EFFECTS OF ADDED SUMMER RAINFALL ON THE HYDROLOGIC CYCLE OF MIDWESTERN WATERSHEDS

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ABSTRACT: The effects of added summer rainfall on agricultural areas in Illinois and the Midwest were investigated by using a quasi-distributed-parameter watershed model. Increases in summer convective rainfall during July-August were simulated and used in the model to describe the changes in soil moisture, crop water use, shallow ground water, and streamflow conditions which could potentially result from precipitation augmentation practices. Two periods, representing very dry and very wet conditions, were used in the simulations with 10% to 25% precipitation increases. Results suggest that the greatest proportion of additional summer rainfall eventually percolates into ground water, and that less than 25% percent of the precipitation increase is used by the crops. Simulated increases in summer rainfall offer limited utility in reducing crop water stress because the rainfall events do not always coincide with the period of greatest crop water need. Methods, such as irrigation, which provide additional water at a specified time and amount can produce significant benefits to the plants.

1. INTRODUCTION

In order to understand the impacts of precipitation augmentation on agricultural productivity and freshwater resources, it is necessary to evaluate these changes on soil infiltration and moisture, shallow ground-water movement, and streamflow. The moisture brought by increases in rainfall (or other sources such as irrigation) could potentially be distributed into one of four hydrologic processes: 1) runoff into a stream, 2) seepage into ground water, 3) evaporation into the atmosphere, and 4) abstraction from the soil into the plant for eventual transpiration into the atmosphere. Only the last of these processes is of primary benefit to the plant.

A quasi-distributed-parameter model was developed to simulate soil moisture and baseflow conditions for agricultural areas in Illinois and the Midwest. A model labeled the PACE Watershed MODEL (PWM) was designed and developed over two years with components sensitive to water movement processes. This provided the potential for evaluating paths for increased amounts of rainfall, and thus offer some possible answers as to the usability of potential augmentation (Durgunoglu *et al.*, 1987). The PWM was calibrated for the Kaskaskia Ditch watershed (at Bondville in central Illinois) by using soil moisture and streamflow records for the period of 1981–1985. The model was validated by using streamflow records for two additional periods, 1951–1954 and 1972–1975. These two periods embrace significantly dry and wet periods of record for the watershed.

This paper describes simulation studies performed for evaluating the hydrologic effects of precipitation augmentation for a watershed in central Illinois and special simulation studies performed for analyzing the effects of using early season rain augmentation and irrigation on crop stress reduction. Several levels of precipitation increase are evaluated to determine the overall benefit to agriculture in terms of crop water status. Results describe changes in soil moisture, crop water use, shallow ground water, and streamflow conditions over periods of years selected to present both wet and dry climatic conditions in the watershed. Included is a brief analysis of the characteristics in crop water supply needed to improve the crop condition.

2. PRECIPITATION AUGMENTATION SIMULATIONS

Precipitation augmentation was simulated for two historical periods, 1951–1954 and 1972–1975. These periods were selected as examples of a very dry and very wet set of years, in central Illinois, respectively. The model was tested with the actual daily rainfall in these eight years, and then precipitation was increased in the months of July and August for days on which rainfall had been recorded. By limiting the rainfall increases to days which historically had experienced precipitation, the original distribution of rain-producing storms is maintained. Further, no evidence exists to suggest that the total number of days with rain in Midwestern convective rain conditions could be increased (Changnon and Semonin, 1975; Changnon and Hsu, 1981).

Four levels of precipitation increase were analyzed:

1. All rain-producing clouds are seeded, causing a 10% increase in all July-August rainfall;
2. All rain-producing clouds are seeded, causing a 25% increase in all July-August rainfall;
3. All rain-producing clouds are seeded (July-August), but causing a 25% increase only for storms which otherwise would have daily precipitation totals in the range of 0.1 to 1.0 inches; and
4. Only half of the rain-producing clouds are seeded (July-August), causing a 25% increase in rainfall for those storm events.

The range of selected increases (10 to 25%) in daily rain events is in agreement with levels used in other regions with convective rainfall regime (Weather Modification Advisory Board, 1978). The selection of increases only in 0.1- to 1.0-inch daily rain was used to match levels believed most useful to agricultural production and soil preservation (Changnon, 1981). The test of increases on 50% of the days was to measure the effect of intermittent modification.

