Hardee Richard Cox. MOISTURE FLUX IN A FIELD OF MAIZE. (Under the direction of Richard A. Stephenson) Department of Geography and Planning, July 1986.

The purpose of this study is to understand the phenomenon of stemflow as it occurs in a field of maize. The approach used is to first develop a conceptual stemflow model and then to observe and collect data for application to the model. Stemflow can be defined as water that is collected on appendages of vegetation and subsequently directed in its path toward the Earth's surface to impact the soil in the immediate vicinity of the intercepting plant.

Stemflow as a variable in interception studies has not been widely studied. There are several reasons for this, such as time, expense and difficulty of measuring stemflow. As a consequence, there is a common conceptual model of precipitation in which stemflow is an underestimated and/or hidden variable. Data gathered from four years of record aided in formulating a new conceptual model with the water variables appropriately arranged as to the soil surface, their area impact and each other. The new stemflow model was used as a basis, in every rainfall event, for portraying the moisture variables and the amounts measured of each.

MOISTURE FLUX IN A FIELD OF MAIZE

A Thesis
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by
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MOISTURE FLUX IN A FIELD OF MAIZE

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CHAPTER I

INTRODUCTION

The purpose of this research is to understand the phenomenon of stemflow as it occurs in a field of maize. Stemflow is a relatively unstudied variable, and many questions should be answered. The first step is to develop a conceptual stemflow model. The second step is to observe and collect data. These two steps comprise the scope of the research.

Research Objectives

The research objectives are: (1) to identify how plant physiognomy is related to stemflow volume relative to precipitation amounts, and (2) how stemflow relates to the spatial variation in recharging soil moisture. Stemflow represents water (precipitation and/or dew) that is collected on the appendages of vegetation and subsequently directed in its path toward the Earth's surface to impact the soil in the immediate vicinity of the intercepting plant. This capability of vegetation, a function of plant structure, causes uneven soil wetting. When rainfall events are of low intensity and brief duration, many plants can effectively concentrate meager precipitation amounts at the soil surface in close proximity to the area of thickest root development. In corn, this capability is especially significant in providing the crop with available soil water during the period prior to maturation. Evidence indicates that leaf characteristics in corn such as leaf area index and canopy cover increases through crop maturity. Thereafter, leaves droop downward, reducing water collection efficiency.

Justification

The application of this research would be to use the information contained herein for: (1) water conservation in agriculture, and (2) regional and national water resource development programs. With the supply of water relatively constant, consumptive use of water by industry, urban complexes, and agriculture is increasing. The result is a conflict in user's priority of water. In response, several states have, or are now considering, legislation that limits consumer use of water from either surface or groundwater sources. This action is designed to prevent, or at least alleviate, critical water shortages that have recently occurred, even in humid regions, and that are predicted to become more severe in the future. In particular, these impending water use restrictions are being structured during a time when agriculturists are drastically increasing irrigated acreages (Snead, 1981). Resolution of the impending "water demand crisis" will be largely based upon more stringent and wiser use of our currently available resources. (Anonymous, 1984)

This study will add to the general body of microclimatic information. The data base developed from

1981 observations in addition to data from three previous crop seasons are the only information known to exist for stemflow of small plants. Also, it will serve as a refinement of existing evapotranspiration models for agricultural purposes. The study will also provide a basis for the further sophistication of crop moisture modeling and could have significance in scheduling irrigation.

Total moisture flux in plant communities has only been studied by forest meteorologists or climatologists who deal with large and widely spaced plants. Simplicity of monitoring water movement within habitats dominated by semi-permanent, large plants has made forest environments ideal sites for monitoring such aspects of moisture flux as infiltration or throughfall, detention, and stemflow. The literature reveals that none of these variables have been adequately measured in microclimatic field studies, that is, within the lower ten feet of the atmosphere. Most of our agricultural economy is based in this realm of boundary layer air.

Background Review

Assessment of the role of water in agricultural climatology has been largely relegated to its significance in evapotranspiration processes. Consequently, most moisture model research relative to field crops has been unidirectional, concerned primarily with movement or potential movement of water from the root zone to the atmosphere. This, of course, solely relates to water research in microclimatic studies and does not refer to water erosion, flood control, or general research of unsaturated soil water flow. When soil moisture is at optimal levels, the concept of field crops operating as hydraulic pumps in response only to energy availability is viable. Optimum soil moisture status, however, is not the norm under field conditions. Even in humid climates, soil water reserves frequently fall below fifty percent potential storage. Monitoring of soil moisture status beneath field corn in eastern North Carolina, during 1977 and 1981, has confirmed these findings. Average soil moisture status of less than one-half potential storage occurred during seventy one percent of the 1977 crop season (Steila and Wall, 1978). In 1981, these conditions were present fifty eight percent of the time. Such periods of deficit moisture status represent times of drying of the rhyzosphere. It is at these times that farm managers attempt to improve crop yield through water applications.

Current research which focuses on stemflow phenomenon and evapotranspiration modeling reveals that the role of plant structure as an element in affecting recharge of soil water via stemflow has not been studied in sufficient detail. This lack of detailed research results in erroneous conclusions about stemflow. Such conclusions generally evolve from four distinct problems: (1) stemflow data are scarce; (2) data are only available for forest species; (3) data are seldom correleted with soil moisture recharge information; and (4) available data are incompatible with other moisture flux indices with which they are compared.

Patric and Helvey (1965) point out that stemflow monitoring is expensive, tedious, and time consuming. Consequently, it is not surprising that this phenomenon has received minimal research attention. Obtaining stemflow data in a forest environment requires the installation of semi-permanent, gutterlike collars on sample trees. The gutter is sealed to the tree to collect stemflow and divert it into retaining tanks for later measurement. The absence of stemflow data for agricultural crops undoubtedly rests in a compounding of the collection problem when dealing with a nonpermanent, small plant.

Steila (1976) has resolved this problem by devising a serviceable, polyethylene collar for use with small plants such as corn. The collar has been tested throughout three growing seasons prior to this study and on a 1981 corn crop.

Seldom have forest stemflow data been correlated with soil moisture status. The few studies that have discussed this relationship have expressed it in qualitative terms. Even so, these studies demonstrate the impact that stemflow may have upon redistribution of precipitation and its capability of concentrating intercepted water into the root zone of plants. The following serves as an example:

> Uneven soil moistening may result from interception of rain by plants. Part of the rain reaches the soil by flowing down the stem of the plant. Some plants such as mulga (Acacia aneura) in Australia intercept virtually all the rain falling on them. In this situation, the soil is moistened deeply around the stem, but remains extremely dry under the canopy of the mulga, while between plants the rain mostly falls directly on the soil. Thus, we have in one large pedon three contrasting regimes: in one, the soil is deeply moistened; in the second, which surrounds the first,the soil receives virtually no moisture; in the third, the soil is intermittently moist and dry (U.S. Department of Agriculture, 1975).

The generally accepted format for expressing stemflow data is incompatible with other moisture supply indices. Previous researchers have obtained volumetric stemflow data from sample trees (or sample plots of trees) and simply divided its volume by the intercepting canopy area to establish an area/depth water equivalent that was subsequently compared with gross precipitation. The outcome was a determination of the stemflow's significance to plants. This approach frequently yields an insignificant measure of water reaching the surface via stemflow. However, this method does not give the real picture, particularly in small plants, such as corn. Stemflow, as demonstrated in the previous quote, is not uniformly distributed over the soil surface. Rather, it impacts the soil surface where it is available for infiltration or in the immediate vicinity of the plant's contact with the ground. To be correctly interpreted, that is, relative to gross precipitation and throughfall which are area impact derived values, stemflow should be defined as an area/depth measure determined by an impact zone circumferential to the intercepting plant (Steila, 1981).

Present State of Knowledge

A search of recent literature reveals few references to substantive stemflow research. Of these studies none dealt with the stemflow phenomenon in agriculture crops. The only known stemflow research in agriculture has been at East Carolina University. Steila and Wall (1977 and 1978) made preliminary studies in the summers of 1976 and 1977. Steila continued and updated this research during the summer of 1979. In 1981 research was conducted and constitutes the data base for this study with supplemental information from the three previous years.

Stemflow is most evident in trees. During a rainfall event, water can be seen running down the trunks. For this reason, earliest references to stemflow were by foresters. Foresters were also the first to monitor stemflow as a variable within interception studies.

Patric and Helvey (1965) proposed that foresters monitor stemflow on randomly selected plots, by using "narrow collars sealed to the trunks of sample trees to divert downflowing water into storage containers." This approach is accepted as the most feasible method for determining stemflow volume and has been universally applied. Of the references cited that related to tree stemflow, all used a narrow collar for intercepting and channelizing stemflow into a retaining collector. In a fashion similar to the technique implemented by foresters, stemflow was monitored in randomly selected corn fields, utilizing a polyethalene collar, during the summers of 1976, 1977, 1979, and 1981. The collars collected stemflow and funneled it into a sealed cylinder from which total volume could be determined and subsequently compared with characteristics of both rainfall events and soil moisture status change.

Analytical results of stemflow data usually vary in accordance with the investigator's interests. Patric and Helvey (1965) related total seasonal and annual stemflow values to the gross precipitation parameter. Their evaluation involved converting volumetric stemflow to an to an area/depth value by dividing its cubic unit equivalent by canopy intercepting area of sampled trees. Their conclusion was that stemflow comprised an insignificant portion of gross precipitation (five percent or less). In Australia while working with a native shrub called mulga (Acacia aneura), Pressland (1973) arrived at an opposite conclusion. After monitoring stemflow in mulga, it was determined that virtually one hundred percent of the rainfall was intercepted by the plant and diverted to the surface, adjacent to its base, as stemflow. This study demonstrated stemflow efficiency in concentrating precipitation within the soil as potentially available transpirable water. Since a large percent of the soil surface beneath mulga canopies is normally dry, the study also illustrated the water conservation potential of plants. In the same line of thought as Pressland (1973), Chang (1968) noted that as much as fifty percent of evapotranspiration may be associated with water evaporated from wet soil surfaces. Dry soil surfaces do not lose water through evaporation.

Other stemflow studies have focused upon precipitation thresholds for initiation of the phenomenon in various forest stands. Ford's (1978) research on canopy structure and precipitation intensity, and studies underway at the Hydraulic Research Station, Wallingford, England, (Steila, 1983) pointedly indicate that forest species attain maximum stemflow efficiency prior to maturation, and then stemflow efficiency tends to decrease. This same increase and decrease of stemflow efficiency holds true for corn.

Stemflow Defined

Stemflow can be defined as water (precipitation and/or dew) that is collected on appendages of vegetation and subsequently directed in its path toward the Earth's surface to impact the soil in the immediate vicinity of the intercepting plant. It is commonly monitored by a gutterlike collar attached to the plant and connected to a retaining tank. Water collected in the retaining tank is converted to an area/depth value by dividing its volume by area of the plant's stemflow impaction upon the soil surface, referred to as stemflow impact area (SIA). The SIA is an area delimited on one side by the basal perimeter of the intercepting plant and on the other side by a circumferential outer boundary. The latter is equidistantly spaced at one centimeter from the former (Steila, 1981).

Earlier interpretations of stemflow defined the phenomenon as depth of plant redirected water uniformly distributed over the soil surface throughout an area bounded by the intercepting plant's canopy. Pressland's (1973) research on mulga stemflow supports the foregoing statement that earlier analytical methods were erroneous. Stemflow is not uniformly distributed over the soil surface. Earlier approaches do not represent the potential of soil moisture recharge. Gross precipitation and throughfall, for example, are monitored in free-catch containers of constant intercept area, and expressed as depth of water impacting the soil. To be equivalent, for comparative purposes, stemflow needs also to be evaluated in relation to the area wherein its water impacts the surface. The one centimeter wide catchment area has been utilized in corn stemflow evaluation. Although the catchment area or Steila's SIA has been presented before professional groups for evaluation, no negative response has been received with regard to areal delimitations. Both Dr. Steila and this researcher consider the SIA to be subject to modification as continued research on the stemflow phenomenon proceeds.

