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Introduction and Notes

This issue of *THE ICAC RECORDER* presents another paper from the Cotton Forum celebrating the Tenth Anniversary of CONALGODON in Santa Marta, Colombia, August 30 to September 1, 1990. The complete proceedings of the Forum are being published in Spanish by CONALGODON, Carrera 7a, No. 33-42, Piso 6, Bogota, Colombia, Fax 287-6820.

- A regional technical meeting of the Cotton Network for the Mediterranean and Middle East is planned for May 13, 1991, in Montpellier, France, on the use of Artificial intelligence for Expert Systems. Presentations will be made by Doron Nevo (Israel) on expert systems for weed control in cotton; Benoit Girardot (France) on the BASEFLO system and the basics of LOGENTO data; and by Pierre Grard (France) on the PANTROP and DIACOT systems. On May 14 there will be a meeting of the Integrated Weed Control working group of the Network. From May 14 to May 17 a congress on how to use artificial intelligence will be held in Montpellier. Contact for additional information: Michel Braud, IRCT, 6 rue du Général Clergerie, 75116 Paris, France, Fax 47-55-46-21.

- The Third Meeting of the Latin American Association for Cotton Research and Development has now been rescheduled to August 19-23, 1991. The meeting will be held at FIEP (the Industrial Organization of the State of Paraíba) in Campina Grande, Brazil, under the Chairmanship of Dr. Agostinho Veloso, President of FIEP. Dr. Edgar J. Barbosa Arp will serve as Vice Chairman. One of the topics of the meeting will be the use and misuse of HVI technology. Contact for additional information: Raimundo Braga Sobrinho, EMBRAPA/CNPA, Rua Osvaldo Cruz 1143, Caixa Postal 174, Campina Grande, Brazil.

- The Technical Seminar at the 50th Plenary Meeting of the ICAC, to be held September 9-13, 1991, in Antalya, Turkey, will be on the topic, "Growing Cotton in a Safe Environment." A number of speakers will discuss efforts to develop less environmentally-sensitive production technologies for cotton, ways of environmental monitoring and self-regulation, government programs and regulations to ensure environmentally sound crop management strategies and programs to communicate with society about these issues. Countries are also being asked to present information on national programs relating to the topic of the seminar.

- Dr. Mohammad Rafiq Chaudhry has been appointed Head of the Technical Information Section of the Secretariat of ICAC. Dr. Chaudhry has been the Director of Research at the Pakistan Central Cotton Committee in Karachi since 1986. Previously, he was Senior Scientific Officer at the Cotton Research Institute in Multan, Pakistan. Dr. Chaudhry, who will take up his duties at ICAC in early May, is a specialist in plant breeding and genetics. He replaces Kees Verbeek who has returned to the Netherlands to take a position with the Netherlands Economic Institute, Rotterdam.

Water Management for Upland and Pima Cotton

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Introduction

Management of water in arid environments has been a critical feature for agriculture for many centuries. This is evidenced by the remains of ancient cultures from the desert Southwest, that left behind elaborate irrigation systems which supported a relatively extensive agricultural operation. The people and their culture seemingly disappeared, leaving behind the artifacts of their systems. It is speculated, for example, that the demise of this culture may have been due in part to the inability to provide consistently adequate amounts of irrigation water to their crops, or to the inability to manage salt accumulations in their agricultural soils. Both of these problems continue to plague modern agriculture, including cotton *(Gossypium* spp.) production in this region today. Therefore, the objective of this paper is to briefly review and outline some of the basic principles and tools we now have at hand for managing water in terms of both quantity and quality.