The additional rainfall associated with each of the levels of augmentation will either 1) run off into the stream during the rainfall event, 2) evaporate from the surface or shallow layers of soil, 3) infiltrate into the soil and later be used by plants for transpiration, or 4) remain in the soil and eventually percolate down to the ground-water table. The processes simulated are listed as follows:

P = Total Precipitation

ET = Total Evapotranspiration

TR = Total Transpiration

SM_{min} = Minimum Available Soil Moisture for the Year

ΔSM = Change in the Soil Moisture for the Year

Seep = Total Deep Percolation from Soil Moisture Component

QR = Total Surface Runoff from Soil Moisture Component

Σ(Seep + QR) = Weighted Total of (Seep + QR) for All Soil Types

Q_{est} = Total Streamflow Estimate from Ground Water Component

Q_{obs} = Total Observed Streamflow

For each of the simulated levels of precipitation augmentation, a summary was developed describing the distribution of the additional precipitation among the various hydrologic processes (Durgunoglu *et al.*, 1988). Examples of these are provided in tables 1 and 2 for two years of simulation, and for both Flanagan and Drummer soils, the two soils in the watershed and typical of prairie soils of the Corn Belt. Also included in these tables are the simulated values of total streamflow for the entire watershed (the Kaskaskia Ditch).

The increase in precipitation was distributed among four variables, as described in the equation:

$$\Delta P = \Delta ET + \Delta Seep + \Delta QR + \Delta(\Delta SM) \qquad (1)$$

where Δ represents the amount of change in the variables, as defined earlier, from conditions with no augmentation. The variable of greatest concern in tables 1 and 2 is TR, the total transpiration for the year. Any increases in TR represent increased crop water use, which signifies a reduction in crop water stress. All values of transpiration are included in the total evapotranspiration value (ET). The change in the minimum soil moisture, SM_{min}, is also significant in that it represents the extent of soil moisture depletion during the growing season. The change in soil moisture for the year, ΔSM, will ordinarily be greater under augmented conditions, but may fluctuate from year to year since this term depends on conditions during the preceding year.

In the summary of total flows for the watershed, the term Σ (Seep + QR) is the weighted total of seepage and runoff for the entire watershed. Over a long period of time, this term will be equal to the estimated runoff of the watershed, Q_{est}. However, because of the effect of ground-water storage, these two terms will be slightly different for any one year. For example, during the drought years (1952–1954, see table 1) the estimated discharge is higher than Σ (Seep + QR) because of the contribution of ground-water storage to the stream.

The simulated conditions suggest that during the wetter years (1972–1975, see table 2), a great percentage of the additional rainfall will run off during storms or percolate down into ground water. For example, in 1973 the estimated increase in rainfall for the largest level of augmentation (25% for all rainfall) is 3.06 inches (table 2). Of this amount, the simulation for the Flanagan soil estimates that a total of 2.97 inches will either run off during the storm events (1.20 inches) or percolate into ground water (1.77 inches). The simulated increase in total streamflow for the watershed in 1973 is 2.86 inches. Because storm runoff is greater, potential increases in the severity of flood events should be a consideration when seeding clouds under wet-soil conditions. Virtually none of the precipitation increase is used by the crops (variable TR), and it is possible that excessively high levels of soil moisture could have a detrimental effect by inhibiting crop growth. Research has shown that overly wet summer conditions in Illinois decrease corn and soybean yields (Huff and Changnon, 1972).

For the dryer years of 1951–1954, the simulated increases in precipitation appear to be more evenly used among the various hydrologic processes. During these years, the average annual increase in summer precipitation (given a 25% level of augmentation) is 1.58 inches. However, the maximum increase in crop transpiration during any of these years is only 0.36 inches for Flanagan soil and 0.21 inches for Drummer soil, both in 1952 (table 1). A majority of the increases in precipitation appear to stay in the soil, unused by the plants, eventually to enter the ground water through percolation (the "Seep" variable).

The average distribution of the additional precipitation into the various hydrologic processes in the dry years is presented in table 3. As noted, most of the additional water eventually percolates into ground water. Little of the precipitation increase tends to be used by the crop. This is likely a result of 1) the limited amount of additional rainfall occurring during any one storm, and 2) the distribution of rainfall-producing storms within these dry years. This relationship between distribution of storms and crop water use is further examined in the following section.

