SOIL TEMPERATURE AND PLANT GROWTH IN THE NORTHERN GREAT PLAINS

W. O. Willis and J. F. Power

Soil temperature has a major influence on plant growth, and discussions of such invariably turn to "cause and effect." This review article presents a few examples of interrelated factors that have a bearing on soil temperature vs. plant growth in the northern Great Plains. For those interested in pursuing the subject, two recent reviews (Cooper, 1973; Willis and Amemiya, 1973) are a recommended starting point.

It is well known that water viscosity and surface tension are inversely related to temperature, and relative hydraulic conductivity increases as temperature increases. A plant needs water to grow and, if temperature affects rate of water flow in the soil, then soil-temperature: soil-water:plant growth relations must be considered. In a similar fashion, as other biological factors are added the system becomes additively complex.

The soil-temperature regime during the growing season can be conditioned by antecedent soil water effects and snow cover during the preceding fall and winter. For example, Figure 1 shows depth of frost overwinter for soil that was wet or dry in the fall before freezing (Willis et al., 1961). A dry soil freezes quicker and deeper than a wet soil, and thaws quicker in the spring. This behavior reflects the higher thermal conductivity and heat capacity of wet soil as compared to dry soil (Willis and Raney, 1971). Crawford and Legget (1957) showed frost depth was reduced about 1 foot for each foot of undisturbed snow cover and, in some instances, as much as 2 feet reduction in frost penetration for each foot of snow. Potter (1956) obtained similar results at Fargo, North Dakota. Observations of snowpacks created by tree windbreaks or snow fences at Mandan, North Dakota have indicated that if a snowdrift is more than about 4 feet deep, the soil under the snowdrift is not likely to be frozen.

Figure 2 shows overwinter frost depth in an area with a fairly high water table (Willis et al., 1964). The water table begins to rise in April even though frost remains in the upper profile. This indicates the frost mass has changed sufficiently to allow some permeation of liquid flow. Generally, as the profile cools or warms, the water table drops or rises in response to the known fact that a cold soil holds more water than a warm soil (Potter, 1956; Willis et al., 1961; Benz et al., 1968). Figure 2 also shows that frost remains in the profile for a significant time after the surface has thawed. Thus, for this or similarly wet soils, if planting is done about May 1, plant roots must grow into soil colder than the surface (Wilkinson, 1967).

Another factor affecting depth and longevity of snowpack is the type and amount of vegetative cover. Figure 3 shows the duration of snowmelt with different heights of standing wheat stubble (Willis et al., 1969). Snowpack runoff is faster and greater with increased stubble height. Conceivably, vegetative cover could be manipulated as a management practice for soil water conversation and for soil temperature regulation.

All plants do not respond the same to a given soil temperature regime, so knowledge of magnitude and variation in soil temperature is necessary. Figure 4 represents the annual temperature curve from averaged measurement at the 1-, 2-, and 3-foot depths (Willis and Amemiya, 1973). Figure 5 shows soil temperature measurements to a depth of more than 20 m at 2-month intervals. Below the 10-m depth, temperature is virtually constant. Figure 6 gives a

---

Contribution from the North Central Region of the Agricultural Research Service, USDA.

The authors are at the Northern Great Plains Research Center, P.O. Box 459, Mandan, ND 58554.

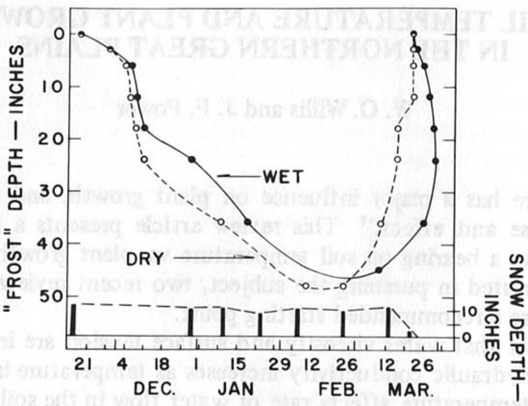

Fig. 1. Depth of freezing temperature (32 F isotherm) as a function of time for a wet or dry soil (from Willis et al. 1961).

