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SPRINKLER AND MIST IRRIGATION FOR COOLING LETTUCE: EFFECTIVENESS AND ECONOMIC CONSIDERATION[1]

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ABSTRACT

Various studies have shown that the ambient temperature can be reduced by irrigation in order to improve crops quality resulting from cool conditions during critical periods of the growth cycle. However, comparatively few studies have focused on a comparison of different irrigation systems for this purpose, and few are available on the economic aspects. The principal conclusions from the study are: (a) evaporative cooling reduces air temperature 5 and 6° C which is usually sufficient to reduce damage to lettuce; (b) twice daily cooling is desirable on very hot days; (c) based on economic parameters and both yield and quality of head-lettuce (*Lactuca sativa* L. cv. Calmar), only the sprinkler system of cooling was justified; (d) sprinkler irrigation is more effective than mist irrigation for reducing atmospheric temperatures; (e) selection of a particular sprinkler system is dependent on relative costs and avialability of equipment and labor.

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آبیاری بارانی وآبفشانی برای خنک کردن کاهو: اثرات وملاحظات اقتصادی

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<u>خلاصه</u>

مطالعات مختلف نشان داده است که میتوان به کمک آبیاری، درجه حرارت محیط اطراف
گیاهان زراعی راپائین آوردوبا ایجادشرائط خنک درمواقع حساسی ازدوره رشدگیاه،

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کیفیت محصول را بالا برد. با وجود این درمورد مقایسه روشهای مختلف آبیاری وجنبه های اقتصادی این مسئله، مطالعات نسبتا "کمی صورت گرفته است. نتایج عمده ای که از این مطالعه حاصل شده نشان میدهدده خنک کردن ناشی از تبخیر، درجه حرارت هوا را ۵ تا ۶ درجه کاهش میدهد که این مقدار برای جلوگیری از خسارت گرما به کاهو کافی است. درروزهای خیلی گرم بهتر است عمل خنک کردن دوبار صورت گیرد. براساس پارامترهای اقتصادی ودرنظر گرفتن عملکرد وکیفیت محصول کاهو (رقم کالمار)، تنها روش قابل قبول خنک کردن، بکار بردن سیستم آبیاری بارانی می باشد. آبیاری بارانی برای پائین آوردن درجه حرارت هوا، از روش آبفشانی نیز موٴثرتر است. انتخاب نوع بخصوصی از آبیاری بارانی بستگی به هزینه نسبی ووجود وسائل ونیروی کار مورد لزوم دارد.

INTRODUCTION

In arid regions, irrigation water is indispensable for intensive crop production, not only for meeting consumptive demand by the crop, but also to allay the frequent detrimental effects of excessively high temperatures for some high value crops. Various reports document such crop injury, mainly by excessive transpiration (1, 2, 4, 7). The magnitude of the problem varies both with the crop and the location.

Under conditions of high temperatures and bright days resulting in atmospheric strèss for lettuce, misting during peak stress hours at the rate of 1 to 1.5 mm/h increased the percentage of marketable heads and reduced physiological abnormalities associated with such a stress (13, 11). Temparature and daylength are the two most important factors controlling reproductive development (8).

Evaporative cooling can be used to facilitate germination, regulate growth, improve crop quality, prevent blossom drop, and render a crop more amenable to mechanical harvesting. Cooling, when practised with suitably designed equipment, and operated in relation to measured meteorological data and crop requirements, can significantly reduce water use per unit of high quality produce harvested (3).

The degree of cooling is dependent upon the amount of moisture that is circulated throughout the crop area, as well as droplet size and relative humidity (1). Consequently, the extent of temperature reduction depends upon the method of irrigation, while the benefits from this practice are crop dependent. A sprinkler system operated at noon reduced the temperature within the canopy of field tomatoes by 10° C (2). Another study (6) showed that sprinkling reduced the temperature of strawberry leaves by up to 15.8° C. Similarly, improved quality of apples in terms of color, firmness, and soluble solid content, was attributed to an induced cooling effect of sprinkling which was designed to operate whenever the air temperature exceeded 30° C (13). With potatoes, cooling by sprinklers increased yield by 11% (5). Furthermore, it was concluded that this method was effective for cooling summer crops such as beans, cauliflower and bell-peppers, and for extending the growing season for cabbage, lettuce and tomatoes (12). Sequential sprinkling has also been shown to be effective in cooling, and mist irrigation involving cycles of 3 min on and 15 min off was shown to achieve maximum micro-climate modification in vineyards (9). With this system, leaf water potential increased by 3.8 bars with a corresponding increase of 60% in pea yield (10).

