Irrigation Rate Calculation for Nursery Crops

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Determination of the irrigation rate based on the concept of potential evapotranspiration has gained full recognition and is widely applied in agriculture. The atmospheric approach for irrigation rate calculation rests upon firm physical principles, is based on well-researched models, and with the help of available high-tech equipment, lends itself to unattended operation. Application of irrigation rates determined on this basis prevents over watering and leaching of nutrients, particularly NO_3, from sandy nursery soils. An automated system of weather data monitoring and irrigation rate calculation for operational use in forest nurseries (developed at the Ontario Forest Research Institute) is based on existing equipment (sensors and micrologger) for monitoring air temperature, global solar radiation, air relative humidity, wind, and rainfall. Data are transferred and archived automatically into an IBM-AT computer that calculates the potential evapotranspiration and then converts it into the irrigation rate expressed in minutes of operation for sprinkler installations based on spacing of sprinklers, pressure, and nozzle type. Tree Planters' Notes 41(3):22-27; 1990.

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The consumptive use of water by nursery crops is an essential factor of growth. It is driven mainly by the atmospheric demand for evapotranspiration and satisfied from the soil water reservoir, which in the case of sandy, permeable soils is limited.

A steady supply of water to crops secures active transpiration and foliage cooling, which, in turn, allows for a positive balance between photosynthesis and respiration. As a physiological process, foliage transpiration occurs in response to a demand, exerted by the immediate atmosphere, that is satisfied-to the extent possible from the root zone of soil. The same demand exerted towards the bare soil results in direct soil evaporation. During the growing season, a crop of seedlings experiences a significant and consistent change in the relationship between these processes; initially the soil evaporation is predominant, but, as the foliage develops, transpiration starts to prevail. The two processes are normally lumped in a unique term: evapotranspiration (ET), expressed as water amount per time and area, most frequently in liters of water per square meter and per day ($1/m^2$ /day) or in millimeters per day (mm/day).

Correct irrigation water management is a delicate activity, performed under numerous constraints. *First,* by choice, in North America, the vast majority of forest nurseries are located on sandy, permeable soils, which are prone to develop severe water stresses if not resupplied with water at regular intervals. *Secondly,* with their reduced cation exchange capacity, sandy soils do not effectively bind the nutrients, especially the soluble inorganic nitrogen fertilizers, which are easily moved out of the root zone during significant rains or excessive irrigation. *Thirdly,* the root zone of nursery crops is initially very thin and thereafter limited usually to about 25 cm, as a result of root undercutting. As a consequence, the nursery crops have available only a limited soil water reservoir to respond to demands for evaporation that may reach, even in Ontario, up to 8 mm/day, normally peaking during mid-day. At the same time, due to its water-related characteristics, this limited reservoir cannot receive much water without it going away from the root zone together with dissolved nutrients.

Careful consideration of these main constraints, combined with practical experience, suggest the correct irrigation strategy: to avoid both stressful episodes between rain events and excessive nutrients leaching, the crops have to be supplied often but with not more than the amount of water potentially transferred from the crop of seedlings and soil to atmosphere during a certain interval.

Traditionally, the subject of irrigation rate (IR) calculation has been approached either through

soil, by following the depletion of the moisture and irrigating when a set threshold was reached, or through **atmosphere,** by calculating the evapotranspiration rate. Both approaches have specific merits and the current research in irrigation science continues in both directions. The subject of this paper is a brief description of a **computerized system for weather data collection and irrigation rate calculation,** based on the atmospheric approach, that is currently in use in two nurseries of Ontario Ministry of Natural Resources in Ontario, Canada.

The Atmospheric Approach

A large body of agricultural literature has been devoted to the concept of **potential evapotranspiration** (ET_p). In crop physiology and irrigation science, it is both a measure of stress and an essential guide for the irrigation rate calculation. A considerable number of empirical or physically based models have attempted to determine its amount from currently monitored weather parameters. Reviews of models and their performance under variable weather conditions have been presented by McGuiness and Bordne (5) and Jensen (3). Currently, the modern irrigation science in North America-in its quest for standardization-appears to agree on two estimates of ET_p, namely, 'grass' and 'alfalfa.' Both imply the consumptive use of water for crops that completely shade the ground and are not short of water; however, the former has a uniform, extensive surface 8 to 15 cm high (2), while the latter has a rough surface with top growth at 30 to 50 cm (4). For these standards, by means of lysimeter installations, the agrometeorologists have calibrated several models that are currently in use in numerous areas of the world, for both design and operations.

