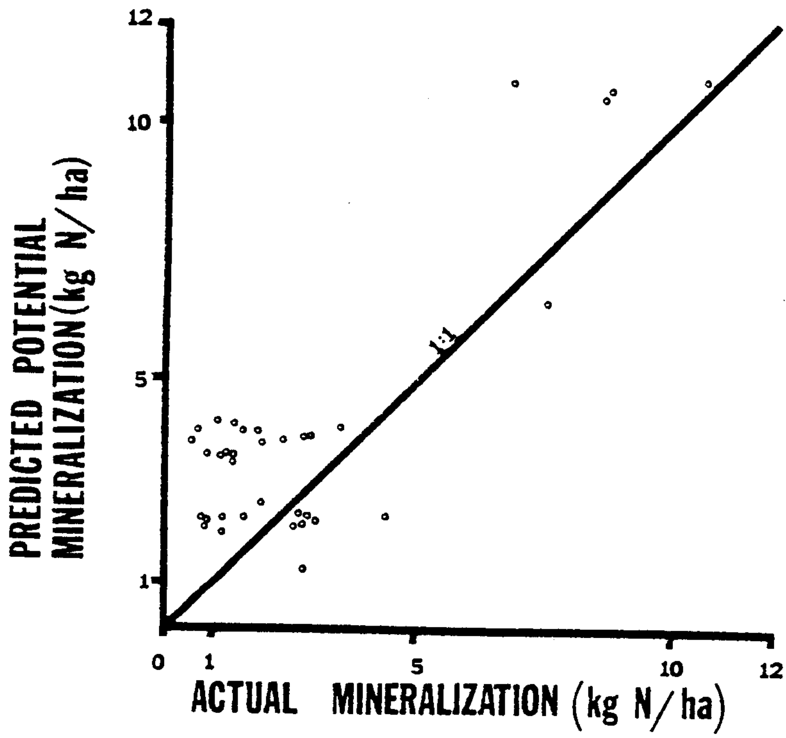


Figure 3. Mean actual and predicted mineralization levels for March 1 - May 26, 1979. 0-180 cm in 30 cm increments for the dry, normal and wet fallow treatments.

mineralization potential and the predicted net mineralization amount compared with the 1978 fallow season (Table 4). However, the realized level of mineralization was of the same magnitude as the previous year and greater than predicted. This discrepancy may be due to incomplete immobilization of the residue load in the upper 30 cm at the time of sampling in September.

The predicted amount of mineralized nitrogen in the upper 30 cm indicates a nitrogen deficit, but the actual nitrogen levels demonstrate a net increase (Table 7). Since the residue load is spacially segregated in the upper 15 cm, the 15-30 cm increment is capable of mineralization without an over-riding tie-up of nitrogen. To determine if immobilization was complete, 33 mm of water was added to the wet fallow treatments during the first week of September. Instead of stimulating mineralization as it had in the previous year, the addition of water and a significantly greater amount of soil moisture in the 0-30 cm increment during August period resulted in a significant decrease in the amount of net mineralization in the upper 30 cm of soil. This suggested that immobilization demands were not yet satisfied. The average realized mineralization amounts in the 30-180 cm profile were less than the predicted potential, but the maximum values agreed very closely with the predicted potential.

It appears that the mineralization model proposed by Stanford and Smith (1972) can be applied to field situations

Table 7. Actual and predicted fallow mineralization amounts from March 1 to September 13. 1978-79 fallow.

Fallow pattern	Actual (kg N/ha) mean	Actual (kg N/ha) range	Predicted (kg N/ha) mean net	Predicted (kg N/ha) mean total	Predicted (kg N/ha) range
		0-30 cm			
Dry	15[a]	12-18	-74	58	55-60
Normal	15[a]	10-21	-78	54	44-59
Wet	9[b]	8-10	-73	59	56-60
Control	15[a]	9-23	-73	59	58-61
		30-180 cm			
Dry	46[A]	35-59	61	61	58-66
Normal	46[A]	37-54	65	65	58-68
Wet	45[A]	34-64	68	68	64-71
Control	46[A]	39-57	62	62	59-64

Means in a column followed by the same letter are not different at the 10% level of significance.

when immobilization requirements and climatic variation are considered. The high degree of field variation encountered in this study suggests that there are other factors limiting field mineralization. These may include denitrification, further unaccounted for immobilization due to both roots and crop residues; and inherent field variation. This study also suggests a potential error associated with nitrogen soil testing of soils with an unsatisfied immobilization requirement.

Crop Season Mineralization

Crop season mineralization was measured using both the Mitscherlick equation after Engelstad and Khasawneh (1969) and a-values (Dean, 1954). Both approaches utilize the principle that the extrapolation to the x-axis of the regression of a response (yield and nutrient uptake, respectively) on soil test and fertilizer nitrogen can infer the level of crop season nutrient contribution. There was no significant difference in the slope of all the regression lines used to calculate the a-values, so they were pooled. There was no significant difference in the intercept used to calculate the a-values for all treatments except the DFNC. All intercepts were pooled except the one for the DFNC treatment. The multiple regression approach of Englestad and Khasawneh (1969) did not lend itself to pooling treatments. Both methods demonstrated comparable results and indicated that the net amount of crop season mineralization decreased with increasing levels of precipitation in both the fallow and crop periods (Table 8). Significant differences cannot be assigned to these extrapolated values; however, significant differences exhibiting a similar trend were observed in the amount of N uptake in the non-fertilized plots of each treatment.

The reduction of net crop-season mineralization with increasing levels of precipitation cannot be attributed to leaching losses beyond the root zone since this situation was not observed. Denitrification losses resulting from temporarily saturated soil conditions may partially explain these results. In the period of time between planting and March of the crop year, the DFNC had significantly more soil moisture infiltrate to the 90-120 cm depth. This was due to the lower water content of the profile promoting more rapid infiltration and redistribution. A rapid rate of infiltration and internal drainage would reduce the temporary denitrifying conditions that can occur with saturated water flow.

