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SMALL PLOT SPRAY SYSTEM: SOFTWARE, VARIABLE PIPETTER, SPRAYER

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Abstract

A small-plot pesticide evaluation system is defined that includes a computerized, tractor-mounted spray system, an automatic pipetter for filling bottles used on the spray tractor, and a computer program for computation of volumes of adjuvants and pesticides to be added to a pre-set volume of carrier.

Introduction

True replication of treatments in insecticide bioassay studies should include individual mixes for each chemical in each replicate as well as spraying all treatments in random order within one replicate in time before moving on to the next replicate. This principle, as discussed by (Robertson and Preisler (1992) for laboratory evaluations is also valid for replicated efficacy evaluations of insecticide that take place in the field on small plots. In order to incorporate this philosophy, a spray system was designed to allow the spray tractor to enter a cotton field and to sequentially spray random treatments on small plots of approximately 50 ft in length. This required a system that would spray one plot with one treatment, rinse the system, and spray the next plot with the next assigned treatment. A system with many booms and one pesticide container per boom, would eliminate the need for rinsing between plots. This, however, was impractical for our needs since the number of treatments in a replicate might be 25 or more. A system was therefore designed to spray out of plastic beverage bottles, requiring one bottle to be used per plot (Reed and Grant, 1990). This required the use of 1 bottle per treatment per replicate and established a need for a rapid, accurate method to mix multiple bottles of the same insecticide concentration. The system thereby complied with all the requirements of proper replication of mixes as well as random application within the field.

In order to facilitate the accurate filling of bottles and to reduce the laboratory time required to fill large numbers of bottles with a known amount of diluent (usually water). An automated pipetter was developed to accurately and rapidly fill four bottles at a time at any of three pre-selected volumes. The system can also be expanded to dispense a larger number of different volumes or to fill more than 4 bottles at a time. Additionally, by filling the bottles to a known level, large numbers of bottles could be filled days in advance of a planned application. A computer program was developed to compute the precise amount of pesticide concentrate required to mix with any given amount of water for any concentration of mixture. In other words, the program would compensate for the increased volume that would be obtained by adding an amount of insecticide without removing the water so that the resulting pesticide concentration in the mixture would be correct.

Finally, a computerized system was designed for the spray tractor to automate all the functions of the spray system except the actual replacement of the bottle of pesticide. The end result of the developed system provided a marriage between the computation of the amount of pesticide to add to a bottle, the filling of the bottles, and the actual application in the field. This precise system eliminates laboratory rinsing of spray containers and the resulting toxic waste, and provides for an extremely adaptable system for small plot spray applications. This paper reviews the three components of the system: the multiple pipetter for filling bottles, the computerized spray tractor, and the basic concepts for the computer program used to calculate the amount of insecticide to add to a given volume of water.

Methods and Materials

Automated, Multiple-Outlet Pipetter

Researchers who conduct a large number of field-plot tests usually pre-mix the spray mixtures in individual containers before going to the field. With this type of operation, they must put a known amount of water and pesticide into each container. Typically the water volumes are measured with a graduated volumetric container (i.e., graduated cylinder, volumetric flask, etc.). This process is time consuming, and the accuracy of the dispensed water volumes depends on the one who is doing the measuring. Because volumetric application rate (L/ha) requirements may differ from one test to another, there is a need to accurately dispense any of several volumes of water into multiple containers. There are many small volume (i.e., generally

<100 mL) dispensers on the market (Fisher Scientific, 1999 and other commercial sources). Nearly all of these devices will accurately dispense varying volumes but only into one container at a time and at volumes far below that required for our system. The objective of this part of the research was to develop and test such a pipetter. Either 0.6, 1.0, or 2.0 L plastic beverage bottles were to be used with the pipetter. It was desired that the unit deliver volumes that were within ±3% of 0.5, 1 or 1.5 L and add water to each of four bottles simultaneously.

Of several concepts that would produce desired results, a design utilizing constant pressure and constant orifice areas with a variable fill time was chosen because it appeared to be the most functional and affordable. Calculations with variables associated with the continuity equation, $Q = A_o v$ (Fox and McDonald, 1992) in combination with the equation, $V = Q t = A_o t v$, where Q = flow rate (cm^3/second), V = volume dispensed (cm^3), A_o = orifice area (cm^2), $v = (K g P / \omega)$ (cm/second), K = proportionality constant (20.38 g / kPa cm^2), $g = 980$ cm/s^2, P = pressure (kPa), ω = density of water (1 gm/ cm^3), and t = fill time (s), indicated that the inlet pressure could vary by ± 6 % while maintaining the output volumes within the desired ±3%.