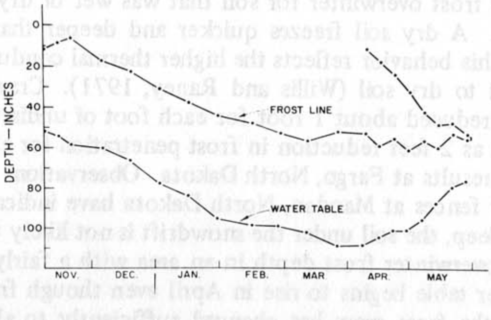

Fig. 2. Measured depths of water table and frost over a winter period (from Willis et al. 1964).

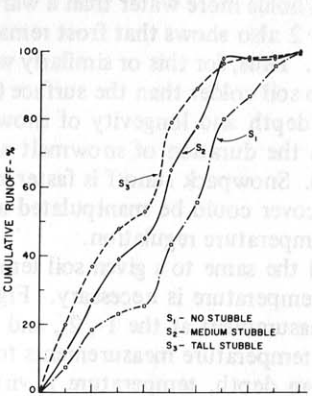

Fig. 3. Percent cumulative snowpack runoff with time and 3 stubble heights for 6 spring thaw periods (1961-1967) (from Willis et al. 1969).

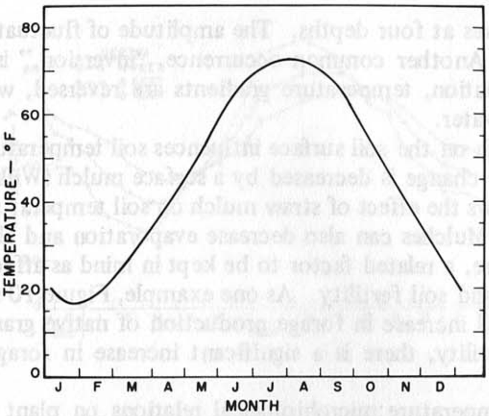

Fig. 4. Composite average of soil temperature at the 1-, 2-, and 3-foot depths, measured at weekly intervals over a number of years (from Willis and Amemiya, 1973).

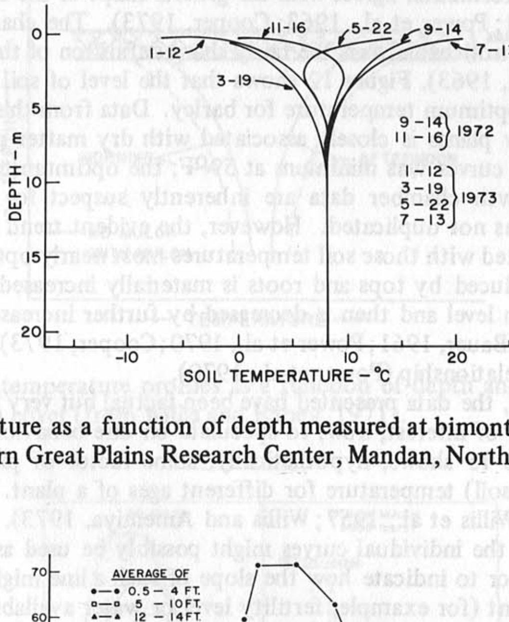

Fig. 5. Soil temperature as a function of depth measured at bimonthly intervals (unpublished data, Northern Great Plains Research Center, Mandan, North Dakota).

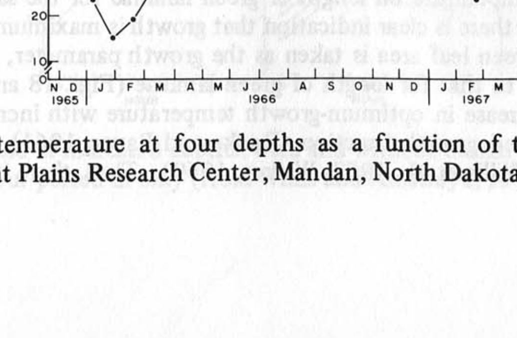

Fig. 6. Average soil temperature at four depths as a function of time (unpublished data, Northern Great Plains Research Center, Mandan, North Dakota).

comparison of temperatures at four depths. The amplitude of fluctuation is more pronounced for the shallow depths. Another common occurrence, "inversion," is more clearly shown in Figure 7. In such a situation, temperature gradients are reversed, which in turn influences liquid and vapor flow of water.

