# The Impact of Climate On World Food Production

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THE PRODUCTION of food depends on many factors. Climate is, of course, one important element in determining the productivity of a region, but it is only one of several important factors. The productivity of the soil, availability of water for irrigation, technological developments of the regional agriculture, management skills of the farmers, and capital for support of the technology are also important.

In the temperate latitudes in the late 20th century, except where population pressures are great, people are generally well fed. This abundance is strikingly seen in table 1. North America, Europe, and northern Asia are able to maintain calorie and protein levels well above the accepted requirements. Only in the tropical regions of the world, where soils are frequently infertile, agriculture development is retarded, and/or population pressures exist, are chronic shortages of calorie and protein supply noted. The further growth of populations will intensify and expand the areas where deficiencies prevail.

In order to provide food for these deficient areas, foreign trade must occur. With the important grains such as corn and wheat, the U.S. and Canada are the primary exporters. Paddock and Paddock (1967) call the U.S., Canada, Australia, and Argentina "the granary" of the world. These countries supply virtually all of the wheat exports. The U.S. and Canada together supply 65% of the wheat export. Although the U.S. exports a significant amount of rice (about 20% of the world export), the primary supply for foreign trade (about 60%) comes from Burma and Thailand. Food commodities for the deficit countries are supplied from the granary surplus of small regions of the world. The effect of local crop failures or yield reductions will be noted in the food baskets of people thousands of miles away. Adverse weather in the world's "granary" will affect the diets of people from the food deficient regions.

**Table 1. Food requirements and availabilities. Daily average values per capita (Guidry 1964).**

| | Calories per capita | | Protein grams per capita | |
|---|---|---|---|---|
| | Consumption | Deviation from requirement | Consumption | Deviation from requirement |
| U.S. and Canada | 3150 | +500 | 95 | +35 |
| U.S.S.R. | 2950 | +250 | 91 | +31 |
| Europe | 2900 | +250 | 78 | +18 |
| Latin America | 2650 | +150 | 66 | + 6 |
| Africa | 2400 | + 50 | 63 | + 3 |
| W. Asia | 2800 | − 50 | 73 | +13 |
| Far East | 2150 | −150 | 60 | 0 |

Often a region or country with permanent or temporary deficits in calorie and protein supply cannot shop at the world's marketplace because of a lack in foreign credits. In absence of grants-in-aid from the affluent nations, insufficient credits make foreign trade virtually impossible. Countries are not free to withdraw from the world "granary" unless they have other resources to pay for the trade. With a free market, world trade redistributes commodities from surplus regions to areas with resources to trade.

## *Technology and Food Production*

To place a proper perspective on the importance of climate to productivity of food, it should be recognized that other factors contribute to the variations in productivity. For example, technology provided by agricultural research and adult education is a contributing factor to increases in production. Through this technology, agriculture uses energy (from the sun and from fuels) for increases in food production.

There has always been a genetic component in the contribution of agricultural research. The recent "green revolution" resulted from the development of rice and wheat varieties of greater productive potential. A similar development occurred in the 1940s for corn, with the introduction of hybrid varieties. Large increases in the productivity of soybeans have occurred since 1940, due to genetic improvement. There appears to be a a genetic potential

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for further increases in productivity for this high oil and protein crop.

Another reflection of technology is the worldwide use of chemical fertilizers. As the use of land for crop production becomes more continuous, the soil must receive additions of the essential fertilizer elements, such as nitrogen, potassium, and phosphorus. Since 1900, the annual amount of fertilizer applied in the U.S. has increased by 50 times, while the number of acres in production has remained virtually constant. (Land harvested in crop production actually declined by 11% from 1930 to 1969.) Most of this land was returned to production by U.S. agriculture in the early 1970s. The trend in national use of fertilizers is shown in fig. 1. Except for the two-decade period from 1920 through 1940, when the agricultural economy was depressed and the serious droughts of the 1930s occurred, the rate of fertilizer use has virtually doubled every decade since 1900.