The finished device is housed in a sheet metal container (Fig. 1) that is about 0.62 m wide, deep and tall. Water from a standard faucet is fed into the pipetter using a hose. The hose is attached to a reinforced rubber (i.e., 1400 kPa burst pressure) input line. Water from the input line flows through a solenoid valve (Dayton Electric Mfg Co., Noles, IL, model 3A440, 120 V. A. C.), then into two pressure regulators (Watts Industries, Inc., North Andover, MA, Model ES-N35-Z9) mounted in series. A pressure gauge (Dresser Industries, Chicago, IL, 7.6 cm diameter, 0-414 kPa pressure gauge) mounted on the front panel was connected to a tap installed between the solenoid valve and the first pressure regulator so that the line pressure could be read while the bottles were being filled. The face of the gauge was marked to indicate the maximum and minimum allowable pressure.

The two pressure regulators were used in series to stabilize the water pressure even though the line pressure may vary while bottles are being filled. The first regulator was set to reduce the pressure to 256 kPa while the second one reduced the output pressure to a nominal 221 kPa. The second pressure regulator was internally modified so that no water could back-flow through the small holes that allowed water to pass through the center of the rubber diaphragm.

A momentary contact switch (Telemecanique Model ZA2BP2, Granger Co., 3551 I-55 S., W. Frontage Rd., Jackson, MS 39212-4963) and a three position rotary switch (Carlingswitch Model 700-BL, Granger Co., 3551 I-55 S., W. Frontage Rd., Jackson, MS 39212-4963) were mounted on the front face of the pipetter. The three positions on the rotary switch were wired so that each position activated one of three solid-state timers (Dayton Electric Mfg. Co., Model 6A858) mounted inside the pipetter housing. This switch-timer system allowed selection of three different time intervals in order to dispense three different volumes of water.

Water from the second pressure regulator flowed into the center of a 2.5 cm i.d. square manifold. The manifold was drilled and tapped to accept four, equally spaced, Quick TeeJet adapters and caps (Spraying Systems Co. Wheaton, IL, part nos. QJ 1/4 TT-NYB and CP25607-NY). Each adapter was equipped with a plug tip (Spraying Systems Co., No. CP3942) in which a 1.7 mm diameter orifice had been drilled based on calculations using the continuity equation when the pressure was set at 221 kPa. Copper tubing (0.95 cm o.d.) was fitted to each adapter and the tubing was connected to a 90º elbow. One end of a piece of plastic tubing (1.6 cm i.d.) was attached to the 90º elbow with hose clamps, and the other end was mounted immediately above the opening to each of the four bottles used to collect the water. A bottle rack was constructed of angle iron and mounted across the front of the pipetter to hold the four bottles.

With orifice diameters of 1.7 mm and a pressure of 221 kPa, the continuity equation was used to estimate the time needed to dispense 0.5, 1 or 1.5 L of water. Based on this information and some preliminary testing, the timers were set for nominal times of 8, 16 and 24 seconds. After initial testing, the orifices had to be enlarged by filing in order to off-set minor variations in the flow rates between bottles.

In order to operate the pipetter, the selector knob on the rotary switch is set to the 0.5, 1 or 1.5 L position. A bottle is placed under each plastic tube and the momentary contact switch is pushed. When the flow stops, the bottles are set aside, empty bottles are positioned on the rack and the process is repeated.

Computer Program to Facilitate Mixing

The amount of a formulated pesticide needed to obtain a predetermined volume of spray solution may be obtained by simple calculations based on the rate of active pesticide ingredient present in the formulated pesticide, the total volume of spray to be applied per unit area, and the volume of spray solution to be mixed. Thus, if you desire 1 L of spray mix, and the volumetric application rate is 50 L / ha, you would need to add 1/50th of the amount of formulation you would need to spray 1 ha. If the concentrated pesticide is to be applied at the rate of 100 g of active ingredient (ai)/ ha, you would need 1/50th of 100 g or 2 g ai / L of mix for a concentration of 0.2 g / 100ml. Thus if the formulation were 25 g ai / L, you would need 4 L of insecticide per ha. That is 2 % of 4 L of formulation or 80 ml of formulated insecticide to add to 920 ml of diluent to provide 1 L of total mix. Such computations are routinely made and are incorporated in computer programs designed for small plot applications. However, such computations require that a specific volume of water be measured to which a specific volume of liquid insecticide be added in order to result in the predetermined total volume. Careful measuring of water volumes for such mixtures is time consuming, particularly for a system where each pesticide treatment must be mixed in multiples according to the number of replicates. If one begins with a preset, standard volume (i.e. the desired volume of 1 L in our example), then an amount of water must be decanted prior to adding the insecticide. This also, is time consuming when many bottles must be mixed.

