AUTOMATIC FIVE HEADED NUTRIENT INJECTOR SYSTEM

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1. INTRODUCTION

Fertigation generally implies the use of a computerized control system for precisely providing water and specific nutrients to plants at the appropriate time. While environmental computer systems have been used successfully by the greenhouse industry (Geiling, 1985) for temperature, humidity, and light control, fertigation control has not advanced at the same rate (Papadopoulos and Liburdi, 1989). A development of a complete controlling device would be able to minimize chemical and water waste, prevent ground contamination, and increase application effectiveness (Fynn and Roberts, 1992).

The computerized fertigation system was jointly developed by the department of Food, Agricultural and Biological Engineering at the Ohio State University/Ohio Agricultural Research and Development Center (OARDC) in Wooster, Ohio, and Q-COM Inc., Irvine, California. Fynn and Roberts (1992) designed a fertigation system that offered the capability of controlling the concentration of essential nutrients according to type of crop, crop conditions, environmental conditions, grower input, and other external inputs. When in use, crops were to be continuously feed precisely calculated quantities and ratios of water and nutrients to meet hourly, daily or weekly needs for optimum growth and health. This computerized system was predicted to reduce greenhouse water use up to 80 percent and fertilizer use by 50 percent (Fynn, 1992).

Bauerle (1988) described the main components of an ideal fertilizer injector system and its envisaged operation. His computerized fertilizer injector system was a 10-headed fertilizer injector without a mixing tank system. Papadopoulos and Liburdi (1989) developed the concepts into a fertigation system and tested working prototypes of a computerized fertilizer injector. Jensen (1990) and Fynn (1993) provided information on evapotranspiration in evaluating evapotranspiration data received from various sources. Jensen presented the FAO-Penman's ET calculation method and the Penman-Monteith ET calculation method which was used in this study. Fynn added Canopy Area Index which was related to the percentage of floor area covered by plant leaves. An decision analysis and expert system model for nutrient selection in a drip irrigation system was introduced by Fynn (1988, 1989). He established the control of the nutrient injector by using a decision model that incorporated mathematical modeling, decision analysis and expert systems to come to a unique decision about the nutrients required for each time period. Fynn (1992) introduced the detailed information of a fertigation system based on a five head individualized fertilizer injector device used in this study.

The overall goal of this research was to evaluate how precisely a specific fertigator was controlled. This included the testing of nutrient injection pumps, flowmeter feedback, control software, and control firmware (local microprocessor). After modification and enhancements based on the experimental results, the accuracy of the fertigation system was again investigated.

2. MATERIALS AND METHODS

A comprehensive greenhouse plant growth control system that integrated communications, sensors and control logic for climate and fertigation, was used in this study. New fertigation algorithms were formulated to predict when a crop needed irrigation, and then a comprehensive recipe selection control system was designed based on the predicted evapotranspiration of the crop and the quantities of each nutrient required (Fynn, 1992).

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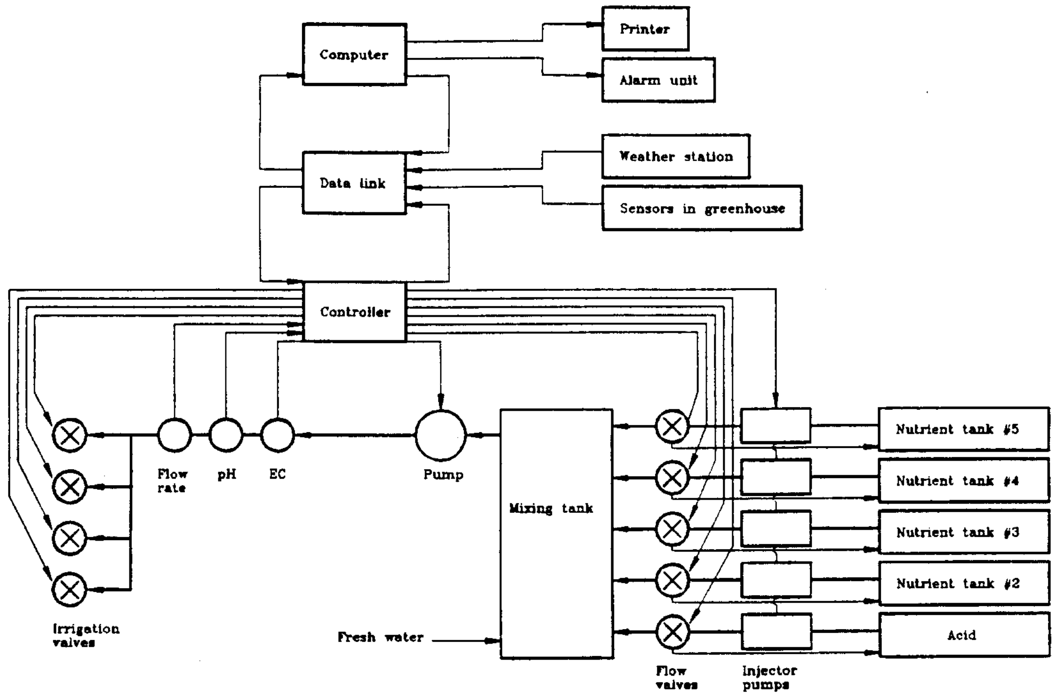