Irrigation Scheduling

There are many different methods or systems available for scheduling irrigations in cotton that range from pure science to pure art. In reality, those systems that are most successful and most efficient develop some optimal blend of science and art. One very important aspect of irrigation management is that one must consider both the unique characteristics of the soil and the plant. Ignoring the soil and focussing solely on the plant (or vice versa), will severely limit any irrigation management program. In this regard, one must consider the soil and its water holding capacity and the relation of the soil-water content at any time in conjunction with its effects on cotton as a function of stage of growth and environment. This is not an easy task to accomplish, and it is often compounded by not only the question of when or how much water to apply but also the problem of availability of water and its delivery in a timely, effective manner.

Consumptive Use Patterns

The water required by a crop at a given time depends on soil physical properties in a given field, weather patterns the variety, the quality of water being used to irrigate, the efficiency of water delivery, and ---- very importantly ---- upon the stage of growth of the crop. Characterization of crop water needs has been in development for a number of years. Erie and his associates have published general consumptive use patterns for cotton (Erie et al., 1965 and 1981) and a number of other crops. These are referred to as general in light of the fact that consumptive use rates by cotton have been shown to vary considerably across various locations. For example, optimum yields in cotton often require over 40 inches of water in furrow irrigated full season production systems of the desert southwest, while optimum yields may require only 30 - 35 inches in more humid regions of the mid-South and Southeast cotton belt. Therefore, generalized consumptive use rates need to be regionally specific for application in an irrigation management system. Although, consumptive use rates in cotton may vary among regions, much of the information provided by Erie in 1965 is still pertinent to cotton production in Arizona today. Erie’s studies showed the classic consumptive use pattern of low water use early in the season increasing to about 0.2 inches per day at first bloom, a peak use of about 0.4 inches per day at peak bloom, and then a gradual decline in use rates with a total seasonal use of approximately 41 inches. Erie and his associates were also able to show that about 60% of the water consumed in the production of the cotton crop came from the top two feet of soil, nearly 75% from the top three feet and only 10-15% was removed from the five to six feet levels. Recent soil water depletion studies have confirmed these general patterns for Upland cotton (*G. hirsutum L.),* with slight increases in water removal rates from lower portions of the profile in Pima cotton (*G. barbadense L.)*

Weather Based Scheduling

Another term that is often used somewhat synonymously with consumptive use, is evapotranspiration (ET). The ET refers collectively to the soil evaporation loss of water (E), and to the transpirational (T) loss of water from the crop canopy. It is perhaps a more descriptive term and has been used more prevalently in recent years. Weather has been recognized as the fundamental driving force in the ET process. The weather serves as an indicator or reference feature which actually describes the amount of energy being supplied by the atmosphere (solar intensity, solar angle, etc.) which serves to drive the ET process. Generally speaking, ET is directly proportional to solar radiation, temperature, and wind; while being inversely proportional to humidity levels. Weather parameters such as these can be measured by weather stations, and the resultant data can be referenced for use in determining ET values for cotton.

There are other crop-specific factors that affect ET. Such crop-specific factors are classified as physiological (stomatal control of water loss) or morphological (stomata[exposure and density, cuticle thickness, crop geometry, stage of growth, etc.). It turns out that stage of crop development and crop geometry are very important in terms of crop ET values (Brown, 1989).

In practice, ET values are calculated based upon weather data, a crop coefficient (specific for the crop and stage of growth), and a reference ET value (ETo) (Brown, 1989) . The ETo value, by definition, is the water lost by the combined process of soil evaporation and plant transpiration from a three to six inch tall cool season grass surface that is well watered. For example, this could be a tall fescue rough on a golf course. The ETo applies to the reference crop because it is relatively constant.

In Arizona, a statewide agricultural meteorological network (AZMET) utilizes weather station data from many sites, and calculates ETo values hourly by use of the Modified Penman Equation. Crop coefficients are simply factors used to convert ETo values to actual crop ET values. Such crop coefficients (Kc values) have been developed for cotton at various important stages of crop development. An actual ET value can then be calculated by simply multiplying the Kc x ETo for daily or weekly estimates of crop ET. The ETo values can be easily accessed on a daily or a weekly basis through the computer based-system, AZMET. Therefore, water management in Arizona cotton production can be facilitated by the use of real-time weather data and crop use estimates (Brown, 1989).