The solution is to dispense with the need for an exact predetermined volume of spray solution and, by use of the computer, calculate the amount of insecticide to mix to compensate for added volume when the insecticide is added to a standard volume of water. Basically, if you start with 1 L of water and add the 80 ml of concentrated insecticide, the resulting volume is 1080 ml and the concentration is 2 g/1080 ml. One needs to add enough insecticide to compensate for 80 additional ml, an increase of 8%. Thus one adds an amount of insecticide equal to 8% of the original addition of 80 ml (6.4 ml) that brings the total up to 1086.4 ml of total mix. This results in an error of only 0.59%. If we compute the amount of insecticide to add to the total mix to compensate for this, one needs to add only 0.59% of the original 80 ml of insecticide or 0.47 ml of insecticide to compensate for the additional 6.4 ml of volume obtained with the second addition of pesticide. A third computation results in an insignificant amount of insecticide needed to add to compensate for the additional 0.47 ml of insecticide. These computations can readily be calculated in a spreadsheet format as in Table 2. The computer program simply checks the difference between the amount added in one loop and the amount added in the next loop and when it reaches a predetermined value that is considered insignificant (near zero) the computations stops. In addition to calculating the changing and ever decreasing volumes to add to compensate for previous additions, the computer program adds each addition of insecticide and displays the total at the end of the final loop of the program.

Tractor-Mounted Computerized Spray System

During the summer of 1989, a modification was made to a header for a hand-carried spray boom marketed by R&D Sprayers Inc., (419 Hwy 104, Opelousas, LA 70570) that allowed rapid removal of a plastic bottle from the header and facilitated rapid replacement with the next bottle (Reed and Grant, 1990). Following the development of this device, a spray system was developed that used electrical solenoid valves to control compressed air, spray solution, rinse water, and purging of the spray system. The task of spraying a test plot was greatly simplified by activating the valves in a correct sequence. At the end of a sprayed plot, switches were manually operated to complete the following sequence of events. 1) open the purge valves to allow the compressed air to void the lines of unused insecticide; 2) close purge valves to force air through the nozzles; 3) close compressed air valves; 4) open the rinse water valve; 5) close the water valve; 6) open the compressed air valve to force rinse water through the system; 7) open the purge valves to purge the rinse water from the system; 8) close the purge valves to force air through the nozzles; 9) close the compressed air valve; and 10) open the purge valves to remove all air pressure from the system in order to load a new chemical. As a result of the procedure, the bottles would be sufficiently rinsed to be filled and used in the next trial.

In order to reduce confusion and operator fatigue, and to provide a format for more accurate rinsing, the development of a computerized spray system was begun. Prototypes were subsequently built and results were reported in 1996 (Reed et al.) and 1997 (Reed et al.). These devices utilized custom, laboratory constructed, electronic controllers that linked a palmtop computer (model Hp-200, Hewlett Packard Co., 3000 Hanover Street, Palo Alto, CA 94304-1185.) to the solenoid valves. Based on the experience gained from these systems, a new generation of automated plot sprayer was developed. Upon power up, the new system has a default "program" that is automatically made available and the user can execute it by pressing a designated key. A "program" in the new system is a set of timing values that determine the length of time (seconds) each step of the spray sequence takes. The currently active program is displayed at the bottom of the screen with a program ID and the set of timing values shown in a comma separated list between two brackets ("id<..>"). When the program is executed, the associated timing value of each step is decremented and displayed, thus the program shown at the bottom of the screen also serves as a status display. The execution of a program is interrupted when a key is pressed while it is running. The user can enter up to 99 different programs into the system, and the retrieval of the program is done in a menu driven basis. The programs are stored in a non-volatile memory, which means they are "remembered" even through electrical power is removed from the system.

