ON THE IMPACT OF CORN AND SOYBEANS TO THE LOCAL MOISTURE BUDGET IN IOWA

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Abstract

Land use in general, and agricultural crops in Iowa specifically, can under certain circumstances account for a significant component of the local moisture budget. Numerical modeling studies have shown that land use can impact the development of convection, and that subtle changes in dew point can be the difference between thunderstorms occurring or not.

Corn and soybean acreage each comprise one-third of the total land area in Iowa during the growing season. In July and August, atmospheric demand (i.e., the combination of atmospheric elements such as temperature, wind, relative humidity, etc. which determine the amount of water a crop uses) for crop evapotranspiration is maximized and the crops are at their peak water-using stage. Assuming non-advective conditions and a well-watered crop, it is shown that corn and soybeans can increase local dew points up to several degrees, depending on the height of the boundary layer and the amount of evapotranspiration. The approach developed in this study can be applied to other locations given a local knowledge of land use, crop/vegetation water use, and agronomic practices (e.g., irrigation usage).

1. Introduction

It is not uncommon for operational meteorologists to discuss the impact of land use in general, and corn in the Corn Belt specifically (Fig. 1), on the local moisture budget. In fact, a recent study by Cheresnick and Basara (2005) cited local moisture from evapotranspiration (ET) vs. moisture advected from the Gulf of Mexico as a factor in the severe weather episode of 11 June 2001 in southern Minnesota. Numerous modeling studies (e.g., Pielke et al. 1999; Rozoff et al. 2003, etc.) have shown that land use can impact convective development. The impact of land use is becoming a more important consideration in the forecast process for NOAA/National Weather Service (NWS) meteorologists producing high time and space resolution forecast grids for a variety of parameters, and can certainly be a factor for any forecaster providing site-specific, high detail forecasts.

For areas where land use is dominated by agriculture, it follows that an understanding of crop water use and seasonal crop growth changes could be important, at times, in the forecast process. While scientists in the agricultural community have conducted extensive research to quantify crop water use, little of this work has translated into understanding and practical application in the operational meteorological community, exclusive of some operational numerical models where proxy estimates of land use can be incorporated based on satellite-observed greenness values (Kurkowski et al. 2003).

In Iowa, agriculture dominates land use across the state. The main crops are corn and soybeans, *each* comprising approximately one-third of the total land area in the state (National Agricultural Statistics Service 2005). Pastures comprise another 10% of the land area, while woodlands, farm lots, and developed areas comprise most of the remainder.

Crop water use can be evaluated using a general form of the surface energy budget (Rosenberg et al. 1983)

$$R_n = S + LE + H \qquad (1)$$

where the total net radiation at the earth's surface (R_n) is partitioned into the sensible heat term (S), the latent heat term (LE), and the soil heat flux term (H). The latent heat term represents the energy used in the process of ET. ET is defined as evaporation of free surface water and soil water, plus transpiration from vegetation. Transpiration is the evaporation of water which has already passed through the plant (Rosenberg et al. 1983). Several factors influence ET including the availability of both free and soil water, soil type, solar radiation (R_n), temperature, wind, relative humidity, and vegetation type and stage of growth. This paper will focus on how the last two factors, vegetation type and stage of growth, are a variable part of the local moisture budget in Iowa. The approach presented here can be applied to other agricultural and non-agricultural regions of the country to estimate the impact of local vegetation in the water budget under non-advective conditions.

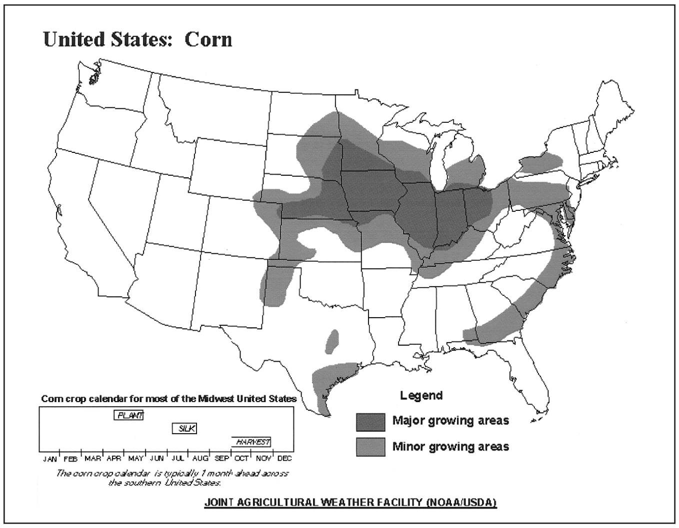

Fig. 1. The Corn Belt is indicated by the darker shaded area stretching from Nebraska and South Dakota on the west to Ohio on the east. Figure courtesy of the NOAA/USDA Joint Agricultural Weather Facility.