Infrared Thermometry

The use of infrared thermometry has become a recent tool under development for irrigation scheduling of crops including cotton. Most infrared thermometers that are being developed for agricultural purposes measure light in the 7,000 to 14,000 nm (nanometer) range which is often referred to as the “thermal infrared" region (Slack, 1989). The basis for use in irrigation of crops is the fact that plant transpiration cools the plant surface. In a cotton field, we find that as the soil water is reduced, plant transpiration is reduced, and the canopy temperature increases.

Considerable research has been directed toward the development of this concept into a practical approach for irrigation scheduling (Idso et al., 1981; Jackson, et al., 1981; Idso, 1982; and Clawson et. al., 1989). A common index now in use is the "crop water stress index”(CWSI). The CWSI relates canopy temperature to ambient air temperature by difference (ΔT), and the vapor pressure deficit (relative humidity). Most infrared thermometers in use today measure canopy temperature, air temperature (calculate a ΔT), solar radiation, and vapor pressure deficit. The empirical CWSI (Idso, 1981) depends on the development of non-stressed baselines for determination. Possible drawbacks with this technique include the fact that the baseline changes as a function of growth stage for each crop, and that CWSI calculations are limited to conditions under which the baselines were developed. Infrared guns and CWSI determinations must also be made near solar noon ($\pm$ 2 hours), under clear sky conditions, and with very low wind speeds. It also does not estimate amounts of water needed by irrigation. However, the technique is easy to use, and has shown some application to cotton production conditions in Arizona for both Upland and Pima cotton (Garrot et al., 1989a; and Garrot et al., 1989b).

A recently established research project in Arizona has attempted to compare the utility and efficiency of irrigation scheduling using three scheduling systems. The systems used include: the Erie system (based upon historic consumptive use curves for cotton), a checkbook system (using daily AZMET weather data, Penman-derived ETo values, and appropriate Kc values), and also irrigation scheduling by use of the CWSI approach using thermal infrared thermometry (Scherer et al., 1989). The results from 1988 revealed essentially no differences among treatments in terms of yield, and slightly higher irrigation requirements for the checkbook system. This work has been continued in 1989, with preliminary results indicating similar yield responses as found in 1988.

Leaf Water Potentials

The actual plant-water status is of ultimate interest in irrigation management and is the focus of systems such as infrared thermometry and use of CWSI values. The CWSI values are plant-related, but in an indirect manner, in that it is essentially a remote sensing device. Another plant-oriented tool that is a direct measurement is the pressure chamber. The pressure chamber measures the leaf water potential (LWP) in bar units, which are always negative values. The basis for these measurements is founded upon the assumption that the tension holding the water in the plant can be offset by applying just enough pressure to cause the plant sap to exude from an excised leaf petiole. In cotton, the youngest mature leaf is often used to make this determination. When this leaf (and petiole) is cut from the plant, the plant sap is held in the tissue by the "xylem water potential," which is essentially the average water potential of the plant cells and xylem (Slack, 1989).

The procedure involves inserting the cut leaf (excised) into the pressure chamber, with the cut petiole exposed externally. The leaf is then subjected to a pressure by a gas (usually N_2) which causes water to exude from the cut at a pressure level called the "point of incipient exudation." This point will be equal to the total water potential in the plant (suction) (Slack, 1989). More complete descriptions of this technique and its principles can be found in Ritchie and Hinckley (1975).

Considerable research effort has been extended towards developing relationships between LWP values in cotton plants and irrigation management needs. A good example of this type of work is that conducted the past few years in California by Stephanie Johnson-Hake and her colleagues (Johnson et al., 1989). Their work has provided for a basis of initiating first irrigations and subsequent irrigations on several varieties of Acala cotton grown extensively in the San Joaquin Valley, with attendant relationships to final yield. This is an excellent demonstration of the use of this tool, and further evaluations on other varieties and species (Pima) in other production areas certainly seems to be warranted.