Fig 1. Block diagram of the computerized fertigation system tested in the experiment.

The fertigator was designed to use four nutrient feed tanks and one acid feed tank as depicted in Fig 1. The basic control was a GEM3 (Q-COM Inc.). The nutrient injector consisted of a set of five recirculating injection pumps and three way solenoid flow valves, a main mixing tank, and a master repressurization pump. The five recirculating injector pumps and three-way solenoid flow valves were computer programmed to meter correct proportions of nutrient and acid from the feed tanks into a common mixing tank of fresh water at atmospheric pressure. A repressurization pump was designed to pump the nutrients and water from the mixing tank to the growing area. The fertigation controller hardware consisted of a sensor motherboard with three inputs that measured electirical conductivity (EC), pH, and water flow. The EC and pH sensors were used for alarms. The sensors of flow rate, pH, and EC were located on a vertical pipe (0.0254m diameter) where the flow was upward. The flow meter was an OMEGA 8500 Low Flow Sensor. The pH and EC sensors were OMEGA PHTX-80 and CDTX-82, respectively. A five channel digital output card was used to activate injector pumps, flow valves, irrigation zone valves, and main irrigation pump.

The flow of concentrated nutrients into the mixing tank was precisely metered through fast acting, three-way solenoid flow valves. Each valve was pulsed on and off by the local control microprocessor according to the desired recipe formulation. These switching valves either permitted the flow of chemicals into the mixing tank or directed the flow back to the nutrient tanks for mixing. The fresh water was delivered to the mixing tank according to a predicted irrigation requirement and adjusted for pH by the controller with an acid. When the nutrient recipe leaves the mixing tank, the computer moniters its flow rate, EC, and pH for control and alarming. If the pH does not fall within the computed limits for the formulation in use, the grower can choose to set an alarm, turn off the system, or adjust the pH by increasing or decreasing the flow volume from the acid feed tank. The water delivery hose (D = 0.0159m) was used to deliver water from the nutrient injector to four irrigation valves installed at the end of the water delivery line as shown in Fig 1.

The computer software was designed to apply a small amount of water and nutrients several times during a day. The water supplied depended upon the plant requirements, which were calculated using a mathematical evapotranspiration model (Fynn, 1993). The GEM- 3 software was written to interact with a multi-tasking program called DESQview. The monitor continually displayed the status of all components in the system. The data link box, the alarm unit, and the printer were also connected into the computer.

Some important control options of the GEM-3 configuration menu were run time, clear and fertilized volumes, and actual and target average concentrations. The computer calculated how much water had been used by plants evapotranspiration equaling water requirement. When the calculated water loss reached an arbitrary water requirement value chosen by the user, an irrigation event was triggered. The irrigation event was called run time; and, it consisted of initial clear volume, fertilized volume, and final clear volume. The purpose of the clear volume was to purge the irrigation lines with fresh water. During the fertilized volume period, selected nutrient solutions were injected into the mixing tank, mixed with the fresh water, and then supplied to the plants. The target nutrient concentration was selected by the user and increased by the computer in proportion to the rates of total run time to fertilized time. This adjusted concentration accounted for dillution effect of the clear volume.