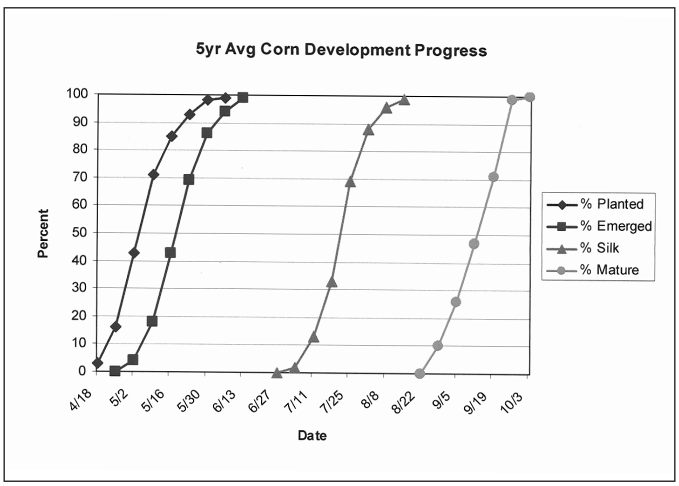

Fig. 2. Corn development in Iowa, 5-year average for 2000-2004 (NASS 2005).

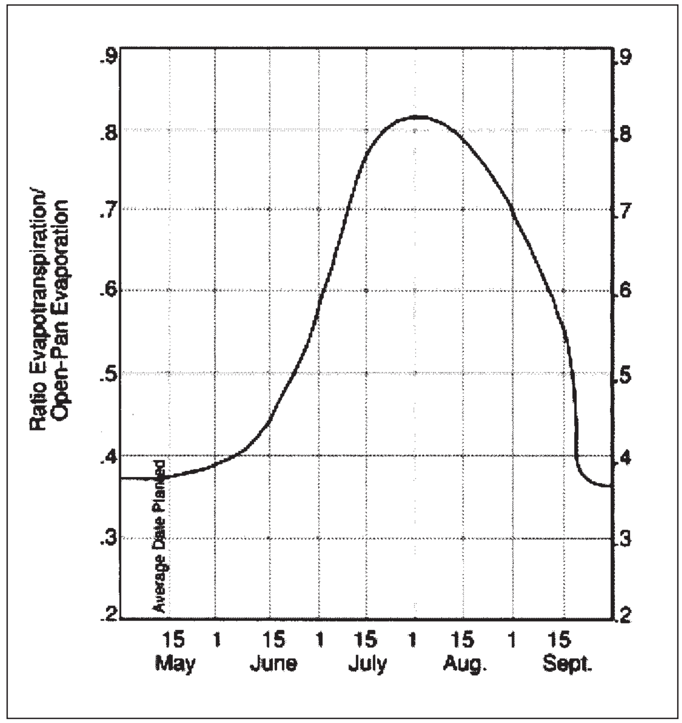

Fig. 3. The ratio of corn evapotranspiration to open-pan evaporation throughout the growing season in Iowa (from Denmead and Shaw 1959).

2. Crop Water Use

Crop type and stage of growth are the two agronomic factors that have the greatest impact on crop water use. In subsequent discussions, the assumption is made that soil moisture is NOT a limiting factor in crop water use, i.e., that evaporation and transpiration are not limited by a lack of soil moisture.

a. Corn

In Iowa, corn planting typically begins in late April and continues through May (Fig. 2). Crop emergence depends on soil and air temperatures plus soil moisture, and usually occurs in a 1-2 week period following planting. ET use during this period and the subsequent few weeks is small and mostly results from soil water evaporation, since the crop has either not yet emerged or is small in leaf area available for transpiration.

During July, the crop reaches the silk stage during which water use is at its peak (Fig. 3). The crop canopy has filled in at this point (i.e., covers all bare soil) resulting in more leaf area to facilitate ET. In Fig. 3, crop water use is expressed as a proportion of open pan evaporation. Note the rapid increase in water use rate from late June to early July. At its peak, crop water use averages about 0.30 in. per day or 80% of open pan evaporation in Iowa (Denmead and Shaw 1959; Shaw 1976). This value can vary depending on climatic factors. For example, water use during this period would be higher in the western-most portions of the Corn Belt since atmospheric demand (higher solar radiation/less cloudiness and lower humidity levels) is higher (Neild and Newman 1986).