Soil-Water

Any measurement of plant-water status has some relationship to the soil-water status, which ultimately must be considered to some extent in terms of rates and amounts of irrigation water required for any irrigation event. Accordingly, soil-water measurements have provided the basis for many irrigation management systems. This involves an indirect measurement of the plant-water condition and directly takes into account levels of water available to the plant from the soil. There are many different methods for determining or estimating the soil-water status which include: tensiometers, gypsum-blocks, soil samples for gravimetric water analysis, the "feel" method, and radiation methods (neutron moisture meters). The neutron probe has been a tool which is often considered to be quantitatively more accurate than other measurements of soil-water.

The neutron probe emits fast neutrons from a source and measures slow neutrons. The theoretical basis for water measurement in the soil is based upon the fact that hydrogen (H) atoms are heavy enough to slow down the fast neutrons emitted. The detector then measures (or counts) the number of slow neutrons over a short time period (usually 16 seconds). Essentially, the more water in the soil, the more H atoms, and therefore more slow neutrons will be counted. A basic assumption is that there are no other sources of H atoms present. Soil organic matter (O. M.) can serve as a source of H atoms, but O. M. levels are low in most soils of the desert southwest or any subsoil, so this serves as a reasonable assumption. Most new neutron probes now have software systems that convert slow neutron counts to common soil moisture units (Roth, 1989).

Soil moisture depletion rates and levels are often used from resultant information of tools such as the neutron probe to schedule irrigations. This is a useful technique but requires several measurements per field for overall accuracy and also requires use of radioactive sources, which is a deterrent in some cases for neutron probe use.

It does not remove the fact that soil-water depletion and replenishment levels between irrigation cycles are very important in terms of irrigation rate and management.

Irrigation Water Quality

When considering water management in cotton, the attention is commonly directed toward irrigation scheduling, water rates, timings, and methods of application. However, another very important consideration is that of irrigation water quality, which impacts important soil chemical and physical parameters, which, in turn, has a tremendous impact on the cotton plant. This is particularly true in the desert southwest, where saline and/or sodic soil conditions are a common problem. Growers should be alert to these conditions and their potential in terms of the irrigation management of the crop.

By definition, "a saline soil is a nonsodic soil which contains sufficient soluble salt to affect the growth of most plants adversely." Saline soils are characterized by use of the measure of electrical conductivity from a soil extract (ECe). When the ECe4 mmhos per cm, the soil is classified as saline. Cotton is a crop that is considered to be moderately salt tolerant. Cotton seems to tolerate salt levels up to ECe values of about 10 mmhos per cm. Salt levels above that point begin to exert negative effects on the yield potential of cotton (Table 1). In this case, saline irrigation waters are commonly a cause or contributing factor.

Saline irrigation waters are commonly used without harming a cotton crop. However, care must be taken to provide an amount of irrigation water above and beyond that dictated or required by the plant alone, so as to provide sufficient leaching. This additional amount of water for salt management is often referred to as the "leaching fraction." One must also consider salt accumulation patterns on beds and irrigation patterns, such as alternate row irrigation. It is often necessary to develop a crop rotation program to take fields out of cotton at regular intervals to crops such as wheat, barley, or alfalfa. It is not the crop that is particularly important in this case, but rather the irrigation method. For example, grain and forage crops commonly employ border irrigation which can facilitate removal (leaching) of soluble salts which may be accumulated over time on the beds from furrow irrigation (as in cotton).

