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Fuzzy controller decreases tomato cracking in greenhouses

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ABSTRACT

Sunlight heats the greenhouse air temperature during the day and can encourage tomato cracking and decrease marketable product. A fuzzy controller was designed to control greenhouse climate to reduce tomato cracking using as variables solar radiation, substrate temperature and canopy temperature. A movable shade screen reduced incoming radiation during warm and sunny conditions; meanwhile irrigation was controlled according to canopy and substrate temperature. The shade screen was opened or closed with a gear motor driven by a photovoltaic system. The motor controlled by a pulse width modulated inverter started softly decreasing its starting current. The fuzzy system injected additional water and nutrients between 12:00 and 15:00 h; irrigation cycles were removed during very cloudy days. Tomato cracking decreased from 52% to 17% using the fuzzy controller and canopy temperature never exceeded 30 °C.

1. Introduction

Light has a large impact on growth (plant size, fresh mass, dry mass, branching and flower number) while temperature influences how fast leaves and flowers develop. Reducing sunlight intensity can decrease irrigation needs as plants and soil are kept cooler, increasing plant growth as temperature drops off (Tanny et al., 2006). At night, heat must be supplied to maintain the required thermal environment. Cuticle cracking is a physiological disorder that occurs at the beginning of the last phase of fruit growth (Bakker, 1988); skin elasticity decreases while cell wall degrading pectinase activity increases. Cuticle cracking downgrades tomato quality and reduces shelf life (Hayman, 1987). Tomato becomes unmarketable for fresh consumption with losses ranging from 10% to 95% of the total fruit (Dorais et al., 2004). In Mexico, Macías et al., 2010 reported an increase in fruit cracking from 52.1% to 83.1% when tomato plants were irrigated 2 and 3 h, respectively. Summer crack unmarketable tomatoes are caused by high air temperature within the greenhouse (Wada et al., 2006), so shading becomes an alternative, although tomato yield decreases. Shading decreases fruit sugar content, weight and fruit temperature (Cockshull et al., 1992) as well as tomato cracking.

Movable screen systems (heat blankets, thermal screens) reduce heat radiation losses at night, and decrease the energy load on the greenhouse crop during sunny conditions. Retractable roof shade houses are structures covered with polypropylene, polyethylene, or composite fabrics (Bartok, 2005), saving up to 30% in energy (Plaisier and Svensson, 2005). External screens do not limit airflow and air temperature within the greenhouse drops by 2 °C on hot days (Hemming et al., 2006). The screen becomes another light-intercepting layer in the greenhouse and should be selected to reflect as much near infrared radiation as possible while maintaining a high PAR-transmission.

Constant daily light integral achieved through shading or supplemental lighting (Albright et al., 2000) induce plant growth passing from its initial transplanting state to its harvest state in 25 days. Seginer et al. (2006) revealed that light control signals may use 3-day light integrals rather than a single-day integral. An embedded controller for greenhouse shade curtain controlled solar radiation, reducing the temperature inside the greenhouse (Dogra et al., 2006). Automatic retractable shade structures operate with motorized roll-up systems controlled by light sensors to regulate the amount of sunlight that reaches the plants (Pass and Mahrer, 1997). Decisions to close or open the shade screen were taken on an hourly basis throughout the day, using a predictive model of the amount of solar radiation that will be received for the rest of the day (Mathieu et al., 2004). Mobile shade screens were used under intense sunlight in Spain increasing tomato marketable yield by 10% (Lorenzo et al., 2006).

Fuzzy theory interprets real uncertainties and becomes ideal for nonlinear, time varying and hysteretic system control. Temperature fuzzy control in greenhouse based on a MCS196 microcomputer was developed presenting strong robustness and easy debugging (Errahmani et al., 2009). A fuzzy controller system developed for water saving in greenhouses resulted cheap to implement (Javadi et al., 2009). A greenhouse fuzzy climate

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controller was reported by Lafont and Balmat (2002) indicating that for proper operation required of 81 rules and depended on the number of inputs. Most of the irrigation systems uses ON/OFF controllers, but optimal results are difficult to achieve due to varying time delays and system parameters.

The following paper describes the design, implementation of a fuzzy greenhouse controller which monitored radiation, substrate and tomato canopy temperature. Screen shading and irrigation control were applied to the greenhouse in order to reduce tomato cracking during a hot summer.

2. Control system design

The experiment was carried out at the University greenhouse at Tlapeaxco, Chapingo (19° 29′ N, 98° 54′ W, altitude 2244 m). The 80 × 40 m greenhouse presented natural cooling through lateral and cenital openings. It was conditioned with a cable and truss retractable roof screen that used a 120 V AC (1/2HP) gear motor to move the screen in both directions when a control signal was applied. The motor with a rated torque of 10 kgcm was rotated at 5 rpm to move the 50% transmission black Raschel net, Fig. 1.

