Monitoring the response times to variable-rate herbicide application in a Direct-injection sprayer (C0663)

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CONTEXT & OBJECTIVES
An intelligent direct-injection implement for variable-rate herbicide application (VRA) was designed and constructed under the RHEA project: Robot Fleets for Highly Effective Agriculture and Forestry Management. This system provides precise herbicide application rates based on weed infestation maps, resulting in minimal operator exposure to chemicals. The use of weed infestation maps is becoming more widespread with the development of remote (satellite, aerial imagery), and small aerial unmanned vehicle) and proximal (soil, weed, and crop parameter) sensors. However, it is crucial to determine the limitations of the hydraulic system of the herbicide application device in use. The primary issue with injection sprayers is that there is a continuous transport lag in the system. The transport lag is the time required for the mixed solution to flow from the injection point to the spray nozzles.

The specific objectives were i) to develop an automated sprayer that is suitable for RTK-DGPS control based on a weed map and ii) to develop a theoretical method for measuring the performance of the injection metering system and to use this method to assess the dynamic response characteristics of the proposed system in experimental investigations.

MATERIAL & METHODS
Twelve high-speed solenoid valves (Model VC01, N-Tech Industries, Inc., CA, USA) were mounted on a stainless steel sprayer boom with an equidistant spacing of 0.5 m. These solenoid valves consist of a ¼” hose barb brass inlet for the incoming liquid, a spray nozzle, a nozzle cap, an LED indicator, a 3-pin electrical connector (signal, negative, and positive), and two captive screws. The boom sprayer was divided into twelve sections, each containing one solenoid valve. Each of these valves was energized by a 12 V source that allowed the spray from each section to be controlled independently. The LED indicator was on when the solenoid was open.

A commercial central direct-injection system (Model Sidekick Pro, Raven Industries Inc., Sioux Falls, SD, USA) was equipped with a water tank (200 L) and a separate container for the herbicide (15 L) injection according to the prescription information from the High Level Decision Making System (HLDNS). The controller (SCS-sidekick) unit was controlled by the HLDMS and signal inputs from various sensors. The HLDMS program, written in LabVIEW, uses the RTK-GPS position and the application rate map to determine the desired application rate. A PCB interface between the sprayer and HLDMS was created and installed to accommodate the signal sensors and to host the injection system controller and the automation (PLC) device. The injection system controller supplied a variable voltage to the gear motor to power the injector pump. This voltage caused the injector pump to turn at the appropriate speed to generate the desired flow rate of the active ingredient. An encoder integrated into the system measured the flow rate of the active ingredient based on the injector pump speed. The controller used the active ingredient flow rate from the pump speed to determine whether a change in the active ingredient flow rate was needed.

INITIAL RESULTS
During initial period, the experimental concentration did not follow the theoretical model but then gradually approached the experimental values until they matched. This phenomenon can be explained by the behavior of the injection pump due to the time required to stabilize the injection rate to the required value assuming a null injection flow. (Figure 1)

This alteration causes the value of p to not start from t=0 to its nominal value of 0.1 L/L but, rather, to start from scratch and increase following the transient function p=f(t), thereby amending the expected theoretical results until it reaches its final value.

To account for this additional transition in the general model, the value of p increases linearly from t=0 to t=25 s, representing a growth rate of 0.04 L/L per second.

A comparison of the fit of the experimental values with the resulting final model was performed by calculating the estimated values at discrete time intervals of 1 s, considering the value of the concentration in the second i will behave as follows:

\[ c_i = c_{i-1} + \frac{Q_w}{V} + c_{i-1} \cdot \left( 1 - \frac{Q_w}{V} \right) \cdot (p + 1) \]

Where \( c_{i-1} \) is the value of the concentration in the second equation prior to calculation, starting from an initial value \( c_0 \) equal to zero, allowing for the use of a different value of \( p \) for each discrete value of time in the initial 25 s. (Figure 2) The estimated versus the experimental trend line and a coefficient \( r^2=0.9995 \) for a relationship between these values of 1, it is represented (Figure 3)

STUDY CONTRIBUTIONS & OUTLOOK
The principal results of this research are:
- The developed model is able to predict discrete hydraulic profiles by applying the control volume element method, aiding in the design of an optimal boom for a direct-injection sprayer.
- This study has been focused in the most difficult response time of a direct-injection system on one nozzle. Has been shown very satisfactory fit of the proposed theoretical model.
- To reduce the concentration increase time, the injection process should be optimized to reach the desired chemical concentration as fast as possible. This study shows that 25 s are required to stabilize the injection rate to the required value assuming a null injection flow. Proportional-integral-derivative controller (PID controller) adjustment may reduce this time.
- Knowing the transport lag time allows to anticipate it between the new solution in the herbicide concentration and the arrival of this new solution at the sprayer nozzle.

ACKNOWLEDGEMENTS
This project is funded in part by the 7th Framework Programme of the European Union under Grant Agreement No. 245986. The authors want also to express recognition to the RHEA beneficiaries: CSIC (Spain), CogVis (Austria), FTW (Austria), Cyberbotics (Switzerland), University of Pisa (Italy), University Complutense of Madrid (Spain), Tropical (Greece), SAP (Spain), Polytechnic University of Madrid (Spain), AirRobot (Germany), University of Florence (Italy), IRSTEA (France), CNHi (Belgium), Bluebotics (Switzerland) and CM (Italy).