All treatment differences in the 1980 crop were masked due to a wet crop season in conjunction with cool conditions from heading to ripening that produced extremely high plot yields. The application of the Mitscherlick equation to the pooled fertilizer responses indicated that -14 kg N/ha were mineralized in this crop season, i.e. there was a 14 kg deficit of nitrogen. This level of net crop mineralization indicates not only the denitrification effects of a wet crop period, but may also reflect the unsatisfied

Table 8. Crop season mineralization (1979)

Pattern	Net crop season mineralization using the Mitscherlick equation (kg N/ha)	Net crop season mineralization using a-values (kg N/ha)	Measured plant N in non-fertilized treatments (kg N/ha)	Crop season infiltration to the 90-120 cm depth (mm)
DFNC	45	48	58[a]	17[a]
NFDC	39	35	45[b]	13[b]
NFNC	35	35	53[ab]	13[b]
NFWC	29	35	46[b]	14[b]
WFNC	24	35	45[b]	11[b]

Means in a column followed by the same letter are not different at the 10% level of significance.

immobilization requirement in the upper 30 cm predicted for the 1979 fallow season (Table 7).

LITERATURE CITED

1. Baier, W., and G.W. Robertson. 1968. The performance of soil moisture estimates as compared with direct use of climatological data for estimating crop yields. Agric. Meteorology 5:17-31.

2. Balba, A.M., and R.H. Bray. 1957. New fields for the application of the Mitscherlick equation: 2. Contribution of soil nutrient forms to plant nutrient uptake. Soil Sci. 83:131-139.

3. Bremner, J.N. 1965. Organic nitrogen in soils. In: Soil Nitrogen. ed. W.F. Bartholomew and F.E. Clark. No. 10. Amer. Soc. Agron. Madison, Wis. pp. 43-92.

4. Cary, A. Unpublished data. Graduate Research Assist. Oregon State Univ.

5. Dean, L.A. 1954. Yield of phosphorous curves. Soil Sci. Soc. Amer. Proc. 18:463-466.

6. Engelstad, O.P., and F.E. Khasawneh. 1969. Use of a concurrent Mitscherlick model in fertilizer evaluation. Agron. J. 61:473-474.

7. Glenn, D.M., R.L. Henderson, and F.E. Bolton. 1980. A retractable neutron-probe access tube. Agron. J. 72:1067-1068.

8. Goring, C.A.I., and F.E. Clark. 1948. Influence of crop growth on mineralization of N in the soil. Soil Sci. Soc. Amer. Proc. 13:261-266.

9. Harmsen, G.W., and G.J. Kolenbrander. 1965. Soil inorganic nitrogen. In: Soil Nitrogen. ed. W.V. Bartholomew and F.E. Clark. No. 10. Amer. Soc. Agron. Madison, Wis. pp. 43-71.

10. Leggett, G.E. 1959. Relationships between wheat yield, available moisture and available nitrogen in eastern Washington dryland areas. Wash. Agric. Exp. Sta. Bull. 609.

11. Parker, D.T., W.E. Larson, and W.V. Bartholomew. 1957. Studies on nitrogen tie-up as influenced by location of plant residues in soils. Soil Sci. Soc. Amer. Proc. 21:608-612.

12. Ramig, R.E., and H.F. Rhoades. 1963. Interrelationships of soil moisture level at planting time and nitrogen fertilization on winter wheat production. Agron. J. 55:123-127.

13. Smith, S.J., L.B. Young, and G.E. Miller. 1977. Evaluation of soil nitrogen mineralization potentials under modified field conditions. Soil Sci. Soc. Amer. Proc. 41:74-76.

14. Stanford, G., J.N. Carter, and S.J. Smith. 1974. Estimates of potentially mineralizable soil nitrogen based on short-term incubations. Soil Sci. Soc. Amer. Proc. 38:99-102.

15. Stanford, G., M.H. Frere, and D.H. Schwaninger. 1973. Temperature coefficient of soil nitrogen mineralization Soil Sci. 115:321-323.

16. Stanford, G., and S.J. Smith. 1972. Nitrogen mineralization potentials of soils. Soil Sci. Soc. Amer. Proc. 36:465-472.

17. Szekely, E. 1976. Szechrome analytical reagents. Research and Development Authority. Ben-Gurion Univ. of the Negev.

18. Van der Paauw, F. 1963. Periodic fluctuations of soil fertility, crop yields and of responses to fertilization affected by alternating periods of low or high rainfall. Plant and Soil 17:155-182.

BIBLIOGRAPHY

Aktan, S. 1976. Nitrate-nitrogen accumulation and distribution in the soil profile during a fallow grain rotation as influenced by different levels of soil profile moisture. M.S. Thesis. Oregon State University.

Aldrich, W.W., R.A. Work, and M.R. Lewis. 1935. Pear root concentration in relation to soil moisture extraction in heavy clay soils. J. Agric. Res. 50:975-988.

Alessi, J., and J.F. Powers. 1977. Residual effects of N fertilization on dryland spring wheat in the northern plains. I. Wheat yield and water use. Agron. J. 69:1007-11.

Allaby, M. 1977. A Dictionary of the Environment. Van Nostrand Reinhold. Dallas.

Army, T.J., J.J. Bond, and C.E. Van Doren. 1959. Precipitation-yield relationships in dryland wheat production on medium to fine textured soils of the southern high plains. Agron. J. 51:721-24.

Baier, W. 1973. Crop-weather analysis model: review and model development. J. Applied Meterol. 12:937-47.

Baier, W. and G.W. Robertson. 1968. The performance of soil moisture estimates as compared with direct use of climatological data for estimating crop yields. Agric. Meteorology 5:17-31.

Balba, A.M., and R.H. Bray. 1957. New fields for the application of the Mitscherlick equation: 2. Contribution of soil nutrient forms to plant nutrient uptake. Soil Sci. 83:131-139.

Balba, A.M., and L.E. Haley. 1956. Comparison of results obtained by the Balba-Bray equation and radioactive techniques for the determination of nutrient uptake by plants from different nutrient forms. Soil Sci. 82:365-68.

Bauer, A. 1968. Evaluation of fallow to increase water storage for dryland wheat production. North Dakota Farm Res. Bull. 25(5):6-9.

Bauer, A., and T.J. Conlon. 1974. Effect of tillage interval of fallow on available soil N, some soil physical properties and wheat yields. North Dakota Research Report #51.

Beutler, L.K., and W.H. Foote. 1963. Influence of date of seeding and nitrogen rates on winter wheat varieties in eastern Oregon. Agron. J. 55:4-6.