CHAPTER II

THEORETICAL FRAMEWORK

Precipitation Distribution in Maize

In a study of moisture flux in plants, there are two separate yet related elements. The first, commonly known as precipitation, deals with movement of atmospheric moisture towards the earth. This encompasses the different forms of precipitation and the differing modes of movement of this water. Stemflow, plant detention, precipitation, and throughfall, which is moisture that falls directly onto the soil or has been in contact with plant appendages but has fallen from them, are the modes of downward movement of water. The second element is evapotranspiration, that being the movement of moisture from the soil and/or plant upward into the atmosphere. It is the first element of moisture movement, the earthward direction that is to be presented in this section as it is found in a field of maize.

A standard model of how a rainfall event deposits water upon the surfaces below, both plant and soil, can be shown by the following:

$$PPT = T + (S + PD) \qquad (1)$$

where:

PPT is gross precipitation,

T is throughfall,

S is stemflow, and

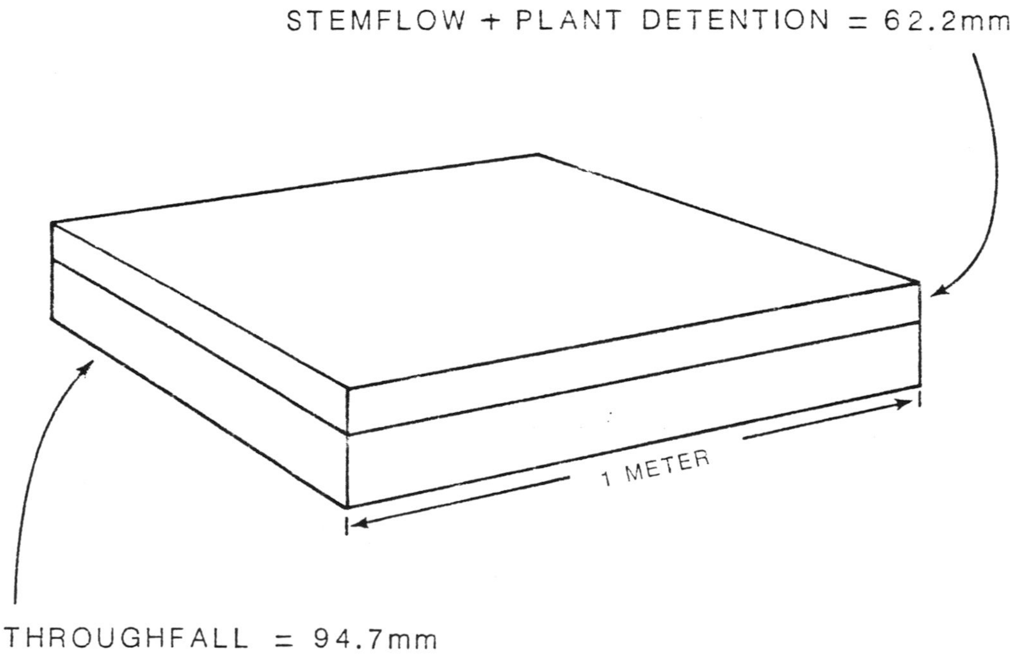
PD is plant detention.

This equation divides gross precipitation into two categories with throughfall constituting one part, and all the remaining amounts of water comprising the second part in unit volume per unit area values (Figure 1).

There are two problems that arise by describing precipitation distribution in this matter. First, by grouping stemflow and plant detention together into a single variable the model is overly simplified. One reason for this grouping is associated with monitoring and/or gathering raw data. Monitoring stemflow is time consuming (Patric and Helvey, 1965). This is compounded when working with a non-permanent plant such as maize. During the monitoring of the 1981 maize crops, the collars used to catch stemflow had to be repaired every time any amount of stemflow was recorded. Also, the collars were replaced every third or fourth monitoring visit to allow for the change in stalk size and/or shape of cross-section. Another factor is that stemflow has only recently been observed scientifically and is still a variable being measured in agroclimatic studies. Plant detention has been studied even less, so the lack of data has generated only a simplistic precipitation distribution model.

The second problem is that by combining stemflow and plant detention, the importance of stemflow in contributing to the total amount of water available for plant use is

COMMON PRECIPITATION MODEL



GROSS PRECIPITATION=

94.7mm+62.2mm =156.9mm UNIT VOLUME/UNIT AREA

FIGURE 1

masked. This format of expressing stemflow is not compatible with other moisture variables. Researchers that have obtained stemflow data have divided its volume by the area of the intercepting canopy to arrive at an area/depth water value. In so doing, stemflow is thought to be insignificant in contributing to available water. However, stemflow is not evenly distributed on the soil surface beneath the plant canopy, but is concentrated adjacent to trunks or stems of plants, or as in maize, the stalk. Since other moisture parameters are derived as area impact values, stemflow values should be determined in the same manner. This means that stemflow should equal a unit depth value related to its soil surface impact area. To apply this approach, the basic conceptual model of precipitation needs to be modified. This refinement changes the precipitation distribution model, and with respect to maize, will more accurately portray the distribution of precipitation.

There are two major modifications of the conceptual model (Figure 1). First, stemflow and plant detention are separated and treated as individual variables. The equation has been reformulated to show this as:

$$PPT = T + S + PD \qquad (2)$$

where:

PPT is gross precipitation,

T is throughfall,

S is stemflow, and

PD is plant detention.

This permits stemflow evaluation relative to its significance as a descrete variable. Also, plant detention can be determined by reformulating equation (2) as:

$$PD = PPT - (T + S) \qquad (3)$$

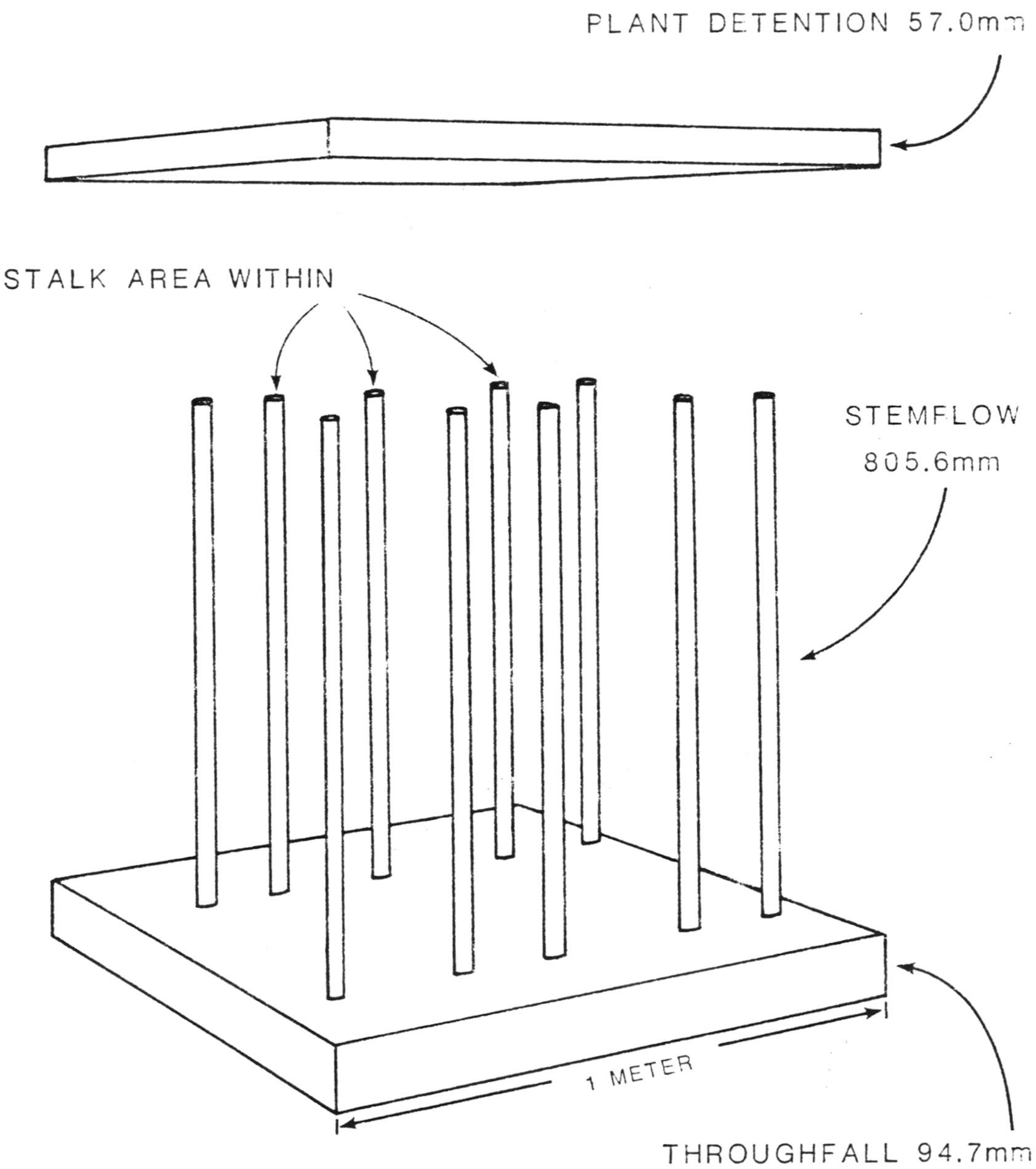
so as to isolate it for analysis.

In the second adjustment, stemflow is treated as an area/depth value, that is the depth of stemflow relative to the unit area of the soil surface it impacts. These changes produce a realistic model of how precipitation is actually distributed in a field of corn (Figure 2). The original model of precipitation distribution is from an unpublished manuscript, based upon data collected for the period 1976 - 1979 (Steila, 1982).

The unorthodox nature of the actual precipitation model (see Figure 2) is a result of how the variables stemflow, throughfall, and plant detention, are located or positioned relative to a stalk of maize in a natural crop setting. For example, examine the moisture pattern on and around a stalk of maize after a brief shower. The soil surface is moistened by water directly impacting it. Water is flowing down the stalk from the blades to moisten the soil adjacent to the stalk. On the extremities of the plant, water neither moving nor yet evaporated is present. This plant detained water is not in direct contact with the soil

ACTUAL MODEL

JUNE 1 TO AUGUST 1



GROSS PRECIPITATION=

94.7mm+(805.6mm+57.0mm)=957.3mm UNIT VOLUME/UNIT AREA

FIGURE 2

surface, so in the model it is elevated above the other moisture variables.

In an effort to include all flow the variables, yet produce a simplified descriptive model, plant detention can be graphically repositioned beneath throughfall and stemflow. This arrangement simplifies the pictorial model and retains an actual portrayal of each moisture variable. In addition, data from the ten stemflow columns which are observed in the field are combined to produce one column encompassing an area equivalent to the ten columns.