3. OTHER SIMULATION TESTS

In order to study and better understand the apparently limited effect of precipitation increases on the amount of simulated crop transpiration, two other types of water increases were simulated in the model. The first case examined a scenario where precipitation augmentation is initiated earlier in the year (during the month of June) in order to increase the general soil-moisture level of the soil. The second case examined the effects of large water applications, potentially available through irrigation, on simulated crop water use. The soil-moisture component was used to simulate these cases for Flanagan soils for the three driest years (1953, 1954, and 1983). Calculations were done for the 8 test years (1951–54, 1972–75) and for 5 recent years.

A crop stress index was defined for use in describing the effect of soil moisture and crop water use on crop development. The crop stress value for any one day is defined as the fractional amount of potential crop growth that is suppressed because of the lack of moisture available to the plant. If, on any one day, the crop is under severe stress and no crop growth occurs, a unit value of crop stress is recorded. Severe crop stress is assumed to occur whenever actual transpiration (as limited by soil moisture) is less than 50% of the potential transpiration (Saxton *et al.*, 1984). Partial stress is assumed to

Table 1. Summary of Water Volumes Used in the Hydrologic Processes and Precipitation Augmentation for 1952, a Dry Year.

FLANAGAN SOIL (1952)

Process	Simulation Condition 0	1	2	3	4
P	33.86 (0.00)	34.35 (0.49)	35.07 (1.21)	34.70 (0.84)	34.28 (0.42)
ET	27.19 (0.00)	27.44 (0.25)	27.73 (0.54)	27.63 (0.44)	27.41 (0.22)
TR	15.54 (0.00)	15.70 (0.16)	15.90 (0.36)	15.86 (0.32)	15.70 (0.16)
SM_{min}	12.94 (0.00)	13.20 (0.26)	13.59 (0.65)	13.36 (0.42)	13.15 (0.21)
ΔSM	-2.83 (0.00)	-2.62 (0.21)	-2.33 (0.50)	-2.50 (0.33)	-2.67 (0.16)
Seep	8.41 (0.00)	8.42 (0.01)	8.47 (0.06)	8.44 (0.03)	8.42 (0.01)
QR	1.07 (0.00)	1.09 (0.02)	1.18 (0.11)	1.11 (0.04)	1.09 (0.02)
Seep + QR	9.48 (0.00)	9.51 (0.03)	9.65 (0.17)	9.55 (0.07)	9.51 (0.03)

DRUMMER SOIL (1952)

Process	Simulation Condition 0	1	2	3	4
P	33.86 (0.00)	34.35 (0.49)	35.07 (1.21)	34.70 (0.84)	34.28 (0.42)
ET	25.22 (0.00)	25.34 (0.12)	25.46 (0.24)	25.44 (0.22)	25.34 (0.12)
TR	15.59 (0.00)	15.69 (0.10)	15.80 (0.21)	15.78 (0.19)	15.70 (0.11)
SM_{min}	11.36 (0.00)	11.58 (0.22)	11.91 (0.55)	11.72 (0.36)	11.55 (0.19)
ΔSM	-0.01 (0.00)	0.02 (0.03)	0.02 (0.03)	0.02 (0.03)	0.02 (0.03)
Seep	6.90 (0.00)	7.16 (0.26)	7.63 (0.73)	7.38 (0.48)	7.12 (0.22)
QR	1.67 (0.00)	1.74 (0.07)	1.88 (0.21)	1.77 (0.10)	1.72 (0.05)
Seep + QR	8.57 (0.00)	8.90 (0.33)	9.51 (0.94)	9.15 (0.58)	8.84 (0.27)

TOTAL FLOWS AT BONDVILLE (1952)

Process	Simulation Condition 0	1	2	3	4
Σ(Seep + QR)	9.04 (0.00)	9.22 (0.18)	9.58 (0.54)	9.36 (0.32)	9.19 (0.15)
Q_{est}	12.24 (0.00)	12.57 (0.33)	12.85 (0.61)	12.63 (0.39)	12.50 (0.26)
Q_{obs}	10.65 (0.00)				

Condition:

0 = No cloud seeding is done (natural condition);
1 = All rain-producing clouds are seeded during July-August, causing a 10% increase in all rainfall;
2 = All rain-producing clouds are seeded during July-August, causing a 25% increase in all rainfall;
3 = All rain-producing clouds are seeded during July-August, causing a 25% increase, but only for storms which otherwise would have daily precipitation totals in the range of 0.1 to 1.0 inches;
4 = Only half of the rain-producing clouds are seeded during July-August, causing a 25% increase in rainfall for those storm events.