A direct comparison was made of the effectiveness of both sprinkler and mist irrigation for cooling crops. Based on the results of this trial an economic analysis was carried out by the extrapolating to a 1-hectare basis.

MATERIALS AND METHODS

This study was carried out at the Agricultural Research and Education Center of the American University of Beirut in the Beka' Valley of Lebanon. The soil at the experimental site was representative of very fine clayey, mixed, mesic family of Vertic Xerochrepts, and was formed from fine-textured alluvium derived from limestone. The climate is mediterranean, with moist cool winters and hot dry summers. Cropping is dependent upon irrigation in summer. The 18-year average maximum daily temperature increases from 18.7° C in April to 31.0° C in July, decreasing to 29.1° C in September. Relative humidity is low, ranging from 17 to 40% over this period. Wind speed averages 8.3 km/h with a range from 0 to

21 km/h. Normal direction is from north east to south west.

The experimental design consisted of three plots of 10 x 10 m. Treatments were (1) mist cooling system, (2) sprinkler cooling system, and (3) a control sprinkler system which was operated usually before 10 A.M. before the temperature reached 25° C. A buffer zone of 2 m separated the experimental plots. It was assumed that data from the adjacent weather station would approximately represent conditions in the control plot. The misting system consisted of 16 misters (Rain Bird A - 771 type) in a square grid of 2 m. Sprinklers (3.57 mm nozzle at 1.5 bars, Rainbird 25 A-7° FP - TNT model) were sited at each corner of the other two plots. A 3-m high wind barrier of well perforated burlap was erected around the plots to minimize wind speed and water drift, and promote uniformity of water application. The Christiansen uniformity coefficient was 87% for sprinkling and 90% for misting as calculated from records of catch cans placed on 2 m x 2 m grid. Thermohydrographs were used to record temperature and relative humidity at 30 cm from the ground surface in each cooled plot. Wind speed was recorded by a three-cup totalizing anemometer placed at 2-m height in the middle of the sprinkler-cooled plot.

Seedlings of crisphead-type lettuce (*Lactuca sativa* L. cv. Calmar) which thrives best in a relatively cool growing season with mean monthly temperature of 13 to 16° C, were planted on flat land at a spacing of 30 x 60 cm. The commercial fertilizers ammonium sulfonitrate and triple superphosphate applied at rates of 200 kg/ha N and 87 kg/ha P, recommended for optimum yield. Potassium was not applied since adequate levels (i.e. 450 ppm avialable K) were available in the soil. During the growing period of 60 days (from seedling stage) water volume applied, temperature, relative humidity and wind volecity were recorded.

Cooling by irrigation was practised when the ambient air temperature reached 25° C. Examination of the previous year's data revealed that the fastest rise in temperature occurred between 7:00 A.M. and 12:00 noon. After that time, the temperature rose less rapidly, peaking at about 2:30 P.M. To maintain a lower peak and a slower rate of temperature increase, the sprinkler and mist systems were operated between 10:30 and 11:30 A.M. for six of cooling runs made for the season. As the depth of water applied for cooling exceeded the crop water consumptive use determined from Blaney Criddle, no further irrigation was necessary in the sprinkler and mist-cooled plots. Measurements were made of plant weight and marketable plants weighing more than 800 g. as well as the number of bolted plants.

The economics of cooling by sprinkling and mist irrigation system, were considered on a more meaningful 1-hectare basis. A comparison was also made with another system, i.e., buried P.V.C. pipe using current costs and assuming equal cooling effectivenss, and therefore equal production, to that of the solid set system. Such a comparison allows assessing the economic potential of some irrigation systems used on out of season lettuce. Normally, this crop is surface irrigated and grown during the cooler months of the year.