Even with this increased use of fertilizer the soils of the U.S. still respond with improved crop yields with increased application of fertilizers. This concept has been shown quite effectively by Sweeney (1969) when he generalized the relationship between productivity and fertilizer use on a national basis. Yields as shown in fig. 2 respond to fertilizer in a nonlinear fashion. On a national basis the flat portion of the curve has not yet been attained and productivity will continue to increase with increased application of fertilizer. However, many individual farmers now apply fertilizers in amounts adequate to maximize yields for their soils.

A review of recent trends show that fertilizer use, particularly the application of nitrogen, is not continuing the rapid increase noted since 1940. Fertilizer use in 1971 was only 7% greater than in 1970, while the use in 1972 was less than 1% greater than 1971. Because the average annual increase over the past 30 years was about 10% per year, it appears that either availability and/or the cost of fertilizer is now limiting the use. In 1974 both cost and availability served to limit use of fertilizer.

## *Yields of Grains*

In general, agricultural yields of feed grains and protein crops have increased dramatically during the past 30 years. These increases were the product of improved technology, progressive farm management programs, expanded human population, and stimulated economic conditions. Over the past century the U.S. productivity of all grain crops has followed similar trends. Nearly constant productivity per unit area occurred from the mid-19th century until the late 1930s. A sharp upturn in yields began with the war years with the largest increases occurring during the late 1960s.

Fig. 3 shows the yield of corn in Missouri for the period since 1866. A trend line has been drawn by eye. The similarity between the trend of corn yields and the trend of fertilizer use shown in Figure 1 should not be missed. It will be noted that there are extreme variations from trend. The primary cause of this variation is weather, although the influence of pests (insects and disease), economic considerations, and government control programs are confounded with the effects of weather.

Rice yields in the U.S. have also been increased through applications of technology. For the period 1925–1960, this increase was about 45%. In the Far East, which produces and consumes the greatest quantity of rice, the technological development has not occurred.

## *Weather Variability and Yield*

*Dynamic modeling of weather effects on yield.* The agricultural crop is an energy converter. Through the process of photosynthesis, solar energy is converted into plant tissues (in effect, carbohydrates). The efficiency of growth (in effect, food production) depends upon the utilization of energy. Obviously the weather, through cloudiness and atmospheric turbidity, determines the amount of energy reaching the earth's surface. The weather also influences the utilization of energy through the temperature effects on growth processes and through the demand for water by plants.

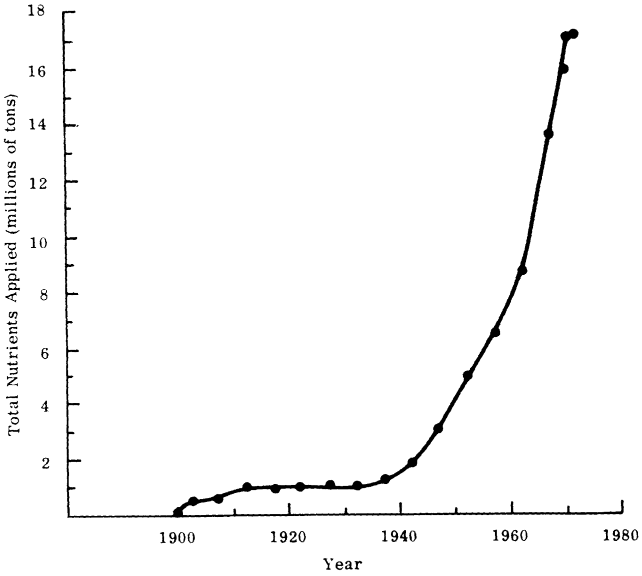

**Fig. 1.** Trend of fertilizer use in the United States. Data from Hargett (1972) and U.S.D.A. (1966).

Growth not only requires solar energy but also a transfer of carbon dioxide to the leaf surfaces. Carbon dioxide is taken from the atmosphere and combined with water to form carbohydrates. The sequence of weather events provides the mechanisms for the mechanical or thermal turbulence necessary to transport $CO_2$ from the free atmosphere into the crop canopy.

