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NOAA TECHNICAL MEMORANDUM NWS CR-100



A GUIDE TO FORECASTERS IN JUDGING WEATHER IMPACT ON GROWTH
ENVIRONMENTS AND FARM OPERATIONS IN THE MIDWEST

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DECEMBER 1989

**U.S. DEPARTMENT OF
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TABLE OF CONTENTS

	<u>Page No.</u>
ABSTRACT	1
I. INTRODUCTION	1
II. SPRING SUMMARY	2
A. Key Factors of Spring Climatology and Phenology	2
B. Specific Agricultural Activities During March Through May	4
C. Ag-Weather Forecast Elements and Their Use in Advisories	5
III. SUMMER SUMMARY	9
A. Key Factors of Summer Climatology and Phenology	9
B. Specific Agricultural Activities During June Through August	10
C. Elements of the Ag-Weather Forecast in Summer	11
IV. AUTUMN SUMMARY	13
A. Key Factors of Fall Climatology	13
B. Specific Agricultural Activities During September Through November	14
C. Elements of the Ag-Weather Forecast in the Fall	15
V. WINTER SUMMARY	18
A. Key Factors of Winter Climatology	18
B. Specific Agricultural Activities During December Through February	20
C. Elements of the Forecast Relating to Agricultural Activity in the Winter	21
VI. DISCUSSION	22
VII. ACKNOWLEDGEMENT	24
VIII. REFERENCES	24

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ABSTRACT. The key elements of agricultural weather forecasts are examined with respect to their related impact on crops, livestock, and farm operations. Air temperature, precipitation, relative humidity, wind, sunshine, and soil temperature are all described in the context of their seasonal cycles and day to day fluctuations. Corresponding changes in the growth environments of crops and livestock are detailed. Special emphasis is given to the critical thresholds of weather elements that create stress for plants and animals or interfere with farming operations such as spraying, cultivation, or harvest.

Information is organized according to season. Each of the four sections presents a summary of the climatology across the Midwest during that season. This is followed by a discussion of the specific farm activities unique to the season and the effects of each of the weather elements on those activities. The range of normal temperatures and critical growth thresholds is explained. The seasonal water balance and shorter term changes in soil moisture are compared. The importance of soil temperature information for scheduling planting or fertilization is cited, and the factors of relative humidity, wind, and sunshine are considered both independently and in combination with respect to their net impact on evaporative rates.

This is a guidebook intended for use by operational meteorologists preparing agricultural weather forecasts. It outlines fundamental relationships between weather conditions and growth environments to supplement the forecaster's technical knowledge. At the same time, its emphasis on weather's impact illustrates the importance of the weather forecast from the user's perspective.

I. INTRODUCTION

Nowhere is the impact of weather more profound or sustained than in the agricultural community. Day to day weather conditions control the nature and extent of activities, and seasonal trends determine the success or failure of crop and livestock enterprises. This guide is intended to give weather forecasters a better understanding of how the weather elements they describe are

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transferred into the decision making process by users in the field of agriculture. At the same time, this guide evokes an appreciation of the continuous process of adjustment that crops, livestock, and human beings make in response to the constant fluctuations in their environments.

The relationships described between weather elements and crop or livestock responses are based on general principles that apply to a wide range of localities, but the focus of this discussion is on the Midwest. Generally speaking, the Midwest encompasses a large section of the central United States, extending from the North and Central Plains eastward to the Ohio River Valley and the central Great Lakes. It includes, but is not limited to, the corn belt. It is an agriculturally diverse region, stretching from the spring wheat and sunflower fields of the Dakotas to the winter wheat belt in Kansas. Its mosaic of corn and soybean fields can be traced from Nebraska to Ohio and from Michigan to Missouri. Commercial fruit and vegetable enterprises thrive along with the dairy industry around the Great Lakes, while at the southern rim of the region tobacco and cotton are major crops.

Although many farm and orchard operations employ irrigation as a supplement, the Midwest is, for the most part, a region of rain-fed agriculture. It depends upon the regular addition of moisture from precipitation throughout the growing season to meet crop needs. While climatologically normal conditions of temperature and precipitation satisfy those needs, the extreme variability of weather conditions around those climatological normals leaves agriculture in the Midwest vulnerable to serious stresses.

In formulating weather forecasts for agriculture, the meteorologist must retain a good sense of climatology and be aware of what weather elements are most critical to crops or livestock at different stages of the growing season. In order to help the forecaster gain this needed perspective, this guide is divided into four seasonal sections, each describing the fundamental climatology that provides the framework for agricultural activities followed by details of the weather information needs peculiar to that season. It is hoped this guide will prove to be an informative and useful reference, for review at the beginning of each season and consultation as needed throughout the year.

II. SPRING SUMMARY

A. Key Factors of Spring Climatology and Phenology

Lengthening periods of daylight combined with seasonal intrusions of warmer air are beginning to trigger growth responses in overwintering crops as the late winter period gives way to early spring. A stepwise process of early growth and development follows the alternating pattern of warm and cool air masses characteristic of the season. Each successive warming cycle provides more impetus for movement of buds and greening of grasses.

Attempts to develop an objective standard to relate this growth response to prevailing weather conditions have provided a variety of growing degree day schemes for calculation of accumulated heat units above a given threshold temperature. The thresholds vary with the type of crop, but two of the most commonly used are 40 and 50 degrees. These apply to cool season (winter grains)

and warm season (corn, soybeans) crops, respectively. Thus, a day with mean temperature of 60 degrees (maximum of 70 and minimum of 50, for example) would yield 20 growing degree days calculated at base 40 and 10 at base 50. At southern locations where cotton is grown, a base 60 degree day system is employed.

On average, certain cumulative totals of growing degree days correspond to notable stages of crop development. Starting with the current total at any particular time and using forecast temperature patterns, the timing of future crop stages can be estimated. At any point during the season, the cumulative totals can be compared with the average total based on long term climatological normals. The departure from normal of growing degree day totals should correlate closely with the length of time that a crop is ahead or behind the normal calendar. Conversely, the occurrence of other perennials can serve as environmental signals of how the average weather conditions in a given season compare with normal.

This seasonal progression affects insect populations as well as crops. Certain stages in a particular insect pest's life cycle occur in conjunction with the passage of corresponding heat unit thresholds. One threshold that is commonly used by entomologists is 48 degrees. The advancement of the alfalfa weevil, an especially destructive pest to that forage crop, can be tracked and forecast based on the accumulated totals of base 48 heat units. Other base temperatures are also used depending upon the characteristic life cycle of the specific insect pest.