RESULTS

Average diurnal air temperature readings from the sprinkler and mist-irrigated plots and the adjacent weather station outside the experimental plot site are presented in Fig. 1. There were consistent and marked differences between the two treatment systems, both of which deviated from the unmodified environmental temperature. The control is represented by the weather station data. The modified plots had lower temperatures than those recorded at the weather station during the night, but higher from about 8 A.M. to about 1 P.M. at which time both systems were turned on for cooling purposes at about 25° C.

Operation of the sprinklers (33 min on the average) and misters (56 min) caused a rapid and marked reduction in

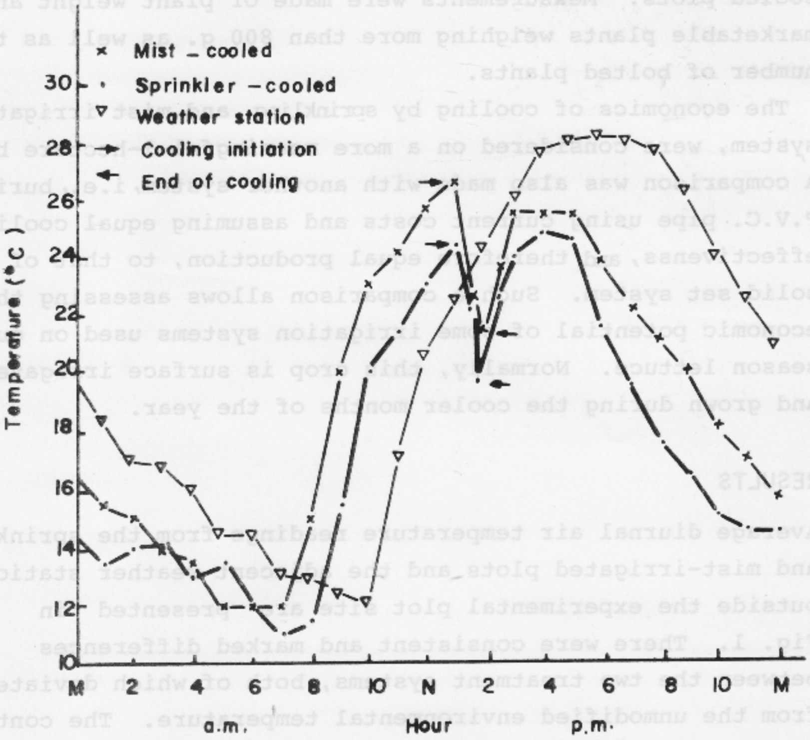

Fig. 1. Air temperature averages for 29 days in cooled plots and weather station.

temperature; for both systems, it dropped by about 4° C within 5 min. Cooling efficiency, however, was higher for misting than sprinkler, i.e., 67 to 75% less water was required by the misters to cause an equal temperature drop compared to the sprinklers. Since these temperature decreases are averages of 35 days, the variation in the extent of temperature reduction for both systems was examined.

During 86% of the time, the sprinkling system reduced temperature by 2 to 5° C while for the remaining 14%, the reduction was 6 to 7° C. The corresponding figures for the misting system were 49 and 51%, respectively. The significance of these irrigation pulses was that, although temperature again tended to rise after operation, they were effective in maintaining a crop ambient temperature several degrees lower than the atmospheric temperature.

During the 6 very hot days, where the systems were operated once before noon and once at about 2:30 P.M., the effect on temperature reduction was similar (Fig. 2). The discrepancy between temperature from both methods of irrigation was greater on those days than during the "normal" days. The twice-daily cooling by misting maintained the highest relative humidity during the night and mid to late afternoon, with peaks following each pulse (Fig. 3). While sprinkling maintained a somewhat higher humidity during the night and late afternoon than the unmodified environment, variation during the day was minimal. Daily data indicated that the increase in relative humidity never exceeded 20% with the sprinkler system, while over 90% of the observations with the mist system revealed an increase of 31 to 46%.