Numbers in parentheses indicate increase from condition 0.
All values are in inches.

Table 2. Summary of Water Volumes Used in the Hydrologic Processes and Precipitation Augmentation for 1973, a Wet Year.

FLANAGAN SOIL (1973)

	Simulation Condition				
Process	0	1	2	3	4
P	49.20 (0.00)	50.43 (1.23)	52.26 (3.06)	50.52 (1.32)	49.86 (0.66)
ET	28.74 (0.00)	28.79 (0.05)	28.85 (0.11)	28.84 (0.10)	28.80 (0.06)
TR	15.52 (0.00)	15.55 (0.03)	15.59 (0.07)	15.59 (0.07)	15.56 (0.04)
SM_{min}	16.62 (0.00)	16.68 (0.06)	16.78 (0.16)	16.78 (0.16)	16.70 (0.08)
ΔSM	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Seep	17.02 (0.00)	17.77 (0.75)	18.79 (1.77)	18.09 (1.07)	17.56 (0.54)
QR	3.40 (0.00)	3.84 (0.44)	4.60 (1.20)	3.56 (0.16)	3.47 (0.07)
Seep + QR	20.42 (0.00)	21.61 (1.19)	23.39 (2.97)	21.65 (1.23)	21.03 (0.61)

DRUMMER SOIL (1973)

	Simulation Condition				
Process	0	1	2	3	4
P	49.20 (0.00)	50.43 (1.23)	52.26 (3.06)	50.52 (1.32)	49.86 (0.66)
ET	26.77 (0.00)	26.80 (0.03)	26.85 (0.08)	26.85 (0.08)	26.81 (0.04)
TR	15.78 (0.00)	15.80 (0.02)	15.83 (0.05)	15.83 (0.05)	15.80 (0.02)
SM_{min}	13.40 (0.00)	13.46 (0.06)	13.55 (0.15)	13.55 (0.15)	13.48 (0.08)
ΔSM	0.06 (0.00)	0.06 (0.00)	0.06 (0.00)	0.06 (0.00)	0.06 (0.00)
Seep	17.75 (0.00)	18.43 (0.68)	19.36 (1.61)	18.74 (0.99)	18.25 (0.50)
QR	4.52 (0.00)	5.03 (0.51)	5.88 (1.36)	4.77 (0.25)	4.65 (0.13)
Seep + QR	22.27 (0.00)	23.46 (1.19)	25.24 (2.97)	23.51 (1.24)	22.90 (0.63)

TOTAL FLOWS AT BONDVILLE (1973)

	Simulation Condition				
Process	0	1	2	3	4
Σ(Seep + QR)	21.31 (0.00)	22.50 (1.19)	24.28 (2.97)	22.54 (1.23)	22.07 (0.76)
Q_{est}	21.18 (0.00)	22.30 (1.12)	24.04 (2.86)	22.32 (1.14)	21.73 (0.55)
Q_{obs}	21.56 (0.00)				

Condition:

0 = No cloud seeding is done (natural condition);

1 = All rain-producing clouds are seeded during July-August, causing a 10% increase in all rainfall;

2 = All rain-producing clouds are seeded during July-August, causing a 25% increase in all rainfall;

3 = All rain-producing clouds are seeded during July-August, causing a 25% increase, but only for storms which otherwise would have daily precipitation totals in the range of 0.1 to 1.0 inches;

4 = Only half of the rain-producing clouds are seeded during July-August, causing a 25% increase in rainfall for those storm events.

Numbers in parentheses indicate increase from condition 0.

All values are in inches.

Table 3. Average Distribution of Additional Precipitation to the Various Hydrologic Processes during Dry Years (1951–1954).

Hydrologic Process	Flanagan Soil	Drummer Soil
Soil Evaporation	6%	2%
Crop Water Use	23%	15%
Surface Runoff	16%	15%
Percolation	55%	68%

occur when the actual transpiration rate is between 50% and 80% of the potential rate. The total crop stress index is the cumulative number of crop stress values for the growing season.