Meanwhile, as the existing insect problems and condition of perennial crops are being monitored throughout the season, the agriculturist is concerned with field conditions as they affect completion of spring tillage and subsequent establishment of spring and summer seedings. Soil moisture supplies are normally being replenished by ample spring rains between mid-March and mid-May, a condition that also imposes a limit on the opportunities available to enter fields with tillage, planting, or fertilization equipment. Furthermore, depending upon the amount of moisture injected by rains during the previous fall, the addition to soil moisture levels during the spring may be of critical importance for sustained crop development during early summer when peak rates of consumption combine with less frequent rainfall to create a net loss in soil moisture supplies.

Based on these considerations, farmers will have a keen interest in both short range and long range weather forecasts during the upcoming months. The successful establishment of summer crops will depend upon timely completion of a variety of field chores that are in turn dependent upon short term weather conditions. Longer range outlooks of temperature and precipitation trends compared with normal provide valuable input to decision making with regard to timing of crop maturity, risk from disease or insect injury, effectiveness of chemicals, and projected harvest.

Finally, in addition to short term working conditions and long term temperature and precipitation trends, one of the most important concerns to growers during this season is the danger of late spring frost or freeze to perennial fruit crops as well as young transplants. The following sections

list the typical activities that growers are engaged in during the course of the spring season, their specialized needs for weather information, and the elements of the agriculture weather forecast as they relate to those needs.

B. Specific Agricultural Activities During March Through May

1. Depending upon progress of field work during the previous fall, tillage of ground intended for spring planted crops have highest priority in March and early April. Prior to tillage, early applications of fertilizers or lime are often made. Where limited tillage or no-till practices are employed, pre-plant herbicides are applied to prevent weed problems and allow seedings to become established without competition.

Top dressing (fertilization) is applied to winter wheat as it emerges from dormancy and begins its stage of vegetative growth. Seeding of oats and pasture grasses are accomplished as early as field conditions (moisture, softness of ground) permit. Orchard activities are focused on pruning and application of dormant sprays.

2. Mid-April through May is perhaps the busiest period of the year. Where tillage is complete and the soil moisture and temperature conditions are favorable, planting of corn and then soybeans move into full swing. When those crops have emerged by mid to late May, side dressing (between row application of fertilizer) and cultivation begin. Spraying of herbicides both before and after field crop emergence and the application of fungicides and thinning agents to orchard crops are all time-critical activities fully dependent on weather conditions.

3. Pasture growth is advancing rapidly throughout the spring, and livestock are being turned out for grazing as the primary element in their diet. While cold stress is still critical in the early spring period, especially for young and newborns, the livestock manager becomes more concerned with adequate nutrition and the capability of pastures to support animal grazing. One dangerous side effect to early grazing is often the disorder of "grass tetany" which arises as a result of magnesium deficiency in the rapid spring growth. Another hazard is that of "prussic acid poisoning," an after effect of frost or freeze that interrupts the growth of sorghum and sudan grasses. Here is another area where temperature reports and forecasts are of fundamental importance.

4. When grasses such as alfalfa and clover are intended for harvest rather than grazing, the first hay cuttings are often made in mid to late May, depending upon the progress of the crop. For this reason, the expressed wishes of farmers during the month of May commonly alternate between wanting more rain to boost crop growth and needing at least four days of dry weather to harvest the best quality hay.

5. As row crops emerge and cool season crops advance, transplants of vegetable crops are being set in the field from late April through May. The balance of precipitation and evaporation rates determines the need for irrigation, while the assessment of frost and freeze risk remains of utmost importance to these growers as well as orchardists.

C. Ag-Weather Forecast Elements and Their Use in Advisories

1. Temperature forecasts are important for all of the reasons cited previously in regard to direct impact on crops and operations. An accurate temperature forecast also provides the basis of forecasting other derived elements such as relative humidity or degree days. When extreme temperatures are forecast, the amount of time that readings will remain below or above a critical threshold may be equally important for assessing the impact on crops.

- a. In early spring, before cool season crops break dormancy, the impact of freezing temperatures is mainly on livestock or in a less critical sense on stored grain and tobacco. These effects are usually linked to concurrent conditions of strong winds or high relative humidities. The potential for livestock chill, respiratory stress, and condensation within barns and grain bins will be stressed in advisories.
- b. Once fruit buds advance and transplants are put in place, the risk of frost or freeze becomes critical. Buds that can withstand readings in the teens or low 20's during earliest development become progressively more susceptible to kill as the season moves along. A ninety percent rate of kill can be expected with apple buds in full bloom if temperatures of 25 or lower are sustained. Only a ten percent kill is likely for the same buds if minimum temperatures level off at 28. Most plants can endure a light freeze for a short period of time, but if late spring readings drop below the upper 20's for more than an hour, serious damage is inevitable.
- c. At the other end of the spectrum, extreme maximum temperatures often exert stress on crops and livestock during the late spring. Afternoon temperatures reaching above the middle 80's may cause wilting as transplants respond to excessive moisture loss. The same temperatures combined with relative humidities of 50 percent or higher put the Livestock Safety Index into the danger category, and producers are advised to observe precautions during the transport or confinement of animals. The same dangers of heat stress exist for people as well.

2. Relative humidity and/or dew point information provides the basis for estimating the rate of moisture loss from soils or vegetation, an integral part of scheduling field work, irrigation, or application of chemicals. Drying capacity of the air is also crucial to the effectiveness of moisture control systems in barns and grain bins. Deposition of moisture in the form of dew or frost is another factor in the overall moisture budget of fields, orchards, and storage enclosures.

- a. Potential evaporation is estimated from the expected combination of temperature, relative humidity, sunshine, and winds. This quantity is verified by measured pan evaporation and in turn can be used to derive estimates of actual moisture loss through particular crop canopies (evapo-transpiration). The combined factors of precipitation and evaporation enter into calculations of short term crop moisture and long term drought indices.
- b. Estimating vegetative drying time is another application of relative humidity data. Whether initial wetting is from precipitation, irrigation, or dew, growers need to determine how long vegetation will remain wet under given temperature conditions in order to assess the potential activation of disease pathogens. A variety of fungal and bacterial infections are possible at particular combinations of temperature and moisture conditions. Drying of hay cuttings also becomes increasingly important as spring passes into summer.
- c. Condensation occurring inside buildings and grain storage bins is a significant moisture source that can lead to spoilage of stored agricultural products.
- d. Moist air persisting within livestock confinement buildings for a lengthy period of time without compensating ventilation can lead to serious respiratory ailments and production deficiencies. The livestock safety index described earlier is weighted by relative humidity as well as temperature.

3. Wind speed and direction are controlling factors in planning and completing tasks such as spraying, burning, or construction on the farm. While the potential for strong, damaging winds from spring storms concerns farmers as well as the general population, farm operations can also be disrupted by otherwise less serious wind conditions.