Most agricultural crops have maximum growth

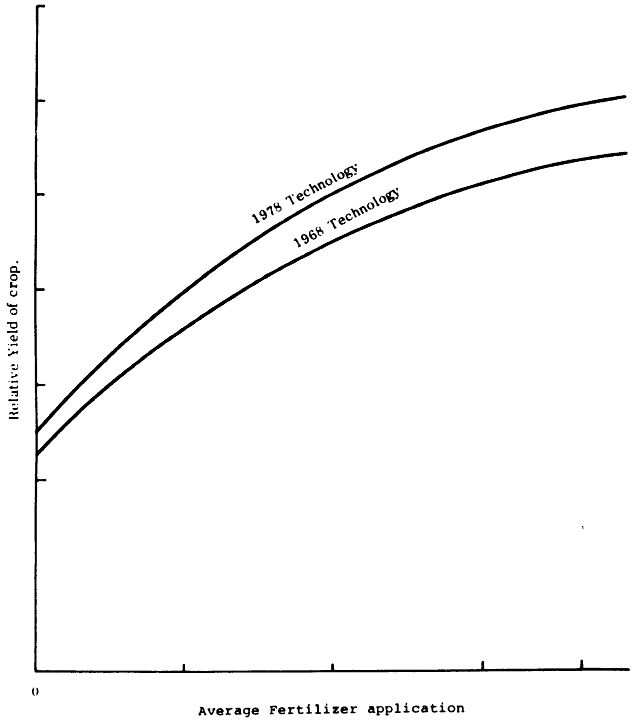

**Fig. 2.** Conceptual relationship between national crop yield and national average fertilizer application. Adapted from Sweeney (1969).

rates of between 350 and 500 kilograms per hectare per day. The energy required for this amount of growth over a hectare is $1.3 \times 10^9$ to $1.9 \times 10^9$ calories. At 40° latitude, the average solar radiation in summer is about $6 \times 10^{10}$ calories per hectare. The daily efficiency of energy use is from 2.1% to 3.2%. The mass of $CO_2$ required for this growth is 140–200 kilograms per hectare per day.

Mathematical models based on the conservation energy, the physical processes involved in the transport of carbon dioxide into the canopy, and the dependence of the biochemical reaction on temperature and moisture have been developed. The models, for example, the one discussed by Lemon et al. (1971), simulate the rates of growth and may be integrated over periods as long as a day. There is, of course, abundant evidence that these models do approximate actual growth rates; and, therefore, represent the real effect of weather on plant growth. But generally these sophisticated models of the canopy have not proved successful in simulating the total seasonal growth or partitioning the growth into the components for stover and grain production. Less rigorous statistical models have proven more useful in predicting yields of grain from weather information.

*Crop failure and weather.* A total loss of a yield normally occurs over an area smaller than a few square kilometers. Such losses are usually caused by a major local catastrophe such as flood, hail, insect attack, or disease outbreak. These occurrences are disastrous to the individual producers, but in most cases the impact is negligibly small in comparison to the total production of a region, the nation, or the world.

Drought can also be quite local, but the effect is more likely to be widespread, because the atmospheric conditions favoring prolonged periods of dry weather are caused by larger scale circulation features. It is certainly easy enough to recognize the occurrence of a major drought. Tannehill (1947) has discussed the important droughts in the U.S. through the period of historical record.

For many years the recognition of drought on a "real time" basis has been difficult. When does a dry spell become sufficiently acute to be considered a drought? Palmer (1965) has provided an analytical answer to this question through the design of a "drought index." This index weighs the climatic rainfall expectation, the expected evaporative power of the atmosphere, and the antecedent condition, to provide an index of the severity of dry weather.

Using applications of Palmer's technique, it is possible to compute on a current basis an index related to the consequence of rainfall deficiencies. Fig. 4 shows such a presentation as of late July 1974. The drought conditions of the Midwest and the central and southern Great Plains is quite apparent.