Any kind of mulch on the soil surface influences soil temperatures. Figure 8 shows the amplitude of temperature change is decreased by a surface mulch (Willis and Raney, 1971). In more detail, Figure 9 shows the effect of straw mulch on soil temperature at different depths in the soil during one day. Mulches can also decrease evaporation and thereby increase available water to plants. Therefore, a related factor to be kept in mind as affecting plant growth is the interaction of soil water and soil fertility. As one example, Figure 10 shows that with low fertility, there is only a small increase in forage production of native grass as available soil water increases; with higher fertility, there is a significant increase in forage as available water increases (Smika, 1965).

Effects of soil temperature:microbiological relations on plant growth will not be discussed, although they can be important.

Figure 11 shows the growth rate of maize seedlings as a function of temperature (Lehenbauer, 1914). Other information agrees with the general shape of the curve (Willis et al., 1957; Radke and Bauer, 1961; Power et al., 1963; Cooper, 1973). The change in slope before and after the "optimum" is noticeable, as is the fairly sharp definition of the optimum peak. From other data (Power et al., 1963), Figure 12 shows that the level of soil phosphorus can extend the range of generally optimum temperature for barley. Data from this same work (Figure 13) show that water use by plants is closely associated with dry matter production and that the slope of this family of curves was minimum at 59°F, the optimum temperature indicated in Figure 12. These growth chamber data are inherently suspect for extension to the field, because field climate was not duplicated. However, the evident trend is that maximum water use efficiency is associated with those soil temperatures most nearly optimum for plant growth.

Dry matter produced by tops and roots is materially increased by increasing soil temperature to an optimum level and then is decreased by further increase in temperature (Willis et al., 1957; Radke and Bauer, 1961; Power et al., 1970; Cooper, 1973). Figure 14 is presented as one example of this relationship (Power et al., 1970).

Up to this point, the data presented have been factual but very brief to highlight particular major effects. It is of interest, now, to speculate on one behavioral response of plants to soil temperature; Figure 15 shows, hypothetically, some factor of plant growth (say growth rate) as a function of (soil) temperature for different ages of a plant. This concept has been previously considered (Willis et al., 1957; Willis and Amemiya, 1973). The dotted line passing through the maxima of the individual curves might possibly be used as an index number for a particular plant species or to indicate how the slope of such a line might change in response to a given cultural treatment (for example, fertility level or water availability). Figure 16 shows dry weight versus temperature for four growth stages of barley (Power et al., 1967). The dotted lines are added in the absence of data points to show a possible position of maximum growth. The same data are shown in Figure 17 but in terms of relative growth, using the highest weight for a given growth stage as 100 percent. There is partial indication that the maximum has shifted to a lower temperature as the plant becomes older. Figures 18 and 19 show the effects of temperature on length of green laminae for the same plants as in Figures 16 and 17; in this case there is clear indication that growth is maximum at a lower temperature as the plant ages. If green leaf area is taken as the growth parameter, the growth:temperature relation is very similar to that for length of green laminae (Figs. 18 and 19). For sugarbeets, Figure 20 shows a decrease in optimum-growth temperature with increased age when relative weight was the measured growth function (Radke and Bauer, 1961). A similar response has been shown for corn (Willis et al., 1957; Walker, 1969). Thus, there is factual support for the

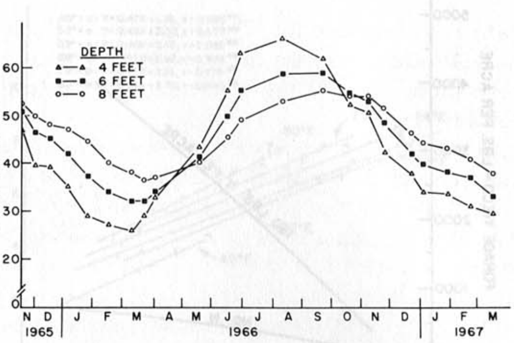

Fig. 7. Soil temperature at the 4-, 6-, and 8-foot depths as a function of time (unpublished data, Northern Great Plains Research Center, Mandan, North Dakota).