- a. Periods of sustained winds in the 15 to 25 mph category are common with the migrating low pressure systems of spring. When those winds occur in combination with sunshine and low relative humidity, the accelerated drying potential is usually beneficial in this season of surplus soil moisture. During spring and early summer, when new transplants are becoming established, the rapid depletion of moisture from the upper soil layers is less favorable. Furthermore, once surfaces are dry the soils become vulnerable to wind erosion, and transplants or seedlings could be displaced in extreme cases.
- b. Moderate winds in the 12 to 18 mph range maintain a favorable drying rate without as much disruption to the surface. However, winds of this strength still preclude

spraying of chemicals for weed, insect, or disease control. Control of grass or brush fires is also difficult, and drift of vapors from solid fertilizers and manure can be objectionable.

- c. Forecast peak winds of less than 12 mph make spray applications manageable, especially if speed and direction are constant enough to enable control of drift. Of course the lighter the winds, the better control of sprays, but periods of calm are usually limited to early morning or evening hours. In the morning, the presence of dew may interfere with chemical effectiveness.
- d. The formation of dew and its subsequent dissipation are also related to diurnal wind patterns. The same light winds (< 5 mph) that enhance formation of dew will retard the rate of dry off in the morning until convective heating contributes to air movement.
- e. Sustained periods (24 hours or more) of strong winds (20+ mph) from a southerly direction are responsible for transporting some fungus disease spores and insects back into Midwestern crop regions from their more favored winter habitats near the gulf coast and southwest Texas. Entomologists and plant pathologists will be on guard for signs of infection or infestation following such winds.

4. The percentage of possible sunshine expected each day can be translated into an estimate of solar radiation and estimates, in turn, of evaporation and photosynthetic rates. Applications of solar energy technology to grain drying, heating, and power generation have become increasingly important in recent years, making the quantitative estimate of solar radiation of obvious value.

5. Accurate precipitation information is perhaps the product most sought by farmers, as well as the most elusive. How much rain, when will it fall, how hard will it fall, and how long will it last are the underlying questions awaiting every forecast.

- a. Rain amounts are a basic determinant of field workability and of crop health. The concentration of rains in the spring replenishes the available soil moisture supplies, but often at the cost of delaying field work and planting. Generally, a quarter inch or less of rain will have minimal impact on field activity. Occurring over dry soils, it will rapidly dissipate. On wet soils, it will have little additional impact except to delay the drying process for the duration of the rainy period. Increasingly greater amounts will lengthen delays. Half inch to one inch rains following a dry period may necessitate delays of two or three days before equipment can be moved over fields without risk of soil compaction. Where the topsoil

layer is already wet, the addition of a half inch or more will simply ensure saturation and cancel the effect of any intervening dry weather that may have occurred since the last previous rain. Starting with saturated topsoil, it may take a week to ten days of moderate evaporative potential to allow field access.

In addition to delaying the recovery process, rains of an inch or more will likely cause accelerated runoff to streams and ponding in low lying areas. Standing water will contribute to plant diseases and ultimately lead to death if the crop remains under water for more than a couple of days.

- b. An estimate of timing and areal coverage of rainfall are important in planning and most efficient use of time among a host of farm activities. Approximate time of onset and/or ending of precipitation are of special value in determining if certain chemical applications will be effective before dilution or wash off occurs. When precipitation is showery, an estimate of coverage within the forecast area helps the grower interpret the probability of wetting at a given location and the consequent risk to operations.
- c. The rate of fall is important for estimating the impact on vegetation and surrounding soil surfaces. Early in the season, hard rains and brief ponding will result in crusting of the soil surface once drying ensues. That crust will inhibit emergence of newly planted crops. Later in the season, damage to the vegetation itself can result from intense rains, and soil borne pathogens can be splashed on plants to cause infection. In any case, the effective recharge of underlying soils will be reduced by the amount of water lost to runoff in heavy downpours.
- d. An estimate of duration of the rain episode gives further definition to the resulting soil moisture picture. Most farmers will prefer a "soaking rain" (light rate of fall over an extended period) to a thunderstorm, since more of the incoming water will reach deeper soil layers. On the other hand, a lengthy period of rain (12 hours or more) will aggravate disease problems. For example, a primary apple scab infection will occur if vegetative wetness persists for as little as nine to 12 hours at temperatures in the 60's. Other scab, rust, and blight infections affect a variety of field and orchard crops under appropriate conditions of temperature and wetness.

6. As winter gives way to spring, the reported four inch soil temperatures offer a clue to the progress of freezing or thawing of the ground. As the season advances, those temperatures reflect the condition of soils to

support germination of seed. The temperature and moisture environment of the soil remains important throughout the growing season with respect to viability of soil organisms and potential diseases. Effectiveness of certain pesticides and fertilizers may also depend upon soil temperature.

III. SUMMER SUMMARY

A. Key Factors of Summer Climatology and Phenology

By the time of the summer solstice in late June, the climatic variability of spring has given way to the more steady patterns of summer. Although temperatures characteristic of the warmest time of the year may have already been previewed during May over much of the Midwest crop region, the risk of frost is not passed in the northern Great Lakes region until the first of June. The wide range in temperatures during the late spring period are a natural result of the fluctuation in the polar front as its average position progresses northward. The dynamics of this seasonal change normally give June the highest rain totals of any month across the upper Mississippi Valley and the western Great Lakes region.

Important changes are taking place in the character of rainfall during June however. Precipitation patterns are transforming from the more widespread lengthy rain episodes of spring to the scattered brief showers and thunderstorms of summer. By mid-June, the extent of the spring soil moisture recharge has been determined, and the continued health of crops hinges on the timeliness of subsequent showers in meeting the accelerating rate of moisture consumption by expanding vegetation. Where spring rains have been heavy enough to build up subsoil supplies, topsoils can still lose moisture rapidly in the summer heat between shower episodes.

The seasonal progression of temperatures also generates a corresponding expansion in the population of insect pests. Eggs deposited in fields or fence rows early in the spring hatch with onset of warmer conditions. Resulting larval stages first pose a threat to newly emerging row crops or existing fruit crops. Later, the larvae will pupate and moths will emerge to lay eggs that will give rise to a second generation of the pest. That generation often poses a greater threat to crops at advanced stages, depending upon the original timing of planting and pace of development. Entomologists and crop specialists track the concurrent growth of crops and insects, and with the help of growing degree day calculations, project the timing and extent of future infestations.

This interplay of temperature and moisture with the progression of insects and plant diseases continues through the summer months. Warm and wet conditions early in the season promote a variety of diseases, such as scab, rust, and blight, that attack flowering fruit crops, early vegetable transplants, and winter wheat or pasture grasses. Serious infections may result in quality or yield losses that may not be fully apparent until the produce or grain begins to mature.

