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A Decision Support System for the Irrigation and Nutrition Management of Tomatoes Cultivated in Low-technology, Plastic-covered Greenhouses

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SUMMARY. Vegetable production in low-technology (low-tech) plastic-covered greenhouses depends on low investment and cheap production methods that prohibit the adoption of expensive technologies. Nevertheless, advanced technology can be developed for this low-tech situation provided that a personal computer (PC) is available and the software is of low cost

and specially designed to function without the need for additional expensive hardware. This will encourage the adoption of computer technology in an industry where computer illiteracy is still high. In the present paper, a decision support system for irrigation and fertilizer management of tomatoes [*Lycopersicon esculentum* (L.) Mill.] is described. The system is comprised of two modules: 1) an irrigation-fertilization consultation module for the management of water and fertilizer supply and 2) a diagnostic expert system module for the identification and rectification of nutritional disorders. Irrigation requirements are defined on the basis of daily evaporimeter readings. Fertilizer schedules are derived from the literature, but modified on the basis of experience gained during previous cultivations. The urgent need for such a management system is indicated by the relatively low quality of vegetable produce currently grown in low-tech greenhouses and the waste of precious water and fertilizer due to over-application by growers, with concomitant damage to the environment. During tests, irrigation was reduced by as much as 30% in comparison with empirical methods. To enable more widespread assessment and to increase its range of application, the software of this system is offered free of charge for evaluation by interested users.

Plastic-covered greenhouses were first introduced into the horticultural industry in the 1950s. Since then their construction has increased to the extent that worldwide today >200,000 ha (494,000 acres) of such low-tech greenhouses are used for the production of vegetables, fruit, flowers and ornamentals. Of this total area, 62,000 ha (153,200 acres) are

located in China, 30,000 ha (74,100 acres) in Japan and 90,000 ha (222,400 acres) in the Mediterranean basin (Castilla and Hernandez, 1995; Wittwer, 1993). In the United States, ≈3,500 ha (8,650 acres) of plastic-covered greenhouses and high tunnels are used for the production of bedding plants, potted plants, foliage plants, cut flowers and vegetables (Wittwer, 1993).

Plastic-covered greenhouses have been developed on the basis of low capital investment and operating costs; hence technological input is minimal (Lopez-Galvez et al., 1991). Microclimate control is normally confined to the manual regulation of ventilation, in combination with irrigation and fertilizer application on the basis of the empirical knowledge of the grower (Bretones, 1989; Lopez-Galvez et al., 1991). The introduction of drip irrigation has improved the watering and feeding of crops (Castilla, 1989; Baille, 1994). However, in the absence of climate control or soil moisture sensors, crop management depends heavily upon the experience of the grower and is often imprecise. This results in lower quality produce. Moreover, the excessive use of fertilizers and agrochemicals poses a serious threat to the environment (Addiscott et al., 1991; Antonopoulos, 1991).

Although there is an urgent need to improve the management and operation of the low-technology (low-tech) plastic-covered greenhouse industry, e.g., to increase the efficiency of operation and improve produce quality (Lopez-Galvez et al., 1991; Tognoni and Serra, 1994), most of the computerized management systems that are currently available on the market have been developed for the sophisticated glasshouse industry of North America and northern Europe (Stearne, 1995; Flaherty, 1996). The profits of simple, plastic-covered greenhouses, especially those devoted to vegetable production, are usually insufficient to justify the purchase of such systems. Moreover, many growers have a relatively low level of education and technical expertise, which makes them reluctant to adopt computers and software (Crassweller et al., 1993).

At the Agricultural University of Athens, we have recently designed diagnostic and advisory software to help low-tech greenhouse growers and extension officers identify and control common diseases, pests and nutritional

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disorders of vegetable crops (Sideridis et al., 1997; Yialouris and Sideridis, 1996; Yialouris et al., 1997). Although initially intended for use in the Mediterranean region, this software is also applicable to other areas of the world where low-tech greenhouses exist, e.g., North and South America and Asia, since the day to day problems encountered in crop production and the methods for their confrontation are similar irrespective of the location.