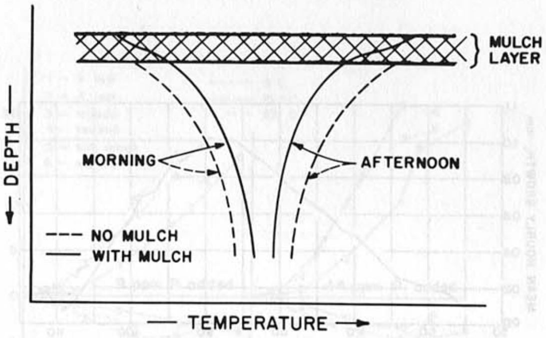

Fig. 8. Expected soil temperature profiles as a function of depth and time in a soil with and without mulch cover (from Willis and Raney, 1971).

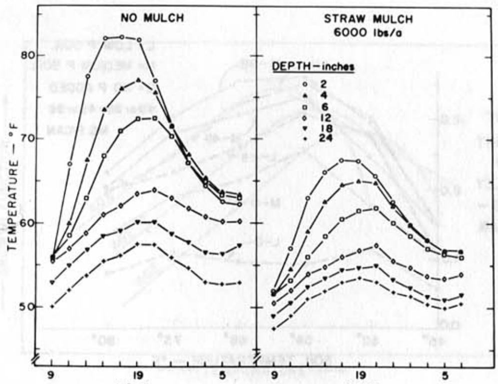

Fig. 9. Soil temperature at indicated depths, with and without mulch taken at 2-hour intervals during a 24-hour period in May (from Willis and Amemiya, 1973).

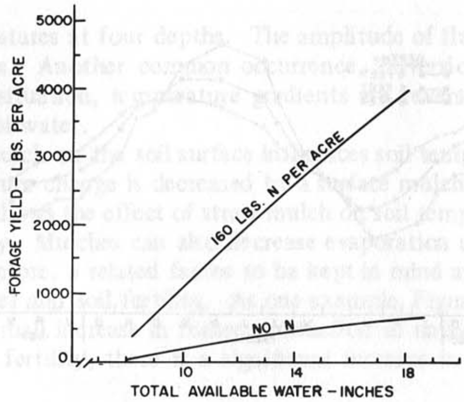

Fig. 10. Effect of available water on native grass forage production with 0 and 160 pounds nitrogen fertilizer applied annually (from Smika et al. 1965).

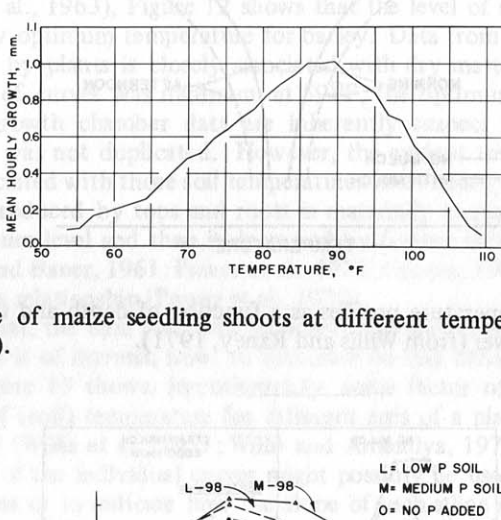

Fig. 11. Growth rate of maize seedling shoots at different temperatures (data from Lehenbauer, 1914).

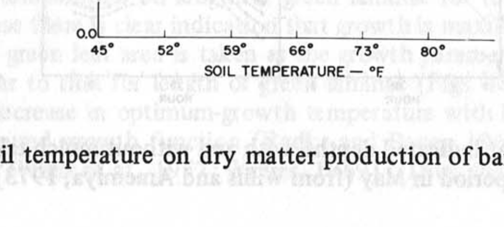

Fig. 12. Effect of soil temperature on dry matter production of barley tops (from Power et al. 1963).