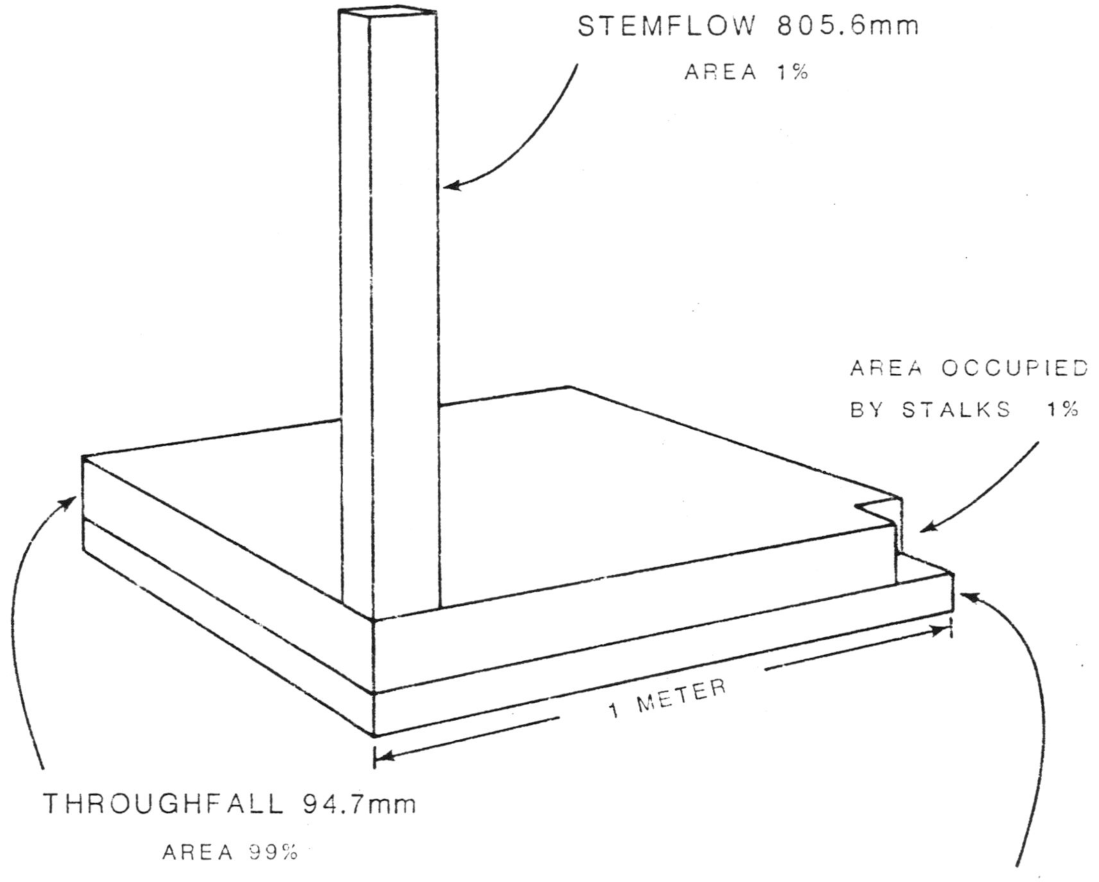
Since the actual model presents variables as area/depth values, another item must be added. Maize stalks occupy soil surface space, wherein water interception cannot occur. This area is represented as a zero area/depth variable in the model. All of the foregoing are portrayed in an idealized model of precipitation distribution (Figure 3). These modifications result in a model that allows stemflow, throughfall, and plant detention to be compared to each other in terms of volumetric amounts with respect to their appropriate areas of impact.

Conceptual Modeling

There are four concepts concerning corn stemflow. They are derived from observations gathered during the summer of 1981 and from three prior years of monitoring, 1976, 1977, and 1979. The first concept states that soil moisture recharge potential changes with respect to the variables'

IDEALIZED MODEL

JUNE 1 TO AUGUST 1



GROSS PRECIPITATION

94.7mm+805.6mm+57.0mm = 957.3mm UNIT VOLUME/UNIT AREA

FIGURE 3

impact area in all directions away from the basal perimeter of a maize plant. This statement differentiates infiltrated soil water from potential absorbed soil water. A conceptual model that expresses the relation between soil moisture recharge potential and distance is:

$$R_p = Th_i + SF_i \qquad (4)$$

where:

R_p is soil moisture recharge potential,

Th_i is water available from throughfall impacting the surface, and

SF_i is water available from stemflow impacting the surface.

This model assumes that in a relatively level field with a uniform stand of corn there will be a distinctive pattern of natural sources of water reaching the surface. The pattern will be columnar in the immediate vicinity of each plant, with the remainder of the surface having a relatively equitable receipt of moisture in lesser amounts. Other factors such as structure, density of plants and soil cover can also influence recharge. Further, the seasonal soil moisture recharge tends to decrease with distance from the basal perimeter of the plants. This is expressed:

$$R_{sm} = W_a/D \qquad (5)$$

where:

R_{sm} is soil moisture recharge,

W_a is water available for recharge, and

D is distance from basal perimeter of a plant.

There are two primary factors relating to actual soil moisture recharge relative to distance from a corn plant: (1) available impacting precipitation, and (2) soil infiltration capacity. As stated previously, more water is available adjacent to the plant than at any other point on the surface due to the additional contribution of stemflow. In addition, more water is infiltrated into the soil adjacent to a corn plant. Another aspect of infiltration potential relates to soil porosity. Water flowing down the corn stalk repeatedly floods the soil close to the plant's basal perimeter. This results in colloidal size particles being subjected to suspension and displaced away from the plant by floatation. The remaining surface soil in the immediate vicinity of the stalk is usually coarse textured relative to the soil surrounding it, and is more capable of infiltrating water. This does not suggest that all stemflow infiltrates the soil.

In addition, stemflow efficiency is related to the stemflow/precipitation ratio and precipitation intensity. This is modeled as:

$$SE = SP_r/P_i \qquad (6)$$

where:

SE is stemflow efficiency,

SP_r is the unit depth stemflow/unit depth precipitation, and

P_i is precipitation intensity.

The most effective funneling of water to the plant's soil contact zone yields high ratios, which can be in excess of 3:1. Such conditions occur when precipitation events are of low intensity and magnitude. When a less than 12 hour storm intensity generates more than 20 mm precipitation, the ratio becomes relatively constant at 2.0 - 2.5:1 (Steila, 1982).

Finally, total water available for plant use (i.e. transpiration) can exceed both gross precipitation and throughfall indices. This is conceptualized as:

$$W_{ta} > P \qquad (7)$$

and

$$W_{ta} > Th \qquad (8)$$

where:

W_{ta} is total water available for plant use,

P is gross precipitation, and

Th is throughfall.

Evapotranspiration models normally assume gross precipitation to be representative of the maximum water available for potential evapotranspiration demands. The underlying theory of such models generally relates to zonal climatic and soil conditions, and to a combination of energy availability and water supply components for determining water loss from a vegetative cover and its associated soils. Although these models can reasonably estimate long term evapotranspiration, they cannot distinguish between water budget components such as evaporation or transpiration. As a result, potentially available plant water has normally been determined by gross precipitation or throughfall. However, it has been observed that in corn, during drought periods, low intensity precipitation is directed via stemflow to selected areas where plant roots are concentrated and that wetting of potential evaporative soil surfaces is largely eliminated. The significance of these findings is that for specified rainfall events, the plant's available water can be in excess of either of the two generally accepted potential soil moisture recharge indices.

CHAPTER III

RESEARCH TEST SITE DESCRIPTION

Pitt County, North Carolina lies in the physiographic province known as the Atlantic Coastal Plain. The sediments comprising the area were deposited by both marine and fluvial processes. Coastal Plain soils have formed on unconsolidated sands, silts, and clays that have been subjected to a weathering sequence encompassing 225,000 - 250,000 years (Steila, 1982). Of the more than thirty different soil series found through Pitt County, seventy four percent are grouped within the soil order Ultisols, an order containing the most weathered soils in the conterminous United States.

"The climate of Pitt County is influenced by elevation, by distances from the Atlantic Ocean and the Pamlico Sound, and by latitude and location of the county in the continent" (Hardy, 1974). Temperature averages for the year are 73° maximum daily and 50° minimum daily based upon monthly averages. The growing season lasts from March until November, or about 220 days.

Precipitation averages forty eight inches per year with July being the wettest month and November, the driest. "Thunderstorms account for a large part of the rainfall received during the growing season" (Hardy, 1974). The remainder of the year large low pressure storms influence precipitation.

The location of this research project is in the northern tip of Pitt County, two miles east of Bethel (Figure 4). The area is drained by Grindle Creek which flows southeast into the Tar River. Approximately fifty percent of the area is under cultivation. Pasture and woodland cover the remainder of the area surrounding the test sites. Of the cultivated fields, many have an extensive subsurface drainage system. Subsurface drainage, using tiles in conjunction with open ditches, enable rapid removal of water.

The individual test plots are scattered through two adjoining fields (Figure 5). Plots one, two, and three are in a field with tile drainage. Sites four and five are in a field that does not have tile drainage. However, this field has a greater elevation and more slope. A large open drainage ditch separates the fields and connects to a natural drainageway.

A standard weather shelter was positioned in an open space adjoining the T.W. Bowers farmstead. The station housed several meteorological instruments, including, a Bacharach Recording Hygro-thermograph. The close proximity of an inhabited house detered tampering and vandalism of the instruments, thereby aiding in the accuracy of the readings.

Soils

There are two soil types that have evolved in the test

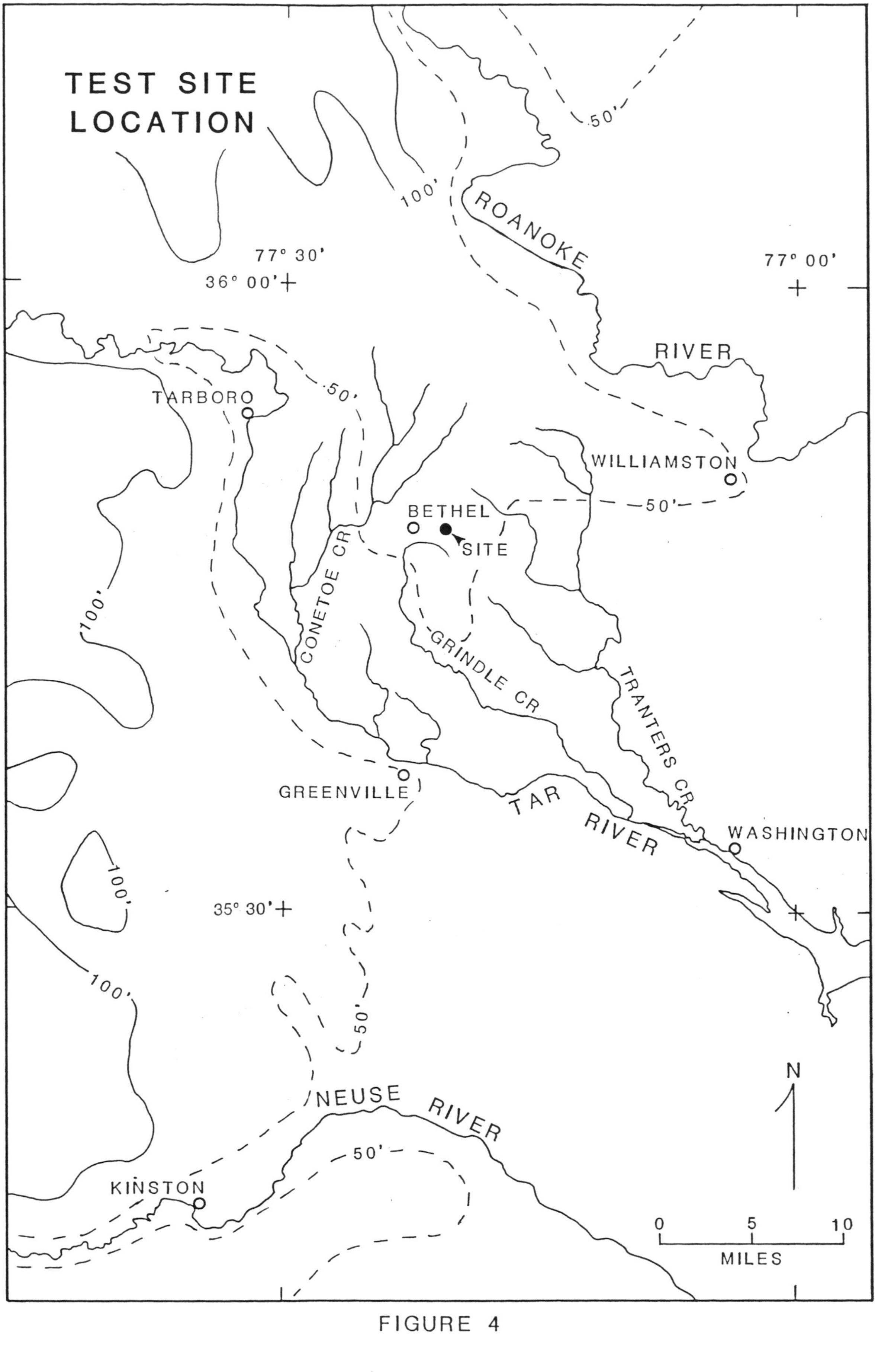

TEST SITE
LOCATION
77° 30'
36° 00'
77° 00'
100'
50'
ROANOKE
RIVER
TARBORO
50'
WILLIAMSTON
50'
BETHEL
SITE
CONETOE CR
100'
GRINDLE CR
TRANTERS CR
GREENVILLE
TAR
RIVER
WASHINGTON
100'
35° 30'
100'
50'
NEUSE
RIVER
50'
KINSTON
N
0
5
10
MILES