Drought conditions may stress crops early in the season, causing weak establishment and increased vulnerability to insects or disease. Drought at

mid summer may hit field crops at sensitive reproductive stages of development and ultimately reduce yields. Often the dry periods that favor harvest of early crops become a detriment to vigorous growth of crops that mature later.

Although lengthy periods of dryness are more often a problem than persistent wetness during the summer months, the thunderstorms that occur during the mid to late summer period can bring locally heavy downpours in a short period of time. The slow progression of large scale pressure systems and light winds aloft characteristic of the season contribute to slow movement of heavy thunderstorms that discharge their contents over a relatively small area. The occasional flooding of fields that occurs may in turn aggravate stalk rots that ultimately weaken stands of grain, making them vulnerable to lodging (falling down) before harvest time.

For all of the above reasons, the need for accurate rain forecasts is the number one priority among farmers throughout the summer. Long range outlooks are of interest for assessing growth rates and projecting soil water balance, but the short and intermediate range forecasts are the key to successful management of farm resources. Time critical tasks such as application of insecticides and herbicides or harvesting of wheat and hay crops depend upon the fortuitous spacing of wet and dry weather periods to ensure optimal quality and minimal loss.

B. Specific Agricultural Activities During June Through August

Unless wet weather has forced delays, the corn crop is in the ground in nearly all areas by the first of June. Soybean planting may extend into June, and where double crop soybeans follow wheat harvest, beans may be planted in early July in those southern areas with a sufficiently long growing season.

Asparagus emerges for harvest in late May and early June. Harvest of strawberries progresses northward across the region during the month of June, followed by raspberries and early blueberries in July. Blueberry harvest will continue into August, to be joined by peaches, plums, and earliest apples. Tomato harvest begins in late July and continues through August. The pace of fruit and vegetable harvest must respond promptly to changing temperature and precipitation trends in order to minimize losses due to excessive moisture or heat.

As spring planted crops continue to grow, winter wheat is maturing and ripening in late June and early July. Harvest of the wheat crop and the second cutting of hay crops can normally be accomplished during the lengthy dry periods that separate episodes of thunderstorms during this mid-summer time frame.

The period mid-July through mid-August is usually the most critical time for summer field crops. Early in the period, corn is moving through its pollination stage. Later, soybeans will move through their flowering stage. Demands on moisture supplies from these crops reach maximum rates at this time

of the season. Rapid forage growth also continues where ample moisture is available, requiring the third cutting of hay in most areas during the month of August.

The proportion of livestock sustenance derived from pasture is determined by the available precipitation to support healthy growth of grasses. When growth is weakened by dry weather, the capacity for grazing and the potential yield of hay are reduced, and livestock managers must make adjustments by providing supplemental feed or by marketing animals to reduce cost. When feed supplies are not a problem, normal summer stress from heat and humidity demand extra attention to cooling, ventilation, and watering systems. Close confinement and transportation of animals must be managed carefully to minimize stress or weight loss and avoid fatal consequences.

C. Elements of the Ag-Weather Forecast in Summer

Keeping in mind the same general considerations outlined in the spring summary, forecasters should be aware of these additional specific concerns with respect to forecast elements during the summer:

1. Temperature

The critical temperatures of summer are, of course, those at the high end of the scale. Temperatures above 90° raise the stress on both crops and livestock. In fact, temperatures above 86° have been determined to produce little additional growth potential in corn, and the modified base 50 growing degree day calculation assigns a value of 86 to any maximum temperature of 86 or higher. Temperatures moving into the 90's also begin to have an adverse effect on the pollination of corn. When temperatures reach 100°, tops and tassels are killed, and at 105°, the pollen itself is killed. The combination of temperature and humidity is also important here as it affects the rate of moisture consumption and the drying of silks.

2. Relative Humidity

With relative humidity in its normal afternoon range of 45 to 50 percent and temperatures in the mid to upper 80's, evaporative potential averages between .20 and .25 of an inch. Higher temperatures and/or lower humidities boost evaporative rates toward .30 of an inch or more, depending upon strength of wind and amount of sunshine available. Extremely dry days with temperatures in the mid 90's or higher, relative humidities below 30 percent, and winds of 15 mph or more can push evaporative rates to between .40 and .50 of an inch.

The livestock safety index often moves into the danger category during afternoon hours, even with relative humidities as low as 40 percent, when temperatures move into the upper 80's. Higher temperatures push the index up at even lower humidity levels, and with relative humidity above 50 percent, the index can reach the danger category with temperatures as low as the mid-80's.

3. Precipitation

Forecast rain amounts are important not only with respect to impact on field work, but for management of irrigation systems as well. A net soil moisture loss is expected during the summer months, as consumption exceeds the input from rain. When rainfall is below normal, underlying subsoil supplies can fall to critical levels, resulting in serious crop stress and consequent yield reductions. Although irrigation systems are designed to provide the necessary supplement to rainfall, managers must also be wary of over-irrigating. When substantial rains are imminent, watering is not only wasteful and expensive but also it can threaten crop health if the result is saturation and flooding.

Rains of a quarter inch or less (amounting to a normal day's evaporation) may briefly relieve plant stress without adding to reserve soil moisture. Rains of an inch or more will soak deeper into soils and supply plant needs for a week or more, depending upon subsequent conditions of temperature and heat stress. The rate of rainfall is equally important. Lighter amounts spread throughout the day under cloudy skies and high humidities will produce a gain over evaporative rates. Heavy downpours producing runoff will reduce effective moisture reaching the soils and may also contribute to stalk rot or other plant diseases.

4. Wind

Accurate wind forecasts are important for two reasons: the possible limitation on spraying operations, and the determination of evaporative rates. Spraying of chemicals during summer is often restricted to the morning and evening hours when wind speeds are less than 10 mph. Even if afternoon winds are that light, the temperatures are often too high, increasing the volatility of chemical solutions and contributing to evaporative as well as mechanical drift. Strict control of chemical applications is imperative, not only to reduce waste and cost, but also to prevent unwanted and adverse effects on adjoining properties.

5. Sunshine

The amount of sunshine expected is already factored into daily temperature projections by the forecaster, but the agricultural user also needs some quantitative estimate of sunshine to help determine drying conditions, growth potential, and possible stress on livestock and workers. Direct solar radiation is a fundamental element in estimates of evapo-transpiration rates.

6. Condensation

During the mid-summer period spanning late June to early August, the amount and duration of morning dew is reduced by factors such as longer periods of daylight and less effective radiational cooling. Even during peak summer heat however, light dew may result from the humid air masses that often stagnate over the nation's midsection. The resultant moistening of vegetation can help reduce plant stress during otherwise dry periods,

but it can also contribute to expansion of disease problems during wet spells by keeping the vegetation damp for longer periods.