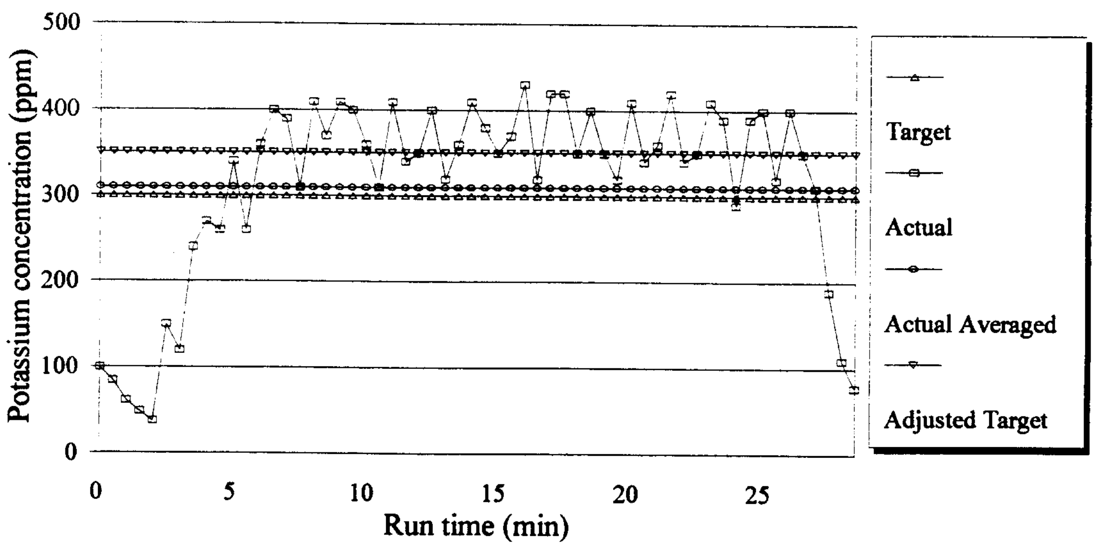

Fig 2 An example of how the fertigator was designed to deliver nutrients and adjust the target concentration to account for run time. The change of actual potassium nitrate concentration from the fertigator during a run time of the fertigator. The water requirement was 300 liters and each 20 liters was programmed for the initial and final clear volumes.

The accuracy of the nutrient injector was tested under select parameters for irrigating and fertilizing crops with hypothetical values of irrigation demand based on evapotranspiration parameters. The irrigation queue was chosen to have only one valve open while the system was designed to coordinate many valves based on menus and irrigation demand.

An example of a typical run

During the entire run time of the fertigator, the change of the nutrient concentration from the fertigator output was measured with the Cardy meter. The change of nutrient concentration of the output is shown in Fig 2 where the water requirement for each run time was arbitrarily chosen to be 300 liters. The target nutrient concentration was 300 ppm, and each 20 liters was programmed in the computer for the initial and final clear volumes.

The change of nutrient concentration could be divided into three distinct sections : the initial clear volume, the fertilized volume, and the final clear volume. During the initial and final clear volumes, the nutrient concentration was low because the water supply line was being purged by only fresh water. After the initial clear volume, the nutrient concentration increased above the target value based on a built in adjustment ratio of total run time to injection time. The measured fluctuations during this stage were because the main volume consisted of intermittent flows of the injector pump.

The results showed that the actual average nutrient concentration was 310 ppm even though the target nutrient concentration was 300 ppm. Adjusted target nutrient concentration was 350.8 ppm.

3. RESULTS AND DISCUSSION

In the first set of tests, the calculated run time from the computer and measured run time from the fertigator were compared. The ranges of errors for Cases 1, 2, and 3 were -5.52 % to +1.84 %, +10.65 % to +19.29 %, and +86.83 % to +101.44% respectively. The values obtained for case 1 were the most accurate, and the case 2 happened most frequently (about 40 - 50% of the total replication). Case 3 happened whenever the fertigator was operated just after a long non-working period. The error of the run time of the fertigator appeared to decrease after the fertigator was continuously operated for over one day. The relationship of ground area and water requirement programmed in the computer was also important for precise operation of the fertigator. For example, on a high temperature, sunny day, high evapotranspiration calculations caused the fertigator to work more frequently and then generated potential for overlapping of irrigation periods which caused the serious confusion in the software. The error of the run time of the fertigator was very high when the initial clear volume was lower than 9 liters. Later, it was found that the GEM 3 software had been programmed as if at least 10 liters of the initial clear volume was needed for purging the water supply line.