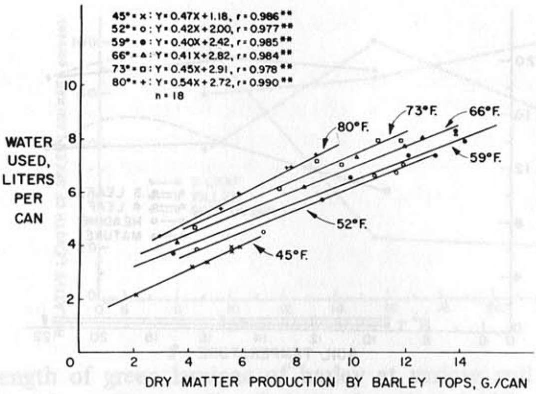

Fig. 13. Relationship of barley water use to dry matter production at indicated soil temperatures (from Power et al. 1963).

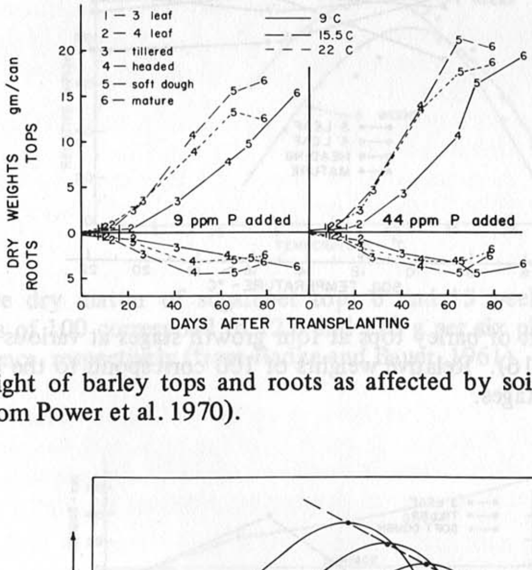

Fig. 14. Dry weight of barley tops and roots as affected by soil temperature, P supply and time (from Power et al. 1970).

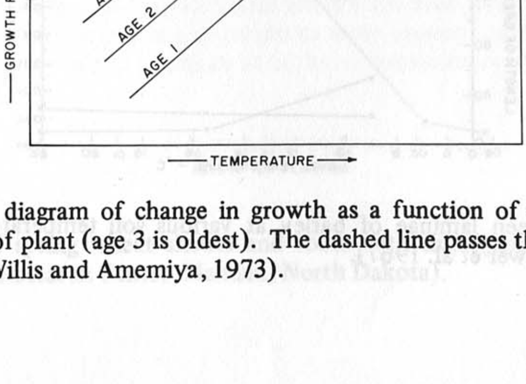

Fig. 15. Hypothetical diagram of change in growth as a function of soil temperature for increasing age of plant (age 3 is oldest). The dashed line passes through the apex of each curve (from Willis and Amemiya, 1973).

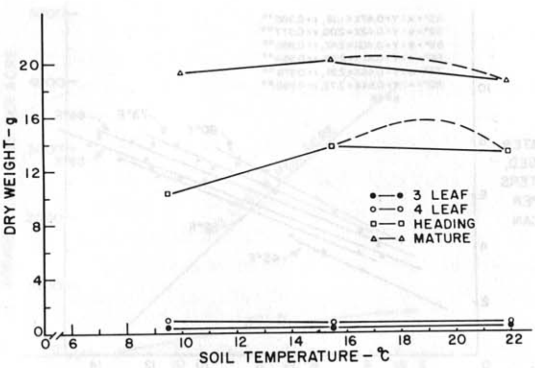

Fig. 16. Dry weight (tops) of barley produced at four growth stages at various soil temperatures (data from Power et al. 1967). Dashed lines are projections.