III. AUTUMN SUMMARY

A. Key Factors of Fall Climatology

As the thunderstorms of summer become less frequent, one of the driest periods of the year often occurs in the months of September and October. Occasionally, the dying remnants of tropical storms or hurricanes from the Gulf of Mexico carry moisture into the Midwest and give rise to heavy rain events as far north as the Ohio Valley or lower Great Lakes. However, long term averages show the early fall period to be one of relative calm in the atmosphere, and the resulting fair weather has come to be associated with the celebration of harvest.

The slowly decreasing day length, which becomes apparent in August and grows even more pronounced as the autumnal equinox approaches in late September, reduces the amount of effective field work time available. The shortening daylight periods also trigger the onset of maturity in many crops, while lengthening night periods combine with seasonal intrusions of colder air to bring minimum temperatures occasionally below growth thresholds. Cool mornings may display a heavy coating of dew on such occasions, but the risk of frost does not normally become high until October.

The average date of the first freezing temperature in autumn occurs within the month of October across most of the Corn Belt. It ranges from near the first of October in southern Minnesota and Wisconsin to early November in the mid-Mississippi River Valley. Further north, the first freeze occurs by mid-September in the Dakotas, northern sections of Minnesota and Wisconsin, and the interior of Michigan's upper and northern lower peninsulas. Closer to the Great Lakes' shores, the first freeze is normally delayed until mid or late October by the moderating influence of the relatively warm waters.

The early fall period of late September and October normally provides the sunny days and less humid air needed for reduction of moisture in maturing grains. This does not mean that full drying and harvest of crops is necessarily finished by the time that cooler and wetter weather becomes predominant in November. Harvest of grain, late vegetable, and fruit crops often face delays and consequent losses due to deteriorating weather conditions at harvest, despite an otherwise favorable growing season.

More frequent outbreaks of cold air draw average temperatures downward at an accelerating pace after the mid point of fall, making the rate of temperature decline from mid-October to mid-November the sharpest of the year, corresponding to the dramatic spring rise in average temperatures from mid-March to mid-April.

The first snowfalls normally occur by mid-November over the northern regions and by late November or early December in the heart of the Corn Belt. Although precipitation nearly always increases during this seasonal transition, the occurrence of snow is much less certain due to the highly variable

temperature patterns associated with the alternation of cold and warm air masses. In many seasons, snowfall may be limited to the northern Great Lakes until the development of large scale winter storms in late December. Over the lakes region in general, the arrival of colder air above relatively warm waters reduces stability and contributes to extensive cloud cover with more frequent precipitation in November and December, whether in the form of rain or snow.

B. Specific Agricultural Activities During September Through November

While producers wait for corn and soybean crops to mature, a final hay cutting is usually made in September. Cuts can be made this late in the season as long as adequate regrowth is still possible before the crop is forced into dormancy by cold weather. The most desirable conditions at this time of the year are mild temperatures with low humidities that maintain a rapid pace of drying in both hay and grain crops.

Livestock grazing continues, but managers should be planning ahead for the end of the growing season. Pastures must not be overgrazed to the extent of preempting healthy regrowth. Once frost or freezing temperatures do occur, the hazard of prussic acid poisoning arises where animals continue to graze sorghum and sudan grasses. Bloating in cattle from grazing alfalfa too soon after frost is another danger.

Renovation of pasture land and seeding of overwintering grain or cover crops are accomplished during the fall period. Careful timing of these tasks is needed to minimize the risk of damage from insects or from chemicals that may be retained in soils from earlier in the season.

The Hessian fly is one insect that affects wheat and other small grains, but its impact is effectively controlled by delaying planting until the pest is in the non-damaging stage of its cycle. This "fly free" date varies from mid-September in the northern regions to mid-October in more southern locations.

Tillage of land where wheat has been harvested, whether reseeding of wheat or another crop is intended, is often accomplished during the early fall. This is late enough to minimize moisture losses and keep regrowth of weeds down, but usually before the demands of corn and soybean harvest begin to occupy time and resources.

Harvest of corn for silage gets underway in late August or early September. Corn harvest for grain begins at the southern end of the Corn Belt as early as mid-September and proceeds northward through the month of October. Although soybeans are normally seeded later than corn, they are ready for harvest at nearly the same time. All other things being equal, producers may choose to harvest beans before corn, leaving more field drying time for the corn and less risk of loss to beans, since beans may reabsorb moisture during wet weather periods while corn moisture content holds more nearly steady.

In central lower Michigan where dry beans, such as great northern and pintos are a major crop, harvest is often disrupted by the seasonal shift to

wet weather and poor drying conditions. This sometimes necessitates delay of harvest until the ground begins to freeze, even though beans will be subject to molds during the protracted period of wet weather.

Once grain harvests are completed, decisions as to drying of the grain in storage must be made. This drying involves expenditure of energy that can be best managed by planning around weather elements wherever possible. During the least humid periods, air can often be circulated through grain bins without supplemental heat and still be effective in removing excess moisture from the grain. Even if high heat is used initially to bring grain moisture content to desired levels in a short time, the process of aeration with unheated outside air will still be needed later to reduce the difference between grain temperatures and prevailing outside air temperatures. This lowers the potential for condensation on bin walls and keeps moisture pockets from developing and causing spoilage.

Fruit and vegetable crops also require careful management through the fall harvest, storage, and processing activities. The first freeze of autumn will end the growing season for most of these crops, but certain ones such as cabbage and brussels sprouts can remain in the field for additional growth after experiencing short periods of minimum temperatures as low as the lower 20's. Apples and grapes are the major fruit crops that remain on trees or vines late into the fall. These fruit can stand a light freeze without significant quality loss, but harvest should be finished before sustained minimum temperatures in the mid-20's occur.

Tobacco harvest normally begun in August is brought to completion during September, and attention is then turned to quality of the barn environment where leaves are hung for curing. The subsequent process of stripping necessitates a moderate range of relative humidity to keep the leaves in "case," that is at the optimum moisture level to make them pliable without being subject to damage from mold.

Though the variety of harvest, tillage, and seeding tasks that must be accomplished easily fill the autumn agenda, time must also be set aside for renovation for maintenance of livestock facilities. Before freezing temperatures become commonplace, ventilation, heating, watering, and feed delivery systems must all be put into good order to ensure a smooth transition for animals into a stable indoor environment for the winter.

C. Elements of the Ag-Weather Forecast in the Fall

1. Temperature

After an otherwise successful growing season, no grower wants to see a crop yield reduced by an early freeze. While frost or freeze in the spring can be devastating to buds or seedlings, the corresponding event in the fall is usually not as sweeping in its impact. Still, growth can be suspended prematurely by a freeze, before grains are fully developed or filled, reducing the ultimate yield. Fruit and vegetable produce can often be harvested early to avoid a hard freeze, but adequate warning of such an event must be forthcoming.

