INFLUENCE OF CLIMATIC WATER BALANCE AND SOIL TYPE ON WORK DAYS IN MISSISSIPPI FORESTS

*Charles L. Wax and **Jonathan W. Pote
*Department of Geosciences
**Mississippi Water Resources Research Institute
Mississippi State University

INTRODUCTION

The warm, humid climate of the southern region of the U.S. is favorable to the growth of forests. The value of the timber produced annually is increasing and the region has recently surpassed the Northwest to lead the nation in lumber production (Forest and Wildlife Research Center 1996). In the state of Mississippi, the net value added of the timber harvest reached an all-time high of $4.6 billion in 1992, and more than seven million cords of pulpwood were produced that year (Barnett and Reinschmiedt 1996).

Weather is the primary control affecting the timeliness of timber and pulpwood harvest. Weather exerts its control on harvest operations primarily through the soil moisture regime. Field work when the soil is too wet, even if physically possible, results in serious damage to the soil structure and increased time required for an operation (Hassan and Broughton 1975). Soils that are too wet to support heavy equipment will be compressed and rutted during harvesting of trees. These physical alterations of soil lead to increased bulk density, loss of soil macroporosity, increased erosion, decreased availability of water, and potential loss of productivity (Rachael and Karr 1989; Guo et al. 1991; Karr et al. 1991). Therefore, the obvious advantage of the forest productivity stemming from the humid climate type is often offset by the excess rainfall resulting in soils that are too wet for harvest operations.

The interaction between evapotranspiration, rainfall, and soil moisture storage influences tractability of soil and determines the number of work days for a specific soil, providing periods of time on both annual and monthly scales when harvest is limited or possible. This water balance aspect of the natural environment is governed by climate, and the temporal pattern of occurrence should become evident by analysis of the corresponding climate record.

Therefore, the objective of this study is to establish the relationship that exists between climate and the pattern of work days in the state and then to provide guidance on the number of potential work days based on sets of probability levels. This information will be organized by soil type and location, both monthly and annually.

BACKGROUND INFORMATION

The Water Balance Technique

Water balance analyses evaluate the amounts of water added to landscapes by precipitation, stored in the environment as soil moisture, or lost from landscapes by evapotranspiration or runoff. Carried out daily, this assessment provides an accounting of moisture fluctuations resulting from climatic processes that determine the workability of soils for forest harvest. Data needed for water balance analyses include precipitation and energy inputs which are used to estimate evapotranspiration. Soil storage capacity is also needed to evaluate the condition of the soil and the resulting pattern of soil moisture for supporting harvest activities.

Studies of the water balance aspects of climate have been conducted for a variety of environmental and economic objectives such as reforestation on water yield from watersheds (Muller 1966), groundwater availability (Robertson 1973), streamflow analysis (Shelton 1974), insect outbreaks (Kalkstein 1974), and flood origins and analyses (Muller 1976; Wax and Tingle 1981). Growth in the use of water balance techniques has also led to application-oriented publications. For example, Muller and Larimore (1975) produced an atlas of seasonal water budget components of Louisiana, and Wax (1982) produced a similar document for Mississippi.

Recent use of the technique has been directed toward the immediate needs of industries and agriculture. The water balance approach has been used to assess the impact of climatic variability on aquacultural ponds seasonally, annually, and spatially (Pote and Wax 1988; Wax and Pote 1990). The results of this method have also been used to establish the drying potential, field work potential, and wet-dry periods that impact agricultural and forestry production on a daily basis (Wax et al. 1990). Irrigation system design criteria have been established using water balance methods (Pote and Wax 1986). The method has been used to investigate opportunity for land application of wastewater (Pote and Wax 1995) and to model quantity and quality of overflow from aquacultural ponds (Pote et al. 1996). The water balance method of climatic analysis, therefore, is a useful tool for investigating atmospheric interactions with environmental processes and economic endeavors of humans.

Climate and Soil Conditions

In Mississippi, a strong gradient of precipitation and evaporation occurs from the Gulf Coast to the interior that strongly influences the water balance patterns across the state (Wax and Pote 1996). Soils in the state are highly variable in texture both locally and regionally. The resulting marked differences in permeabilities cause large variations in the soil moisture storage component of the water balance. Therefore, moisture, energy, and soil moisture conditions are often found in many combinations which affect tractability and consequently the number of field working days.