By late August as the crop matures, water use begins to decline rapidly. Thus, ET in corn is at a maximum for only a fraction of the total growing season, and in Iowa, that period is July through mid-August.

b. Soybeans

Soybean water use parallels corn except that the peak is displaced a few weeks later in the growing season. In Iowa, soybean planting occurs after corn in May through early June (Fig. 4). Soybean water use begins to increase rapidly in mid-July as the plant enters the bloom or flowering stage and the canopy has filled in (Fig. 5) (Shaw and Laing 1966; Van Doren and Reicosky 1987). Water use continues at a high rate through September when the

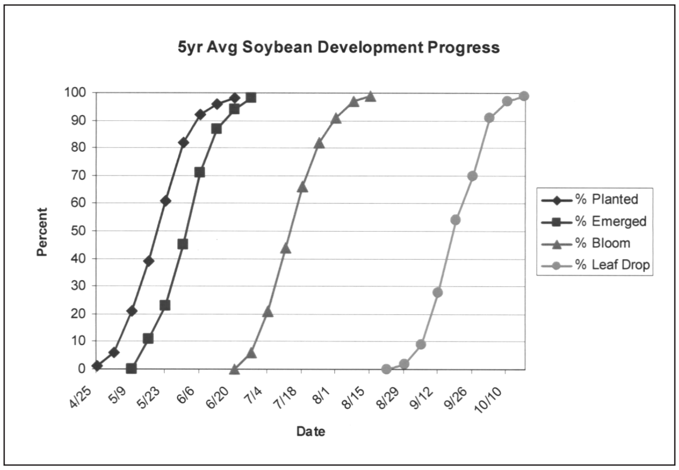

Fig. 4. Soybean development in Iowa, 5-year average for 2000-2004 (NASS 2005).

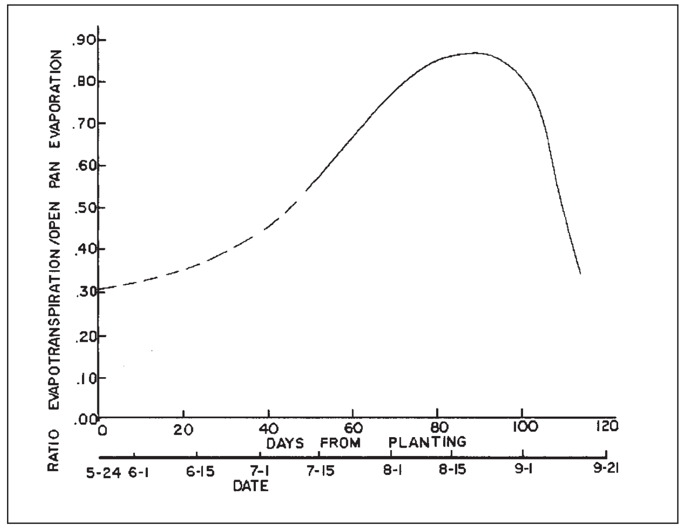

Fig. 5. The ratio of soybean evapotranspiration to open pan evaporation throughout the growing season in Iowa (from Shaw and Laing 1966).

crop begins to mature and drop its leaves. Peak water use is slightly higher than corn, roughly 0.33 in per day or about 85% of open pan evaporation.

c. Pasture

Pasture water use is complicated by the fact that the hay is typically cut twice or more per season, and the loss in leaf area from the cutting limits water use (Fig. 6). Note that water use increases to the maximum rate much earlier in the season than either corn or soybeans. This occurs because pastures start the growing season with a well-developed root system, and above ground growth begins before corn and soybeans. Similar to corn, peak water use values average about 80% of open pan evaporation, but a significant decrease in water use occurs after the hay is cut. Subsequently, water use begins to increase again as the crop grows toward full ground cover before the next cutting.

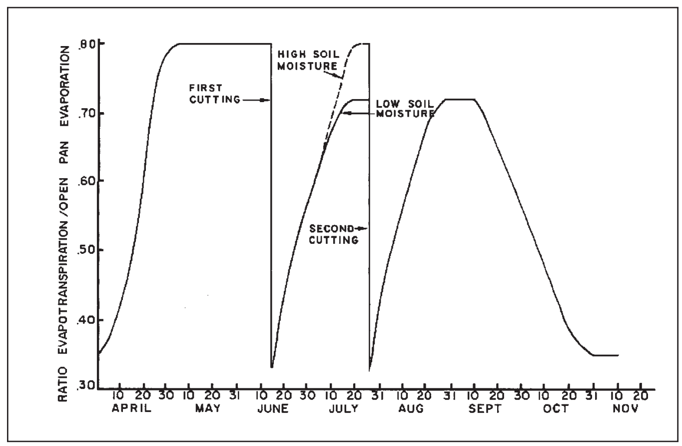

Fig. 6. The ratio of pasture evapotranspiration to open pan evaporation throughout the growing season in Iowa (from Shaw 1964).