The spray sequence is executed in the following steps:

- Initialization – the boom is depressurized by shutting off the compressed air and by opening the spray valve. The amount of time it takes to initialize the system is a timing parameter that is defined by the user. At the end of initialization, the system prompts the user of the fact and it asks the user to install the bottle. The user signals the completion of bottle installation by pressing a key.

- Pressurization – The system is pressurized with the spray valve closed.
- Spray – following the bottle installation, the spray is initiated. A short delay (user defined) is included before the user is prompted to move the sprayer so that there is time for all nozzles to begin spraying evenly. The amount of time for spraying (after the sprayer is in motion) is also user defined and the speed of the sprayer is shown on the screen. The final speed is frozen at the end of the spray time so the operator may record it if desired.
- Rinse – a rinsing process is initiated immediately after the spraying ends. Two rinsings are performed and the amount of time each rinsing takes is defined by the user. Rinsing involves the filling of the bottle with water and forcing of the water through the nozzles or purge valves with compressed air.
- Purging – after the rinse sequence is completed, the boom is purged twice: first by introducing compressed air into the spray system and by opening the purge valves at the ends of the boom. Then the purge valves are closed and the compressed air is forced out through the nozzles. The amount of time for each purging is defined by the user. After purging is done the system is reinitialized making it ready for the next spray run.

The diagnostics feature incorporated in the system includes the turning on/off of any valves and speed display. These functions are accessed by following the menu. The programming of the system and the retrieval of a program are also done by following the menu. There is no programming skill required to operate the system, only the ability to follow instructions.

The hardware constituting the new automatic spray system was developed using an Intel 80188 based embedded computer. The system is enclosed in a weather proof, NEMA-4 fiber glass enclosure and the user interface is a weather proof terminal with a 4-line LCD character display with 20 keys from QSI Corp (Figure 3). In addition to the programmed operation, an override feature is incorporated to allow manual operation of the individual valves. Other capabilities of the system that are not currently utilized are a GPS (global positioning system) interface and a host interface for data transfer.

Results and Discussion

Automated, Multiple-Outlet Pipetter

Accuracy of the volumes dispensed into the four bottles was determined by computing the average volume and maximum percent error. This was calculated by subtracting from the mean the volume that was numerically the most distant from the mean, multiplying the difference by 100, and dividing by the mean. Measuring the dispensed volumes with the pipetter set at 0.5, 1.0 or 1.5 L resulted in a mean maximum percent error of 0.79, 0.28 and 0.28%, respectively, based on 7 replications (Table 1). Results (seven replications) of placing the pipetter on an uneven surface (2.5 cm higher on one side) produced similar results at the 0.5 L setting with a mean percent maximum error of 0.48%. Dispensed volumes (9 replications) were evaluated on each of nine separate days to determine if there were changes over time. The dispensed volumes were measured in either a 1000 or 2000 ml graduated cylinders depending on the magnitude of the dispensed volume.

The average volumes dispensed for the four pipetter outlets in replicated tests were very close to the nominal volumes and were within 3-4 ml of each other except in one case (6.4 ml). The maximum percent errors for same-day evaluations were all $\leq$ 1.08 % and were typically < 0.7 %. When the pipetter was tilted to one side, the average dispensed volumes were very close to the nominal values, and the percent errors were 0.63% or smaller. When the volumes were measured over 9 days, the largest maximum error was 0.66%, and the average dispensed volumes were very close to the desired volumes. One of the design criteria for the pipetter was to be able to dispense volumes of water to within $\pm$ 3 % accuracy. Clearly, all of the maximum percent errors were well below the 3% mark, and all except one were <1%. The pipetter is currently being used in conjunction with an entomology insecticide screening program that requires the use of hundreds of bottles to be mixed with a given amount of insecticide and water.

Computer Program to Facilitate Mixing

The computer program written in basic and the spreadsheet program both provide an accurate method for computing the volume of liquid chemicals to be added to a pre-set volume of carrier to provide a desired concentration of pesticide and/or adjuvant. Reed and Fritzius (1993) reported on the computer program that included routines for the mixing of solutions containing multiple insecticides and or additives such as adjuvants (Figure 2). They noted that different insecticide formulations contain different non-miscible components. Thus, known amounts of flowable concentrates, soluble liquids, and emulsifiable concentrates, when mixed individually with a known amount of water, result in minutely different total volumes. Although these differences are so small as to be insignificant when used in field applications of insecticide, results of mixtures using the computer program that is able to compensate for such differences in solubility are more accurate than results of the identical mixtures using the decant method. Thus not only did the system incorporating the automated pipetter and the computer program save mixing time, but it was inherently more accurate than the decant method. The spreadsheet program should provide a level of accuracy as good as or better than the decant method, because one step of the operation is deleted, providing less opportunity for error.