Fortunately, the residual warmth of the ground and vegetation can mitigate the effect of freezing air temperatures, and this often makes the difference between the occurrence of frost or heavy dew on surfaces. In other instances, some protective measures can be employed to add heat in the crop canopy and avert a crisis. During seasons when the ground surface is especially dry, the radiative cooling process is enhanced, thereby increasing the potential for frost at the surface.

Therefore, early forecast and warning of frost or freezing temperatures are of fundamental importance to farm operations in the early fall period. Once freezing temperatures have been recorded, then the next important threshold that warrants highlighting is the potential for a hard freeze, that is temperatures dropping to the mid 20's or lower.

Except for the obvious effects of freezes, fall temperature patterns are not as critical to farm operations as during other seasons. Growers expect to have adequate warmth retained in soils for easy germination and early establishment of winter wheat and other grasses. A progressive, stepwise decline in temperatures is desirable for hardening overwintering crops in preparation for the coming winter season. The secondary impact of freezing the ground surface can be a help or a hindrance depending on whether equipment access for harvest or for tillage is desired.

While warm weather can be of benefit for drying grain and establishing seedings, episodes of cooling in the fall are desirable for improving the color of apples and for maintaining the quality of sugar beets. The latter are stockpiled outdoors while awaiting processing, and warm sunny days can result in losses due to increasing rates of respiration, i.e., breakdown of sugar.

2. Relative Humidity

The normally low relative humidity associated with the mild days of early autumn is ideal for sustaining good drying rates in the field. The same considerations given to evaporative potential earlier in the growing season apply here as well, with some additional applications. Pan evaporation potential of a quarter inch may translate into reduction of corn moisture content of as much as one percentage point, when the corn is at its initial high moisture state. Typical corn moisture content varies from around 30 percent early in the fall to near 20 percent or lower later in the season. The target moisture level for storage is around 15 percent. Slightly lower figures apply to soybeans.

Forecast of maximum and minimum relative humidities provides the basis, along with temperature, sunshine, and wind conditions to estimate drying rates in the field. High relative humidity persisting for a long period of time, such as that with precipitation under a warm front, not only curtails effective drying in the field but raises the potential for spoilage of stored grain, produce, and tobacco.

Including dew points in agricultural weather forecasts provides additional information useful for drying of grain in storage. Some agriculturalists have found this element to be a more useful indicator of effective drying periods than the more highly variable quantity of relative humidity. The amount of heat applied in the drying process can be adjusted for a targeted level of relative humidity, with knowledge of dew points in the prevailing air mass.

3. Precipitation

As in all other seasons, forecast of the timing of fall precipitation is fundamental to the management of field operations. The quantitative forecast of precipitation is also important for a number of reasons.

A lengthy wet spell could set back harvest and lead to a reduction in the yield recovered from the field. Accurate forecast of a heavy precipitation event allows a producer to exercise the option of early harvest. Even if additional cost would be incurred by the need for more drying of grain in storage, the value of loss from grain stranded in the field may often be worse. After a certain point in time, the potential gain from field drying is outweighed by the risk of deteriorating harvest conditions.

Similar considerations apply to fruit and vegetable crops, though the cost is not in terms of drying but of balancing acceptable quality with the risk of loss by rotting or cosmetic damage from heavy precipitation. Severe thunderstorms, local flooding, or simply extended periods of wet vegetation, can have adverse impact on ripening produce.

Quantitative precipitation forecasts can be used by the producer to project trends in soil moisture and to track the progress of denigration of chemicals applied to soil earlier in the season. The residual effects of herbicides and fertilizers vary depending upon the amount of moisture moving through the topsoils in a given period of time. This knowledge may be crucial in years when seasonal precipitation has an unusual departure from normal.

4. Wind

Wind forecasts in autumn have the same application as those in spring and summer with respect to calculation of evaporative potential. In addition, winds above 30 mph can have damaging impact on crops nearing harvest. Grain stalks weakened by disease or soaked by fall rains will give way under strong winds. The increased lodging of stalks means a reduction in grain that is within the reach of harvest equipment. Tree fruit will also fall prematurely under the pressure of high winds.

There are spraying operations in the fall that depend on light winds for successful completion. Herbicides or desiccants are sometimes applied to kill weeds and foliage prior to harvest of soybeans, making the combining process more efficient. In fruit crops, chemicals such as ethereal are often applied to accelerate ripening. Of course, insecticide and fungicide treatments may also be appropriate, not only in the field but for preparation of storage facilities as well. Another autumn activity on the farm that requires close

attention to wind conditions is burning of some fields and fence rows. The danger of uncontrolled fire cannot be understated, and it stands as a constant reminder to forecasters of the need for accurate wind information.

Wind chill stress becomes serious in the fall with arrival of the first seasonal outbreaks of colder air. As temperatures begin to fall below the 40° threshold and are accompanied by strong winds, highlighting of wind chill temperatures puts livestock producers on alert.

5. Soil Temperatures

Soils retain considerable warmth through the early fall periods, especially where ample moisture is in place to further retard the rate of cooling. For this reason, the germination conditions for fall seedings remain good even beyond occurrences of freezing air temperatures. Normally, seedlings are established and hardened into dormancy by the prevailing air temperatures before the ground itself begins to freeze.

An important threshold that soil temperatures must pass through in the fall is 50°. Once the average soil temperatures remain consistently below this threshold, it becomes economically feasible to make nitrogen fertilizer applications. Above that threshold, a significant amount of the nitrogen undergoes chemical conversion and loses its effectiveness as a nutrient for spring crop growth.

The soil can also be thought of as the initial storage environment for crops such as potatoes, carrots, onions, and sugar beets. Soil temperatures give an indication of the corresponding produce temperatures and the consequent vulnerability to spoilage immediately following harvest.

Once soil temperatures drop below 40°, most growth is suspended, though slow development may continue in heat and other grasses at temperatures in the upper 30's. Four inch soil temperatures continue to be monitored through the winter season, since they provide an indication of the severity of the impact on overwintering crops from the cold air above. Though actual measurement of the lowest depth of a freeze may not be available, the four inch temperatures signal the movement of the freezing level above and below the root zone of dormant grasses.

V. WINTER SUMMARY

A. Key Factors of Winter Climatology

As the dwindling daylight hours reach their minimum in late December, the stage is usually set for the first harsh outbreaks of Arctic air that give the Midwest its preview of the winter season ahead. Though rain may still be the predominant form of precipitation over the lower Mississippi and Ohio River Valleys, snow becomes the more frequent sight over the region to the north, and the first significant accumulations begin to cling to northern fields where the ground has finally lost its residual fall warmth.