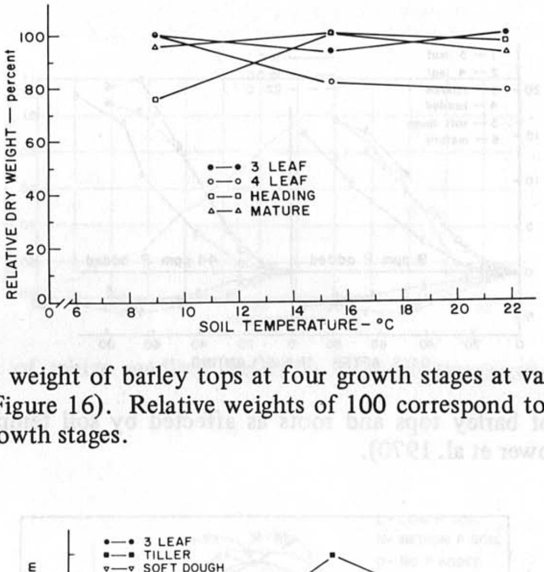

Fig. 17. Relative dry weight of barley tops at four growth stages at various soil temperatures (data from Figure 16). Relative weights of 100 correspond to the highest weight for individual growth stages.

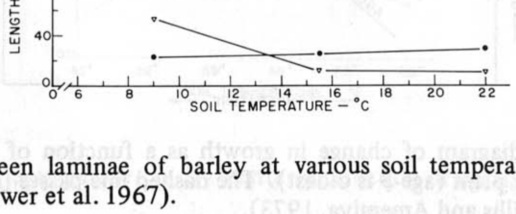

Fig. 18. Length of green laminae of barley at various soil temperatures and growth stages (data from Power et al. 1967).

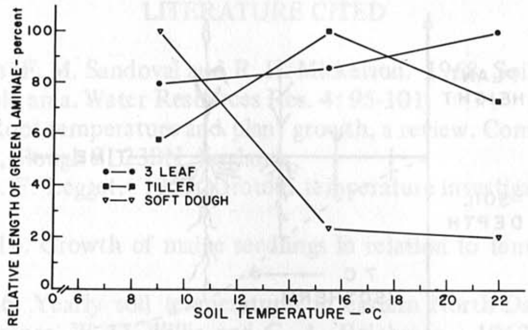

Fig. 19. Relative length of green laminae of barley at various soil temperatures and growth stages (dates from Figure 18). Relative lengths of 100 correspond to the greatest length for individual growth stages.

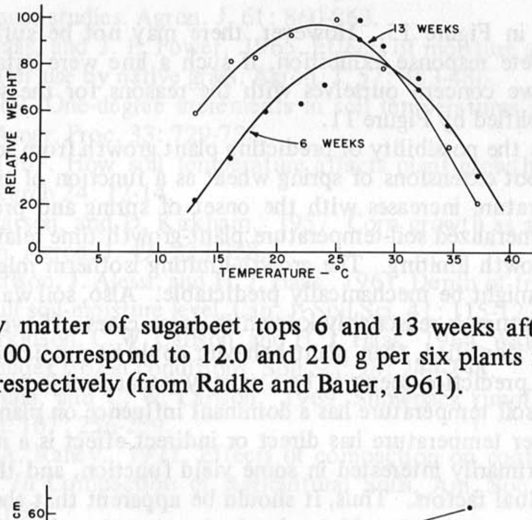

Fig. 20. Relative dry matter of sugarbeet tops 6 and 13 weeks after emergence. Relative weights of 100 correspond to 12.0 and 210 g per six plants for 6 and 13 weeks after emergence, respectively (from Radke and Bauer, 1961).

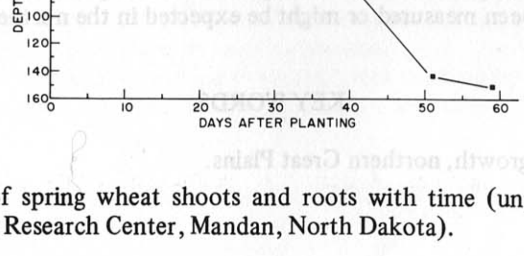

Fig. 21. Extension of spring wheat shoots and roots with time (unpublished data, Northern Great Plains Research Center, Mandan, North Dakota).