Twenty black bags (40 × 40 × 10 cm) were filled with volcanic rock as substrate and spaced 30 cm forming a row, Fig. 1. Each bag was transplanted with a tomato seedling (*Lycopersicon esculentum* var. Roma) the 2nd of March, 2009. Three rows were planted and each one was controlled by a solenoid valve to provide a different irrigation treatment (A, B and control), Fig. 1. The fuzzy controller applied additional irrigation during hot sunny days and closed the solenoid under cloudy conditions (Treatment A). The fuzzy controller added water seven times per day non-dependent whether the day was cloudy or sunny in treatment B. In both treatments A and B a Raschel net screen controlled incoming radiation. The control treatment used a conventional controller without shading and irrigated seven times each day. Red tomatoes were harvested the first of June and 1 month later cracking was evaluated.

2.1. Controller measurements

The intelligent controller moved the shade curtain based on three variables: solar radiation, substrate temperature and canopy temperature, Fig. 1. Two photometric sensors (model LI-210SB, Li-Cor Environmental Division, USA) measured illumination providing 10 mV/100 klux being cosine corrected up to 80° angle of solar incidence. The sensors were calibrated against a standard lamp and presented a sensitivity of 20 uA per 100 klux with a response time of 10 μs. One sensor was placed in the shading area, and the other in an open area without screen. Radiation was acquired every 30 s by the controller and 10 continuous measurements were averaged.

Six substrate temperature measurements were monitored daily on six plants selected randomly for a period of 1 month. In each plant where substrate temperature was measured, canopy temperature was monitored. The temperature sensors (substrate and canopy) from the second plant of treatment A were acquired by the fuzzy controller every 30 s. Substrate temperature was measured with thermocouples fixed horizontally 8 cm from the top of the bag and beneath the dripper (Downs, 1987). Each type-J iron constantan thermocouple was connected to a temperature transmitter (model TxRail 4–20 mA, Novus, Brasil) which provided a continuous 4–20 mA current signal, finally converted to voltage with a 250 Ω resistance. Platinum RTD sensors (model RP502T22, Advanced Thermal Products, Inc, USA) fixed beneath the leaves measured canopy temperature. Temperature and radiation values were stored in a datalogger (model CR1000, Campbell Scientific, USA). Daily data by treatment were compared and a revision of the sensor network and irrigation drippers was carried out when high differences were encountered.

2.2. Fuzzy membership functions and rules

A fuzzy controller was selected for this application as precise mathematical modeling of the controlled object is not required becoming simpler to implement. Fuzzy evaluation methods process all the variables according to predetermined weights and decrease the fuzziness by using membership functions; therefore sensitivity is quite high compared to other index evaluation techniques. The fuzzy input membership functions determine the variables that are going to be acquired to develop the control. Two input membership functions were used decreasing the number of rules and minimizing microcontroller memory data. The first membership function used the difference between canopy and substrate temperature while the second used radiation data. The temperature function presented three groups: negative differential temperature (NDT), zero differential temperature (ZDT) and positive differential temperature (PDT). As noted in Fig. 2, PDT is trapezoidal and can reach values up to 20 °C. The second function is composed of three radiation groups named sunny (SUN), cloudy (CLOU) and very cloudy (VC). The very cloudy group had the lowest

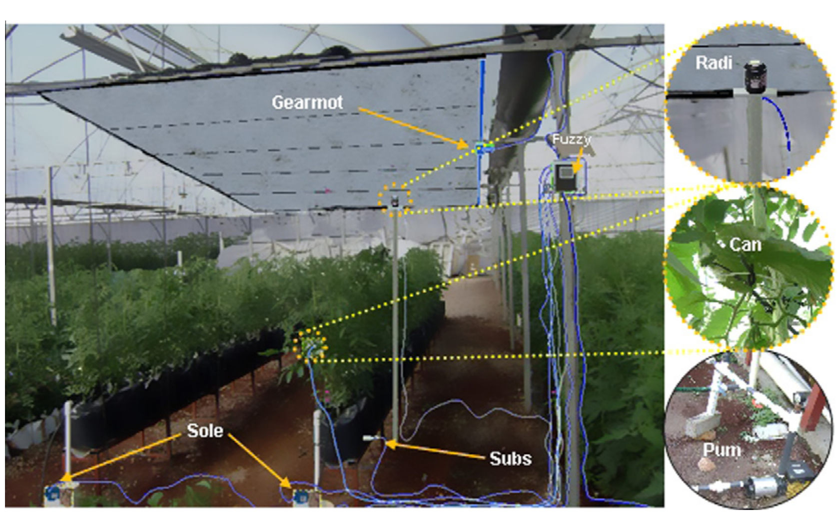

Fig. 1. Greenhouse tomato plants grown in solenoid controlled rows showing sensors, shade screen and external pump.