The accurate control of irrigation and fertilizer application is a problem that is of vital importance for the improvement of yield and quality, but the economic constraints of the low-tech greenhouse industry preclude the introduction of any management system that will greatly increase the costs of operation (Castilla, 1989). In response to this difficulty, we have used research results and local data, collected over 15 years in Southern Greece (Passam, 1996), to build up an irrigation and nutrition management (IRNMA) system for tomato, which is a major crop within these greenhouses. The system consists of two interrelated modules: one for the increased accuracy of water and fertilizer application to the crop, which is entirely new, and the other for the identification of nutritional disorders, which is derived from that previously described and tested by Yialouris et al. (1997). The combination of these two modules provides a cheap and novel way of regulating irrigation and feeding while at the same time enabling nutritional imbalances to be identified and promptly corrected.

Apart from a personal computer (PC), the IRNMA system does not require expensive hardware. Its programs appear simple and very friendly but, at the same time, are sophisticated enough to handle important daily operations within the greenhouse. It is hoped that the system will appeal to tomato growers not just in the Mediterranean, but in North America and other areas of the world where low-tech greenhouses are used for this crop.

IRNMA system analysis

SETTING UP THE SYSTEM. The system is applicable to all forms of greenhouse that are equipped with drip or trickle irrigation systems capable of delivering a liquid feed. Apart from a PC, the only other hardware requirement is a simple evaporimeter based on a modification of the original Jones-Rothwell version

(Fairfield Experimental Horticultural Station, 1977). Briefly, this consists of a conical glass funnel [diameter 2.8 cm (1.1 inches)] filled with washed, coarse sand which is connected by a rubber tube to a 10-mL burette. The apparatus, which may be constructed easily and cheaply by the grower on the basis of a design provided in the system, is mounted upright in a U shape just above the crop so as to be fully exposed to sunlight. Before planting, the grower is required to enter values into the system which define the plant population, soil type and the delivery rate of the irrigation lines.

Preplant fertilization

Preplant fertilization is defined as the nutrient status of the soil as indicated by the results of a soil analysis before planting. The grower enters the data from the soil analysis into the PC, together with a value for the soil type. The amounts of fertilizer to be applied are then calculated by the system and displayed on the screen. The data used for the synthesis of the base dressing are derived from standard Agricultural Development and Advisory Service (UK) methods of soil analysis (Needham, 1973). The program also provides an approximated base dressing formula for farmers who do not carry out a soil analysis before the start of each crop. However, the need for regular soil analysis is stressed and systematic application of the approximated formula is discouraged.

LIQUID FEEDING AND IRRIGATION. With the exception of the initial 2 to 3 weeks after planting and the final 3 to 4 weeks before the termination of the crop, water-soluble fertilizers are included in the irrigation supply throughout the cultivation period. The amount of water to be applied is based on the readings of the evaporimeter. Readings are taken once a day (in winter once every 2 d) and the values are entered into the system, together with values for the height of the plant. The system then determines the quantity of water (in minutes of irrigation) to be applied in relation to the stage of development of the crop, the plant population and the irrigation rate.

The synthesis of the liquid feed is based on the stage of development of the plants and is derived from the recommendations of Bedding (1973) and previous experience of tomato cultivation in plastic greenhouses (Passam,

1996). In principle, it consists of four different feed formulae which differ primarily in the ratio of N to K, as shown in Table 1.

The stages at which the synthesis of the liquid feed changes relate primarily to the height and fruit load of the plant but also take into account the temperature of the greenhouse environment. For example, formula 1 (low N) is applied after transplant and until the setting of the second truss. From the second to the fifth truss, formula 2 (medium N) is applied, followed by formula 3 (medium-high N). Depending on the temperature and light conditions, formula 3 may be succeeded by formula 4 (high N), e.g., in a spring crop, or by reversion to formula 2 (medium N) in an autumn crop. To compute the irrigation and fertilization, the system requests the grower to enter the relevant data (number of trusses, maximum and minimum daily air temperatures, day length) each week. This is in addition to the entry of the evaporimeter readings.

NUTRITIONAL DISORDERS. Nutritional disorders, which may arise during the course of cultivation, can be diagnosed by the activation of an expert system (ES) residing in the first module. The ES diagnoses the disorder on the basis of simple (primarily yes/no) answers to questions concerning visible symptoms of deficiency or toxicity. The knowledge base (KB) of this ES includes the disorders shown in Table 2.