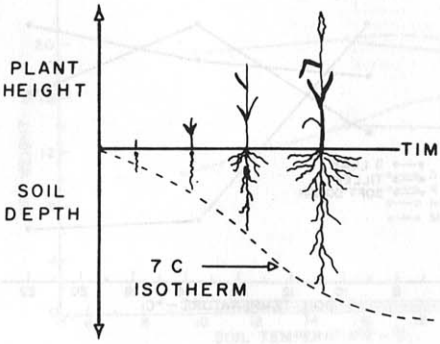

Fig. 22. Hypothetical diagram of plant growth as a function of time and a growth-limiting isotherm.

speculation illustrated in Figure 15. However, there may not be sufficient sensitivity in an "index" line for discrete response exhibition, if such a line were established. Perhaps it is more important that we concern ourselves with the reasons for the shape of the growth response curves as exemplified by Figure 11.

A final point is the possibility of predicting plant growth from soil temperature. Figure 21 shows shoot and root extensions of spring wheat as a function of time after planting. We know that soil temperature increases with the onset of spring and progression into summer. Figure 22 portrays a generalized soil-temperature:plant-growth:time relation; the 7C isotherm is inserted as possibly growth limiting. The growth-limiting isotherm might be established for a particular species and might be mechanically predictable. Also, soil water and nutrient uptake relative to soil temperature is reasonably known in some cases. If average active rhizosphere temperatures could be identified, then plant behavior could be predicted more easily and accurately. Pursuit of such prediction seems to be a worthy research objective.

In conclusion, soil temperature has a dominant influence on plant growth, both directly and indirectly. Whether temperature has direct or indirect effect is a moot question, particularly because we are primarily interested in some yield function, and the plant acts as an integrator of many individual factors. Thus, it should be apparent that there is definite need for additional temperature research to aid in developing practices beneficial to plant growth.

ABSTRACT

Soil temperature can have controlling influence on plant growth in the northern Great Plains. This review article presents some examples of soil temperature regime and its effect on plant growth that have been measured or might be expected in the northern Plains.

KEY WORDS

Soil temperature, plant growth, northern Great Plains.

LITERATURE CITED

Benz, L. C., W. O. Willis, F. M. Sandoval and R. H. Mickelson. 1968. Soil water translocation in a high water table area. Water Resources Res. 4: 95-101.

Cooper, A. J. 1973. Root temperature and plant growth, a review. Commonwealth Agric. Bur. Farnham Royal, Slough SL23BN, England.

Crawford, C. B. and R. F. Legget. 1957. Ground temperature investigation in Canada. Engng. J. 40: 1-8.

Lehenbauer, P. A. 1914. Growth of maize seedlings in relation to temperature. Physiol. Res. 1: 247-288.

Potter, Loren D. 1956. Yearly soil temperatures in eastern North Dakota. Ecol. 37: 62-70.

Power, J. F., D. L. Grunes, W. O. Willis and G. A. Reichman. 1963. Soil temperature and phosphorus effects upon barley growth. Agron. J. 55: 389-392.

Power, J. F., W. O. Willis, D. L. Grunes and G. A. Reichman. 1967. Effect of soil temperature, phosphorus and plant age on growth analysis of barley. Agron. J. 59: 231-234.

Power, J. F., D. L. Grunes, G. A. Reichman and W. O. Willis. 1970. Effect of soil temperature on rate of barley development and nutrition. Agron. J. 62: 567-571.

Radke, J. K. and R. E. Bauer. 1961. Growth of sugar beets as affected by root temperatures Part I:Greenhouse studies. Agron. J. 61: 860-863.

Smika, D. E., H. J. Haas, and J. F. Power. 1965. Effects of moisture and nitrogen fertilizer on growth and water use by native grass. Agron. J. 57: 483-486.

Walker, John M. 1969. One-degree increments in soil temperatures maize seedling behavior. Soil Sci. Soc. Amer. Proc. 33: 729-736.

Wilkinson, Guy E. 1967. How soil temperature affects plant growth. No. Dak. Agric. Expt. Sta. Farm Research 24: 12-14.

Willis, W. O., W. E. Larson, and D. Kirkham. 1957. Corn growth as affected by soil temperature and mulch. Agron. J. 49: 323-328.

Willis, W. O., C. A. Carlson, J. Alessi, and H. J. Haas. 1961. Depth of freezing and spring runoff as related to full soil-moisture level. Can. J. Soil Sci. 41: 115-123.

Willis, W. O., H. L. Parkinson, C. W. Carlson, and H. J. Haas. 1964. Water table changes and soil moisture loss under frozen conditions. Soil Sci. 98: 244-248.