Birch, H.F. 1960. Nitrification in soils after different periods of dryness. Plant and Soil 12:81-96.

Bole, J.B., and U.J. Pittman. (unpublished data)

Bond, J.J., J.F. Power, and W.O. Willis. 1971. Soil water extraction by N-fertilized spring wheat. Agron. J. 63:280-283.

Bracken, A.F., and P.V. Cardon. 1935. Relation of precipitation to moisture storage and crop yield. J. of Amer. Soc. of Agron. 27:8-20.

Bracken, A.F., and J.E. Greaves. 1941. Losses of nitrogen and organic matter from dry-farm soil. Soil Sci. 51:1-15.

Bremner, J.N. 1965. Organic nitrogen in soils. In: Soil Nitrogen. Ed. W.F. Bartholomew and F.E. Clark. No. 10. Amer. Soc. Agron. Madison, Wis. pp. 43-92.

Broadbent, F.E., and F.Clark. 1975. Denitrification. In: Soil Nitrogen. Ed: W.F. Bartholomew and F.E. Clark. Amer. Soc. of Agron. Inc. Madison, Wis. pp. 347-362.

Brown, P.L. 1971. Water use and soil water depletion by dryland winter wheat as affected by nitrogen fertilization. Agron. J. 63:43-47.

Burns, I.G. 1974. A model for predicting the redistribution of salts applied to fallow soils after excess rainfall or evaporation. J. Soil Sci. 25:165-178.

Campbell, C.A., V.O. Biederbeck, F.G. Warder, and G.W. Robertson. 1973. Effect of rainfall and subsequent drying on N and P changes in a dryland fallow loam. Soil Sci. Soc. Amer. Proc. 37:909-915.

Cary, A. Unpublished data. Graduate Research Assistant. Oregon State University.

DeJong, E., and D.A. Rennie. 1969. Effect of soil profile type and fertilizer on moisture use by wheat grown on fallow or stubble land. Can. J. Soil Sci. 49:189-197.

Dean, L.A. 1954. Yield of phosphorous curves. Soil Sci. Soc. Amer. Proc. 18:463-466.

deWit, C.T. 1958. Transpiration and crop yields. Inst. Biol. Chem. Res. on Field Crops and Herbage. Wageningen, The Netherlands, Verse-Landbouk, Onder Z. No. 64.6-S Gravevage.

Eck, H.V., and B.A. Stewart. 1959. Response of winter wheat to phosphate as affected by soil and climate factors. Agron. J. 51:193-195.

Eck, H.V., and B.B. Tucker. 1968. Winter wheat yields and response to nitrogen as affected by soil and climatic factors. Agron. J. 60:663-666.

Engelstad, O.P., and F.E. Khasawneh. 1969. Use of a concurrent Mitscherlick Model in fertilizer evaluation. Agron. J. 61:473-474.

Ferguson, W.S., and B.J. Gorby. 1964. Effect of straw on availability of nitrogen to cereal crops. Canadian J. of Soil Sci. 44:286-291.

Gardner, E.H., T.W. Thompson, H. Kerr, J. Hesketh, F.H. Hagelstein, M. Zimmerman, and G. Cook. 1975. The nitrogen and sulfur fertilization of dryland winter wheat in Oregon's Columbia Plateau. Proc. 26th Pacific Northwest Fert. Conf., Salt Lake City, UT. pp 99-104.

Glenn, D.M., R.L. Henderson, and F.E. Bolton. 1980. A retractable neutron-probe access tube. Agron. J. 72:1067-1068.

Gogulwar, N.M. 1973. Effect of residual and applied N on the protein content and yield of winter wheat under three moisture regimes. Ph.D. Thesis. Univ. of Neb.

Goring, C.A.J., and F.E. Clark. 1948. Influence of crop growth on mineralization of N in the soil. Soil Sci. Soc. Amer. Proc. 13:261-266.

Greb, B.W., D.E. Smika, and A.L. Block. 1967. Effect of straw mulch rates on soil water storage during summer fallow in the Great Plains. Soil Sci. Soc. Amer. Proc. 31:556-559.

Greb, B.W. 1979. Reducing drought effects on croplands in the West-Central Great Plains. USDA-SEA. Information Bulletin 420, 31 pp.

Halvorson, A.R., C.F. Engle, and E. Field. 1972. The environment and nitrogen fertilization for maximum yield: dryland wheat, eastern Washington. Proc. 23rd Pacific Northwest Fert. Conf. Boise, ID. pp. 37-42.

Harmsen, G.W., and G.J. Kolenbrander. 1965. Soil inorganic nitrogen. In: Soil Nitrogen. Ed.: W.F. Bartholomew and F.E. Clark. No. 10. Amer. Soc. Agron. Inc. Madison, Wis. pp. 43-71.

Hart, P.B.S., K.M. Goh, and T.E. Ludecke. 1979. Nitrogen mineralization in fallow and wheat soils under field and laboratory conditions. N.Z. Journ. of Agr. Res. 22:115-125.

Haun, J.R. 1974. Prediction of spring wheat yields from temperature and precipitation data. Agron. J. 66:405-409.

Herlihy, M. 1979. Nitrogen mineralization in soils of varying texture, moisture and organic matter. Plant and Soil 53:255-267.

Holbrook, F.S., and J.R. Welsh. 1980. Soil-water use by semi-dwarf and tall winter wheat cultivars under dry-land field conditions. Crop Sci. 20:244-246.

Hunter, A.S., C.J. Gerard, H.M. Waddoups, W.E. Hall, H.E. Cushman, and L.A. Alban. 1957. Progress Report - Wheat fertilization experiments in the Columbia Basin, 1953-1955. Ore. Agr. Expt. Sta. Cir. of Info. 570.

Hunter, A.S., L.A. Alban, C.J. Gerard, W.E. Hall, H.E. Cushman, and R.G. Petersen. 1961. Fertilizer needs of wheat in the Columbia Basin dryland area of Oregon. Tech. Bull. 57. OSU.

Isfan, D. 1979. Nitrogen rate-yield precipitation relationships and N rate forecasting for corn crops. Agron. J. 71:1045-51.

Jackson, G.D., and J.R. Sims. 1977. Comprehensive nitrogen fertilizer management model for winter wheat. Agron. J. 69:373-77.

Johnson, W.C. 1964. Some observations on the contribution of an inch of seeding-time soil moisture to wheat yield in the Great Plains. Agron. J. 56:29-35.