The Canadian Society of Soil Science (1967) considers soil tractable if a tractor or other forest machine can move on that soil to satisfactorily perform the function of the machine without causing significant damage to the soil. Elliot et al (1977) suggested that the weather has a considerable effect on available field working days, particularly on certain soil types during months with high precipitation. Rutledge and McHardy (1968) indicated that the soil is not tractable when soil moisture is near or above field capacity. Subsequently they defined the criterion of a work day as one in which the moisture content was less than 95% of capacity. Bolton et al. (1968) classified a day as a work day if soil moisture in the top six inch layer was less than 80% of field maximum for tillage operations on silty clay and sandy soils. For clay soils, the moisture must be at or below 78% of field maximum for all field operations.

METHODS AND PROCEDURES

Model Selection and Assumptions

Matsumoto (1992) first attempted an analysis of available forest working days by using sites and conditions in Mississippi. That study used an original water balance model and assumed a 95% moisture level criterion for all soil types to model daily water balance components over the 20-year period 1970-1989. For this study it was deemed important to use a well-established and flexible model which would allow setting parameters to better account for complex conditions of climate and soils across the state, and to expand the period of analysis to a standard 30-year interval.

McCabe et al. (1985) published a continuous daily water budget model through the Southern Regional Climate Center which uses the Thornthwaite method (Thornthwaite and Mather 1957) of computing potential evapotranspiration. That model was chosen for this study because it allows the capability of setting multiple parameters, therefore providing maximum accounting of the varying soil and climate conditions in the state. The model requires inputs of only daily precipitation and maximum and minimum temperatures, and allows the user to set soil moisture storage conditions such as soil depth and water holding capacity. It also provides the flexibility of setting two layers of soil moisture, the upper with equal availability of soil moisture (available on-demand), the lower with soil moisture becoming decreasingly available.

The following assumptions were made for this study:

1) Soil moisture storage capacity was set at 3" (1.2 inches per foot throughout an effective root zone of 2.5 feet) for sandy soil, 6" for loamy soil (2.4 inches per foot, effective rooting zone of 2.5 feet), and 9" for clay soil (3.6 inches per foot, effective rooting zone of 2.5 feet);

2) the tractability threshold was set for sandy soil at 95% of the capacity (2.85"), for loamy soil at 80% of the capacity (4.8"), and for clay soil at 65% of the capacity (5.85")--these levels are slightly more conservative for clay soils than those in Matsumoto (1992) and Bolton et al. (1968);

3) point locations were used to represent the zones of the state; and

4) no accounting was made for the effect of slope in the analyses.

Site Selection

Sites were chosen to represent climate conditions across Mississippi. Criteria for site selection were: 1) spatial dispersion providing representation of the climatic gradient from the coast to the interior; and 2) availability of serially complete and homogeneous daily climatological data in digital format.

Based on the best possible combination of these criteria, the following sites in Mississippi were selected: Poplarville representing the coastal zone, State University representing the interior zone, and Meridian between the two (Figure 1). All three soil textures are found in forested areas in the vicinity of each of these locations.

Climatological Data

Daily precipitation and maximum and minimum temperatures for the period 1961-1990 were obtained from observations of the National Weather Service Cooperative Observation System stored on CD-ROM (Earth Info 1992). There were cases where data were missing for up to a month. In these cases, data from the next-nearest location on the same dates were substituted to make the records serially complete. It is estimated that less than 0.5% of the data were thus derived.

Model Verification

In her study, Matsumoto (1992) measured soil moisture on 10 different days in 1992 at three soil texture sites for comparison with her calculated data for the same times and soil types. For purposes of verification, the model adopted for this present study was run three times for the entire year 1992, with soil moisture capacity set for 3, 6, and 9 inches, respectively. Calculated soil moisture was then extracted for each of those 10 sampling days for comparison with the measured data. Observed and calculated results matched on 29 of the 30 sample dates, providing a high level of confidence that the model was accurately simulating the pattern of soil moisture in the forest locations.

In field sampling, Matsumoto (1992) used a moisture level greater than 95% of field capacity as the criterion on all soils to designate an unsuitable workday; less than 95% indicated a suitable workday. The criteria used in this study to designate an unsuitable workday were as follows: soil moisture greater than 95% for sandy soils, 80% for loamy soils, and 65% for clay soils. Table 1 shows a comparison of Matsumoto's measured results along with the results calculated by the model used in this study.