Willis, W. O., H. J. Hass, and C. W. Carlson. 1969. Snowpack runoff as affected by stubble height. Soil Sci. 107: 256-259.

Willis, W. O. and W. A. Raney. 1971. Effects of compaction on content and transmission of heat in soils. *In* Compaction of Agricultural Soils. Am. Soc. Agr. Eng., St. Joseph, Mich. pp. 165-167.

Willis, W. O. and M. Amemiya. 1973. Tillage management principles:soil temperature effects. *In* Proc., Nat. Conserv. Tillage Conf., Soil Conserv. Soc. Amer., Ankeny, Iowa. pp. 22-42.

LITERATURE CITED

Benz, L. C., W. O. Willis, F. M. Sandoval and R. H. Mickelson. 1968. Soil water translocation in a high water table area. Water Resources Res. 4: 95-101.

Cooper, A. J. 1973. Root temperature and plant growth, a review. Commonwealth Agric. Bur. Farnham Royal, Slough SL2 3BN, England.

Crawford, C. B. and R. F. Legget. 1957. Ground temperature investigation in Canada. Engng. J. 40: 1-8.

Lehenbauer, P. A. 1914. Growth of maize seedlings in relation to temperature. Physiol. Res. 1: 247-288.

Potter, Loren D. 1956. Yearly soil temperatures in eastern North Dakota. Ecol. 37: 62-70.

Power, J. F., D. L. Grunes, W. O. Willis and G. A. Reichman. 1963. Soil temperature and phosphorus effects upon barley growth. Agron. J. 55: 389-392.

Power, J. F., W. O. Willis, D. L. Grunes and G. A. Reichman. 1967. Effect of soil temperature, phosphorus and plant age on growth analysis of barley. Agron. J. 59: 231-234.

Power, J. F., D. L. Grunes, G. A. Reichman and W. O. Willis. 1970. Effect of soil temperature on rate of barley development and nutrition. Agron. J. 62: 567-571.

Radke, J. K. and R. B. Bauer. 1961. Growth of sugar beets as affected by root temperatures Part I: Greenhouse studies. Agron. J. 61: 860-863.

Smika, D. E., H. J. Haas, and J. F. Power. 1965. Effects of moisture and nitrogen fertilizer on growth and water use by native grass. Agron. J. 57: 483-486.

Walker, John M. 1969. One-degree increments in soil temperatures affect maize seedling behavior. Soil Sci. Soc. Amer. Proc. 33: 729-736.

Wilkinson, Guy E. 1967. How soil temperature affects plant growth. No. Dak. Agric. Expt. Sta. Farm Research 24: 12-14.

Willis, W. O., W. E. Larson, and D. Kirkham. 1957. Corn growth as affected by soil temperature and mulch. Agron. J. 49: 323-328.

Willis, W. O., C. W. Carlson, J. Alessi, and H. J. Haas. 1961. Depth of freezing and spring runoff as related to fall soil-moisture level. Can. J. Soil Sci. 41: 115-123.

Willis, W. O., H. J. Parkinson, C. W. Carlson and H. J. Haas. 1964. Water table changes and soil moisture loss under frozen conditions. Soil Sci. 98: 244-248.

Willis, W. O., H. J. Haas, and C. W. Carlson. 1969. Snowpack runoff as affected by stubble height. Soil Sci. 107: 256-259.

Willis, W. O. and W. A. Raney. 1971. Effects of compaction on content and transmission of heat in soils. *In* Compaction of Agricultural Soils. Am. Soc. Agr. Eng., St. Joseph, Mich. pp. 165-167.

Willis, W. O. and M. Amemiya. 1973. Tillage management principles: soil temperature effects. *In* Proc., Nat. Conserv. Tillage Conf., Soil Conserv. Soc. Amer., Ankeny, Iowa. pp. 22-42.

ABSTRACT

Soil temperature can have controlling influence on plant growth in the northern Great Plains. This review article presents some examples of soil temperature regime and its effect on plant growth that have been measured or might be expected in the northern Plains.

KEY WORDS

Soil temperature, plant growth, northern Great Plains