There were marked differences between the cooling and non-cooling treatments on the lettuce crop. There were no bolted plants with the cooling treatment, while the uncooled plot had 34.7% bolted or abnormal plants. Average plant weight was significantly lower where no cooling was practised (1200 g for sprinkler, 1170 g for mist vs. 840 g for

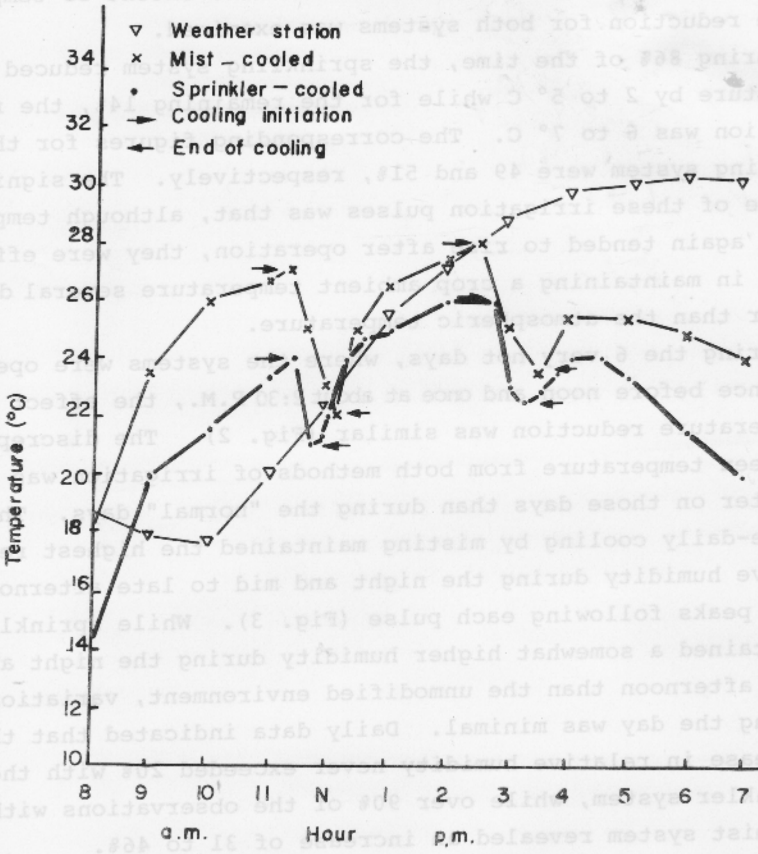

Fig. 2. Air temperature averages for 6 hot days in cooled plots and weather station.

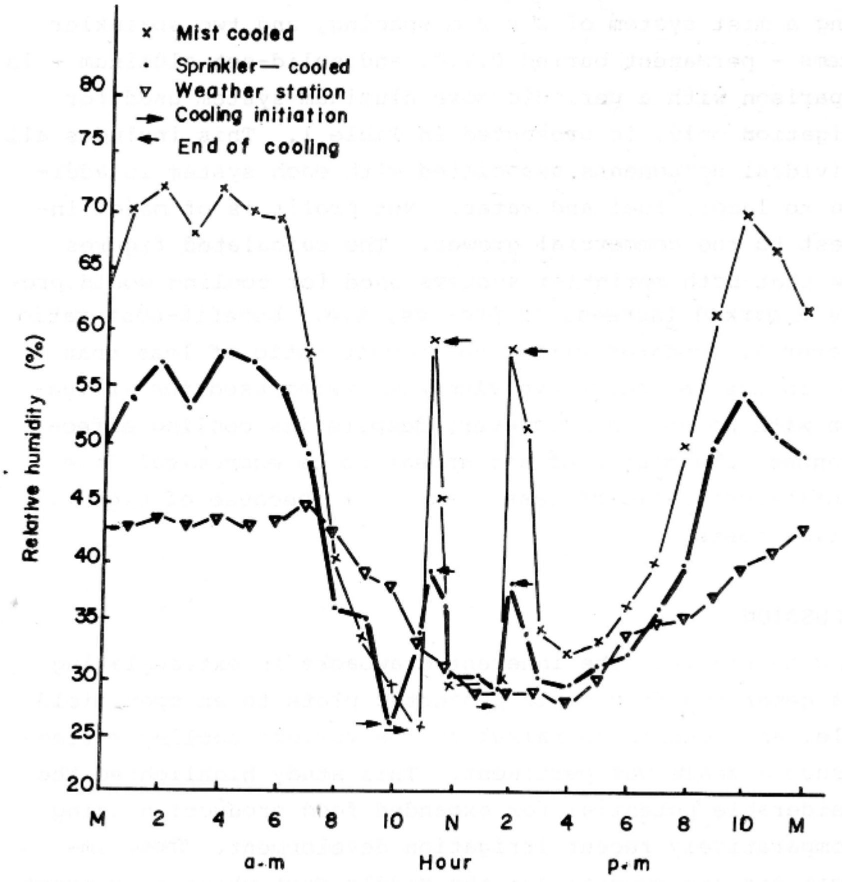

Fig. 3. Relative humidity averages for 6 hot days in cooled plots and weather station.