FIGURE 4

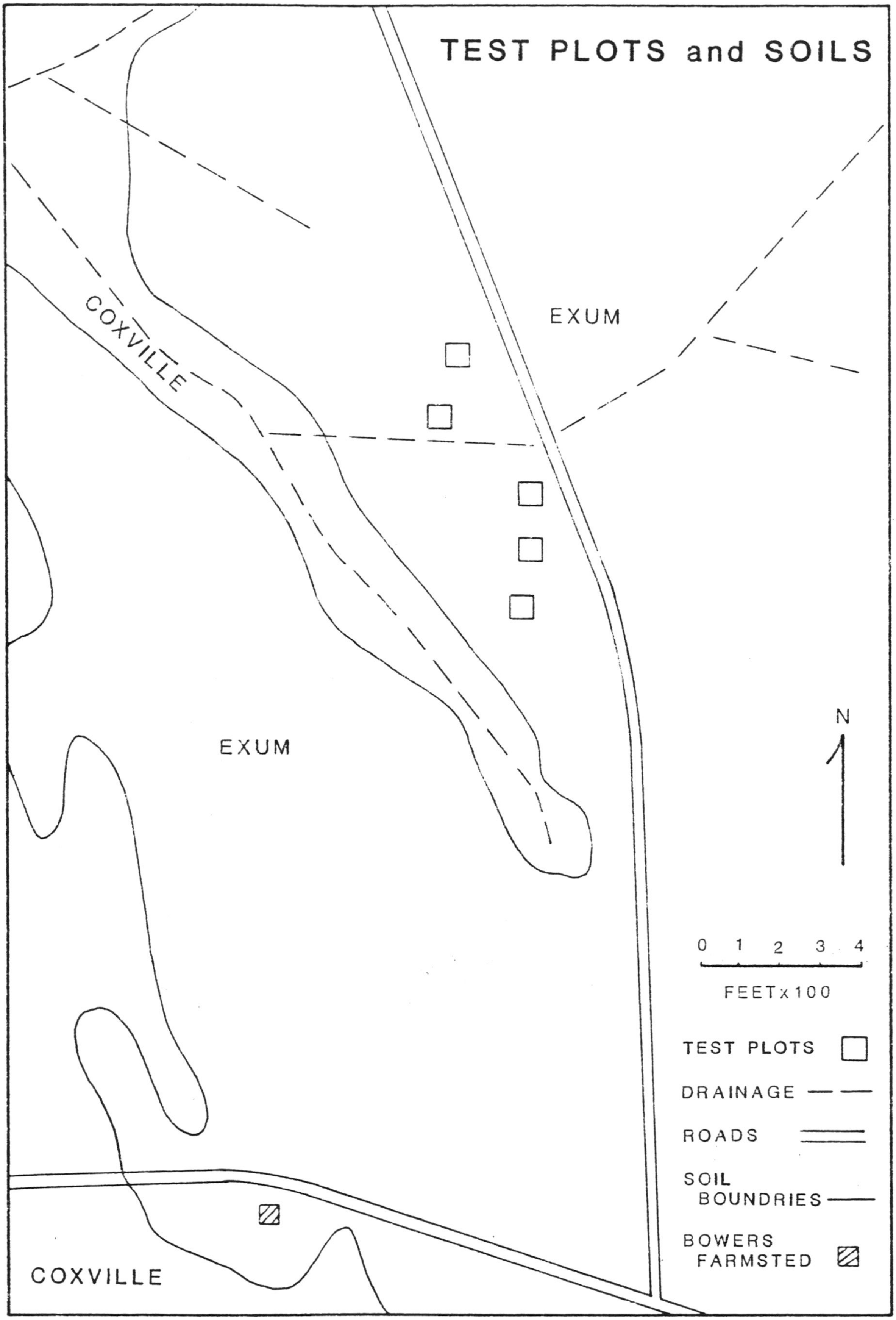

TEST PLOTS and SOILS
EXUM
COXVILLE
EXUM
COXVILLE
N
0 1 2 3 4
FEETx100
TEST PLOTS
DRAINAGE
ROADS
SOIL BOUNDRIES
BOWERS FARMSTED

FIGURE 5

area. The Exum series dominates the area with the Coxville series occuring sporadically between individual Exum polypedons. Both soils are fine sandy loams suitable for cultivation. The study area is located between the inner and outer portion of the Atlantic coastal plain. This location results in a landscape which is partly composed of fairly well preserved marine derived forms, and partly fluvial forms related to subaerial erosion. The marine terraces are vividly portrayed with relict beach strands and shallow offshore flats. Much of the marine terraces are poorly drained as the drainage system has, as yet, not become mature or integrated. However, some areas have succeeded in being drained, both naturally as well as anthropically. This geomorphologic situation has allowed a wide variation in topographic and drainage expression, and in the soils as well.

There are seven soil associations derived from forty two mapping units in Pitt County (USDA, 1974). The Norfolk-Exum-Goldsboro soil association which includes Coxville, is moderately well to well drained, although the Coxville tends to be poorly drained, and located on the Wicomico strand, and a small area of Penholloway strand. This is the only true upland soil association in the county (Stephenson, 1985). All five test plots are situated in Exum soils (Figure 5). The Coxville soil series occupy slightly lower topographic elevations with anthropic drainageways.

Instruments and Equipment Used

Several instruments were used to monitor moisture flux. The equipment consisted of:

(1) 28 small cylindrical rain gauges
(2) sheets of plastic for stemflow collars
(3) tin cans to collect stemflow
(4) a one square metering grid
(5) a rod marked in inches for crop height
(6) a gypsum block for soil moisture
(7) a soil moisture resistance meter
(8) a Hygro-thermograph
(9) two thermometers
(10) tape and other supplies as needed

Each test plot had at least two collars and containers for stemflow, three rain gauges for throughfall, and the buried gypsum blocks (Figure 6). Data was gathered for each moisture variable and related items. They are: (1) stemflow, (2) throughfall, (3) gross precipitation, (4) soil moisture under the stalk, (5) soil moisture between the rows, (6) crop height, (7) percent crop cover, (8) blade length, (9) blade width, (10) maximum temperature, (11) minimum temperature, (12) relative daily humidity, and (13) average daily temperature. The maize crop in these fields was observed from planting in April through post-maturity in mid August.

Equipment Siting and Use

Gypsum blocks were implanted in all five test plots. The blocks were in groups of three with two groups per test plot. One group was centered under corn stalks at depths of six, twelve, and eighteen inches below the ground

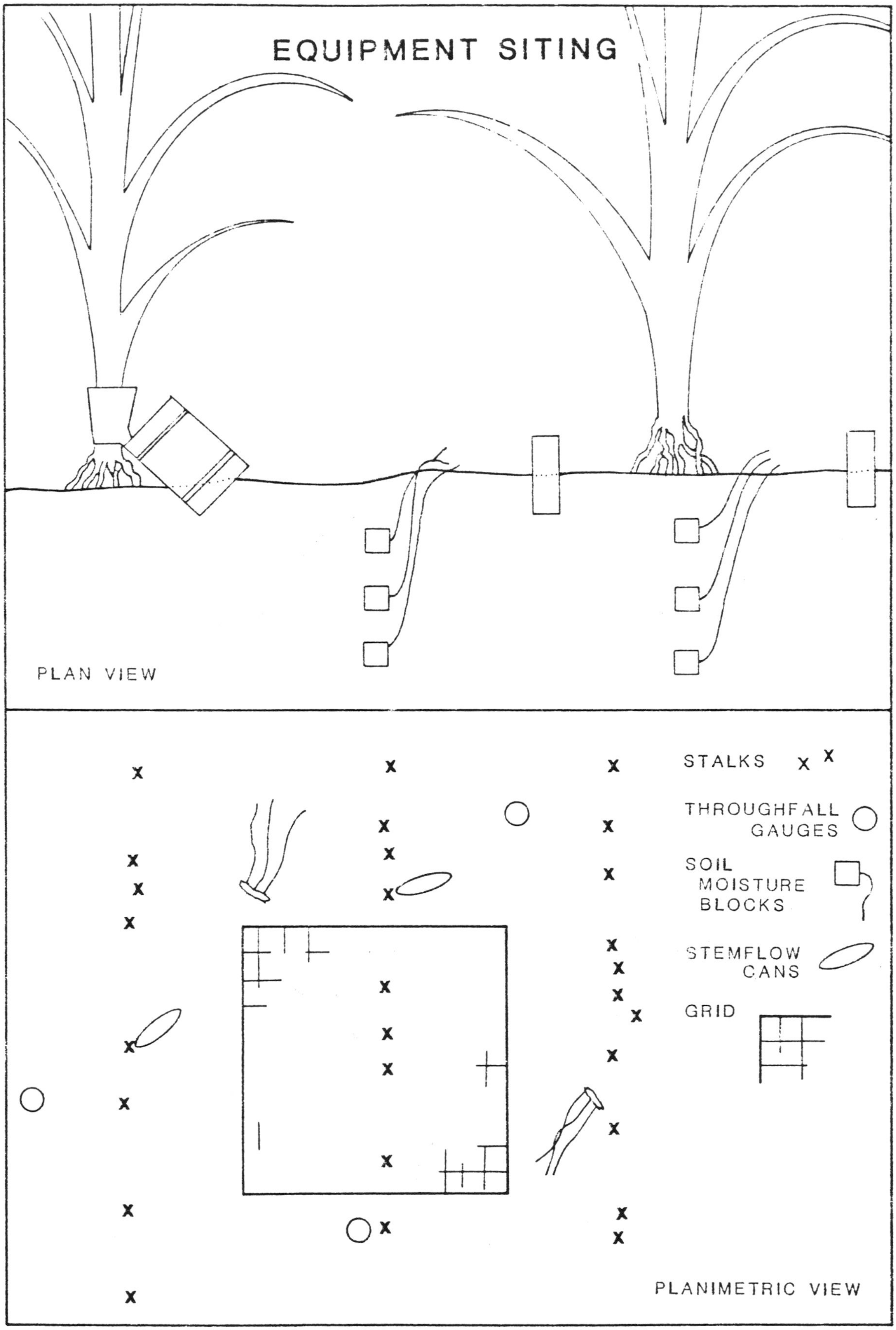

EQUIPMENT SITING
PLAN VIEW
STALKS x x
THROUGHFALL GAUGES ○
SOIL MOISTURE BLOCKS
STEMFLOW CANS
GRID
PLANIMETRIC VIEW

FIGURE 6

surface (Figure 6). The second group was implanted between rows at the same depths. The wires leading to the blocks were arranged and marked to indicate depth of each block and to increase speed in monitoring. When the blocks were implanted the soil was replaced keeping the texture and structure as undisturbed as possible. Each test plot had a similar monitoring system and equipment layout. Soil moisture percentage was observed with a resistance meter at each depth and then recorded. Each test plot was positioned in the fields to avoid intense water run-off or collection.

To monitor stemflow, polyethylene collars, designed by Steila (1976), were fashioned and fitted around selected stalks slightly above the support roots. A gallon can with the top almost entirely covered was positioned underneath the spout of the collar to catch stemflow (Figure 7). A total of fourteen catchment units were constructed. Each sample plot contained a minimum of at least two units. After each rainfall event the stemflow collected in each catchment container was emptied into a bottle calibrated in cubic centimeters and the volumetric measurement recorded. The collars and cans required constant maintenance and repair throughout the growing season, particularly during rapid stalk development prior to tasselling.