Two of the more commonly recognized storm systems that affect the Midwest during winter are known as the "Colorado Low" and the "Alberta Clipper." As the names of these low pressure centers imply, the former gains its identity as it moves into the Plains from the central Rockies, while the latter heads southeast from its origin over the Canadian Rockies. Low pressure systems approaching the Midwest from the southwest, such as the Colorado Low, often become intense as they move slowly toward the Great Lakes and Ohio River Valley, picking up Gulf moisture that will ultimately be dropped in a band of snowfall just north of the low center's path. The Alberta Clipper has less moisture available, and while its rapid movement through the Great Lakes region may produce brief snow squalls, the most striking feature of this storm variety is the rush of Arctic air that causes temperatures to plummet in its wake.

Whatever their origin, the snows of winter affect central U.S. fields in varying degrees from late October through early April. At the latitudes of the northern Great Lakes, continuous snow cover may span much of that time period. Further south, the bulk of the season snowfall is concentrated between late December and early March. Even within that time frame, it is rare for snow cover to remain continuous without occasional melting brought on by warm intervals.

The presence or absence of snow cover on the agricultural landscape is not only an aesthetic consideration. The insulating quality of snow cover can provide needed protection for winter wheat and forage fields from severe winter cold. The depth to which freezing temperatures descend in the soil is also dependent upon the thickness and duration of snow cover. A minimum cover of about two inches is desirable to blunt the direct impact of subzero temperatures on grasses beneath. Even that minimal protection will not prevent freezing temperatures from penetrating deeper into the ground layer. A simple freeze is not harmful to dormant grasses, but the alternation between freezing and thawing periods can cause heaving of the soil layer and disruption to the crop's root system. A protective snow cover will reduce this range of fluctuation as well as shielding the crop from extreme temperature minima.

Depending upon its timing and associated temperatures, winter precipitation may or may not contribute to soil moisture supplies. The water equivalent totals of precipitation are lower in winter than in other seasons and not as crucial to long term water balance. However, when substantial rains occur in December and sometimes in January before the ground has been frozen, soil moisture reserves often receive a boost. Later in the winter when the ground is normally frozen, most precipitation arrives in the form of snow and is retained at the surface. Unless subsequent melting is brought on rapidly or enhanced by heavy rainfall that causes accelerated runoff, the moisture from the snow cover also seeps into the soil. Furthermore, where thick snow cover has stayed in place during the coldest periods, the underlying layer of frozen soil will be thin enough to permit a complete thaw in a relatively short period of time. The earlier the thaw occurs, the greater the proportion of early spring rain that will be added to soils.

Temperature and precipitation patterns remain fundamentally important to agricultural operations in winter, just as in other seasons. Not only are

dormant crops and soil moisture supplies affected by winter weather, but the health of people and livestock is a perpetual concern under the stresses of the winter season.

B. Specific Agricultural Activities During December Through February

When wet weather dominates the fall period, harvest of corn, soybeans, or dry beans is often postponed until December with the expectation of freezing weather that will add strength to the ground for support of equipment. Normally harvest of summer crops is complete and winter wheat is well established by December, and once freezing temperatures become the rule attention is turned to the maintenance of grain and produce in storage.

Grain in storage bins must be aerated periodically to ensure an even distribution of grain temperatures and moisture within the bin and to minimize the difference in temperature between the grain inside and the air outside. The fans may be run initially to move heated air through the grain and reduce grain moisture content to its optimum storage level. Later, unheated outside air may be circulated through the grain to achieve an equilibrium between grain and air temperatures. The success of this process depends upon the relative humidity of the air, since unwanted moisture could be reintroduced into the bin if the air is too humid. Farm managers will continue to monitor conditions in storage through the winter season, taking advantage of seasonably cool and dry weather periods to aerate the bins.

Between the time when harvest is complete and when snow cover develops, there is usually an opportunity in December for tillage of ground intended for spring planting or for application of nitrogen fertilizers. This is accomplished once average soil temperatures have dropped below the 50° threshold, making the environment conducive to retention of the nitrogen. Field work comes to a halt in most areas by late December, though such tasks as manure spreading or work in woodlots may continue through the winter months. With the ground frozen, mobility across fields is not a problem unless heavy snow cover is present.

Exposure to harsh temperatures is the primary danger of winter, and livestock operations experience the most direct impact among all agricultural activities from the season's weather. Animals will spend at least part, if not all, of their time indoors during the winter, but changes in the outdoor temperature environment trigger corresponding management decisions regarding fuel consumption and ventilation in livestock buildings. Feed requirements also vary depending upon the need for animals to respond to external stress and maintain a stable metabolism. Since animals do not have access to pastures during this season, the task of livestock management becomes even more complex during winter, while other agricultural activities slacken.

C. Elements of the Forecast Relating to Agricultural Activity in the Winter

1. Temperature

Extreme minima and wide variability in temperature patterns present a challenge to the adaptability of both dormant crops and active livestock. The equivalent wind chill that accompanies winter temperatures aggravates the impact on animals and humans. Even in sheltered surroundings, adjustments are required in response to changes in the outside air in order to maintain a stable environment for animals and stored grain.

The transition period from fall to winter can be critical to plants. A normal step-by-step decline toward winter temperatures eases overwintering crops into dormancy, and enables them to better withstand the harshness of mid-winter. When subfreezing temperatures arrive earlier than normal, before plants have a chance to become "hardened," a crop may face the full force of winter in an already weakened condition.

An analogous situation occurs with livestock. Animals go through a conditioning period in the fall as they develop thicker coats for protection against the colder weather ahead. If winter temperatures arrive prematurely, especially if coupled with precipitation and strong winds, exposed animals can suffer acute stress. Even when animals have become gradually acclimated by a normal transition season, exposure stress remains a concern throughout the winter. Livestock producers must restrict the amount of time animals are outdoors and ensure that adequate shelter is readily available.

Though little can be done by growers to shield dormant crops from winter extremes, accurate forecasts of temperature, wind, and precipitation can give livestock producers the lead time needed to take precautions. Animals may need to be moved to shelter or, if already in confinement, may need to have heat, water, feed, or ventilation adjusted.

As an example, an adult cow with its full winter coat can withstand temperatures as low as 18°F without feeling chilled. In the fall before such a coat has developed the same animal can be chilled at temperatures below 45° (the same critical temperature for a one week old calf). If a quarter inch or more of liquid precipitation (enough to break down the insulating benefit of the animal's coat) is added to the formula the threshold for stress is as high as 59°.