Table 4 provides values of the crop stress index estimated by the soil moisture component, and the average yield for corn crops in Champaign County, Illinois (obtained from the Illinois Department of Agriculture), for the 13 years simulated by the model. Although the period of 1950s demonstrate little relationship between crop stress and crop yield, there exists a strong relationship between these variables in the 1970s and 1980s. The crop stress index appears to be an adequate tool for evaluating the effect of soil moisture on crop yield.

Table 4. Comparison between the Crop Stress Index and Average Corn Yield for Simulated Years.

Year	Crop Stress	Average Yield (Bushels/Year)
81	0.00	137
82	0.01	147
83	18.42	89
84	4.66	128
85	0.00	154
72	0.00	129
73	0.98	123
74	5.06	98
75	0.00	136
51	0.00	58
52	0.61	62
53	9.18	61
54	11.14	63

3.1 Simulation of June Augmentation

It was thought that by increasing rainfall in June as well as in July and August the soil moisture might be increased prior to the dry periods which cause the most severe stress conditions for the crops. Examination of table 5, however, indicates that the additional June rainfall did little to increase the amount of crop water use in these 3 dry summers. Even with the 2.29 inches of additional rainfall simulated for June 1983 (in addition to July-August augmentation), transpiration for that year is increased by only 0.13 inches from the July-August augmentation condition. An examination of the rainfall record for the summer of 1983 indicates that a 28-day period occurred (between July 5 and August 3) in which the precipitation was only 0.30 inches. During this period there were only two days with rainfall. Assuming the highest level of precipitation augmentation simulated in this study, only 0.075 inches of additional rainfall would occur during these two days. The model shows this to have been of negligible value. This period also experienced several weeks having extremely high evapotranspiration demand.

The difference between the potential and actual transpiration simulated for this period in 1983 is shown in figure 1a. Similar periods of high evapotranspirative demand and little rainfall can be seen in other dry years simulated (see figures 2a and 3a). The differences between the bottom line (unaugmented transpiration) and the middle line (transpiration with augmentation) indicate that increased rainfall does little to increase the crop water use, which would in turn decrease crop stress. Therefore, regardless of the soil moisture conditions at the beginning of these periods, significant crop stress would be expected because of lack of rainfall.

The above example indicates that simulated augmentation conditions were unable to substantially reduce crop stress because of the lack of rain-producing storm events. A conclusion from this example is that in order to achieve considerable benefit during dry years, augmentation efforts will need to produce significant amounts of rainfall (for example, near 0.5 inches) from conditions where little rainfall would otherwise be expected. This conclusion may be further supported by the results of the other simulation test in which larger amounts of water were brought to plants in otherwise dry conditions by irrigation.

3.2 Simulation of Heavy Water Applications

Two cases of heavy water applications were simulated for the Flanagan soil: one in which a total of 3 inches of irrigation water was applied (1 inch applied 3 times during the year), and the other where 4 inches of water was applied (1 inch applied 4 times). The presumption in both cases is that water supplies are available to provide these amounts via irrigation. The applications of water were triggered when the soil moisture in the top 12 inches of the soil column fell below a threshold level. For the case involving a total of 3 inches of application, a lower level of soil moisture was tolerated before application.

A summary of the distribution of these heavy applications to the various hydrologic processes within the soil is given in table 5. The lowest increase in crop transpiration for any one year of simulation was 1.38 inches in 1954. This value can be obtained by subtracting the TR value with no augmentation (15.19 inches) from the TR value with irrigation (16.57 inches). On average over these three years, 64% of the water added during irrigation is used for crop water use (see table 6). The values in table 6 can be compared with those in table 3 to detect the major differences in the distribution of water between likely precipitation augmentation and heavier applications from irrigation. Without considerations for cost differences or availability of water, irrigation is more efficient in supplying moisture to the crops because the water is supplied at the time when the plants need it most. The irrigation events are primarily needed only during those extended periods which ordinarily would have little, if any, rainfall.

The effect of heavier water applications from irrigation events in improving the crop transpiration conditions is illustrated in figures 1b, 2b, and 3b. For all three years, the irrigation water reduces the differential between the potential transpiration and actual transpiration to less than half of the origi-

Table 5. Summary of Water Volumes Used in the Hydrologic Processes of the Soil Moisture Component: Precipitation Augmentation and Irrigation Simulations for Flanagan Soil (All values are in inches).