The modern irrigation science has accepted the **energy balance ET_p models** as the most accurate for estimating the actual irrigation needs (1, 2). Unlike empirical models, normally devised for monthly intervals, the models based on energy balance can be used with any time interval. From these models, for the present system, the Penman grass standard model was selected, although the software written has provision also for several other models, such as the Penman alfalfa standard, and standards developed by van Bavel, Blaney-Criddle, and Priestley-Taylor. The Penman alfalfa standard model results in ET_p amounts 15 to 20% higher than the grass standard (2), where as the van Bavel model allows for an explicit definition of crop roughness (5).

Weather Monitoring

The main parameters influencing the energy balance of a green crop are air temperature, solar radiation, air humidity, and wind, for which local measurements have to be obtained. The first two variables are responsible for the so-called heat term in the Penman equation, whereas the latter two constitute the aerodynamic term of the same formula. Additional influences are exerted by the albedo and canopy roughness. However, since these characteristics do not evolve dramatically from one day to another, they can be approximated with functions or coefficients. At the cooperating nurseries the monitoring of the main parameters, plus rainfall and soil temperature, is accomplished using the 21 X micrologger manufactured by Campbell Scientific (Logan, Utah). The microloggers are programmed to store in internal memory 10-minute records of these listed parameters as well as day-of-year and time.

Computer System

The 21 X micrologger can be connected to a telephone line by a modem link for efficient data transfer. The environmental information is downloaded once a day, via the telephone line, into IBM-AT computer clones located in nursery offices, also connected to modems, and operating under the communication package Crosstalk Mk4. A main script (communication program) written in Crosstalk Application Script Language (CASL) acts as a shell and accomplishes, daily, the following routine: (a) transfer weather data, (b) call a compiled QuickBASIC (.EXE) program for data archiving, daily summaries, calculation of ET_p, and irrigation rate, and (c) print a document for operational application of irrigation rate and subsequent filing. These operations are accomplished automatically before office hours. This approach releases the computer for other uses during the day. The system can be implemented in any IBM computer clone operating under MD-DOS version 3 and upwards. If the computer operates under the Microsoft Windows environment or with a multitasking operating system, such as Concurrent DOS or Desqview, the CASL script can be placed in the background partition of the computer.

Another computer program has been written in QuickBASIC version 4.5 for the visual analysis of weather data and calculated parameters for a 24-hour interval. This program can display information on CGA, EGA, and VGA monitors and takes full advantage of color computer screens, if such exist. Graphics are available through a menu-driven program in 10 combinations of measured variables and/or calculated parameters. The graphics allow for determination of times when extreme values for temperature, relative humidity, or wind have occurred. Also, the graphics show the time, duration, and intensity of rain. If the user desires, through a screen dump utility that is part of MS-DOS, the graphics can be copied to dot-matrix printers. In such a case, the computer converts the screen colors to different line shades.

A Real-life Example

The operational information of the computerized irrigation system is exemplified below with 2 days of real data from 1989 at St. Williams nursery. Day 199 (July 18, 1989) was a warm sunny day with low wind; day 216 (August 4, 1989) had an overcast sky, with uniform temperature and higher wind, as well as 6.25 mm of rain. The information for the 2 days is summarized in table 1, and some of the variables and parameters are shown in their hourly variation in figs. 1 and 2.

A comparison of the averages or sums for the weather elements of these days helps with the understanding of their influences on the ET_p daily sums. On day 199, the net radiation was triple that on day 216, which is reflected in the heat effect in the same proportion, although day 216 was warmer. Day 216 had double the wind run but, because the air had been closer to saturation with water vapors, the aerodynamic effects were lower. The magnitude of the four inputs to Penman model controls the proportion between heat and aerodynamic effects. In this respect, the 2 days are remarkably similar, with the aerodynamic effects representing slightly more than one-quarter of ET_p. However, even in the sub-humid climate of Ontario, during days with high winds and sizable saturation deficits, ET_p due to aerodynamic effects may reach up to 45% of total. Under drier climates, the contribution of this factor, which in fact quantifies the energy adverted to crops, can be considerably greater and may desiccate, in a few hours, crops of seedlings poorly supplied with water.