Field rain collectors were stationed throughout the test area (Figure 5) at a mature canopy level to measure

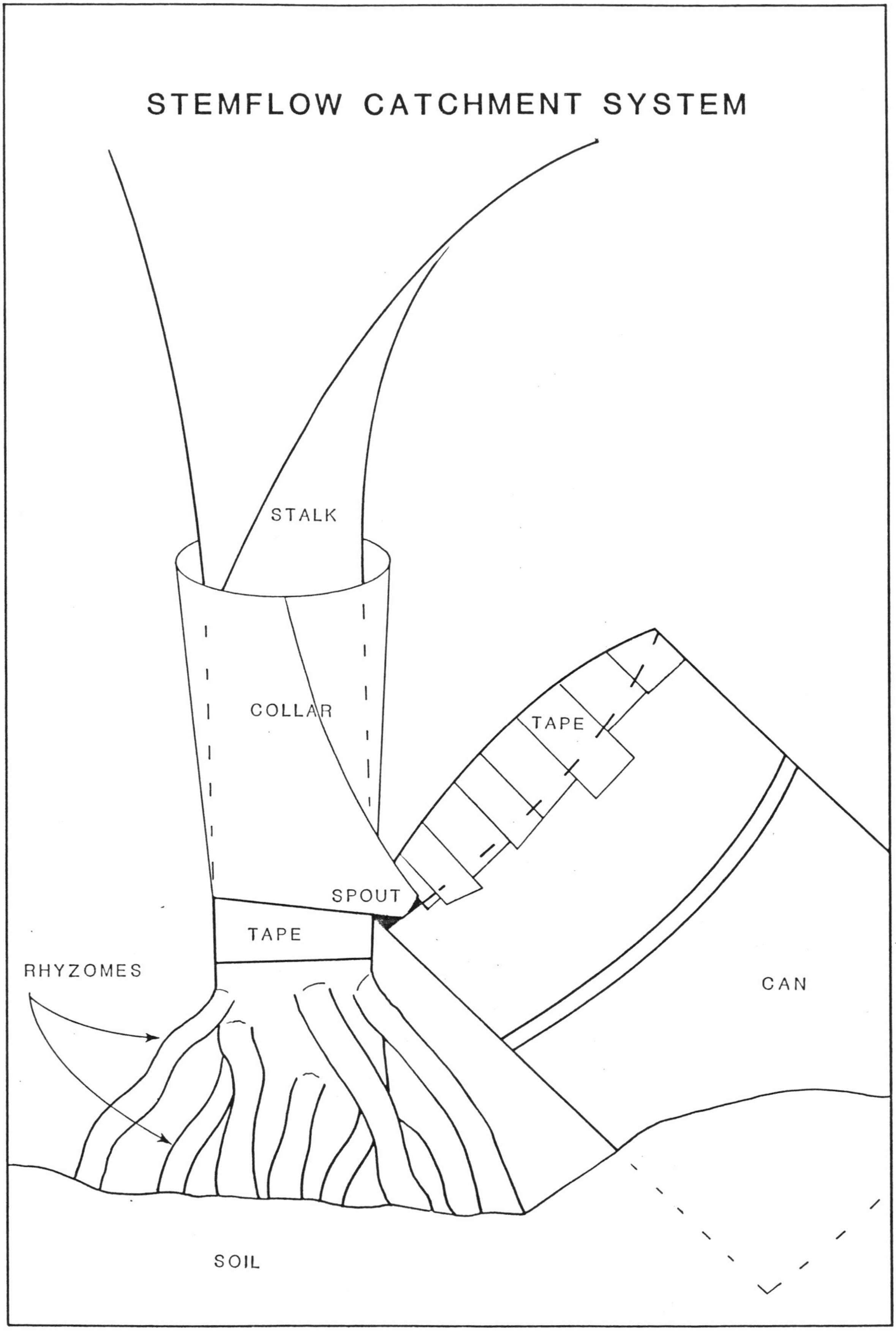

STEMFLOW CATCHMENT SYSTEM
STALK
COLLAR
TAPE
SPOUT
TAPE
RHYZOMES
CAN
SOIL

FIGURE 7

gross precipitation. The same type of gauge was used to collect throughfall, which is precipitation that directly impacts the ground beneath the crop canopy. Each test plot was equipped with three collectors for measuring throughfall (Figure 6). These were randomly placed on the ground in an effort to achieve accurate sampling.

A one meter square grid, divided into one hundred one square decimeter sections, was positioned on the ground covering a section of the number one test plot (Figure 6). A rod could then be positioned perpendicular to the grid at each decimeter corner. Where the rod touched a stalk or blade, that point was considered covered by the crop. All one hundred points were tested on each site visit to arrive at a representative percentage of crop cover for the field.

A hygro-thermograph was placed in a U.S. Standard Weather Shelter and subjected to unrestricted air flow. The recording graphs were changed weekly. Averages of daily temperature and daily relative humidity were computed from the graphs. Also inside the station were two thermometers. The station was located near the T.W. Bowers farmstead (Figure 5).

The weather station, test plot equipment and outlying rain gauges were checked every other day starting June 1, 1981 and continuing through August 1, 1981. The generated data provides a continuous record of moisture variables for a large part of the growing season. The following variables were observed for each test plot:

(1) Stemflow, in cubic centimeters, with two observations or more per plot in five plots,
(2) Percent soil moisture at six, twelve, and eighteen inches below surface,
(3) Three throughfall measurements,
(4) Crop height in inches, and
(5) Crop cover in percent.

For overall test site conditions, the following variables were recorded:

(1) Relative humidity,
(2) Temperature,
(3) Three gross precipitation readings.

Throughout the growing season crop conditions such as plant size, growth, shape, and aging were noted as they related to stemflow and/or soil moisture.

The 1981 Corn Crop

Corn at the study sites was planted in mid-April 1981. The field was prepared using normal tillage equipment and methods, except that only small ridges were formed. By the time the crop had been cultivated and sprayed there were no ridges and furrows, the surface was relatively uniform. After the last sprayings, for weed and insect control, were completed the Buoyoucos gypsum blocks were implanted and the test plots established. A hybrid seed corn, Pioneer 3184, was planted in the field where test plots one, two, and three were eventually located. Dekalb XL34 was planted three weeks before in the adjoining field where plots four and five were located. The earliest planted corn had reached a height for forty inches by June 1, 1981. Though planted later, the field of corn containing plots one, two and three grew extremely rapid, so that by June 13 both stands were approximately the same height. Both hybrids then developed and matured at a similar rate throughout the remainder of the season. The first tassels appeared by June 14, and by June 29, ears were forming. The plants in both fields reached maturity the first week of July. At this time, plant height and foliage cover had reached their maximum development. Heights ranged between 8'6" and 9'. The crop covered at least ninty two percent of the field surface area with the greatest percentage of cover being ninty six percent at plots one, two, and three. The crop was harvested in early September with a yield of 160 bushels per acre for both hybrids, according to Mr. T.W. Bowers, the owner. Neither hybrid showed signs of stress at anytime due to a deficiency in moisture.

Precipitation was spread evenly throughout the two months of record. A total of five rainfall events were of over one-half inch (12.7 mm.) accumulation. There were three light rains (0.25 - 2.54 mm.). The crop received a total of 6.3 inches (160.0 mm.) of precipitation between June 1 and August 1. In addition, soil moisture content readings were more than ninety percent for all the test plots when recording began, indicating a wet Spring month. Soil moisture was not as uniform as precipitation throughout the study period, but fluctuated greatly. Each rainfall event increased soil moisture to one hundred percent although the gypsum blocks showed approximately a one day lag in measurement response. Afterwards, soil moisture decreased in various amounts. Late July was accompanied by the highest evapotranspiration demands of the season causing water, available for the plants, to be almost nil. By then, however, the corn had fully matured and subsequent crop production was not damaged.

CHAPTER IV

OBSERVATIONS OF PRECIPITATION PATTERNS

In Chapter II a new model of precipitation distribution was developed. This Idealized Model (Figure 3) depicts a basic precipitation distribution framework. Into this framework, measurements representing the variables of stemflow, throughfall, and plant detention can be added. In this chapter, the Idealized Model (Figure 3) will be graphically presented to portray each of the recorded rainfall events of the observation period.

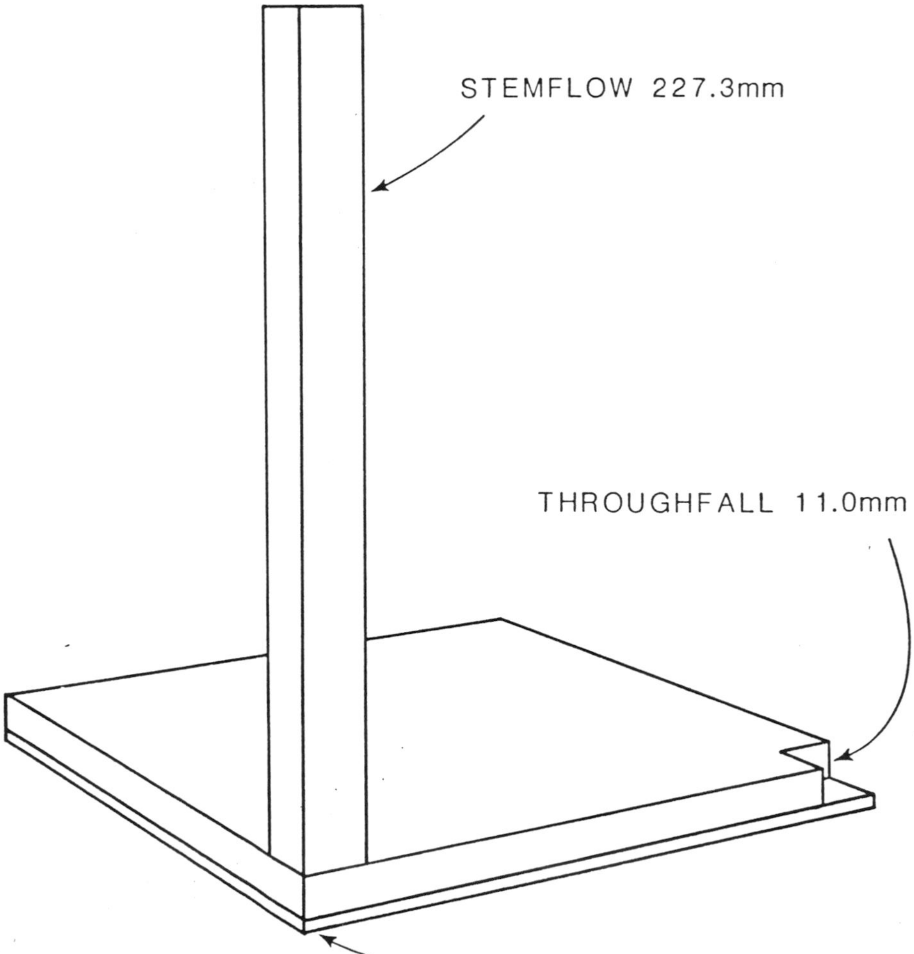
For each rainfall event, gross precipitation and two of the three idealized model variables, stemflow and throughfall, were measured. These measurements were converted to area/depth values. Plant detention was determined by subtracting stemflow and throughfall from gross precipitation. Originally, plant detention was not considered. As the maize stalks cover the ground area, plant detention tends to be spread evenly over the one meter section. With the four "water" variable measurements in their appropriate area and depth amounts, each rainfall was graphically illustrated using the Idealized Model form (see Figure 3). The nine rainfalls and the resulting pattern of water distribution are shown by date of occurrence. The values used in the illustrations are the result of a number of samples. These samples were taken from the five test plots and then averaged. Each variable shown had at least 14 sample readings. The drawings of the rainfall events suggest a pattern of precipitation that impacted the soil surface for a given maize stalk in the field. As the illustrations show, each rainfall event was unique.

There were nine measurable rainfall events recorded during the period of time from June 1 to August 1 which comprises the data base. The largest precipitation event in terms of amount of gross rainfall was 50 mm., (approximately 2 inches) which occurred on July 6. There were five additional rainfalls of over 11 mm., (approximately .5 inches) and three rainfalls of relatively small amounts (0.25 - 2.54 mm.).