Simulation

The model simulated the water balance components daily over the 30-year period 1961-1990. For each of the three locations, the 30-year period was modelled multiple times to estimate soil moisture in sandy (3" capacity), loamy (6" capacity), and clay (9" capacity) soils. The combination of three soil texture classes and three locations required that the model be run nine times to produce the needed data.

Analyses of Simulation

Daily soil moisture storage estimates were separated from the remainder of the water balance components and put into electronic spreadsheets, one for each of the three soils at each of the three sites. Each day's soil moisture value in these nine spreadsheets was then subjected to the criteria for suitable or unsuitable workdays. These results were counted and tabulated, first annually and by months, resulting in 30 numbers for annual values and 30 values for each month. These 30 yearly and monthly data were ranked in descending order, then divided into 10% quantiles from which empirical probabilities could be determined. Probability tables and graphical analyses were thus produced to show potential for work days on all three soil types, both spatially and temporally.

RESULTS AND DISCUSSION

Annual Analyses

Results of the annual analysis for northern Mississippi are shown in Table 2. The study shows that not only are there fewer suitable working days on clay soils, but also that the number decreases dramatically at the higher probability levels. For example, at least 192 days are expected each year at the 10% level on clay soils, while only 52 are expected at the 90% level. In comparison, sandy soils in that zone show much less variability in number of annual working days at the different probabilities. At least 260 are expected 10% of the time on sandy soils and at least 216 are expected at the 90% level. On loamy soils the equivalent values are 233 and 141, respectively.

Table 3 shows results for central Mississippi. On clay soils the variability of number of work days is even more dramatic. At the 90% probability level at least 200 work days/year are expected, while at the 10% level only 7 work days/year are anticipated. On sandy soils in that zone, the expected work days/year are 282 and 225, respectively, at the two probability levels. Loamy soils have equivalent values of 239 and 108 for those probability levels.

In southern Mississippi (Table 4) clay soils allow 221 and 88 work days/year at the 90% and 10% levels of probability. On sandy soils, harvesters can expect 273 and 219 work days/year at these two levels. Loamy soils provide at least 219 and 273 work days/year at these levels of probability in this zone.

The number of work days expected annually in the three zones at the 80%, 50%, and 20% probability levels is shown in Figure 2 for comparison. These results indicate that clay soils in all zones are limiting, and harvesters with holdings on these soils will need to be especially careful to take advantage of the windows of opportunity that are available through the year. Sandy and loamy soils, on the other hand, offer so many more potential work days that balancing holdings in mixed soil types, if possible, would strongly enhance harvest operations throughout the state.

Even though there are, on the average, limitations on work days on all soil types and particularly on clay soils, results indicate that over a number of years there are a remarkably high number of work days available on all soils, even on clay soils. While any given or single year may not fulfill such positive expectations, with the right timing or planning there is systematically better access to all soil types at all locations than may be generally recognized.

Of particular interest, it can be seen that sandy soils allow more potential workdays/year in the southern portion of the state than in the northern portion of the state while clay soils allow more workdays/year in the north than in the south (Figure 2). The most likely explanation for this phenomenon is climatic in nature. Higher annual rainfall amounts in the coastal region keep clay soils near saturation a higher percentage of the time there, whereas higher average temperatures cause sandy soils to dry more rapidly in that region on an annual basis. Since one season may be dominant enough to skew the annual averages, these phenomena may be better understood by comparison of seasonal or monthly results rather than annual results.

Monthly Analyses

Figure 3 shows monthly probabilities of work days at three levels for three soils in all three zones of the state. It is immediately obvious that sandy soils exhibit consistently high probability for work days throughout the state with few limitations from about mid-March through November. Also, the sandy soils exhibit very little difference at all three levels of probability. By comparison, the high probability period on loamy soils is reduced by over a month in the spring. Additionally, moving from north to south there is a noticable loss of probable work days at the 80% level compared to the other levels. An even stronger contrast is seen on clay soils, as the high probability period is reduced by yet another month in the spring throughout the state and the 80% level practically disappears in the coastal zone of the state.

CONCLUSIONS

The following conclusions are drawn based on the data and analyses:

1) This model can be used to predict forest work days at different levels of probability on different soils across Mississippi.