CORRECTIVE FEEDING. In the event of a nutritional disorder arising, the ES diagnosis is followed by an appropriate therapy. This may take the form of a foliar application of a deficient element (e.g., Fe, Ca, or Mn), or a temporary modification of the liquid feed schedule. In either case, the relevant treatment, number of sprays, or the duration of the modified-feed application, are highlighted on the screen for the duration of the nutritional therapy, as indicated in Table 2. In the event of excessive nutrient application, i.e. the ES diagnoses toxicity, the system provides recommended treatment based on the leaching of the soil.

System architecture and operation

The system consists of two modules: the diagnostic module (DM) and the irrigation-fertilization consultation module (IFCM) as shown in Fig. 1. Within the DM there is an ES aimed at identifying nutritional disorders of the

Table 1. Basic fertilizer formulae for liquid feeding.

N concn	Fertilizer (g·L ⁻¹)	N : K ₂ O ratio	Dilution rate	Final N : K ₂ O ratio (mg·L ⁻¹)
Formula 1: Low	162 KNO ₃	1:3	1:200	105:335
Formula 2: Medium	162 KNO ₃ , 43 NH ₄ NO ₃	1:2	1:200	170:355
Formula 3: Medium-high	162 KNO ₃ , 80 NH ₄ NO ₃	1:1.5	1:200	225:335
Formula 4: High	162 KNO ₃ , 100 NH ₄ NO ₃	1:1	1:300	225:225

²In formulae 2-4, 43 g MgSO₄·7H₂O is included.

¹1 g·L⁻¹ = 1000 ppm.

plant. This ES is derived from that described by Yialouris et al. (1997). The IFCM module regulates the irrigation and nutrition of the crop. During the phase before planting, it defines the preplant fertilization of the soil on the basis of a soil analysis, or empirically in the absence of analysis. During the cultivation period, it defines the daily irrigation and fertilizer requirements of the crop relative to the stage of plant growth, plant population, soil type and the quantity of water evaporated from the soil of the greenhouse, as measured by the evaporimeter.

The two modules are structurally and functionally independent in the sense that both can be used as stand-alone systems for consultation by the user. It is the user's option to input observed information or not. If the user observes some symptoms on the plant and/or has some microclimatic data to input into the system then he does so through a simple selection menu. The system responds by either activating the DM, in the case of observed symptoms of a disorder, or by ignoring it. Next, the system incorporates the data and the processed information of the first module into the IFCM. At this stage, the system activates an algorithm and provides the appropriate liquid fertilizer feed, according to the information pro-

vided, by either activating the DM or not. We repeat again that the decision is made on the grounds that certain user observations and measurements are made and provided to the system through the user interface.

SYSTEM EVALUATION. The IRNMA system uses evaporimetry for the estimation of the irrigation requirements of greenhouse crops, which is an established and well recognized method (Bedding, 1973). Although this method has been applied to tomatoes with complete success (e.g., in the UK), it has not previously been applied to the low-tech plastic greenhouses of the Mediterranean. In the present system, the simple Jones-Rothwell evaporimetry method (Fairfield Experimental Horticultural Station, 1977) has been modified to include constants for the root substrate, stage of plant development and irrigation delivery rate, so as to increase the accuracy and ease of crop irrigation.

The KBs that have been used for the compilation of the base dressing, standard and corrective liquid feeds are derived from the literature (Bedding, 1973; Roorda van Eysinga and Smilde, 1981) and local experience (Passam, 1996).

To test the system under local greenhouse conditions, tomatoes ('Dombito') were cultivated in 12-L

(3.2-gal) pots containing a soil-peat substrate (2:1) from October 1997 until April 1998. Maximum and minimum air temperatures and the readings of the evaporimeter were recorded daily. These were fed into the IRNMA system, which then defined the feeding and watering requirements. Water and fertilizers were applied by hand and soil moisture level was checked by tensiometers inserted into the pots at a depth of ≈15 cm (6 inches). The principal results of the test were as follows.

The growth and development of the plants was satisfactory and no symptoms of nutritional disorder were observed. By the end of the trial (4 months from planting), plant height was 2.3 m (7.5 ft) and five fruit trusses had formed.