Johnson, W.C., and R.G. Davis. 1980. Yield-water relationships of summer-fallowed winter wheat. USDA-SEA. Agric. Res. Result ARR-S-5.

Kmock, H.G., R.E. Ramig, R.L. Fox, and F.E. Koehler. 1957. Root development of winter wheat as influenced by soil moisture and nitrogen fertilization. Agron. J. 49:20-25.

Koehler, F.E. 1960. Nitrogen uptake and moisture use by wheat. Proc. 11th Annual Pacific Northwest Fert. Conf. Salt Lake City, UT pp. 141-146.

Kowalenko, C.G. 1978. Nitrogen transformations and transport over 17 months in field fallow microplots using N^{15}. Can. J. Soil Sci. 58:69-76.

Leggett, G.E. 1959. Relationships between wheat yield, available moisture and available nitrogen in eastern Washington dryland areas. Wash. Agric. Exp. Sta. Bull. 609.

Lindstrom, M.J., F.E. Koehler, and R.I. Papendick. 1974. Tillage effects on fallow water storage in the eastern Washington dryland region. Agron. J. 66:312-316.

Mathews, O.R., and T.J. Army. 1960. Moisture storage on fallowed wheat land in the Great Plains. Soil Sci. Soc. Amer. Proc. 24:414-418.

Michalyna, W., and R.A. Hedlin. 1961. A study of moisture storage and nitrate accumulation in soil as related to wheat yields on four cropping sequences. Can. J. Soil Sci. 41:5-15.

Miller, R.D., and D.D. Johnson. 1964. The effect of soil moisture tension on carbon dioxide evaluation, nitrification and nitrogen mineralization. Soil Sci. Soc. Amer. Proc. 28:644-646.

Nuttonson, M.Y. 1953. Phenology and thermal environment as a means for a physiological classification of wheat varieties and for predicting maturity dates of wheat. American Institute of Crop Ecology. Wash. D.C.

Olson, R.A., and H.T. Rhoades. 1953. Commercial fertilizer for winter wheat in relation to the properties of Nebraska soils. Nebr. Agr. Exp. Sta. Bull. 172.

Olson, R.A., C.A. Thompson, P.H. Grabouski, D.D. Stukenholtz, K.D. Franks, and A.F. Dreier. 1964. Water requirements of grain crops as modified by fertilizer use. Agron. J. 56:427-432.

Olson, R.V., L.S. Murphy, H.C. Moser, and C.W. Swallow. 1979. Fate of tagged fertilizer nitrogen applied to winter wheat. Soil Sci. Soc. Amer. Proc. 43:973-975.

Oregon State Cooperative Extension Service. 1976. Fertilizer Guide for Winter Wheat (non-irrigated - Columbia Plateau. FG 54.

Papendick, R.I., V.L. Cochran, and W.M. Woody. 1971. Soil water potential and water content profiles with wheat under low spring and summer rainfall. Agron. J. 63:731-734.

Parker, D.T., W.E. Larson, and W.V. Bartholomew. 1957. Studies on nitrogen tie-up as influenced by location of plant residues in soils. Soil Sci. Soc. Amer. Proc. 21:608-612.

Parker, D.T., and W.E. Larson. 1962. Nitrification as affected by temperature and moisture content of mulched soils. Soil Sci. Soc. Amer. Proc. 26:238-242.

Passioura, J.B. 1973. Sense and non-sense in crop modeling. J. Aust. Inst. Agri. Sci. 39:181-183.

Pengra, R.F. 1952. Estimating crop yields at seeding time in the Great Plains. Agron. J. 44:271-274.

Po chop, L.O., R.L. Cornia, and C.F. Becker. 1975. Prediction of winter wheat yield from short-term weather factors. Agron. J. 67:4-7.

Ramig, R.E., and H.F. Rhoades. 1963. Interrelationships of soil moisture level at planting time and nitrogen fertilization on winter wheat production. Agron. J. 55:123-127.

Rasmussen, P.E., R.R. Almaras, C.R. Rohde, and N.C. Roager, Jr. 1980. Crop residue influences on soil carbon and nitrogen in a wheat-fallow system. Soil Sci. Soc. Amer. Proc. 44:596-600.

Rasmussen, V.P., and R.J. Hanks. 1978. Spring wheat yield model for limited moisture conditions. Agron. J. 70:940-944.

Read, D.L.W., and F.C. Warder. 1974. Influence of soil and climatic factors on fertilizer response of wheat grown on stubble land in southern Saskatchewan. Agron. J. 66:245-248.

Rhode, C.R. 1963. Effect of nitrogen fertilization on yield, components of yield and other agronomic characteristics of winter wheat. Agron. J. 55:455-458.

Rickman, R.W., R.R. Allmaras, and R.E. Ramig. 1978. Root sink descriptions of water supply to dryland wheat. Agron. J. 70:723-728.

Russelle, M.P., and F.E. Bolton. 1980. Soil temperature effects on winter wheat and winter barley emergence in the field. Agron. J. 72:823-827.

Russell, J.S. 1968. Nitrogen fertilizer and wheat in a semi-arid environment. 2. Climatic factors affecting response. Aust. J. Exp. Agric. and Animal Husb. 8:223-231.

Rydrych, D.J. 1979. Weed control for minimum tillage systems. Proceedings of the Thirteenth Annual Northwest Fertilizer Conf. Spokane, Wash.

Sharma, R.B., and B.P. Ghildyal. 1977. Soil-water-root relations in wheat: water extraction rate of wheat roots that developed under dry and moist conditions. Agron. J. 69:231-233.

Singh, R., Y. Singh, S.S. Prihar, and P. Singh. 1975. Effect of N fertilization on yield and water use efficiency of dryland winter wheat as affected by stored water and rainfall. Agron. J. 67:599-603.

Smika, D.E., and G.A. Wicks. 1968. Soil water storage during fallow in the central Great Plains as influenced by tillage and herbicide treatments. Soil Sci. Soc. Amer. Proc. 32:591-595.

Smika, D.E., A.L. Black, and B.W. Greb. 1969. Soil nitrate, soil water and grain yields in a fallow wheat rotation in the Great Plains as influenced by straw mulch. Agron. J. 61:785-787.