Year	Process	No Augmentation	Heavy Applications (3 Inches)	Heavy Applications (4 Inches)	25% Augmentation (July-August)	25% Augmentation (June-August)
1953	P	26.09	29.09	30.09	27.22	27.95
	ET	24.33	26.46	27.21	24.70	24.87
	TR	15.90	17.55	17.59	16.25	16.25
	SM_{min}	12.28	13.43	13.80	12.49	12.49
	ΔSM	-2.11	-1.27	-1.04	-2.43	-2.43
	Seep	2.86	2.90	2.91	3.78	4.28
	QR	0.99	0.99	0.99	1.15	1.20
	Crop Stress Index	9.18	0.00	0.00	6.96	6.96
1954	P	29.70	32.70	33.70	31.60	32.28
	ET	25.92	27.72	27.72	26.26	26.46
	TR	15.19	16.57	16.57	15.39	15.51
	SM_{min}	14.15	15.23	15.23	15.02	15.22
	ΔSM	3.63	3.51	3.28	4.03	4.24
	Seep	-0.37	0.82	1.05	0.12	0.81
	QR	0.52	0.63	0.64	0.59	0.76
	Crop Stress Index	11.14	3.81	3.81	9.66	9.22
1983	P	50.26	53.26	54.26	51.77	54.06
	ET	30.21	32.70	33.52	30.74	30.90
	TR	18.18	20.74	21.56	18.66	18.79
	SM_{min}	12.40	12.83	12.96	12.63	13.14
	ΔSM	0.06	0.06	0.06	0.06	0.06
	Seep	14.29	14.63	14.76	14.86	15.58
	QR	5.65	5.82	5.87	6.05	7.46
	Crop Stress Index	18.42	3.82	1.72	14.82	14.25

Table 6. Average Distribution of Large Water Applications to the Various Hydrologic Processes during Dry Years (1951–1954).

Hydrologic Process	Flanagan Soil
Soil Evaporation	8%
Crop Water Use	64%
Surface Runoff	3%
Percolation	25%

nal differential. Because stress conditions affect the growth rate of crops, the potential transpiration rate can actually be increased by supplying the crops with sufficient moisture earlier in the year. This occurs in 1954 (Figure 3b), when at the end of the growing season potential transpiration is greater and the corn crop is more developed. In the same manner, a well-developed crop is more susceptible to crop stress during dry conditions simply because its transpirative demand is greater.

The reduction in the crop stress index resulting from irrigation is provided in table 5. Irrigation reduces the crop stress to zero in 1953, and the indexes for 1954 and 1983 are reduced to 35% and 21% of the original values, respectively. The improvement in stress conditions resulting from large water applications from irrigation help substantiate the view that, in order to the most good, precipitation augmentation would need to create rainfall within otherwise dry or marginal periods.

