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# Climate Change and the Potential Impact on the Soil Resource[1]

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Climatic change will lead to changes in the carbon dioxide $CO_2$, temperature, and precipitation. There have been many predictions of the effect of climatic change on plant growth but none on the soil parameters or water use. To fully understand the implications on soil management from climate change the expected changes in soil temperature, water use, and water and nutrient use efficiency need quantification.

INDEX DESCRIPTORS: Climate change, soil temperature, soil water, nutrient use, soil management.

Three resources make the earth a hospitable planet which supports life; climate, water, and soil. Climate and water resources are often considered to be intimately linked because agricultural practices are related to rainfall. There is large variation in climatic and water resources within a year and around the earth. Climates range from the cold to hot deserts to the humid tropics. Within a yearly cycle there is considerable variation with the changing of the seasons, and passage of fronts and pressure systems add an additional complexity to the system. Soil, on the other hand, is considered to be stable, having evolved over eons of time and changing at a much slower rate, notwithstanding, the rapid episodal erosion events.

Climate change has caught the attention of both the scientific community and the public. There is concern over the potential impact of climatic change on agriculture production. Thompson (1988) evaluated the corn and soybean yields for the midwest United States and showed that the present variation in yield could be attributed to unstable weather patterns. Mitchell (1989) summarized the present changes in the global climate and offered several suggestions as to possible changes based on the global circulation models. His arguments follow the changes in the atmospheric concentrations of the "greenhouse" gases, e.g., carbon dioxide, tropospheric ozone, methane, and nitrous oxide, which have increased over the past 40 years. There are several common predictions from the global circulation models which may have an impact on agriculture. These include: 1) a warming of the troposphere and surface with variation due to latitude, 2) an increase in atmospheric water vapor content along with atmospheric temperature, 3) increases in global mean rates of precipitation and evaporation, and 4) greater variation in precipitation with a reduction in soil water availability in the northern-mid-latitude continents during summer. The last prediction carries with it the greatest degree of uncertainty (Mitchell, 1989).

Thompson (1990, this issue) has shown that variation in the mid-latitude weather can be explained by the El Niño in the Pacific Ocean. Enfield (1989) described the El Niño event and the coupling between the oceans and continents which cannot be ignored in the discussion of the changing climate. Climatic research has shown the coupling between the ocean and land surfaces is an important factor in determining the land surface climate response. The El Niño is only one example of the coupling which exists.

The current explanations and predictions of the impact of climatic change on agriculture have not accounted for the role of the soil in response to climatic change. This report focuses on the role of the soil and the implications on water and fertilizer use efficiency.

## Soil Temperature

Germination and establishment of plants is determined by the soil temperature. These relationships have been known for most crops for many years, e.g. corn (Lehenbauer, 1941), soybeans (Edwards, 1934) and cotton (Arndt, 1945). The common response is that all seedlings have an optimum temperature range for germination and emergence, which is species-specific.

There has not been an estimate of the effect of climatic change on soil temperature, however, we can draw some conclusions based on possible changes in air temperature. Soil temperature is related air temperature and has been effectively estimated from air temperature as described by Hasfurhter and Burman (1974). If we project an increase in air temperature, then we can predict a concurrent increase in soil temperature.

An increase in soil temperature would in effect cause the planting dates to occur earlier in the year. Warmer temperatures would also increase the rate of root proliferation and possible root length density in the soil. The effect of the early season environment on the harvested yield would have to be quantified to determine whether a positive or negative effect on yield would result from a change in soil temperature. Rykbost et al. (1974), found an increase in early season plant growth caused by increasing soil temperatures. Positive changes of this type may be beneficial for plant growth and the rates of microbial and biological activity within the soil profile. Changes in the soil temperature regime would possibly impact the microbial populations and their rates of reaction upon the organic matter and chemical cycling (Tate, 1987). The impacts of increasing soil temperature and rapid changes in the surface soil water content could initiate changes in the microbial populations within the soil. The impacts or effects of these changes have not been completely studied in agricultural systems. The estimated air temperature change over the next 30-50 years is predicted to be 1-2°C, which would only cause a small increase in mean annual soil temperature (Mitchell, 1989). Over a long-period (10-15 years), this relatively small change in air temperature would cause an increase in the soil temperatures at 1 to 2 m depth. This change could have a significant impact on the chemical and biological processes which are mediated by temperature.

## Soil Water Availability

In rainfed agriculture, precipitation either through snow or rain is the source of available soil water. There is variation among soils in the amount of soil water which can be held within the soil profile and made available to plants. The amount of water held within the upper 1 m may range from 50 to 200 mm. The more important aspect is the rate of water extraction from the soil volume and the rate of resupply. Currently, the belief is that the variability in supply (precipitation) will increase with the impacts already demonstrated by Thompson (1988). With an increase in temperature and evaporation, there will be an increase in water use rates, thus more rapid depletion of the soil reservoir. A combination of more rapid depletion with less reliable supply could lead to the occurrence of more periods of severe water stress on crops.