Smika, D.C. 1970. Summer fallow for dryland winter wheat in the semiarid Great Plains. Agron. J. 62:15-17.

Smith, S.J., L.B. Young, and G.E. Miller. 1977. Evaluation of soil nitrogen mineralization potentials under modified field conditions. Soil Sci. Soc. Amer. Proc. 41:74-76.

Stanford, G., and S.J. Smith. 1972. Nitrogen mineralization potentials of soils. Soil Sci. Soc. Amer. Proc. 36: 465-472.

Stanford, G., M.H. Frere, and D.H. Schwaninger. 1973. Temperature coefficient of soil nitrogen mineralization. Soil Sci. 115-321-323.

Stanford, G., J.O. Legg, and S.J. Smith. 1973. Soil nitrogen availability evaluations based on nitrogen mineralization potentials of soils and uptake of labeled and unlabeled nitrogen by plants. Plant and Soil 39:113-124.

Stanford, G., J.N. Carter, and S.J. Smith. 1974. Estimates of potentially mineralizable soil nitrogen based on short-term incubations. Soil Sci. Soc. Amer. Proc. 38:99-102.

Stanford, G., and E. Epstein. 1974. Nitrogen mineralization-water relations in soils. Soil Sci. Soc. Amer. Proc. 38:103-107.

Stephens, D.E., M.M. Oveson, and G.A. Mitchell. 1943. Water requirement of wheat at the Sherman Branch Experiment Station. Station Technical Bull. 1. 27 pp.

Stickler, F.C., and A.W. Pauli. 1964. Yield and winter survival of winter barley varieties as affected by date and rate of planting. Crop Sci. 4:487-489.

Storrier, R.R. 1962. The availability of mineral nitrogen in a wheat soil from southern New South Wales. Aust. J. of Exp. Agric. and Animal Husb. 2:185-192.

Swenson, R., W.C. Dahnke, and D.D. Patterson. 1979. Nitrate-nitrogen accumulation and management in some North Dakota soils under dryland conditions. North Dakota Farm Res. 36(5):3-8.

Szekely, E. 1976. Szechrome analytical reagents. Research and Development Authority. Ben-Gurion Univ. of the Negev.

Taylor, A.C., R.R. Storrier, and A.R. Gilmore. 1974. Nitrogin needs of wheat. I. Grain yield in relation to soil nitrogen and other factors. Aust. J. Exp. Agric. and Animal Husb. 14:241-248.

Thompson, L.L. 1975. Weather and technology in the production of wheat in the United States. Science 188:535-541.

Van der Paauw, F. 1962. Effect of winter rainfall on the amount of nitrogen available to crops. Plant and Soil 16:361-380.

Van der Paauw, F. 1963. Periodic fluctuations of soil fertility, crop yields and of responses to fertilization affected by alternating periods of low or high rainfall. Plant and Soil 17:155-182.

Van der Paauw, F. 1966. The omission of the aspects of soil fertility in relationships of weather to crop yield. In: Agroclimatological Methods. pp. 333-335. UNESCO, 1968.

Viets, F.G. 1962. Fertilizers and the efficient use of water. Adv. in Agronomy 14:223-264.

Whittlesey, N.K., and L.J. Colyar. 1968. Decision-making under conditions of weather uncertainty in the summer fallow-annual cropping area of eastern Washington. Wash. Agric. Exp. Sta. Tech. Bull. 58.

Wiese, A.F., and D.E. Lavake. 1979. Influence of weed growth and tillage interval during fallow on water storage, soil nitrates and yield. Soil Sci. Soc. Amer. Proc. 43:565-69.

Woodruff, D.R. 1975. Decision making for wheat growers in Queensland. Dept. of Primary Industries. Agriculture Branch Tech. Bull. 10.

Young, R.A., L.J. Ozburn, A. Bauer, and E.H. Vosey. 1967. Yield response of spring wheat and barley to nitrogen fertilization in relation to soil and climatic factors. Soil Sci. Soc. Amer. Proc. 31:407-410.