First Rainfall Event

The first measured rain amounted to 18.0 mm. (.73 inches) (Figure 8). This is an average value derived from all the rain gauges located in the test area. The maize had reached between 48 and 54 inches in height, with the first large wide blades reaching across the rows to touch the adjacent plants. This type of plant structure produced a very noticeable funnel shape. The blades on the upper most section of the stalk were the widest with a considerable surface area sloping toward the stalk. A total of 227 mm. of stemflow was collected relative to its impacting surface area which is a square decimeter. Again, this is an average value based on a number of sample

JUNE 7, 1981



DUE TO SIZE CONSTRAINTS AREA/DEPTH VALUES
ARE PORTRAYED AT HALF THE LABELED VALUE

FIGURE 8

readings. Throughfall quantities were 11 mm., which is significantly less than the gross precipitation of 18.0 mm. This was postulated to be a result of the interception by the maize blades of the rain drops that would have reached the soil surface at a distance of 25mm. - 305 mm. (1 - 12 inches) from the stalk. Plant detention constituted only a small portion of gross precipitation. In this instance, it is assumed that the shape and orientation of the primary blades effected plant detention. The blades at this time were funneled inward towards the stalk. A majority of the water drops that struck the blades did not remain there, but gravitated toward the ground either to add to throughfall, or in this case, to stemflow.

Second Rainfall Event

The precipitation distribution pattern of the June 19 rain was very different from the June 7 event. In this case, 1.71 inches (43.6 mm.) of rain was recorded. This rainfall event was intense but of short duration, typical of a summer thunderstorm. While gross precipitation was significantly greater than June 7, stemflow was much smaller at 79.9 mm. (Figure 9). Throughfall, on the other hand, was twice as much at 22.3 mm. Plant detention was several times that which occurred from the June 7 rainfall. Because the totals of the water distribution variables from the June 19 event was different from the

JUNE 19, 1981

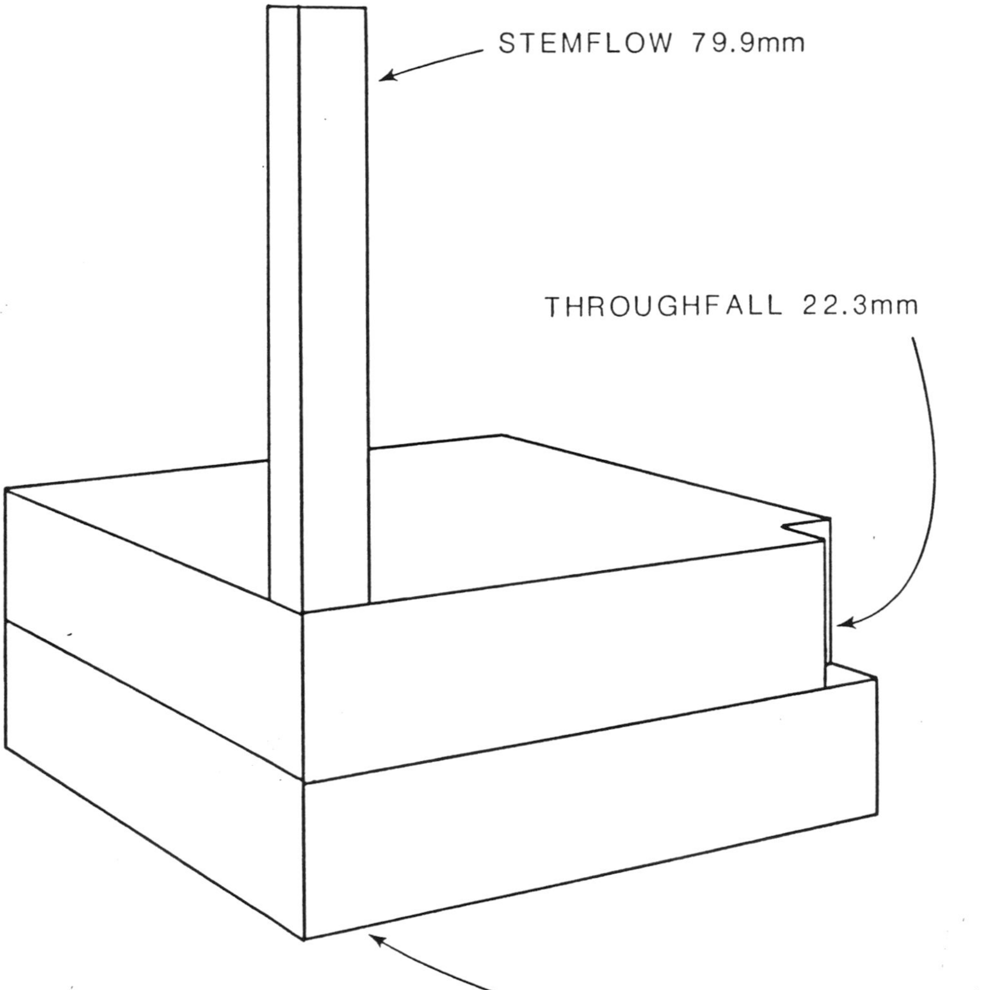
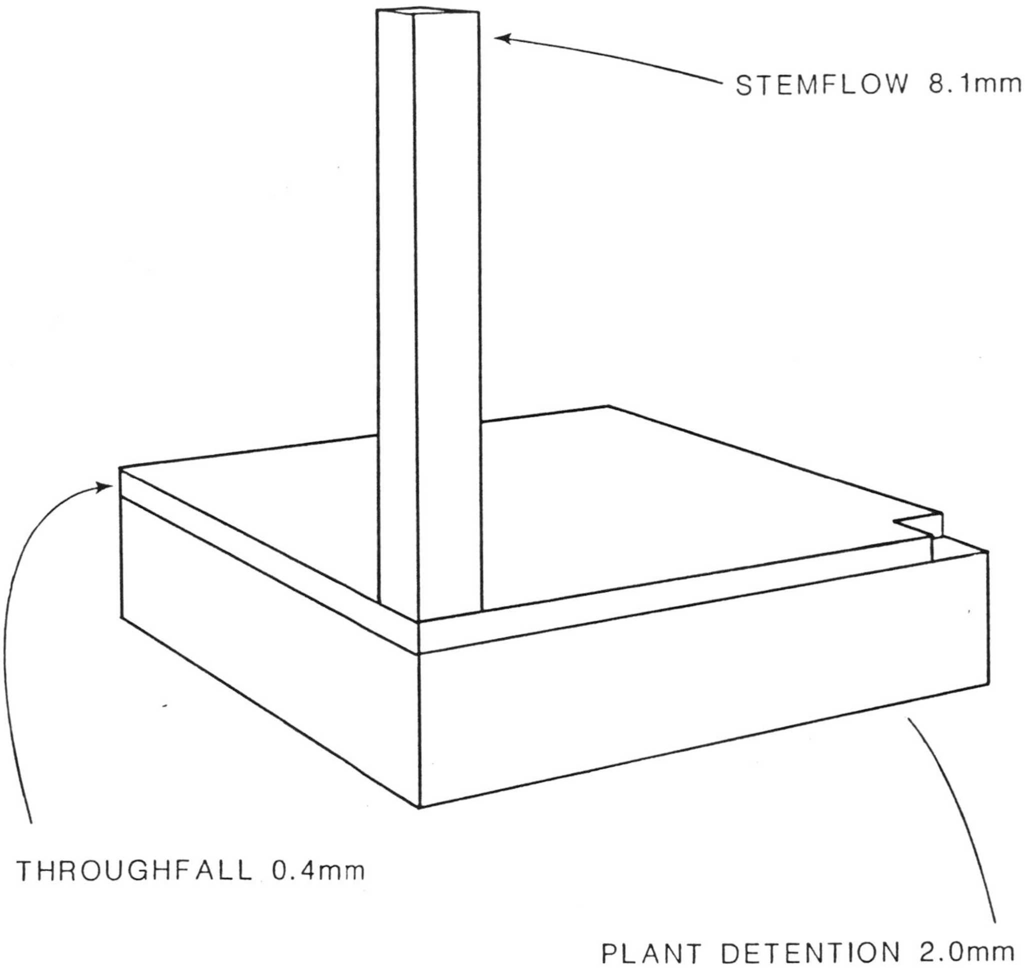


FIGURE 9

earlier rainfall, it can be suggested that rainfall intensity is a major variable in determining stemflow efficiency. For example, typical eastern North Carolina thunderstorms usually begin with large raindrops which acquire considerable velocity, sufficient to bend or bounce off the maize blades and pass to the ground. Consequently, throughfall is increased as stemflow is decreased during high intensity rainfall events. As the storm wanes the size and speed of the raindrops decrease. The blades withstand impact of the latter, redirect this water, and contribute more to stemflow, but less to throughfall. During final stages of the storm event, mists or sprinkles fall. These types of moisture are not sufficient to move down the blade either as stemflow or throughfall. Also, these droplets are detained on the blade surface due to the coarse textured surface of the blade. In this situation, plant detention comprises a major portion of the available water from the remaining rainfall. The thunderstorm activity that produced the June 19 rainfall is postulated to have contributed to the resulting pattern of fairly even water distribution among all variables.

Third Rainfall Event

The rainfall of July 2 was very light (Figure 10). A depth of 0.1 inches (2.5 mm.) of gross precipitation was recorded. In this case the plant intercepted a majority of the rain that fell. Only a trace of throughfall was



JULY 2, 1981

FOR CLARITY AREA/DEPTH VALUES ARE PORTRAYED x10
TO THAT OF THE PREVIOUS DRAWINGS

FIGURE 10

measured (0.4 mm.). By this time in the growing season the maize stalks, and blade were at their peak size and percent surface cover. The blades touched and in some instances overlapped between rows. Here is an example where the plant physiology radically effects the pattern of precipitation distribution of the soil surface. Stemflow accounted for 77.1% of all water measured. This stemflow was directed to the soil surface in the immediate vicinity of the roots of the stalk where it could potentially be utilized by the plant. Of the small volume of water that fell, little was wasted. This indicates that maize, originating in the Southwest United States as a grass in a dry climate, has survived through its evolving physiology.

Fourth Rainfall Event

On July 6, two inches (51 mm.) of rain fell, the largest amount for the season of record (Figure 11). A period of intermittent showers, at times heavy or light, produced a typical pattern of variables. Stemflow totaled 129.8 mm., throughfall was 24.1 mm., and plant detention amounted to 24.0 mm. This precipitation episode saturated the soil at each test site to a depth of at least 18 inches beneath the surface. Saturation occurred between the rows and under the plants in the test beds.

Fifth Rainfall Event

Another rain shower was recorded on July 8 (Figure 12). The shower was at the end of a wet weather period in