2) The predicted values are considered valid because the analyses are based not on a theoretical distribution but on actual daily climatic records over a 30-year period.

3) Overall, the analyses show the expected trend of sandy soils providing more probable work days than clay soils. Unexpectedly, the analyses showed an increase in probable work days on sandy soils going south across the state, whereas the number of work days on clay soils increased going north. This finding is considered to be climatological in origin.

4) At lower probability levels (20%, 50%), few unexpected findings resulted either by soil type or by location in the state. In contrast, at high probability levels (80%) dramatic changes in work day potential were evident by both soil type and location.

5) Trends resulting from the annual analyses were dominated by seasonal or monthly variation.

6) These results show very positively that there are more opportunities for harvest operations than are generally realized even on the most limiting soils. Therefore it is concluded that if these opportunities are systemmatically maximized, significantly increased or stablized incomes could potentially result.

7) Overall the results of this study appear to offer significant information to several aspects of the industry. These include land owners, timber harvestors, sawmill and chipping mill owners, and lenders, all of whom have different perspectives on the number of potential work days in the forests.

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Table 1. Comparison of Observed and Calculated Soil Moisture, Selected Dates

	Sandy		Loamy		Clay	
Date	Obs	Model	Obs	Model	Obs	Model
2/6	U	U	U	U	U	U
2/1	S	U	U	U	U	U
2/14	U	U	U	U	U	U
2/19	U	U	U	U	U	U
2/24	U	U	U	U	U	U
2/26	U	U	U	U	U	U
3/11	U	U	U	U	U	U
4/8	U	U	U	U	U	U
4/10	S	S	U	U	U	U
4/15	S	S	S	S	S	S

U = Conditions unsuitable for a work day
S = Conditions suitable for a work day

Table 2. Probability of Minimum Number of Forest Work Days, Northern Mississippi, Three Soil Types

% Chance	Sandy	Loamy	Clay
10	260	233	192
20	256	224	179
30	244	201	161
40	240	193	149
50	233	183	140
60	230	177	137
70	223	167	123
80	217	157	99
90	216	141	52

Table 3. Probability of Minimum Number of Forest Work Days, Central Mississippi, Three Soil Types

% Chance	Sandy	Loamy	Clay
10	273	238	221
20	260	221	191
30	253	205	176
40	250	197	147
50	243	192	142
60	232	179	135
70	228	163	122
80	227	154	99
90	219	143	88

Table 4. Probability of Minimum Number of Forest Work Days, Southern Mississippi, Three Soil Types

% Chance	Sandy	Loamy	Clay
10	282	239	200
20	274	209	175
30	267	200	147
40	254	180	134
50	252	172	122
60	238	166	98
70	234	140	82
80	232	120	43
90	225	108	7

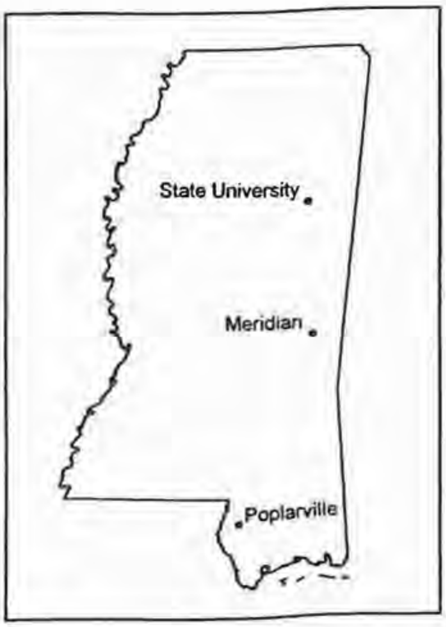

Figure 1. Location of the study sites

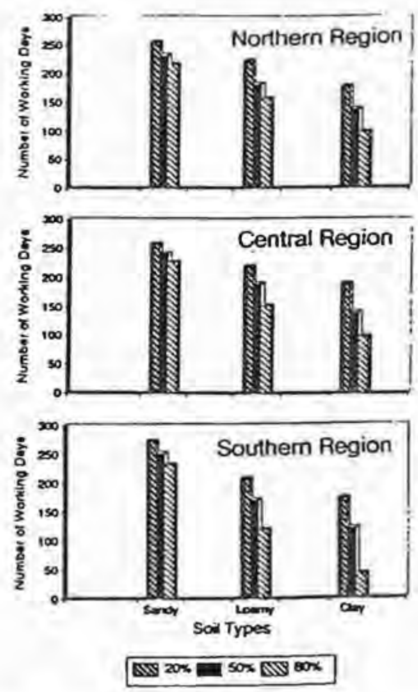

Figure 2. Minimum forest work days annually, three probability levels, three soil types, three sites