APPENDIX

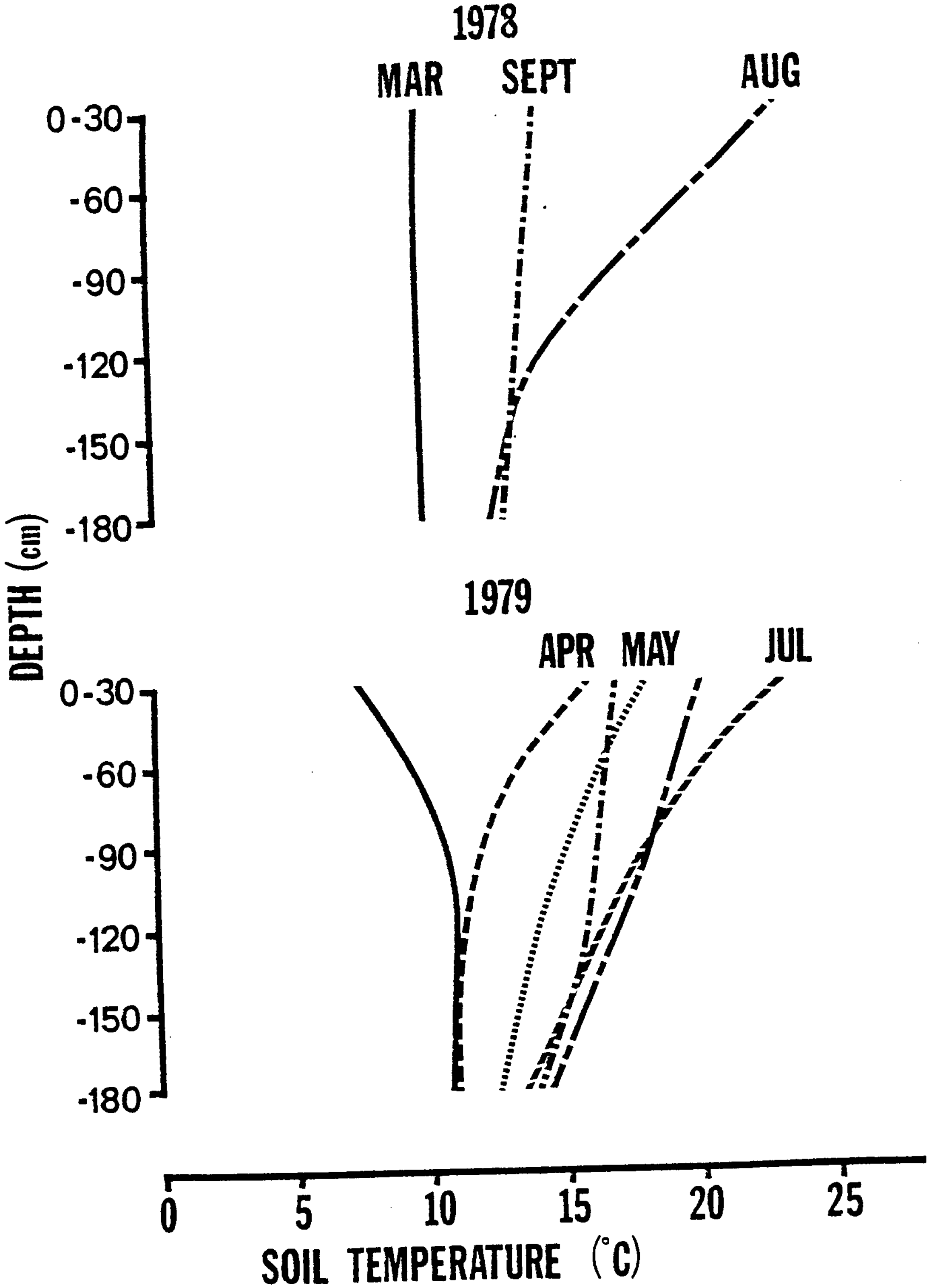


Figure 1. Fallow season soil temperatures.

Table 1. Soil test values for the Walla Walla silt loam at the simulation site 1979-80. (L. E. Kaseberg Farm, Wasco, OR)

	0-30	30-60	60-90	90-120	120-150	150-180	180-210	210-240	270
pH	6.3	6.7	6.9	6.9	7.2	8.1	8.2	8.4	8.4
P(ppm)	28	27	26	20	13	13	11	12	16
K(ppm)	390	304	246	238	242	226	176	160	195
Ca(meq/100 gr)	7.2	8.1	7.3	7.1	6.8	14.5	14.1	14.2	33.9
Mrg(meq/100 gr)	2.3	3.1	3.4	3.8	4.2	5.1	5.6	6.2	6.6
Salts (mmhos/m)	0.67	0.75	0.78	0.70	0.68	0.90	0.92	0.87	1.20
CEC(meq/100 gr)	11.31	11.31	10.95	10.19	10.29	11.00	13.33	10.60	12.22
Organic matter (%)	1.37	1.48	1.01	0.11	0.48	0.48			
Sulfate-sulfur (ppm)	9.70	10.78	6.76	6.86	5.16	5.46	6.06	5.96	5.14
Total N (%)	0.07	0.05	0.05	0.03	0.03	0.03	0.01	0.02	0.01

Table 2. Mean squares and coefficients of determination for the regression of historical grain yield at Moro, OR (1956-76) on monthly precipitation, May temperature and days to emergence.

Source	df	M.S.
Total	16	0.4799
Regression	2	0.7655
Error	8	0.1943
	R^2 = 0.80	

Table 3. Mean squares and coefficients of determination for the regression of potential grain yield at Moro, OR (1956-76) on monthly precipitation and May temperature.

Source	df	M.S.
Total	16	0.6272
Regression	7	1.1757
Error	9	0.2006
	R^2 = 0.82	

Table 4. Mean squares and coefficients of determination for the regression of historical grain yield reduction at Moro, OR (1956-76) on days to emergence.

Source	df	M.S.
Total	16	159.551
Regression	1	2459.62
Error	15	6.2126
	R^2 = 0.96	

Table 5. Mean squares from the analysis of variance for harvest yield in 1979 and 1980.

	1979		1980	
	df	M.S.	df	M.S.
Total	143		167	
Mainplot	23		27	
Rep	3	0.9318	3	0.0807
Trt. (moisture)	5	0.7937	6	0.4652
Error a	15	0.1751	18	0.7016
Subplot	120		140	
Fert. level	5	2.5385	5	17.3747
Trt. X level	25	0.0593	30	0.1763
Error b	90	0.0569	105	0.1174

Table 6. Average harvest yields in 1980 (metric ton/ha)

	Fertilizer level (kg N/ha)					
	0	15	45	60	75	105
DFNC	3.39	3.71	4.71	5.08	5.09	5.74
NFDC	3.14	3.75	4.85	5.38	5.47	5.97
NFNC	3.60	4.13	4.65	4.89	5.01	5.48
$NFWC_1$	3.74	4.02	5.12	5.32	5.07	5.38
$NFWC_2$	3.43	3.87	5.03	5.00	5.04	5.31
WFNC	3.27	3.68	4.20	4.64	4.94	5.39
Control	3.83	3.96	4.58	4.97	5.19	5.43

Table 7. Average harvest yields in 1979 (metric ton/ha)

	Fertilizer level (kg N/ha)					
	0	15	45	60	75	105
DFNC	2.63	2.92	3.07	3.09	3.11	3.21
NFDC	2.59	2.72	3.11	3.43	3.41	3.38
NFNC	2.68	2.96	3.38	3.23	3.40	3.21
NFWC	2.90	3.17	3.52	3.69	4.04	3.73
WFNC	2.71	3.04	3.41	3.63	3.59	3.56
Control	2.60	2.72	3.13	3.50	3.33	3.46

Table 8. Average initial soil moisture in 1977 and 1978 to a 217 cm depth. (mm)

1977	1978
239	230

Table 9. The mean squares from the analysis of variance for initial soil moistures in 1977 and 1978 217 cm depth.

Source	df	M.S.
Total	47	
Date	1	1084.821
Error	46	216.792

Table 10. Average storage efficiencies in the 1978-80 simulation.

Treatment	March 1979	April	May	July	Aug.	Sept.	Nov. 1980
DFNC	.55	.35	.30	.24	.17	.16	.37
NFDC	.44	.29	.26	.21	.17	.15	.41
NFNC	.44	.29	.25	.20	.17	.15	.33
$NFWC_1$	.43	.25	.21	.18	.14	.12	.31
$NFWC_2$	.44	.30	.27	.23	.19	.16	.31
WFNC	.37	.23	.24	.21	.18	.22	.32
Control	.44	.33	.27	.22	.17	.15	.36

Table 11. Mean squares from the analysis of variance for storage efficiency in the 1977-79 simulation.