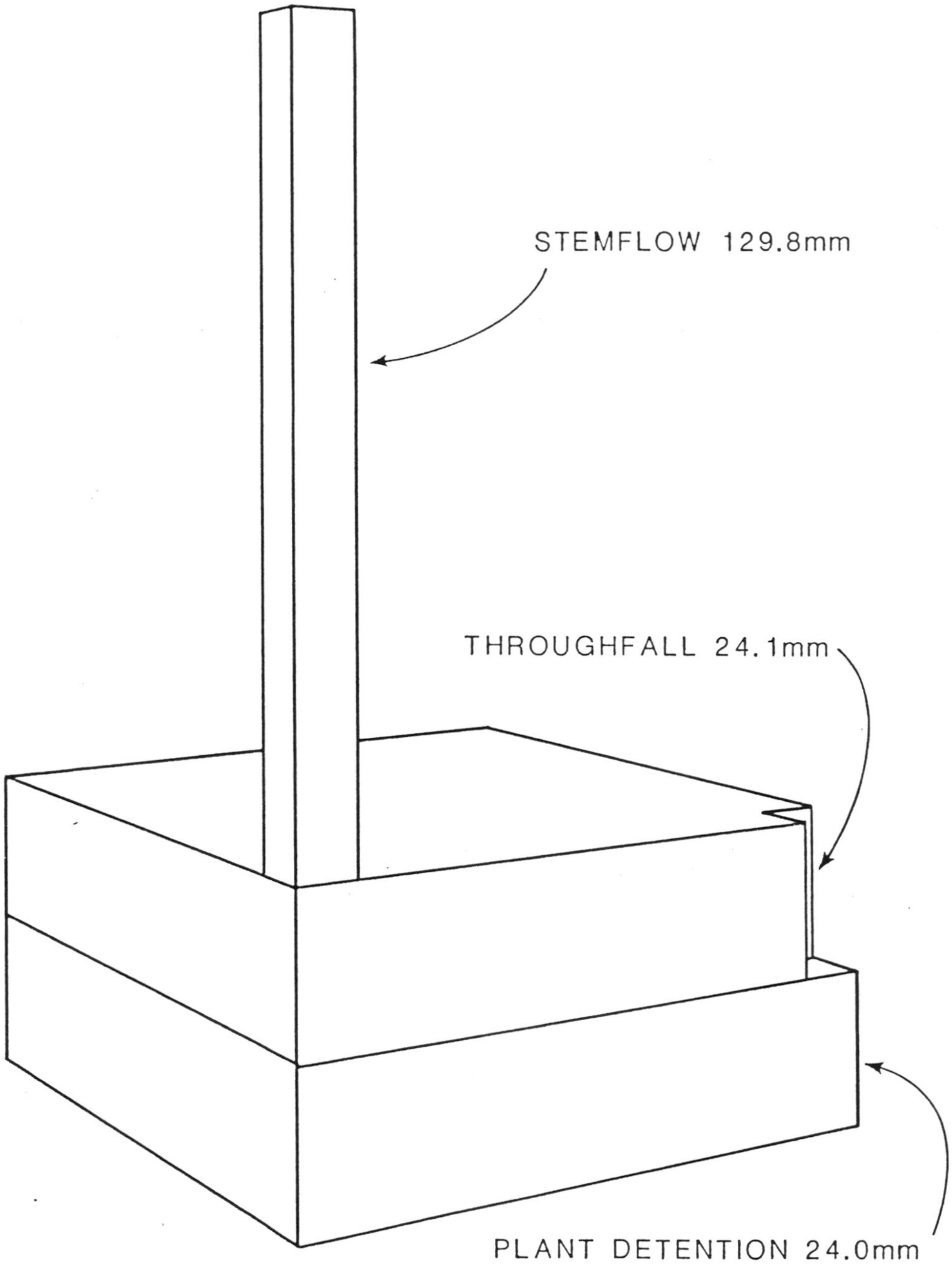
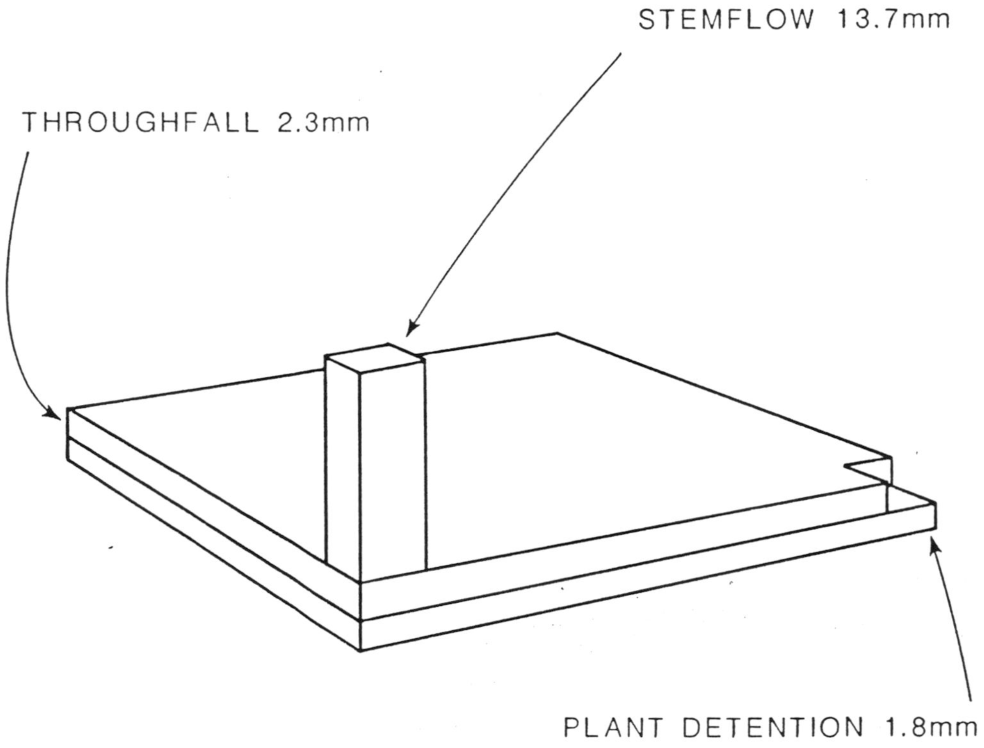

JULY 6, 1981

FIGURE 11

JULY 8, 1981



FOR CLARITY AREA/DEPTH VALUES ARE PORTRAYED x2
TO THAT OF THE PREVIOUS DRAWING

FIGURE 12

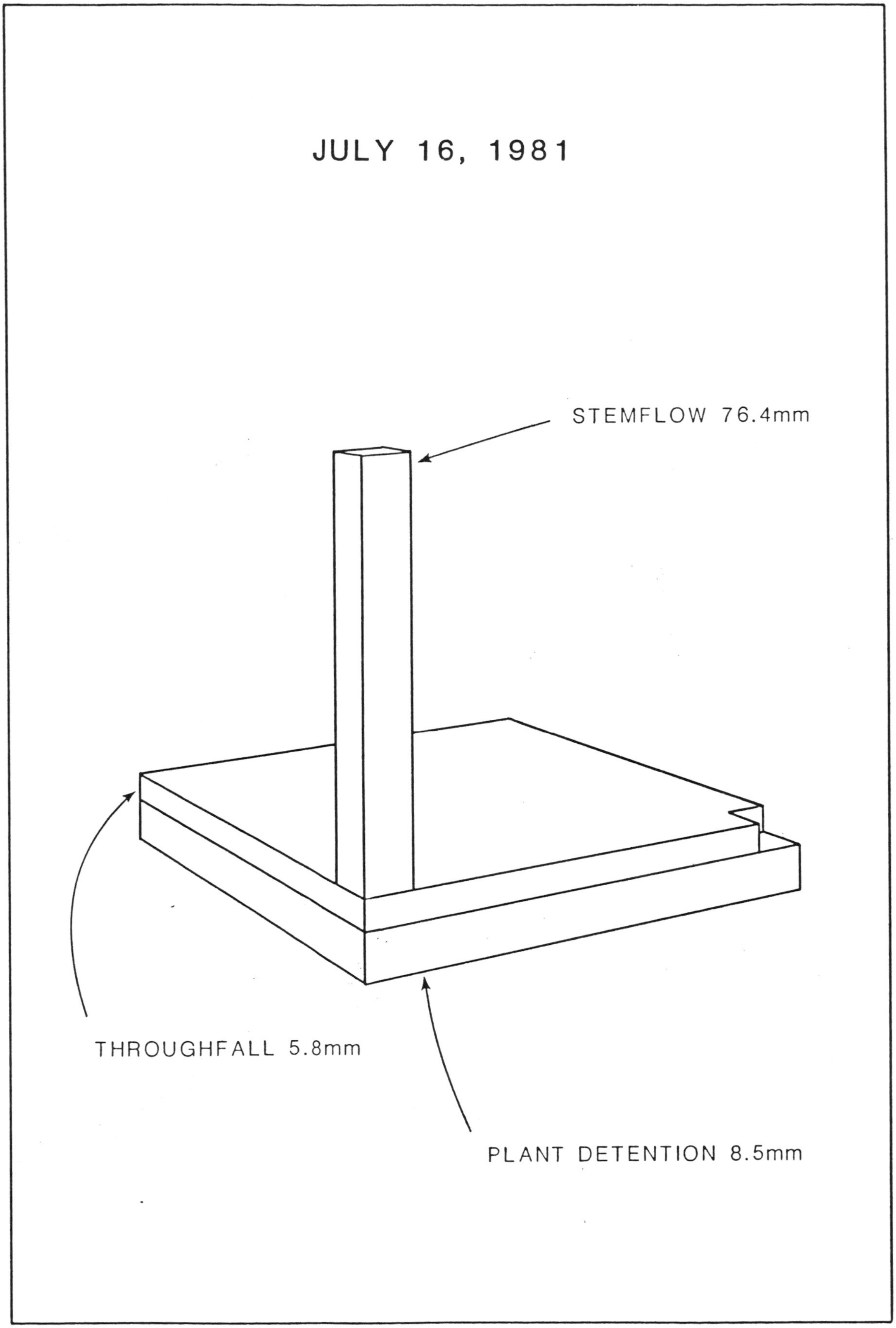
the first week of July. The crop was developing the ears and kernels at this time. Water is needed to "flesh out" the kernels. Again, stemflow contributed a majority of the water available to the plant. It is at this critical time in the growing season that the crop must receive adequate water. Temperatures are high and sunlight can be intense. Moisture demands are at their greatest for the season. And for plant maturation, water must be available for proper ear formation. Figure 12 illustrates the amelioration pattern of water potentially available to the plant.

Sixth Rainfall Event

The rain shower of July 16 (Figure 13) fell upon the maturely developed maize stalks creating a standard or common picture of water distribution occurence. There was 0.6 inches (15 mm.) of rain recorded. Plant detention was greater than throughfall (8.5 mm. to 5.8 mm.). The stalks and blades were fully extended and the stalks laden with ears. This spread the blades to their maximum extent. In the fields, the investigator had to crawl under a maze of blades to reach the test plots as the blades were thickly intertwined. This being the case, the decreased amount of throughfall for a given rainfall event is not surprising.

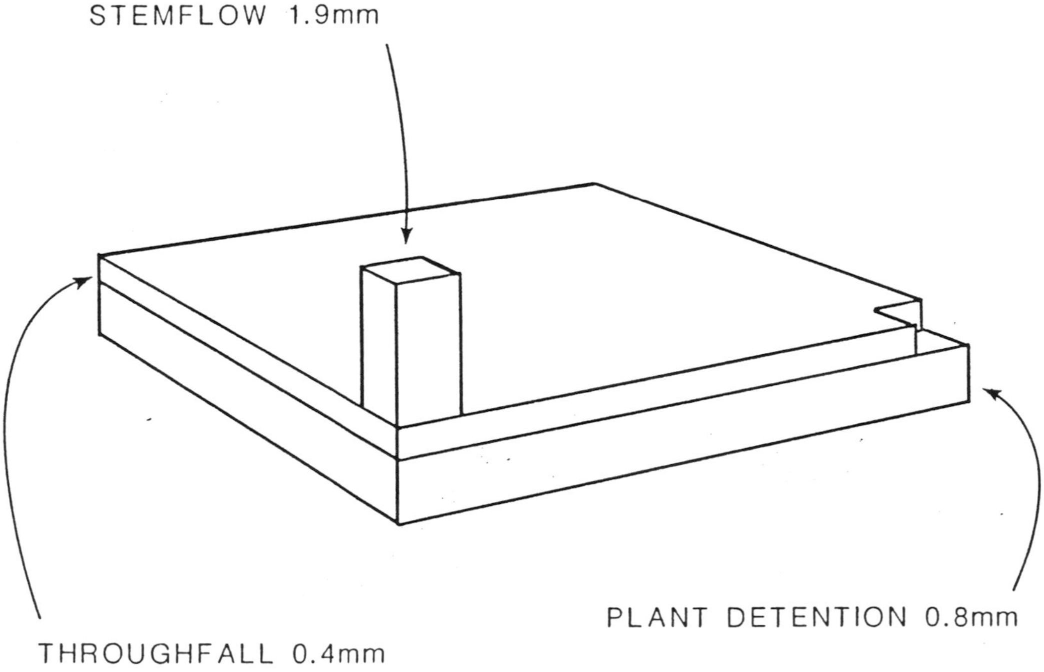
Seventh Rainfall Event

The rainfall distribution for July 18 (Figure 14) portrays the lowest values that could be recorded with the equipment used. Even with only a trace of precipitation in



JULY 16, 1981
STEMFLOW 76.4mm
THROUGHFALL 5.8mm
PLANT DETENTION 8.5mm

FIGURE 13



JULY 18,1981

FOR CLARITY AREA/DEPTH VALUES ARE PROTRAYED x10
TO THAT OF THE PREVIOUS DRAWING

FIGURE 14

the rain gauges, the same pattern of the sixth rainfall event emerged with stemflow being larger in terms of an area/depth value, than either throughfall or plant detention. It is interesting to note that although the amounts of water described are minimal, in the case of plant detention, the investigator became thoroughly wet from the knees up just trying to reach the test plots. This event was similar to the fifth rainfall event in that if followed a wet period.