When drought, that is, a Palmer index of $-2.0$ to $-4.0$, occurs over a major portion of the grain producing area, it has a major impact on food production. Even when drought occurs in a region that is not part of the world "granary" the impact may be

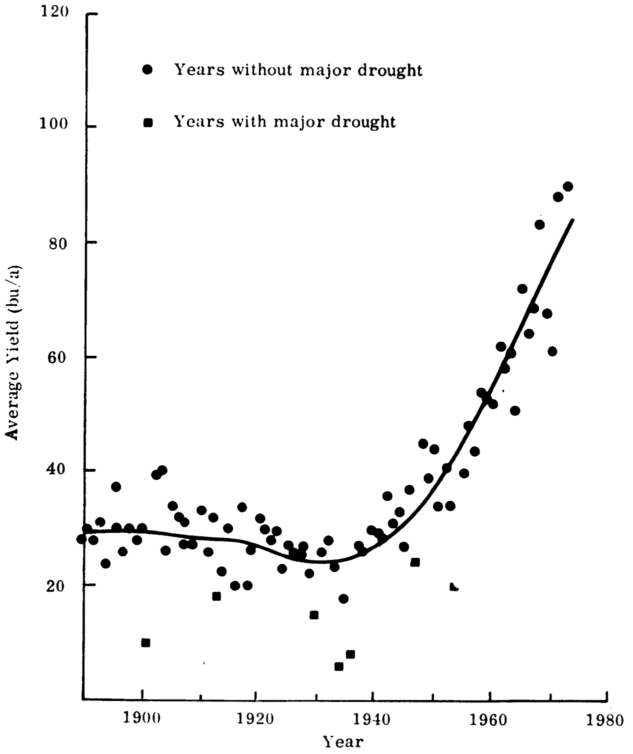

**Fig. 3.** Average Missouri corn yields (in bushels/acre). Data from U.S.D.A. Statistical Reporting Service.

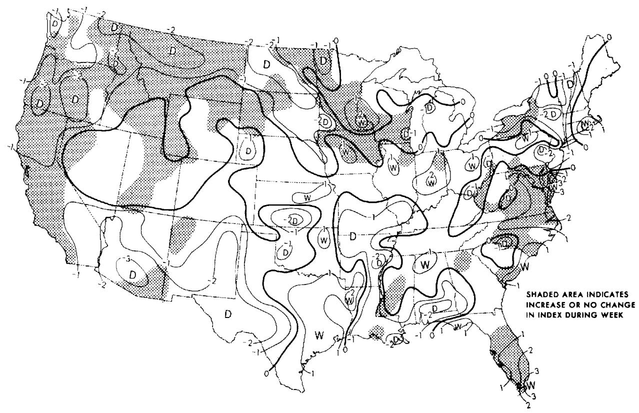

**Fig. 4.** Crop moisture index (derived from Palmer drought index analysis), Aug. 25, 1973. (Reprinted with permission from *Weekly Weather and Crop Bulletin,* National Oceanic Atmospheric Administration.)

felt world-wide because of the increased demand for the available export grains.

The effect of drought is cumulative in many aspects. The second of two drought years in sequence will have a greater impact than the first year. According to Palmer (1965), the five-year period extending from 1930 through 1934 was associated with continuous drought in Kansas; while in the fifties, Iowa experienced drought from 1952 through 1954. Drought continuing through a sequence of years will have at least two adverse effects. First, existing grain reserves from the droughty region will be depleted after the initial year or years of drought. The resulting scarcity may adversely affect pricing and food supplies in other parts of the country and world. Second, as a result of prolonged drought the individual farmer will experience difficulties in the maintenance of bank credits, securing feed for breeding livestock, and payment of land taxes.

What do major droughts mean in terms of production loss? When viewed for the entire region of production for a particular commodity, the yield reduction may not be as great as one would expect. Even a widespread drought will not be as severe in one location as it is in another nearby area. Reviewing the trends and weather over a 23-year period (1939–1961), Auer and Heady (1964) showed that the greatest weather-induced reductions in yield of corn for 16 midwestern states occurred in 1947 when there was a loss of 23% in production. During the years 1953, 1954, and 1955, weather reduced corn yields only 2, 4, and 7 percent respectively.

When consideration is confined to a smaller area the effect of drought is accentuated. Table 2 shows the reduction of a yield, expressed as a percentage of the trend in yield, for the major drought years in Missouri since 1900. From table 2 it is apparent that drought is disastrous when it is viewed in terms of an area the size of a state.