		Mar. 1978	Aug. 1978	Sept. 1978	Dec. 1978	Mar. 1979
Source	df	M.S.	M.S.	M.S.	M.S.	M.S.
Total	23					
Rep.	3	0.0009	.0014	.0055	.0007	.0003
Trt.	5	0.1293	0.1309	.0137	.0051	.0044
Rep. X Trt.	15	0.0006	.0007	.0023	.0008	.0006

Table 12. Average storage efficiences in the 1977-79 simulation.

Treatment	March 1978	August	September	December	March 1979
DFNC	.52	.47	.42	.30	.38
NFDC	.40	.44	.42	.29	.35
NFNC	.41	.45	.42	.32	.36
NFWC	.41	.45	.37	.33	.31
WFNC	.39	.35	.32	.25	.30
Control	-	-	.29	.24	.32

Table 13. Mean squares from the analysis of variance for storage efficiency in the 1978-80 simulation.

		March 1979	April	May	July	August	Sept.	March 1980
Source	df	M.S.	M.S.	M.S.	M.S.	M.S.	M.S.	M.S.
Total	27							
Rep.	6	.0016	.0039	.0020	.0015	.0012	.0010	.0029
Trt.	3	.0116	.0076	.0029	.0016	.0011	.0033	.0051
Rep. X Trt.	18	.0017	.0023	.0013	.0012	.0010	.0007	.0005

Table 14. Average net soil water storage in the 1977-79 simulation (0-263 cm).

	March 1978	August	September (mm)	December	March 1979
DFNC	209	163	126	103	181
NFDC	282	196	157	119	185
NFNC	290	202	159	131	191
NFWC	303	201	140	147	177
WFNC	298	206	155	134	191
Control	-	-	122	111	186

Table 15. Mean squares from the analysis of variance for net soil water storage (0-263 cm) in the 1977-79 simulation.

		March 1978	August		Sept.	Dec.	March 1979
Source	df	M.S.	M.S.	df	M.S.	M.S.	M.S.
Total	19			23			
Rep.	3	1005.4	510.6	3	814.7	122.4	75.4
Trt.	4	5933.2	1226.2	5	1069.0	1033.3	114.3
Rep. X Trt.	12	574.1	278.4	15	318.5	130.4	149.9

Table 16. Average net soil water storage in the 1978-80 simulation (mm)

Treatment	March 1979	April	May	July	Aug.	Sept.	March 1980
DFNC	89	73	58	47	34	38	184
NFDC	92	81	66	56	44	44	202
NFNC	88	73	64	53	44	44	185
$NFWC_1$	82	60	55	46	36	36	180
$NFWC_2$	92	82	70	60	49	48	184
WFNC	99	82	83	74	65	90	205
Control	91	75	60	48	39	40	188

Table 17. Mean squares from the analysis of variance for water storage at the 0-173 cm depth. 1978-80 simulation.

		March 1978	April	May	July	Aug	Sept.	March 1979
Source	df	M.S.	M.S.	M.S.	M.S.	M.S.	M.S.	M.S.
Total	27							
Rep.	6	1176.4	473.3	140.7	121.6	103.1	103.3	218.0
Trt.	3	98.5	254.0	350.2	386.0	431.1	1388.2	381.0
Rep. X Trt.	18	151.9	377.2	80.4	77.7	71.8	65.7	113.5

Table 18. Average water storage at the 0-232 cm depth in the 1978-80 simulation March 1980 (mm).

DFNC	197
NFDC	228
NFNC	199
$NFWC_1$	197
$NFWC_2$	199
WFNC	231
Control	202

Table 19. Mean squares from the analysis of variance for water storage at the 0-232 cm depth. 1978-80 simulation. March 1980.

Source	df	M.S.
Total	19	
Rep.	3	585.1
Trt.	4	1192.1
Rep. X Trt.	12	209.1

Table 20. Average water storage at the 0-30 cm depth. 1978-80 simulation (mm).

	August 1979	September 1979
DFNC	5	10
NFDC	7	10
NFNC	7	11
$NFWC_1$	6	9
$NFWC_2$	8	11
WFNC	9	34
Control	9	13

Table 21. Mean squares from the analysis of variance for water storage at the 0-30 cm depth. 1978-80 simulation.

		August 1979	September 1979
Source	df	M.S.	M.S.
Total	27		
Rep.	3	2.762	8.1
Trt.	6	7.452	322.7
Rep. X Trt.	18	3.484	2.9

Table 22. Average net moisture storage in March of the crop season at 90-240 cm. (mm)

	1979	1980
DFNC	87	76
NFDC	83	104
NFNC	91	80
$NFWC_1$	84	77
$NFWC_2$	--	83
WFNC	93	106
Control	86	78

Table 23. Mean squares from the analysis of variance for net moisture storage at 90-240 cm in March of the crop year.

	1980		1979	
Source	df	M.S.	df	M.S.
Total	27		23	
Rep.	3	299.61	3	41.15
Trt.	6	294.91	5	27.64
Rep. X Trt.	18	82.97	15	50.75

Table 24. Crop season infiltration (mm) to the 60-120 cm depth in March after planting.

	1979	1980
DFNC	17	35
NFDC	13	35
NFNC	13	32
$NFWC_1$	14	33
$NFWC_2$		32
WFNC	11	29
Control	18	35

Table 25. Mean squares from the analysis of variance for infiltration to the 60-120 cm depth in March 1979 after planting.

	1979		1980	
Source	df	M.S.	df	M.S.
Total	23		27	
Rep.	3	22.11	3	7.51
Trt.	5	20.07	6	11.55
Rep. X Trt.	15	6.44	18	9.26

Table 26. Total mineralization (N_t) from a 2-week incubation (ppm-N).

Depth	RI	RII	Mean
0- 30	5.24	6.47	5.86
30- 60	1.81	2.67	2.24
60- 90	1.52	2.48	2.00
90-120	2.28	2.09	2.19
120-150	1.24	1.33	1.29
150-180	1.52	1.24	1.38

Table 27. Temperature variation effects on calculated mineralization (kg N/ha) for a 90-day period at 80% of field capacity.