Eighth Rainfall Event

The July 22 event is a good example of stemflow efficiency on (Figure 15). A fully developed mature maize crop, just before the onset of the drying stage yielded stemflow amounts 15 times that of the other moisture variables. In this case, a half inch of rain occurred in a steady shower allowing the plant's structure and field cover to capture incoming water.

Ninth Rainfall Event

The July 30 rain event occurred at a time when the ears had fully matured (Figure 16). Water demand was reduced and, in fact, the maize was needing to dry its seed to prevent rotting. The blades drooped and percent crop cover was about 60% of the peak coverage. Consequently, the throughfall increased (10.5 mm.) relative to plant detention (3.3 mm.). Stemflow remained high (121.1 mm.). When compared to the previous rainfall event this pattern

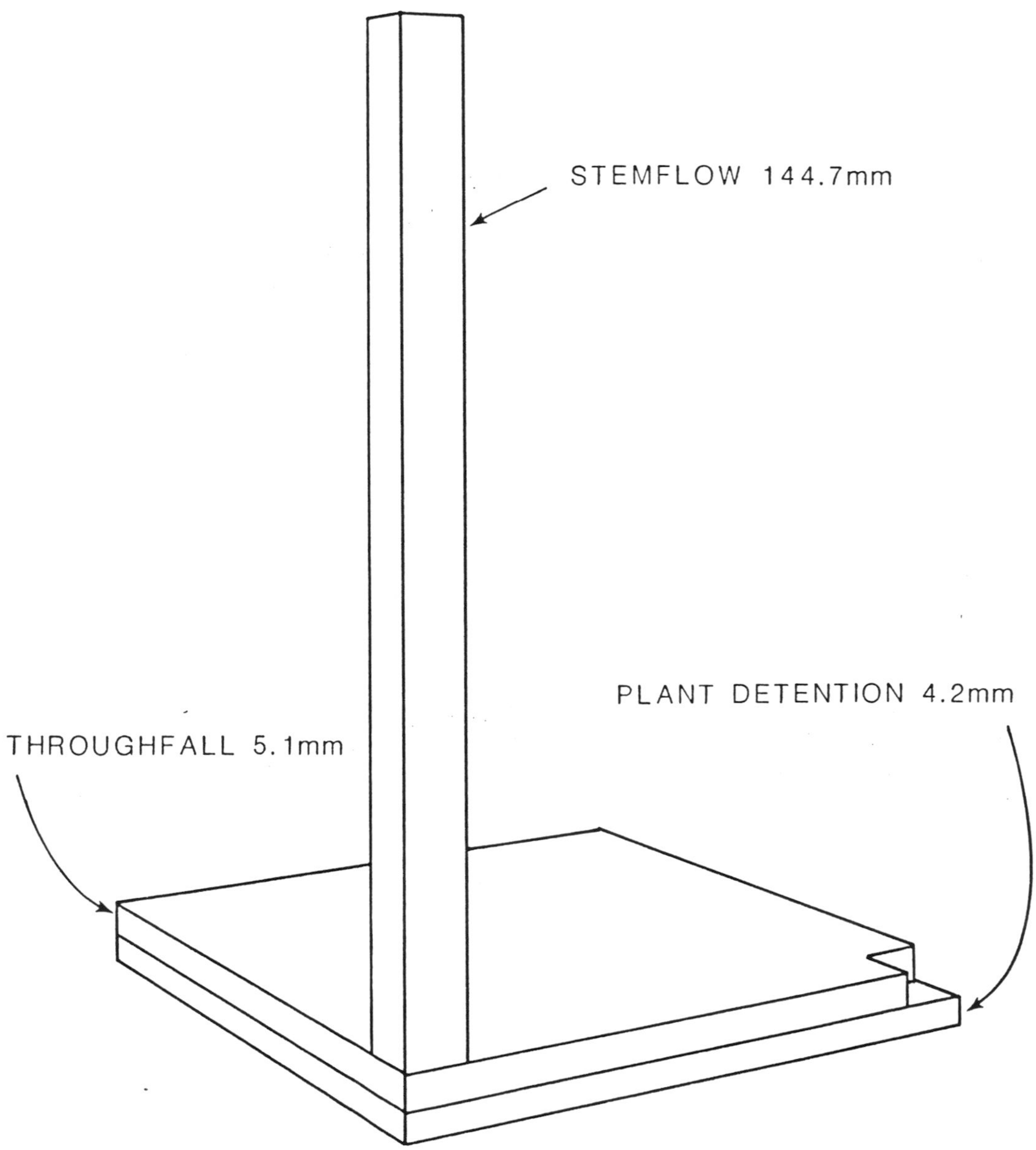
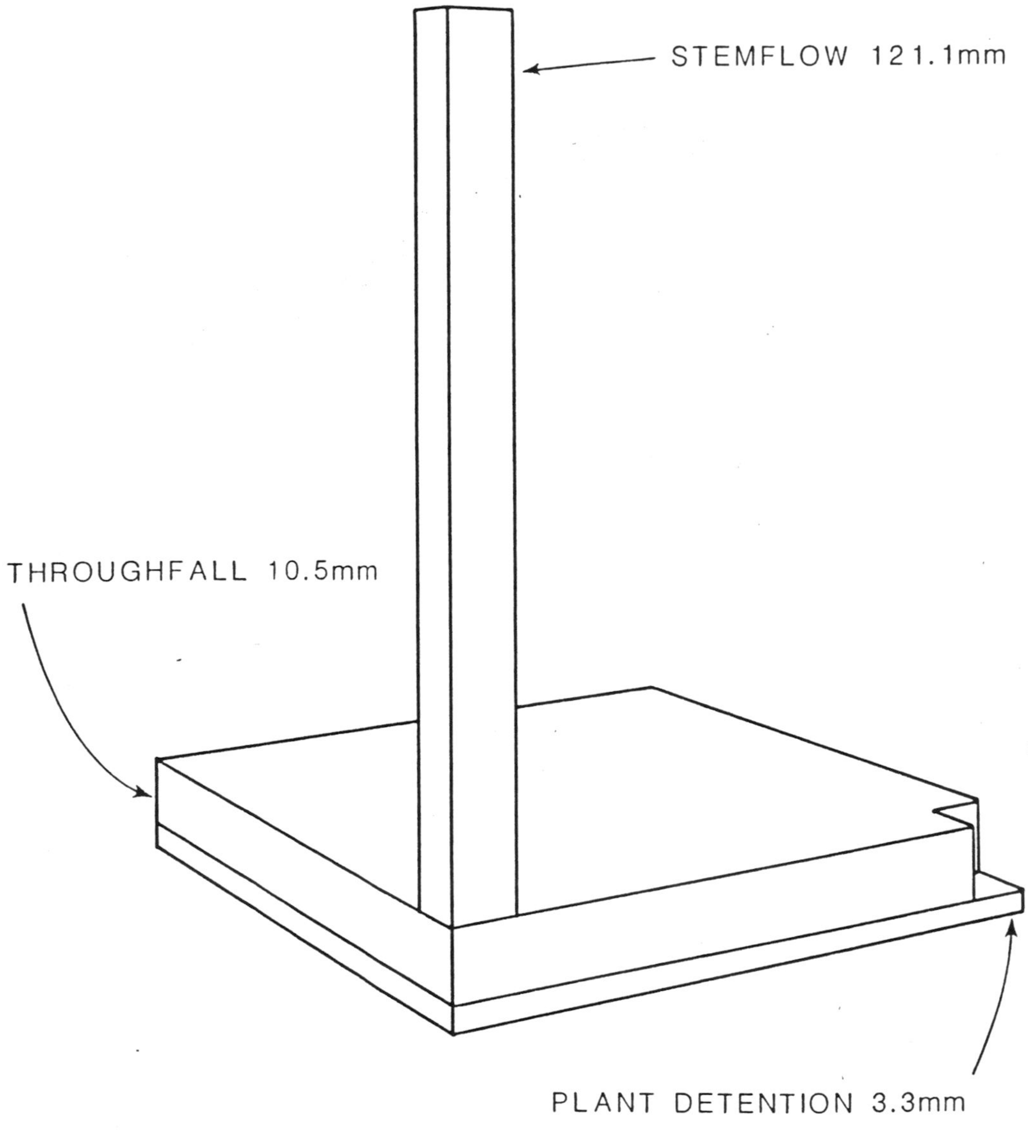

JULY 22,1981
STEMFLOW 144.7mm
PLANT DETENTION 4.2mm
THROUGHFALL 5.1mm

FIGURE 15



JULY 30,1981

FIGURE 16

shows that a decrease in stemflow is related to an increase in throughfall which commonly develops as the stalk starts drying out and the blades droop down. These two rainfalls had approximately the same amount of gross precipitation, yet stemflow was greater on July 22. A total of 0.43 inches (10.9 mm.) fell on July 22 and 0.60 inches (15.2 mm.) on July 30.

Summary

With the Idealized Model (Figure 3) providing the framework, measurements of the moisture variables have been added. The illustrations show each variable in their appropriate position of impacting the ground surface, and in their proper amounts. Through the course of the summer a common pattern emerged, in that stemflow was found to be of greater volume than both throughfall and gross precipitation as per the area of impact. A number of rainfall events had stemflow quantities several times that of the other variables. Three events showed this large difference (Figures 8, 15, and 16) . These observed patterns support the conceptual models in Chapter II.

CHAPTER V

CONCLUSION

Stemflow, as a variable in interception studies has not been widely studied. There are several reasons for this, such as time and expense. The difficulty of measuring stemflow is another. This problem is compounded when a non-permanent plant, such as maize, is studied. These problems tend to produce measurement problems related to stemflow. As a consequence, there is a common conceptual model of precipitation (see Figure 1), but in which stemflow is an underestimated and/or hidden variable. Data gathered from four different years of record aided in formulating a new conceptual model with the water variables, appropriately arranged as to the soil surface and each other (see Figure 2). A final model simplifies the new model (see Figure 3).

There are four additional concepts concerning stemflow. These are derived from the 1981 data base and the three prior years. They deal with stemflow as it relates to the other parameters in the precipitation soil system. The concepts are as follows:

(1) Soil moisture recharge potential changes with respect to the impact area of stemflow and throughfall in all directions away from the basal perimeter of the maize plant (see Equation 4),

(2) Seasonal soil moisture recharge tends to decrease with distance from the basal perimater of the plant (see Equation 5),

(3) Stemflow efficiency is related to the unit depth stemflow divided by the unit depth precipitation and precipitation intensity (see Equation 6), and

(4) Total water available for plant use exceeds both gross precipitation and throughfall indices (see Equations 7 and 8).

The new model of precipitation distribution (Figure 3) was formulated to graphically illustrate each rainfall event. Each event produced a unique pattern of precipitation. However, a common trend emerged from the nine illustrations. Stemflow was measured and found to be a large contributor of water impacting the soil surface with respect to its areal extent. The results enhanced the concepts previously stated above.

After most studies are completed, one question inevitably arises: Where to go from here? In this study a new conceptual rainfall distribution model was formulated and stemflow was identified as an important variable of the model. The next step is to observe and measure a greater number of stalks for stemflow and throughfall. With an increase in data, testable hypotheses can be formulated. The horizontal and vertical movement of water that has impacted the soil surface would help determine how much the plant consumes. With a larger number of observations statistical tests could tell us if what we believe occurs is true, with some degree of significance. Atmospheric variables should be recorded as they relate to the rainfall being measured. In particular, precipitation intensity and its effect on stemflow should be explored. The expense of such equipment to measure intensity has limited research thus far. Researchers must constantly observe and monitor all the field equipment during showers. It is suggested that frequent checks be made of stemflow and throughfall collections so that the conceptual models can be tested.

Armed with additional research, models can determine how a maize crop could best be irrigated. The quantity of water and precisely where this water should be applied to the crop will allow better efficiency of the water used. This is especially important since the human population is greatly increasing, and with it the need for food, while the supply of useable water is not.

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