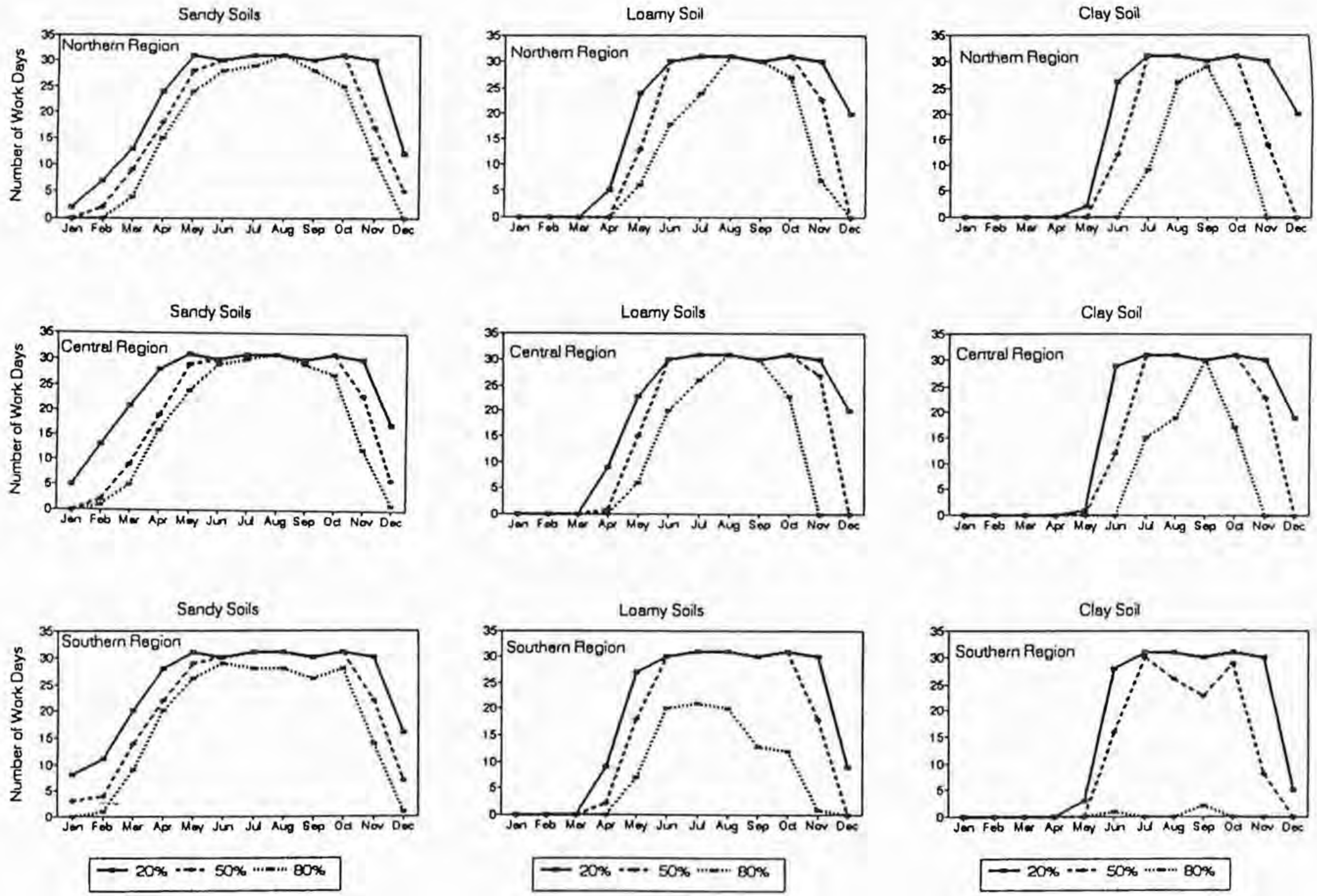

Figure 3: Minimum forest work days monthly, three probability levels, three soil types, three sites