In the tropics, drought occurs with the failure of the monsoon. In the transition zone between the humid equatorial regions and the deserts of the subtropics, there is generally a region with high rainfall during the high sun period (summer). The failure of the monsoon occurs when summer rain does not materialize in this transition zone. This has occurred in the Sahel region of Africa during the early 1970s. There is growing evidence that this tropical drought is associated with changes in the world-wide atmospheric circulation patterns induced by cooling in mid- and polar latitudes (see Bryson 1974).

The failure or lessening of the monsoon rain in southeast Asia is particularly severe because of the importance of the region for rice production. In India, Bangladesh, and Pakistan, where population pressures are acute, such drought becomes critical. In northwest India and Pakistan, Das (1972) observes that the variance of annual monsoon rain is one-third to one-half of the mean value.

*Noncatastrophic yield variations.* In the past 75 years in Missouri, drought has induced major yield reductions seven times. In other years there have been departures from the average yield as predicted by the trend. These departures have occurred because of favorable and unfavorable weather conditions.

Since former Vice-President Henry Wallace (1920) performed correlation analyses of effect of temperature and rainfall on corn yields, there have been attempts to "explain" yield on the basis of weather variability. Perhaps the most successful of these attempts were completed by Thompson (1969a; 1969b; and 1970). Thompson correlated yields against monthly temperatures and precipitation by states using corn, wheat, and soybeans. Table 3 summarizes the weather variables employed for each crop and percentage of the yield variation explained by these climatic variables. In general, over 80 percent of the variation in state yields can be explained by the state climatic averages.

The original reports of Thompson (1969a; 1969b; and 1970) explain the techniques for removing the effect of the time trend in yields induced by technology, the cuvilinear nature of many of the relationships between yield and the weather variable, and the interactions between temperature and precipitation. But a casual review of table 3 and of the manuscripts shows the importance of mid- and late summer rainfall to grain production in the U.S.

**Table 2. Reduction of yield of corn by drought since 1900 (in kilograms/hectare).**

| Drought year | Yield |  | Reduction from trend |  |
|---|---|---|---|---|
|  | Trend | Actual | Yield | Percentage |
| 1901 | 1833 | 628 | 1202 | 66 |
| 1913 | 1745 | 1130 | 615 | 35 |
| 1930 | 1507 | 942 | 565 | 37 |
| 1934 | 1557 | 377 | 1180 | 76 |
| 1936 | 1582 | 502 | 1080 | 68 |
| 1947 | 2091 | 1506 | 585 | 28 |
| 1954 | 2712 | 1256 | 1456 | 54 |

**Table 3. Summary of weather effects on yield in mid-America.**

| Crop | Best prediction climatic variables | Percentage of variation accounted for |
|---|---|---|
| Wheat | Antecedent precipitation:<br>April, May, June, and July precipitation.<br>May, June, and July mean temperature | .81–.86 |
| Corn | Antecedent precipitation:<br>July precipitation.<br>July and August mean temperature | .86–.89 |
| Soybeans | Antecedent precipitation:<br>July and August precipitation.<br>June and August mean temperature | .90–.97 |

"granary." To be sure, wheat production in the southern Great Plains (Oklahoma, Kansas, and Nebraska) is harvested prior to July, but the spring wheat area in the Dakotas, all of the Corn Belt, and the Midwest soybean crop depend on July rainfall. Of course, an August deficiency of rain will adversely affect soybean yields, but it has a minimal effect on corn yield.

These "best predictors," listed in table 3, indicate the high dependence of the crop yield on the water supply. In general, crops produce higher grain yields under conditions with low moisture stress during the flower fertilization and grain filling period of development. The stress is avoided by moderate temperatures and abundant rainfall. In the midwestern U.S. "granary," July rain (and August rain in the case of soybeans) is the weather factor inducing the greatest variability in yields. A climatic change—man-made or inadvertent—which alters this midsummer rainfall will have the greatest impact on calorie and protein production.