These possible impacts should prompt programs to investigate the effective management of the soil water resource. Lascano et al. (1987) showed that evaporation of surface soil water could be 30% of the total seasonal evapotranspiration. Hatfield (1989, unpublished data) found that in a semi-arid environment this amount could be reduced by 60% through the use of standing residues. These results suggest

[1]Contribution from USDA-ARS

that management of the surface residues to reduce soil water evaporation rates will be necessary to offset the increased evaporation rates. Surface residues will also reduce the soil temperature, however, the increased soil temperatures caused by increased air temperature will be partially offset.

Surface residues will also create a more favorable condition for soil management from two aspects; increased infiltration rates and reduced vulnerability to erosion. Sharon (1972) showed that increased variability of precipitation was associated with increased storm intensity. For the mid-latitudes this is due to an increase in convective activity with more intense thunderstorms. To effectively capture that rainfall will require a soil surface which allows a maximum rate of infiltration and is not subject to erosion. This can be achieved by increasing the amount of surface residue maintained on the surface throughout the year.

A positive aspect from the utilization of surface residues is due to the increase in the total amount of available soil water to the plant for transpiration. Assuming that the plant extracts soil water at a given rate then the greater water availability increases the length of time the crop can endure between storm events. Cultural treatment of residue management may become necessary in the humid and temperate regions as is now practiced in the semi-arid agricultural regions.

### Soil Water Use

With a changing climate, e.g., warmer temperatures, modified net radiation, and changing precipitation, the rates of evapotranspiration will change. Rosenberg et al (1989) found that evapotranspiration changed from −20 to 40% with an increase in air temperature of 3°C and either a −10 to 10% change in net radiation. The effect of an increase in $CO_2$ will also impact the stomatal resistance which will lead to a decrease in evapotranspiration. There is little evidence about the effect of climatic change on evapotranspiration, however, the crop water use patterns will be determined by the balance between soil water availability and the crop growth patterns.

### Water and nutrient use efficiency

Water use efficiency can be described as the amount of plant material produced per amount of water transpired by the plant. Nutrient use efficiency is the similar calculation, however, the water use is replaced by the amount of nutrient used by the crop. Both of these terms show considerable variation among crops and cultural practices. There has been an increase in $CO_2$ concentration of over 35 ppm in the past 30 years. This change in $CO_2$ may have large consequences on crop yield since the rate of crop growth is determined by the ambient $CO_2$ concentration. The effect of $CO_2$ on plants is to increase the rate of photosynthesis by the plant and reduce transpiration due to a reduction in the stomatal conductance. Kimball and Idso (1983) found that doubling the $CO_2$ concentration reduced transpiraton by an average of 34% for 18 different species. The degree of response was dependent upon whether the plant utilized $C_3$ or $C_4$ metabolism pathways for the fixation of $CO_2$ within the leaf. There are some unique interactions between $CO_2$ uptake and transpiration between these two plant types which may provide a direction for plant breeding in the areas which are more susceptible to drought and infrequent rainfall. Later, Idso et al. (1987) found that in well watered cotton a doubling of $CO_2$ caused a reduction in transpiration of nearly 10%, a dry matter increase of 84%, to cause an increase in leaf water-use-efficiency of approximately 90%. There is limited data of this type in the literature, but these data would suggest that climatic changes would impact growth and yield of the crops.

The implications for nutrient use efficiency are speculative, but if we are to manage the soil resource most effectively, these issues must be addressed. Increases in crop growth will lead to an increase in the root growth. This is based on the assumption that plants will maintain a fairly constant ratio of root to shoot material. Increased shoot growth will create a demand for more nutrients from the soil. Climatic change requires that the nutrient balance in the soil be more carefully managed to decrease the risk of limited crop growth. This will require more frequent monitoring of the soil nutrients and improved application technology, particularly as the effect of an increased soil temperature would be to stimulate the biological and chemical activity. The complex of reactions within the soil will dictate an improved understanding of the principles involved, e.g., Stanford et al. (1975), found that denitrification increased with temperature. Their results show that as the environment changes there will be changes in chemical reactions and chemical availability.

## CONCLUSIONS

Climatic change does occur and has occurred throughout the history of man. The implications of climatic change and weather variability have not been examined relative to the soil resource. Changing the temperature and rainfall patterns could have serious consequences for agricultural production in the midwestern United States. These effects can be offset by understanding the implications relative to the soil water and soil temperature regimes and their management. These aspects have not been investigated to any extent to date and will require that we expand our understanding of what climatic change means and its effect on the soil.

The agricultural community is concerned today about sustainable agriculture. One of the key variables in sustainable agriculture systems is the soil. A changing climatic regime dictates that we understand how the parameters affecting the soil interface with a sustainable agriculture system.

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