control). There were no significant differences in the percent of nonmarketable plants between the sprinkler and misting systems, i.e., 10.6 vs. 7.6%.

A summary of the principal factors involved in establishing the net benefit of cooling a lettuce crop on a 1-hectare using a mist system of 2 x 2 m spacing, and two sprinkler systems - permanent buried P.V.C. and solid-set aluminum - in comparison with a periodic-move aluminum system used for irrigation only, is presented in Table 1. This includes all individual components associated with each system in addition to labor, fuel and water. Net profit is of major interest to the commercial grower. The calculated figures show that both sprinkler systems used for cooling would produce a marked increase in profits, i.e., benefit-cost ratio of over 3, compared with benefit-cost ratio of less than 1.0 in the periodic-move aluminum system used for irrigation with no cooling. However, despite its cooling effectiveness, the mist does not appear to be economical (i.e., benefit-cost ratio of less than 1.0) because of high initial costs.

DISCUSSION

Not withstanding the inherent drawbacks in extrapolating data generated from small protected plots to an open field scale, an economic appraisal of the various cooling systems on such a scale was pertinent. This study highlighted the considerable potential for expanded food production using a comparatively recent irrigation development. These implications are crucial for the Middle East which is currently experiencing an unprecedented expansion in irrigation-based agriculture. While both sprinkler and mist systems of crop cooling appear equally effective at maintaining a suitable growth environment, other factors have to be considered in the selection of either system. The mist system was more effective in reducing temperature, presumably due

Table 1. Economic comparison associated with crop cooling† on 1-hectare basis.

Irrigation system	Number of marketable plants	Crop value	Annual equivalent cost of system§	Total cost	Cooling cost	Annual net benefit	Benefit/ cost
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Mist (solid-set aluminum)	49,688	14,907	5,760	8,101	5,312	6,897	0.86
Sprinkler (solid-set aluminum)	51,316	15,393	1,051	3,301	603	12,092	3.66
Sprinkler (permanent buried PVC)	51,316	15,393	836	3,086	388	12,307	3.99
Sprinkler (periodic-move, no cooling)	20,453	4,091	448	2,698	-	1,393	0.52

†Assumptions made: number of plants per hectare at 60 x 30 cm spacing = 55,555; percentage of marketable plants based on experimental results in this study; US $ 0.30 per head of lettuce produced with cooling and $ 0.20 per head produced without cooling. Total cost includes US $ 2,250 for seed, fertilizer, labor, water, land rent, etc.

§Life expectancy of various componets of system was assumed to be 35 years for all buried P.V.C. pipes and fittings; 7 years for exposed P.V.C. riser extensions and sprinkler heads; 15 years for pressure regulator, pressure gauge, and flow meter; and 12 years for electric motor and pump. The interest rate was considered 8%.

to the finer droplets which evaporate and thus cool more readily. Moreover, the mist system has the advantage of using less water than the sprinkler system for cooling. The major disadvantage of mist cooling is its inflexibility and high associated costs which render it more suitable for restricted areas such as greenhouses. Another possible disadvantage is the higher relative humidity associated with misting which could promote diseases. The lower temperature associated with the sprinkler system can be accounted for by a greater amount of water applied (1177 liters in one cooling pulse) and thus a corresponding greater cooling effect than the mist system (366 liters). Sprinkling systems, therefore, are more suitable from the technical and economic viewpoints.

The possible economic advantage of using sprinkler cooling of lettuce was shown. It is reasonable to assume that similar benefits would accrue to the use of sprinkler with other commercial crops adversely affected by excessively high temperatures. Though the permanent buried P.V.C. irrigation system was more attractive financially than the solid-set aluminum system, this advantage may not always exist due to fluctuations in the prices and availability of the various components.

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