Rice is, of course, a most important component of the diets of a large portion of the earth's population. Perhaps 90 percent of the world's production of rice is in Asia, and most of this production is under "paddy" conditions. The inundation of water required for the "paddy" culture may be obtained from the monsoon rains, irrigation, or alluvial water in river deltas. Kyuma (1973) estimates that more than 50 percent of the area engaged in rice production relies on local rainfall to supply water for inundating the paddy.

It is possible to use rainfall records and estimates of evapotranspiration to determine the surplus and deficit of water. Kyuma has done this for 230 locations in the important rice production areas of southeast Asia. From these data the months with water available for ponding were computed. If ponding occurs from rain continuously in two or less months the area is not suitable for rice production; 3 months of ponded water is marginal for rice culture; 4–6 months of ponded water is sufficient for one crop; and more than six months of ponded water will support two rice crops per year.

Considering climatic records for southeast Asia, Kyuma concludes that most of southern Burma, North and South Vietnam, Malaysia, the Philippines, and Indonesia will produce one and, in some areas, two crops of rice each year. In these regions the water supply is sufficiently dependable for rice production.

With the above criteria for water supply, much of the Asian subcontinent (India, Bangladesh, Pakistan, and Ceylon) is classified marginal for rice production. A large part of Thailand is also marginal when water for flooding must be supplied by rain. Since the Asian subcontinent has high population densities and since Thailand is a major exporter of rice, it is significant that these regions are marginal areas of production. When the monsoon rains are smaller and less frequent, crop failures are expected in these areas and rice deficits may be expected.

## *Summary*

Grain produced in relatively small areas of the world provides the abundance necessary for the demand by world market and supply of food for trade to deficient regions. The central and Great Plains area of the U.S. is one of these "granaries." Generally, the July and August rainfall will determine whether the harvest in these regions will be bountiful.

Rice production without irrigation depends on the surplus of water sufficient to inundate the paddy for more than three months. In the subtropical border of the equatorial region, the strength of the monsoon will determine the success of production for an individual year.

A great deal is being said about the impact of worldwide climate change on food production. It is generally agreed that the earth has cooled since 1940 and that associated with this change has been a reduction in the amount and dependability of the rain from the monsoon climates of the world. Some climatologists also believe that increased variability in the year-to-year weather of the midlatitudes has occurred. Although there is some uncertainty about the effect of temperature declines on food production in the midlatitudes, there is general agreement that a real crisis surrounds the expectations for reduction in rain in the monsoon climates of the subtropics.

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### *Advantages of Simulation*

As with any other teaching method, there are staunch supporters and sincere critics of simulation. Rejecting the emotional claims of both sides, there are a few statements which can be made on the basis of the results of testing and evaluation programs. Perhaps the most obvious advantage of the method is that it can make the learning of certain skills and facts an active rather than passive process. Tansey and Unwin (1969) state that goal-oriented students seek the information necessary to achieve it. By providing goals and involvement, students are motivated to participate and, thus, to learn. Attig (1967) found that, in general, simulation is more enjoyable and more stimulating than other teaching methods.

There are other advantages to simulation. In traditional classroom or laboratory teaching, the teacher is placed in the uncomfortable roles of both guide and judge. By providing a structured framework with which one can more easily remember information, simulation reduces the strain of this dual role for the teacher.

Simulation is certainly not the only answer to teaching factual and conceptual information, but it is an approach which has not been sufficiently exploited in the biological sciences. Although organisms are still the subject of most of biology, there is an increasing tendency to appreciate life from the molecular viewpoint and to comprehend and explain its origin and interactions in abstract terms. The use of models and simulation in population and ecological investigations is also increasing. Simulation provides a means of understanding living systems by representing only the essential aspects of selected biological processes which might not be readily visualized otherwise.

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## It *Can* Be Done

The Adolph Coors Co., which sells a lot of beer in the West, reports that its cash-for-cans recycling program is achieving a 30% rate of returns. The program presently is responsible for the recovery of 2,000,000 pounds—about 48,000,000 cans—of aluminum a month.

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Many other questions can be asked, and a great deal of meaningful thought and discussion can be engendered.

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