Fig 2 showed that the actual average nutrient concentration was higher than the target nutrient concentration programmed in the computer. The amount of nutrient supplied to the mixing tank might be higher than desired, due to inaccuracy in the nozzle and solenoid valve operation. The large error could be from the flow meter. If it was reading too high because of turbulence, then it would make the injector inject too much nutrient concentrate.

The flow rates of nutrient water from the mixing tank and on the screen of the computer were compared when one, two, and three irrigation valves were kept open at the end of the water supply line. The errors were found to be -4.8%, -3.4%, and -4.6% when the open valves were one, two, and three, respectively. An error in the flow rate could be influenced by a number of the factors. The value of 128 ℓ/min programmed as the full scale output was not correct. The negative error of the flow rate indicated that the water flow calibration was low. Moreover, the flow rate sensor was located too close downstream of the EC and pH sensors, along the pipe, thus affecting the flow meter's sensing capability. The system should be designed to prevent air-water vapor pockets and turbulence causing inaccuracy in the calibration. The pipe in which the flow rate sensor was located, was installed vertically on the wall, so the problem of air pockets was solved. A minimum of 50 pipe diameters of free-flowing straight pipe upstream of the sensor was recommended to prevent the turbulence. However, the distance between the flow rate sensor and the other sensors was only 14 inches even though it should had been over 50 inches.

The flow meter was calibrated again by using the statistical regression analysis to find the water flow rate at full scale. According to the formula, $\ell / \min = 8.2826 \cdot mA - 33.446$, ($R^2$=0.93), the full scale output at 20 mA was predicted to be 132.2 ℓ/min. The water flow at full scale during the preliminary experiment was 128 ℓ/min, so the difference was over 4 ℓ/min.

The CommServer which was the communication link between the GEM 3 system and the fertigator, was investigated. During the preliminary test, significant differences were found between some values from the CommServer and the zone detail display on the screen of the computer, such as cycle volume, clear volumes, and volume left in current. It was found that the problem was in the signal conversion. During the input signal conversion, the range of QCOM software was 51 to 255 counts, however, it was found that the software had operated from 0 to 255 counts.

The actual flow rates from the nutrient injection pumps and the predicted flow rates programmed in the computer were compared. The results showed that the flow rates from five nutrient pumps were different with one another because of the different efficiency of nutrient pumps and the different clean condition of nozzles. The results also indicated that the flow rates originally programmed in GEM 3 were seriously lower than the actual values. It might cause the supply of higher nutrient concentration to the plants than the desired recipe. The correct value of flow of concentrated nutrients into the mixing tank was very important because the computer pulsed the nutrient injection valves on and off in accordance with the desired recipe formulation, the nutrient concentration in the nutrient tank, and the flow rates from the nutrient tanks and the mixing tank.

Based on the preliminary results, the final experiment was run after modifications of Q-COM software, repositioning of the flow meter, enhancement of the nutrient injector and new data points found during the preliminary experiment were programmed in the computer. Moreover, The distance between the flow rate sensor and the other sensors was corrected by adding a new pipe of 40 inches length between the flow rate sensor and the other sensors. After modification and enhancement, the actual average nutrient concentrations were identical with the desired values. It showed that the modifications incorporated and the new data programmed in the computer have improved the precision of the fetigator. The result also showed that the initial non-zero nutrient concentration in the mixing tank (Fig 2) did not seriously affect the average nutrient concentration. However, if a lower nutrient concentration or different recipes were irrigated as compared with previous nutrient solution, it might cause undesirable results.

4. CONCLUSIONS

The preliminary results indicated that the significant error was developed from a number of factors. During the experiment, those factors were enhanced and programmed in the computer. After the modification and enhancement, the average nutrient concentration during the run time of the fertigator was very accurate. It indicated that the modifications incorporated and the new data programmed in the computer had improved the precision of the fertigator. However, the run time of the fertigator were not stable due to inconsistency in the control system. The evaluation results indicated that more adjustments and developments of Q-COM's software and hardware were needed in the future.

There was no doubtful that the complete controlling fertigation device would be powerful tools for minimizing chemical and water waste, preventing ground contamination, and increasing application effectiveness.

5. REFERENCES

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