d. Native prairie

The growing season of the native tallgrass prairie in Iowa is longer than the growing season for corn and soybeans and more similar to pasture since, like pasture, in general root systems are already established as soon as growth can begin in the spring. Studies by Knapp et al. (2001) and Hutchinson et al. (2001) noted that water use totaled over the entire growing season for a well-irrigated tall grass prairie is roughly equal to that of corn and soybeans. Since both prairie and corn and soybeans use about the same amount of water in an entire growing season, *but corn and soybeans concentrate that use in a shorter period of time,* one can logically conclude that the local contribution to the moisture budget has changed due to human factors. Thus during the months of July and August, corn and soybeans add more moisture to the local environment when well watered than native tallgrass prairie growing under similar conditions. Since this would result in locally increased dew points, there is potential for these effects to also impact convective development, human comfort during periods of hot temperatures

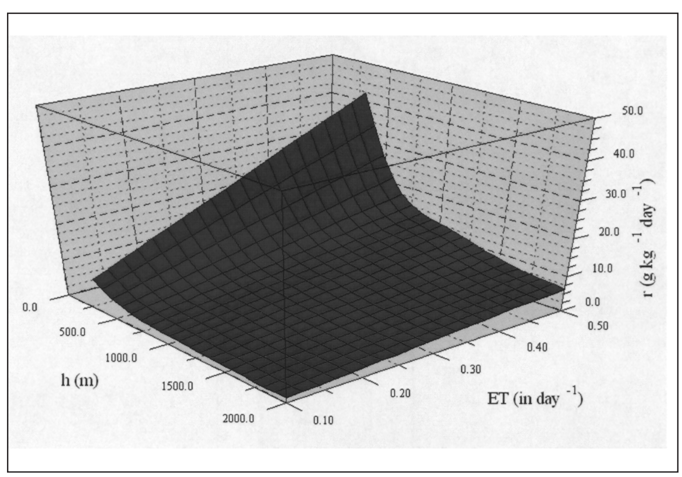

Fig 7. The variation of mixing ratio tendency (***r*** ; g kg^{-1} day^{-1}) as a function of evapotranspiration (***ET*** ; inches day^{-1}) and planetary boundary layer height (***h*** ; meters). Mixing ratio values maximize under high ET values and low PBL heights, and are minimized under low ET values and high PBL heights.

Table 1. Daily liberated moisture (g kg^{-1} day^{-1}) as a function of evapotranspiration (ET) and the depth of the planetary boundary layer (h).

h \ ***ET***	0.10"	0.25"	0.33"	0.50
300 m	8.5	21.2	27.9	42.3
500 m	5.1	12.7	16.8	25.4
1000 m	2.5	6.4	8.4	12.7
1500 m	1.7	4.2	5.6	8.5
2000 m	1.3	3.2	4.2	6.4

(Sparks et al., 2002 and Changnon et al., 2003), and even fog development.

3. Operational Considerations

In an effort to understand the impact of evapotranspiration (ET) on local dew point trends, simple calculations were made of changes in the mixing ratio (***r***) (see Appendix for details). In each calculation, several assumptions were made: 1) horizontal advection is negligible; 2) the ET rate is distributed evenly over 12 (daylight) hours; and, 3) vertical mixing of moisture occurs rapidly throughout the depth (***h***) of the planetary boundary layer (PBL). The total contribution of ET to ***r*** is shown in Table 1. Notice the reduced impact of ET on dew points as ***h*** increases. This dependence of mixing ratio tendency on ET and ***h*** may be visualized in Fig. 7.

Following these examples, 0.10 in. (0.25 cm) of ET from 1 m^2 of surface results in 2.5 kg of liberated moisture. Distributed linearly (using an air parcel density of 1 kg m^{-3}) over ***h*** of 1000 m results in an increase of 2.5 g kg^{-1} in the **r** of a typical parcel over the span of 12 hours. This results in a mean hourly increase of 0.2 g kg^{-1} hr^{-1}. At 1000 mb and a dew point of 70°F (21.1°C), this change amounts to an increase of 4°F (2.2°C) in the dew point temperature over 12 hours.