Depth (cm)	Temperature (^{o}C) 21	11	deviation
0- 30	53.6	26.8	26.8
30- 60	20.4	10.2	10.2
60- 90	18.4	9.2	9.2
90-120	20.2	10.1	10.1
120-150	12.0	6.0	6.0
150-180	12.6	6.3	6.3

Table 28. Means for mineralization amounts in the fallow period of 1979. (kg N/ha)

	May		September	
Treatment	0-30	30-180	0-30	30-180
DFNC	9	25	15	46
NFDC	9	24	14	45
NFNC	8	24	18	47
$NFWC_1$	8	23	17	47
$NFWC_2$	9	24	12	45
WFNC	6	28	9	45
Control	10	26	15	46

Table 29. Mean squares from the analysis of variance for mineralization in the 1979 fallow period.

		May		September	
		0-30	30-180	0-30	30-180
Source	df	M.S.	M.S.	M.S.	M.S.
Rep.	3	47.762	112.610	23.730	212.730
Trt.	6	6.913	11.271	40.011	2.096
Rep. X Trt.	18	5.153	44.933	8.82	37.957

Table 30. Means for mineralization amounts in the fallow period of 1978. (kg N/ha)

Treatment	May		August		September		Sept.-Aug.	
	0-30	30-180	0-30	30-180	0-30	30-180	0-30	30-180
	(cm)							
DFNC	7	16	24	24	32	27	8	3
NFDC	4	10	19	14	30	28	11	14
NFNC	6	9	21	18	28	21	7	3
NFWC	4	11	17	13	25	17	8	4
WFNC	4	7	24	17	41	24	17	7

Table 31. Mean squares from the analysis of variance for mineralization in the 1978 fallow season (0-180 cm).

		May	August	September	Sept.-Aug.
Source	df	M.S.	M.S.	M.S.	M.S.
Rep.	3	581.14	161.85	83.13	382.91
Trt.	5	210.02	764.47	1144.33	561.29
Rep. X Trt.	15	58.94	211.51	451.92	393.85

Table 32. Mean squares from the analysis of variance for mineralization in the 1978 fallow season (0-30 and 30-180 cm).

		August		September		Sept.-Aug.	
		0-30	30-180	0-30	30-180	0-30	30-180
Source	df	M.S.	M.S.	M.S.	M.S.	M.S.	M.S.
Rep.	3	11.58	17.06	49.10	44.73	52.09	58.11
Trt.	4	36.43	86.79	153.11	79.42	71.84	63.23
Rep. X Trt.	12	17.25	36.71	86.74	55.55	78.17	35.45

Table 33. Coefficients and confidence intervals for the regression of nitrogen uptake on fertilizer N level. (1979)

Pattern	a-intercept	$\bar{s}_a$	CI α=0.05	slope b	$\bar{s}_b$	CI α=0.05
DFNC	57.2214	3.1969	± 7.12	0.4914	0.1167	± 0.26
NFDC	45.0250	1.6067	± 3.58	0.5658	.0587	± 0.13
NFNC	47.3786	1.5493	± 3.45	0.6144	.0566	± 0.13
NFWC	46.2321	1.4441	± 3.22	0.5555	.0527	± 0.12
WFNC	44.6786	2.1313	± 4.75	0.5677	.0778	± 0.17
Control	47.0357	1.9238	± 4.29	0.4149	.0725	± 0.16
				$\bar{x}$ = 0.5350		

Table 34. Mean squares and coefficient of determination from the analysis of variance of the regression of N-uptake on fertilizer N level. 1979.

		DFNC	NFDC	NFNC	NFWC	WFNC	Control
Source	df	M.S.	M.S.	M.S.	M.S.	M.S.	M.S.
Total	11	144.24	135.39	156.35	128.43	146.20	84.56
Regr.	1	1014.31	1344.70	1585.47	1295.93	1353.77	722.93
Error	10	57.23	14.46	13.44	11.68	25.44	20.73
R^2 =		0.64	0.90	0.92	0.92	0.84	0.98

Table 35. Average N uptake (kg N/ha) values. 1979.

	Fertilizer level (kg N/ha)					
Pattern	0	15	45	60	75	105
DFNC	56.8	65.2	79.1	76.6	81.5	88.8
NFDC	45.2	53.3	70.6	80.3	76.7	87.6
NFNC	52.4	56.0	77.9	75.8	77.4	86.9
NFWC	45.8	55.2	71.0	81.6	89.1	95.1
WFNC	44.5	53.4	70.2	75.7	88.5	98.9
Control	48.1	51.6	66.3	72.6	78.1	84.6

Table 36. Mean squares from the analysis of variance for N uptake. 1979.

Source	df	M.S.
Rep.	3	14.66
Trt.	5	231.55
Rep. X Trt.	15	44.50
N level	2	3611.69
Trt. X Level	10	17.15
Error b	36	17.79

Table 37. Multiple regression of the nitrogen fertilizer response. 1979.

Yield = 1.91
(metric ton/ha)

-2.84×10^{-6} (total soil + fert. N)^3

$+2.52 \times 10^{-4}$ (total soil + fert. N)(fallow precip.)

$+7.01 \times 10^{-4}$ (total soil + fert. N)(crop precip.)

-8.75×10^{-7} (total soil + fert. N)(crop precip.) x (fallow precip.)

Source	df	M.S.
Total	119	
Regression	4	3.300
Error	115	0.079
	R^2 =	0.59

Table 38. Multiple regression of the nitrogen fertilizer response in the Mitscherlick form. 1979.

$$\ln\left[1 - \frac{\text{actual yield}}{\text{Max. yield}}\right] = -3.0668$$

$- .0397$ (fert. N)

$.0046$ (fallow precip.)

$.0017$ (crop precip.)

$- .0074$ (soil N)

Source	df	M.S.
Total	71	
Regression	4	11.43
Error	67	0.59
	R^2 =	0.54

Table 39. Linear regression of the nitrogen fertilizer response in the Mitscherlick form. 1980.

$$\ln\left[1 - \frac{\text{actual yield}}{\text{Max. yield}}\right] = 0.2750 - 0.01957\ (\text{soil N} + \text{fert. N})$$

(5.72 metric ton/ha)

Source	df	M.S.
Total	20	
Regression	1	2.9173
Error	19	0.6266
	R^2 =	0.82