The amount of water given to the plants throughout the period of the trial was 76.6 L (20.24 gal) per plant (corrected for runoff), which represents a saving of >30% in comparison with the estimates of Asimakopoulou (1998) for irrigation of low-tech greenhouses by empirical methods. Tensiometer recordings indicated a steady soil moisture content throughout the cultivation period.

Since liquid feeding is normally carried out together with irrigation in low-tech greenhouses, there is a corresponding saving in the amount of fertilizer consumed.

In parallel experiments, the system has been found to work satisfactorily for the irrigation-fertilization management of pepper (*Capsicum annum* L.), eggplant (*Solanum melongena* L.) and lettuce (*Lactuca sativa* L.), although each crop requires specific fertilizer programs and constants relative to plant development.

Although the diagnostic ES for the identification of nutritional disorders was not required in the present trial (no

Table 2. Corrective feeding implemented in the event of nutritional deficiency.

Deficiency	Treatment	Duration
N	43 g·L ⁻¹ NH ₄ NO ₃ , dilution 1:200	Continuously for 2 weeks
P	Incorporate P into soil next to plant at 25 g·m ⁻² (8.2 oz/100 ft ²)	
K	1. Apply Formula 1	Continuously for 2 weeks
	2. Spray with 20 g·L ⁻¹ K ₂ SO ₄	Twice at 7-d intervals
Mg	1. 43 g·L ⁻¹ MgSO ₄	Continuously for 2 weeks
	2. Spray with 50 g·L ⁻¹ MgSO ₄	Twice at 7-d intervals
Ca	Spray with 7.5 g·L ⁻¹ Ca(NO ₃) ₂	Twice at 10-d intervals
Fe	Spray with 0.2 g·L ⁻¹ Fe-EDTA	Twice at 10-d intervals
B	Spray with 1.5 g·L ⁻¹ NaBO ₂	Single application
Mo	Spray with 0.5 g·L ⁻¹ Na ₂ MoO ₄	Single application
Mn	Spray with 1 g·L ⁻¹ MnSO ₄	Single application

²1 g·L⁻¹ = 13.4 oz/100 gal.

Fig. 1. The architecture of the irrigation and nutrition management system.

disorders occurred), it has been successfully tested as part of a system which has been developed for the diagnosis and therapy of diseases, pests and nutritional disorders of greenhouse vegetables (Yialouris et al., 1997).

Discussion

The IRNMA system is a new, computer-based management program that has been specially designed for tomato production in low-tech greenhouses. It aims at increasing the accuracy of irrigation and fertilization of the tomato crop, thereby improving produce quality and reducing excessive use of water and fertilizer, which is economically wasteful and harmful for the environment (Rijtema, 1981; Addiscott et al., 1991; Antonopoulos, 1991).

The IRNMA system relies on a very simple, but generally neglected, method of accurately determining crop irrigation requirements on the basis of daily measurements of water evaporation using a simple evaporimeter (Fairfield Experimental Horticultural Station, 1977). By incorporating evaporimetry into a program with standard fertilizer feeds, the low-tech farmer is helped to achieve greater economy in water and fertilizer use, at the same time improving produce quality and reducing environmental damage. As a safeguard to the grower, the DM comes

into function in the case of observed symptoms of nutritional imbalance, and by feeding a diagnosis into the IFCM module nutritional disorders are quickly relieved. As indicated by the results of the evaluation, growth and development of tomato plants irrigated and fertilized for 4 months using the IRNMA system was very satisfactory and no signs of nutritional disorder were observed. Moreover, water and fertilizer consumption was calculated to be 30% lower than that using empirical methods, which represents a significant economic saving (Asimakopoulos, 1998).

The primary purpose for presenting this system in such a simple form was to encourage the adoption of appropriate software by as wide a range of low-tech greenhouse farmers as possible. The system is applicable not only to the Mediterranean region, but also to North and South America, Asia and other parts of the world where low-tech green-

houses flourish (Wittwer, 1993). A direct benefit of its implementation is the introduction of the computer and the subsequent computer literacy acquired by the low-tech farming community.