Sodic soils are defined as "nonsaline soils which contain sufficient exchangeable sodium (Na) to adversely affect crop production and soil structure under most conditions of soil and plant type." Sodic soils are characterized by soil analysis results which reveal exchangeable sodium percentages (ESP) equal to or greater than 15%. Also, sodium adsorption ratios from a soil extract (SARe) with values of 13 or greater indicate sodic conditions. Since calcium (Ca) and magnesium (Mg) are the other basic cations which commonly dominate the cation exchange complex (CEC) in a given soil, the SARe is calculated as follows from the analysis of a given soil extract:

$$SARe = \frac{Na^{+}}{\left[\frac{Ca^{2+} + Mg^{2+}}{2}\right]^{1/2}}$$

where Na, Ca, and Mg are expressed as moles per liter or mmoles per liter.

Sodic soils are problems in crop production and water management because the excessive Na causes a dispersal or separation of soil particles. The dispersion then results in a "sealing" of the soil which impedes water penetration and soil aeration. These conditions often lead to poor seedling vigor, and stunted, slow growing plants. Many times cotton fields suffering from mild to severe cases of sodic soil conditions are mistakenly diagnosed as being nutrient deficient, particularly in micronutrients (i.e. Zn). Irrigation waters and soils from cotton fields should be sampled, analyzed, and interpreted in accordance to these potential problems.

An inadvertent act of management which can ultimately lead to the development of a sodic soil involves a type of fertilization carried out through the irrigation system. Occasionally, anhydrous ammonia (NH_3) is run into irrigation water to a given field. The anhydrous NH_3 causes an increase in the pH of the irrigation water through the formation of ammonium hydroxide (NH_4OH). As a result of the rise in pH, the following reaction can take place:

$$Ca^{2+} + HCO_3^- + OH^- = CaCO_3 + H_2O$$

The precipitation of the calcium carbonate ($CaCO_3$) removes the Ca from the irrigation water, and often leaves a tell-tale white deposit on the irrigation ditch. The resultant irrigation water is often very clear in appearance, but may carry a high level of free Na which is not offset by other basic cations such as Ca, due to their precipitation. This practice can lead to Na problems and sodic soil conditions through the use of irrigation water that otherwise may be hard originally, but of good general quality.

Fortunately, sodic soils can be reclaimed. Gypsum ($CaSO_4$) applications to sodic soils can result in the following reaction:

$$CaSO_4 + 2\ Na\text{-}\langle SOIL\rangle = Ca\text{-}\langle SOIL\rangle + Na_2SO_4$$

The second step in this reclamation process is to flush (leach) the sodium sulfate (Na_2SO_4), which is soluble, and thus the Na, from the soil system with adequate amounts of good quality irrigation water. Again, this requires irrigation water beyond the basic crop requirement. In soils which are naturally calcareous (greater than 5% free lime), the same process may be accomplished by use of sulfuric acid (H_2SO_4). The H_2SO_4 dissolves the Ca present in the soil and accomplishes the reaction shown after gypsum applications. This is also followed by a leaching step for Na removal.

Table I Salt Tolerance of Selected Crops*

	EC (mmhos/cm. 25 C) by which yield will be decreased:		
Crop	**10%**	**25%**	**50%**
Cotton	10	12	16
Alfalfa	3	5	8
Wheat	7	10	14
Lettuce	2	3	5

From L. Berstein, Salt Tolerance of Plants, USDA Bulletin 283, 1964.

Summary

A review of some basic tools, concepts, and practices which are generally applicable to both Upland and Pima cotton production has been provided. There are many other items and details within each of these categories which are important and worthy of consideration by any interested party. Besides the fact that our skills, technologies, and understandings of soil-plant systems have substantially increased in this age of agriculture and cotton production, irrigation management remains an item of paramount importance and continued focus. It is also true that those individuals who are the most efficient and successful water managers are those that incorporate proper levels of science and technology with the age-old and irreplaceable factor of art. Without a "feel" and understanding of the system as a whole, any approach to water management will be incomplete. It is that artistic component that still makes the farmer the unique and special factor in modern irrigated agriculture.

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