In the present approach, we considered the recommended IR as

Table 1—*Summary weather and ET_p information for day 199 and day 216*

	Day 199	Day 216
Weather elements		
Mean air temperature (°C)	22.62	25.07
Mean air relative humidity (%)	71.29	92.27
Total net radiation (langley)	343.42	115.44
Total daily wind run (km)	102.25	229.78
Total rainfall (mm)	0.00	6.25
Daily potential evapotranspiration (ET_p)		
Heat effects on ET_p (mm)	4.49 (73%)	1.48 (71%)
Aerodynamic effects on ET_p (mm)	1.62 (27%)	0.60 (29%)
Total potential evapotranspiration (mm)	6.11	2.08

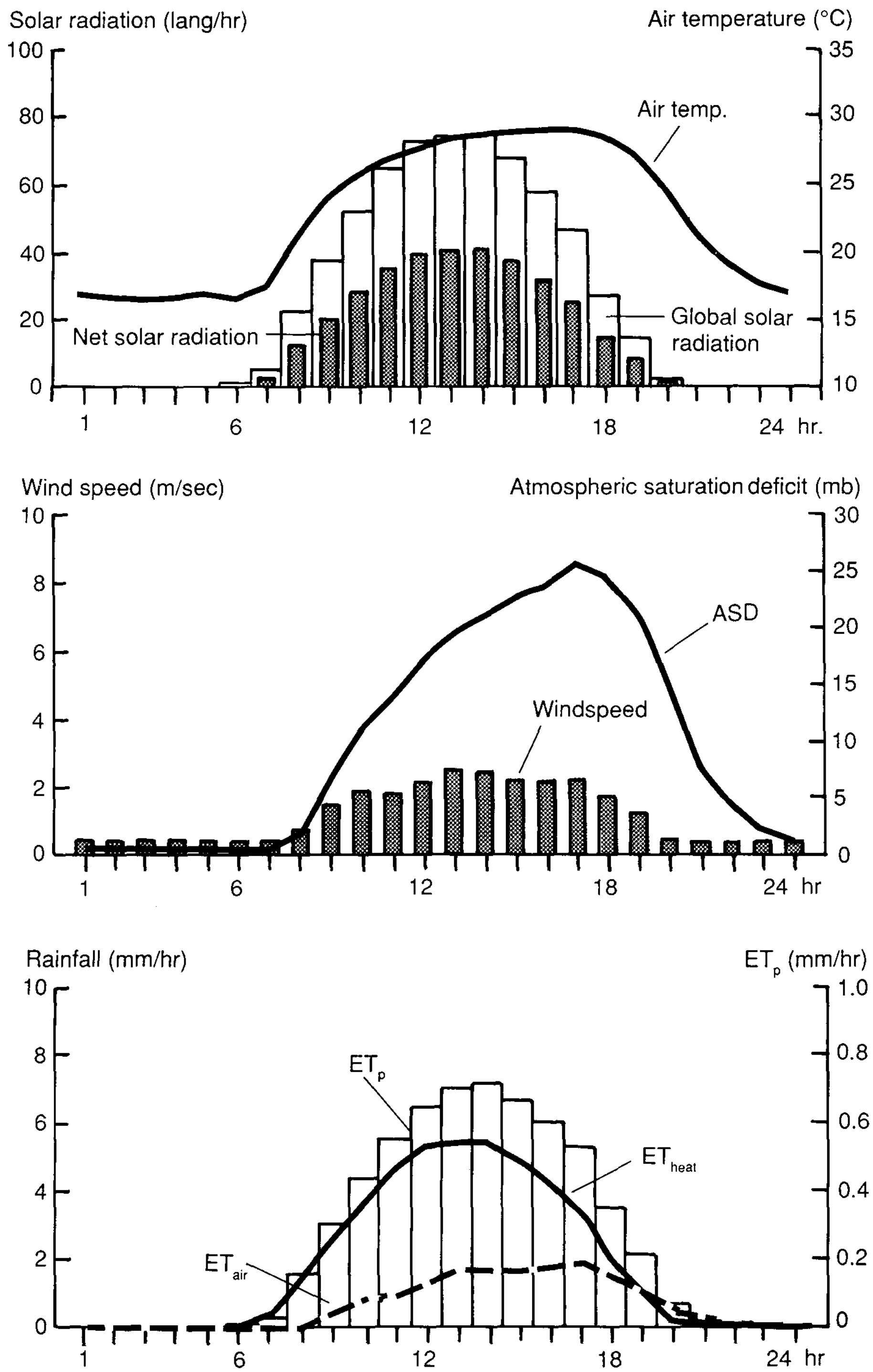

Figure 1—*Atmospheric variables and evapotranspiration (ET) on day 199 (July 18, 1989)*

being equal to 110% of ET_p. The 10% addition is to account for the water lost to evaporation and wind drift, which is estimated at around 8% for open-field sprinkler systems (6) as well as for the time necessary for the whole irrigation lateral to reach the operational pressure. On the basis of these ET_p figures, as well as sprinkler nozzle spacing and operational pressure, the program subsequently calculates the IR in minutes of operation (table 2). These are based on discharge rates given by the manufacturer of the irrigation equipment (7). The sprinkler type and spacing depend on the existing equipment and its allocation to various nursery crops and have to be input to the program at the stage of software implementation. With respect to

Table 2—*Operational sprinkler pressure at the St. Williams Nursery, Ontario for July 18, 1989 (day 199) and August 4, 1989 (day 216)*

Sprinkler nozzle size	Weak pressure	Fair pressure	Good pressure
Day 199			
3/16 by 1/4 inch	37.40	28.89	23.69
3/16 by 7/32 inch	43.99	34.07	27.76
3/16 by 1/8 inch	71.88	53.36	45.42
Day 216			
3/16 by 1/4 inch	12.76	9.85	8.08
3/16 by 7/32 inch	15.00	11.62	9.47
3/16 by 1/8 inch	24.51	18.20	15.49

Sprinklers were spaced at 18 by 18 meters. *Weak* operational pressure measures about 30 pounds per square inch (psi); *fair* pressure, 55 psi; and *good* pressure, 75 psi.