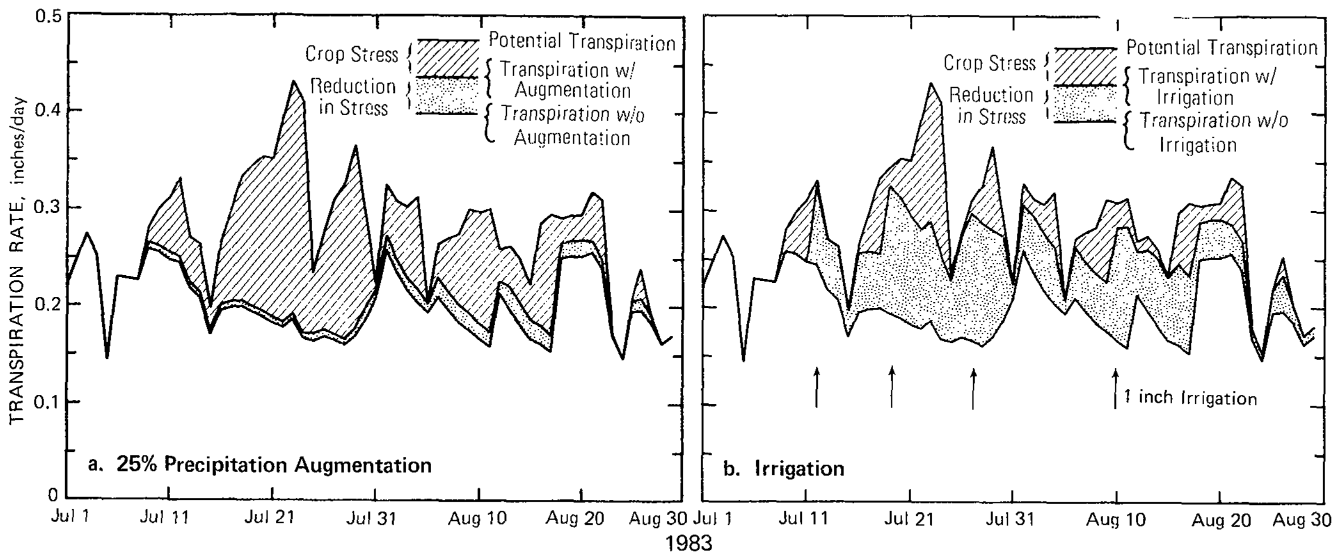

Figure 1. Change in the transpiration rate in 1983 due to a) precipitation augmentation, and b) irrigation (1-inch applications are noted as arrows).

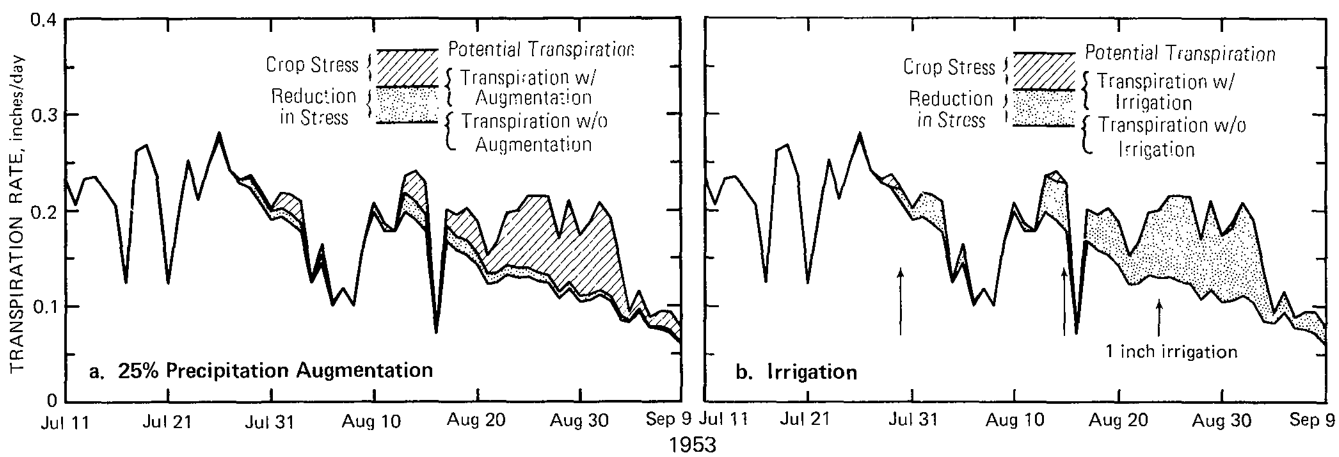

Figure 2. Change in the transpiration rate in 1953 due to a) precipitation augmentation, and b) irrigation.