Because evaluation is a time-consuming process, the programs of the system will be provided to interested users on request. In this way evaluation may be achieved under a wider range of climatic and cultivation conditions. Then, using the experience gained, the software may be developed further or adapted to a grower's special needs. System improvement will also be achieved by the capacity of the program to store information on irrigation, fertilizer application and the occurrence or not of nutritional disorders. At the end of the cultivation period, the grower may complete a crop evaluation form and send it to the program designer to update the program. The need for this type of updating has previously been stressed by Crassweller et al. (1993). In its present form, the software has been written in English. For adoption by farmers in non-English speaking areas, however, the KB as well as the texts of the irrigation-fertilization module, can be translated to any other language with the aid of a recently developed tool (Sideridis et al., 1996).

Literature cited

- Addiscott, T.M., A.P. Whitmore, and D.S. Powlson. 1991. Farming, fertilizers and the nitrate problem. CAB Intl., Wallingford, U.K.
- Antonopoulos, V. 1991. Degradation of streams water quality and irrigation return flow. *Agr. Res. (Greece)* 15:271-281.
- Asimakopoulos, N.A. 1998. Comparative investment in greenhouses. MS thesis, Agr. Univ. Athens, Greece.
- Baille, A. 1994. Irrigation management strategy of greenhouse crops in Mediterranean countries. *Acta Hort.* 361:105-122.
- Bedding, A. J. 1973. Feeding, p. 137-149. In: H.G. Kingham (ed.). *The UK tomato manual*. Grower Books, London.
- Bretones, F. 1989. Greenhouses in Spain. *Plasticulture* 82:33-40.
- Castilla, N. 1989. Programming drip irrigation in unheated greenhouses. *Plasticulture* 82:59-63.
- Castilla, N. and J. Hernandez. 1995. Protected cultivation in the Mediterranean area. *Plasticulture* 107:13-20.
- Crassweller, R.M., J.W. Travis, P.H.

Heinemann, and E.G. Rajotte. 1993. The future use and development of expert system technology in horticulture. *HortTechnology* 3:203-205.

Fairfield Experimental Horticultural Station. 1977. The Jones/Rothwell evaporimeter. *Growers Lft.* 3, Kirkham U.K.

Flaherty, A. 1996. Computers for a smaller budget. *The Grower* 126(12):9.

Lopez-Galvez, J., Sanchez-Carreno, J., Naredo, J.-M. and Castilla, N. 1991. The improvement of the low cost Almeria greenhouse type: Technical-economical possibilities. *Plasticulture* 90: 4-14.

Needham, P. 1973. Cultivations, manuring and base dressing, p. 86-93. In: H.G. Kingham (ed.). *The UK tomato manual*. Grower Books, London.

Passam, H.C. 1996. The quality of vegetables cultivated under plastic in Greece. *Tech. Rpt. Lab. Hort., Agr. Univ. Athens, Greece*.

Rijtema, P.E. 1981. Quality standards for irrigation waters. *Acta Hort.* 119:25-35.

Roorda van Eysinga, J.P.N.L. and K.W. Smilde. 1981. Nutritional disorders in glasshouse tomatoes, cucumbers and lettuce. *Ctr. Agr. Publ. Doc., Wageningen, Netherlands*.

Sideridis, A.B., C.P. Yialouris, and C. Costopoulou. 1997. Advanced software tools for agricultural extension services and farmers through Internet. *Eur. Network Info. Technol. Agr. Workshop: Internet Services*. Alberese, Italy.

Sideridis, A.B., C.P. Yialouris, and H.C. Passam. 1996. High tech software for the low-tech greenhouse industry in the Mediterranean basin. *Eur. Network Info. Technol. Agr. Workshop: Successful applications of information and communication technologies in plant protection*. Rome.

Stearne, P. 1995. Computers in the glasshouse. *The Grower* 124(20):12, 14.

Tognoni, F. and G. Serra. 1994. New technologies for protected cultivations to face environmental constraints and to meet consumer's requirements. *Acta Hort.* 361:31-38.

Wittwer, S.H. 1993. Worldwide use of plastics in horticultural production. *HortTechnology* 3:6-19.

Yialouris, C.P., Passam, H.C., Sideridis, A.B. and Metin C. 1997. VEGES - A multilingual expert system for the diagnosis of pests diseases, diseases and nutritional disorders of six greenhouse. *Computers Electronics Agr.* 19:55-67.

Yialouris, C.P. and A.B. Sideridis. 1996. An expert system for tomato diseases. *Computers Electronics Agr.* 14:61-76.