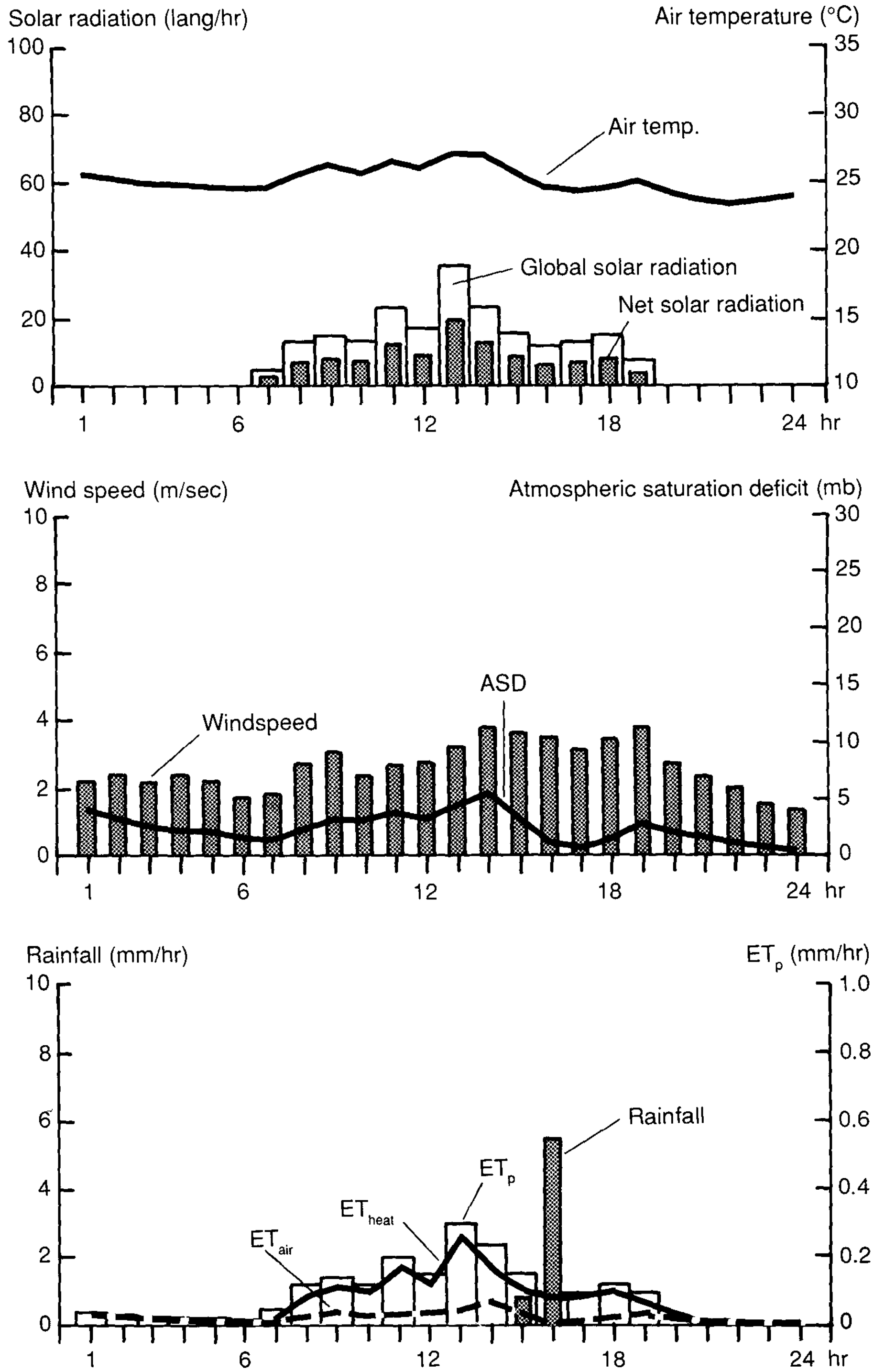

Figure 2—*Atmospheric variables and evapotranspiration (ET) for day 216 (August 4, 1989)*

operational pressure, which normally is not measured at the sprinkler, we opted for qualifiers (that is, weak, etc.). However, these correspond to the pounds per square inch (psi) values given in parentheses. Experienced irrigation operators can assess in a fairly correct manner the pressure from the 'throw' radius and dispersion of the jet.

A comparison of IR for the 2 days shows that if we were to apply the rates corresponding to day 216, in some cases, some of the application times would have been less than 10 minutes. In fact, such times are too short for achieving a good application uniformity. Therefore, judgment has to be exercised to determine whether such low rates should be applied or not. In the concrete case of day 216, however, this application should not be made because, as we have noticed in table 1, there was already a rainfall amounting to 6.25 mm.

An Irrigation Strategy

The development of the computer software is aimed at the operation use of the system in real life situations. The cornerstone of this approach remains the replenishment of the soil water reservoir in the next day with an amount equal to the ET_p of the previous 24 hours. Although it is very important to know how much to apply in order to resupply the soil before the daily consumption peak, the decision whether to irrigate or not has to be made at the beginning of the next working day. This must be done because in the sub-humid climate of the Province of Ontario the weather changes frequently. Therefore, it is necessary to consider the overnight weather evolution and the latest rain forecast transmitted by media. If such a forecast, or at least cloudiness, exists, then no application is to be made because either the replenishment will be natural or the demand will be very low anyway. If no such forecast, exists then the application has to go on with the known amount. This decision is helped by setting the time for the data downloading at 7 AM of the current day. In case of overnight rain, the document would show how much of the demand corresponding to the previous day has already been replenished. At this point in time, it appears that this is the most flexible way to avoid crop water stress during dry spells while suppressing the irrigation during clusters of wet days. Of course, this approach corresponds more to the sub-humid climate of Ontario, as well as the northeast United States, where water is abundant, rains are frequent, and over irrigation has to be avoided mostly in order to curb nutrient leaching. However, application of the same operational principles in drier climates is likely to result in even more important savings of water and pumping energy.

The application time of IR has considerable importance. Since the ET_p is strongly influenced by the incoming solar radiation, which peaks at noon, it is important to replenish the soil water reservoir before the peak demand. Application of the irrigation in the afternoon allows for a long time before the next demand peak. Given the high permeability of typical nursery soils, in this interval much of the water moves out of the root zone.

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