A fundamental short term adjustment mechanism is the animal's own production of heat. In order to respond to increased cold stress, livestock need an increase in rations to fuel their metabolism and maintain a safe body temperature. Animals and humans alike undergo continual adjustment, both voluntary and involuntary, in order to achieve temperature equilibrium between their bodies and the surrounding environment.

2. Wind

As already mentioned, wind in combination with low temperatures elevates the chilling potential and resulting hazard to livestock and humans. Cold dry winds can also cause stress on dormant crops by removing moisture directly from the vegetation. If snow cover is absent, then excessive drying of the soil layer and root systems also may occur. Finally, wind erosion may cause displacement of the exposed soil itself.

3. Precipitation

Winter precipitation may arrive in liquid, freezing, or frozen forms. This moisture may or may not contribute to soil moisture reserves. A more important consideration is the thickness and duration of snow cover that develops during the season. Although liquid equivalent precipitation during the December through February period is relatively light, its associated snow cover is valued for its protective quality. The hazards of ice and snow evident in the community at large are compounded in their impact on farm operations, so definitive forecasts are the basis for planning livestock movements and other necessary chores that could result in dangerous exposure.

4. Sunshine

Though not as important as in the warm season when crops are flourishing, knowledge of the amount of sunshine expected in a given day has gained increasing application with respect to both passive and active solar energy systems. On the farm this energy source may be employed for drying of grain as well as direct heating of buildings or water. During the late winter period, increasing sunshine becomes important to the operation of greenhouses where seedlings are started for spring transplants.

5. Relative Humidity

In combination with temperature, relative humidity information is important for the aforementioned grain drying applications. Livestock managers must also pay close attention to the relative humidity within livestock buildings to avoid triggering respiratory ailments from either extreme dryness or excess moisture.

VI. DISCUSSION

Local climatology provides the backdrop for agricultural activity and defines the limits of crop production in any given region. The growing season varies in length across the Midwest, spanning late March through early November at the southern edge of the region while being compressed between mid-May and mid-September at the colder northern latitudes. A wide variety of agricultural enterprises are carried out along this climatic spectrum, each of which is vulnerable to changes in day to day weather patterns. Outside of the crop production season, the management of livestock operations continues the year around with its unique problems related to weather stress.

In forecasting the elements of weather for the benefit of agriculture, the meteorologist must be aware of the on-going development of crops and the corresponding changes in their critical needs as each season progresses. Temperatures or precipitation that depart significantly from the normal will trigger responses in crops or livestock that may be adverse, depending upon initial conditions. Other elements, such as relative humidity, wind speed and direction, and the amount of sunshine available are related factors that determine the degree of moisture consumption, susceptibility to disease, and resulting growth potential. The detailed weather forecast comprised of these elements gives a producer the complete picture necessary to make decisions regarding the appropriate timing and related impact of many farm operations, such as spraying of chemicals, use of frost protection systems, or irrigation.

As temperature moves through its seasonal cycles, the impact on crops and livestock varies. For example, dormant fruit crops and winter wheat can endure temperatures near zero during the cold season, but once those crops have been drawn out of dormancy by early spring warmth, they become increasingly vulnerable to damage if temperatures backslide too far below normal.

The urgency of a frost/freeze advisory in the spring depends upon both the deviation from normal of forecast temperatures and the stage of development of crops in that particular season. Most buds can withstand temperatures in the mid 20s as long as they have not yet opened to reveal green tissue. When fully opened, a temperature simply at 32 degrees is potentially fatal.

At the other end of the temperature scale, extreme heat during the growing season creates stress of another sort on all growing crops. Above normal temperatures, especially when coupled with low relative humidities, may raise the potential rate of evapo-transpiration beyond a plant's capability to draw from available supplies. When irrigation is available, rates of watering can be adjusted according to forecast temperature and humidity trends. However, at extreme temperatures in the mid 90s or higher there can be adverse effects on plants independent of moisture considerations. This is particularly true during a crop's reproductive phases.

Livestock production can also be impaired at both ends of the temperature spectrum. Winter cold in combination with wind or precipitation can be fatal to animals exposed to the elements. Even those in shelter can suffer indirectly due to respiratory ailments brought on by prolonged exposure to extremes of humidity. In the summer, high temperatures become equally dangerous.

Meat, egg, and milk production decline as temperatures rise to the point of interfering with the animal's maintenance of a stable body temperature. The more energy that is devoted to cooling the body, the less that is available to support production for market. Furthermore, the transportation of animals to market poses an often fatal hazard when respiratory systems cannot cope with a stifling combination of heat and humidity that arises in confinement.

In general, the normal range in seasonal temperatures that allows for crop and livestock production across the Midwest with routine management by producers is from winter lows in the teens to summer highs in the lower 90s. Outside of this temperature range, increasing amounts of energy must be expended in order to limit the adverse impact on crop and animal health. Low temperatures of zero or lower in the winter and highs of mid 90s or higher in the summer stretch the limits of tolerance in their respective seasons.

Precipitation is the other fundamental element of weather that, within its normal range, sustains agriculture but at its high and low extremes may contribute to significant losses. From a seasonal perspective, the peak rainfall periods of spring and late fall across the corn belt provide the bulk of soil moisture reserves. During the growing season, crops must draw on these reserves in addition to consuming the moisture provided by summer rains. Winter precipitation in the Midwest is not as important for soil moisture reserves or crop sustenance, but when in the form of snow it provides an important protective blanket above dormant winter grains such as wheat.

On a day to day basis, precipitation events affect the progress of all field and orchard activities, as well as the scheduling of irrigation. Precipitation amounts of a half inch or more impose delays on movement of equipment onto fields that may range from a couple of days to more than a week, depending upon initial field conditions and subsequent drying rates. Peak moisture consumption rates at the height of the growing season average near a quarter inch per day, so a light to moderate rainfall may preempt irrigation for one to three days. The duration of rainfall and the consequent length of vegetative wetness is also a determinant of the extent of plant disease infections. Mild temperatures in the upper 60s and 70s in combination with lengthy wetting periods of more than twelve hours are responsible for a variety of fungus infections in field and orchard crops.

The interplay of temperature and precipitation trends is often as important as the individual elements themselves in determining impact on growth environments. Related factors of relative humidity, wind, and sunshine further influence the capacity of those environments to capture or retain heat and moisture. Ultimately, it is the natural physical process of establishing equilibrium between crops or livestock and the surrounding atmosphere that determines the degree of profitability of agriculture. Forecasters have the means to affect decision making at every level of agricultural enterprise by producing accurate and timely descriptions of changes in these basic weather elements.

VII. ACKNOWLEDGEMENT

The author wishes to acknowledge James A. Daniels, fellow agricultural meteorologist at the Midwest Agricultural Weather Service Center, for his contribution in consolidating information on livestock cold weather stress.

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