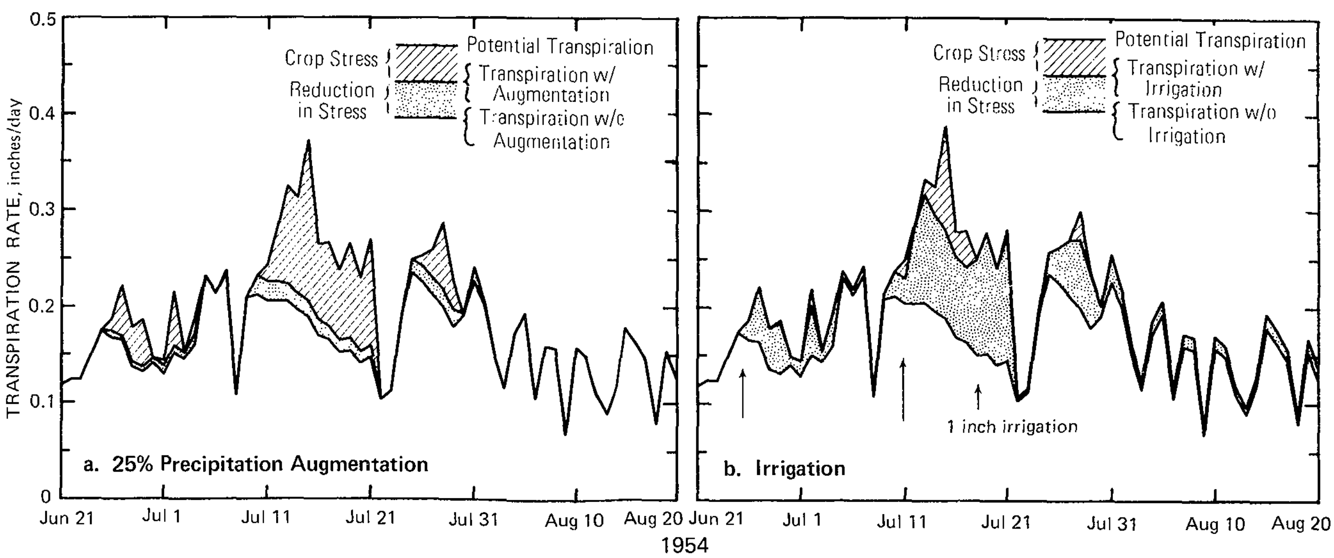

Figure 3. Change in the transpiration rate in 1954 due to a) precipitation augmentation, and b) irrigation.

4. SUMMARY AND CONCLUSIONS

The PACE Watershed Model (PWM) was designed and developed to simulate soil moisture and baseflow conditions for agricultural areas in Illinois and the Midwest. The model was applied to a watershed in central Illinois for two periods, 1951–1954 and 1972–1975. These two periods embrace significant dry and wet periods of record for the watershed. The model represents the hydrologic processes of soil moisture, evapotranspiration, percolation, baseflow, and streamflow. Those were simulated for these two 4-year periods to develop base conditions for examining the effects of precipitation augmentation on soil moisture, crop water use, and streamflow conditions in the basin.

Four levels of increased precipitation were simulated for the watershed, ranging from 10% up to a 25% increase in all precipitation during the months of July and August. All modeled simulations indicated that a great percentage of potential precipitation increase will add to ground water due to increased percolation, and eventually supplement the baseflow. However, only a small percentage of the increased precipitation would be used by the crops. The amounts of increased crop water use resulting from augmentation appear to be insufficient to have significant effects on the total crop water stress conditions or associated crop growth. This insufficiency is mainly due to the temporal distribution of precipitation which does not generate sufficient rain during typically short (one to three week) periods of crop water stress.

Two alternative conditions were examined in an attempt to explain the minimal effectiveness of the precipitation increases to meet crop demands. The first condition involved increasing the summer soil moisture levels by augmenting rainfall earlier in the summer (June). This condition provided little benefit to the crop water status. The second alternative tested was a simulation of heavy water applications (1-inch) by irrigation, and activated based on the soil moisture levels. These simulated conditions caused a significant increase in total crop water use and a reduction in total crop stress. These findings are in agreement with earlier less firm findings that indicated that rainfall increases, to be of reasonable value to crop production in the Midwest, would need to be substantial and greater than an average increase of 25% (Changnon, 1981).

Crop water stress conditions in midwestern prairie soils are produced by long periods of little rainfall. For this reason the temporal distribution of the rainfall is as great a concern as is the total amount of precipitation. Methods, such as irrigation, which can provide additional water to crops at any time and amount during these dry spells obviously produce a maximum benefit to the plant. If precipitation augmentation is to be of greatest utility to the improvement of midwestern agricultural conditions, significant rainfall amounts (for example, ≥0.5 inch) are needed during those periods when little or no rainfall would otherwise occur.

The METROMEX findings based on an outcome of substantial (30 to 70%) increases in certain heavy summer rain events, and subsequent measurable crop yield increase reveal that agricultural benefits can occur from just enhancement of existing rain conditions if they are sufficiently large (Changnon, 1977). The impact of increased (10 to 25%) precipitation on general water resources is found to be beneficial, unless it is done during very wet periods. The results have indicated that additional precipitation can actually increase baseflows, and thus improve water quality during dry periods without significantly increasing surface runoff.

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