Of the assumptions stated previously, the most noticeably violated of these is that of even ET distribution over 12 hours. While the 12 sunlit hours allow transpiration, evaporation can occur anytime. Yet, with relative humidity typically highest overnight, evaporation is effectively limited during the 12 nighttime hours. Moreover, ET is a function of temperature, humidity, and solar radiation (implying impact from cloud cover as well as the diurnal cycle), among others (Rosenberg et al. 1983). The assumption of negligible horizontal advection presumes that the ET is occurring uniformly over a large homogenous area (e.g., similar vegetation type), which may or may not be valid depending on local growing patterns, crop rotations, land use, and the like. Lastly, the assumption of a well-mixed PBL suggests wind profile with significant wind speed changes with height. On days with weak mixing and or low ***h***, the distribution will not occur over as deep a layer and will confine moisture to a smaller, near-surface volume. Should such processes occur over several days, it should be noted that some of the moisture would be recycled as dewfall during the night then re-evaporated during the day.

4. Summary

Land surface effects are known to, at times, have a pronounced impact on local sensible weather. In particular, agricultural crops whether irrigated or not, can be an important component of the local moisture budget. We have explored the impact that corn and soybeans can have on local dew points in Iowa when the crop is well watered during non-advective conditions, and have developed an approach for assessing crop effects on the local moisture budget that can be applied to other regions given those two key assumptions. First, one needs knowledge of the land use patterns in the area of interest (e.g., how much of the area is native vegetation, urban, agricultural, etc). Second, one must understand soil types and be able to monitor soil moisture status to determine if water is available for ET. Third, one must understand patterns of seasonal water use of crops, forests and/or native vegetation, and whether and when irrigation is used (e.g., Pennington and Wolf 1989). Finally, combine the knowledge of those elements to evaluate the impact on dew point temperature, paying particular attention to the assumptions of well-watered crops/vegetation and non-advective conditions.

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Appendix

Simple calculations are made that attempt to translate a measured value of evapotranspiration (ET) into a change in the mixing ratio ($\boldsymbol{r}$) and thus a change in the local dew point temperature (T_d). In each calculation, several assumptions were made: 1) horizontal advection is negligible; 2) the ET rate is distributed evenly over 12 (daylight) hours; 3) vertical mixing of moisture occurs rapidly throughout the depth ($\boldsymbol{h}$) of the planetary boundary layer (PBL), and; 4) density variation over the depth of the PBL is negligible. Note that condition (1) above does not preclude the presence of a wind, merely that horizontal *advection* of moisture is negligible.

Consider the case of 0.33 in. (0.84 cm) of ET yielded from 1 m^2 of surface area. Using the well-known physical relationship whereby

$$1 \text{ cm}^3 \text{ H}_2\text{O} = 1 \text{ g H}_2\text{O} \qquad \text{(A1)}$$

we may multiply the ET (often posed as a depth) by the area from which the moisture is assumed to come

$$0.84 \text{ cm x } 100 \text{ cm x } 100 \text{ cm} \qquad \text{(A2)}$$

and arrive at a volume of moisture of 8400 cm^3 or simply 8.4 kg of liberated moisture. Recall from assumption (2) above that this moisture is distributed evenly in time over 12 hours. Not all of the moisture is liberated at once.

If we assume a PBL of depth $\boldsymbol{h}$ = 1000 m with constant density throughout and use an initial parcel density of 1 kg m^{-3}, then we may think of this scenario as a tower of 1000 1-m^{-3} cubes stacked one on top of the other, yielding a total volume of 1000 m^{-3}. With a uniform, linear distribution of the moisture, 8.4 kg, over the total volume, 1000 m^{-3}, each of the 1000 "cubes" having an initial mass of 1 kg will receive

$$8.4 \text{ kg} / 1000 \text{ m}^3 = 8.4 \text{ kg} / 1000 \text{ kg} = \qquad \text{(A3)}$$
$$8400 \text{ g} / 1000 \text{ kg} = 8.4 \text{ g} / \text{kg(A3)}$$

or an added 8.4 g of moisture in each of the 1 kg parcels by the end of the 12 hour period.

One may then calculate the corresponding increase in the T_d, or simply consult a thermodynamic diagram to assess the corresponding change in T_d. For a pressure of 1000 mb and an initial T_d of 70°F (and thus a mixing ratio of 16.0 g kg^{-1}), a change in mixing ratio of 8.4 g kg^{-1} corresponds to a T_d change of ~12°F, or a final dew point of ~82°F. While this may seem to be an extreme result, one must recognize that, in addition to the preliminary assumptions, this example deals with a high ET rate and a relatively shallow PBL.