Tractor-Mounted Computerized Spray System

The new system improved upon the previous systems by making it a turnkey system and by improving its programmability. It is a menu-based system by which the user can execute a current "program" as well as perform programming and diagnostic tasks. The system automates the entire spraying operation with instructional prompts to guide the operator through the tasks that have to be done manually. The only tasks that have to be done manually are installation of the bottle of insecticide, pressing of a key on the console to initiate the computer program, and the driving and stopping of the spray vehicle. The system was developed as a turnkey system that only requires the operator to turn on a switch. A default program is automatically loaded and ready for use on power up. The operator can store up to 99 sets of spray sequences (programs) into the system, and they are stored in a non-volatile memory. The recalling of any stored program sequence is done in menu driven steps. The currently active program is displayed on the screen at all times and the current state of the sequence is dynamically displayed as well.

With the computerized spray system, a 15 m plot can be sprayed and the spray system prepared for the next compound in approximately 1.5 minutes (dependent upon user settings). The system allows for additional inputs such as Global Positioning System (GPS) data as well as temperature, humidity and time. As the development of the system progresses, it is expected that the time, temperature, humidity and GPS location for each plot will be recorded.

References

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Table 1. Average dispensed volume (ml) and the maximum percent error for each of the four pipette outlets when operating under three different test conditions.

Evaluation type	Replications	Nominal Volume (mL)	Pipetter outlet number 1	2	3	4
Level (same day)	7	500	499.6 / 0.68	499.0 / 0.80	499.6 / 1.08	497.9 / 0.62
	7	1000	998.4 / 0.16	997.1 / 0.29	997.2 / 0.28	996.3 / 0.37
	7	1500	1497.1 / 0.19	1495.0 / 0.33	1495.0 / 0.33	1490.7 / 0.29
Not-level	7	500	492.7 / 0.47	492.3 / 0.55	493.6 / 0.28	491.7 / 0.63
Over time (9 days)	9	500	498.2 / 0.64	496.7 / 0.66	496.7 / 0.66	495.4 / 0.52

Table 2. Spreadsheet computation formulae for computing amount of adjuvant and or insecticide to be added to a pre-determined amount of carrier. Initial volume of carrier is 1000 ml, as listed in cell B2. Total amount of mixture is determined in cell B6. This spreadsheet uses ml as measurement criteria because volumetric measurement devices in the research arena are typically metric, however other factors are based on lb, gal, and acres that are not converted to metric equivalents.

	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**
1	**ml / acre**	**Total volume (ml)**	**Adjuvant rate / ac (ml)**	**Insecticide lb ai/ac**	**Insecticide formulation (lb ai/gal)**	**Adjuvant to add (ml)**	**Insecticide to add (ml)**	**Iteration**
2	37850	1000	500	0.2	2	(B2/A2)*C2	((B2/A2)*(D2/E2))*3785	1
3		B2+F2+G2				(((B3-B2)/B2)*F2)+F2	(((B3-B2)/B2)*G2)+G2	2
4		B2+F3+G3				(((B4-B2)/B2)*F2)+F2	(((B4-B2)/B2)*G2)+G2	3
5		B2+F4+G4				(((B5-B2)/B2)*F2)+F2	(((B5-B2)/B2)*G2)+G2	4
6		B2+F5+G5						

Table 3. Results of spreadsheet (Table 2) computations.

	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**
1	**ml / acre**	**Total volume (ml)**	**Adjuvant rate / ac (ml)**	**Insecticide lb ai/ac**	**Insecticide Formulation (lb ai/gal)**	**Adjuvant to add (ml)**	**Insecticide to add (ml)**	**Iteration**
2	37850	1000	500	0.2	2	13.210	10.000	1
3		1023.214				13.516	10.232	2
4		1023.748				13.523	10.237	3
5		1023.761				13.523	10.238	4
6		1023.761						

Figure 1. Automated pipetter, frontal view.

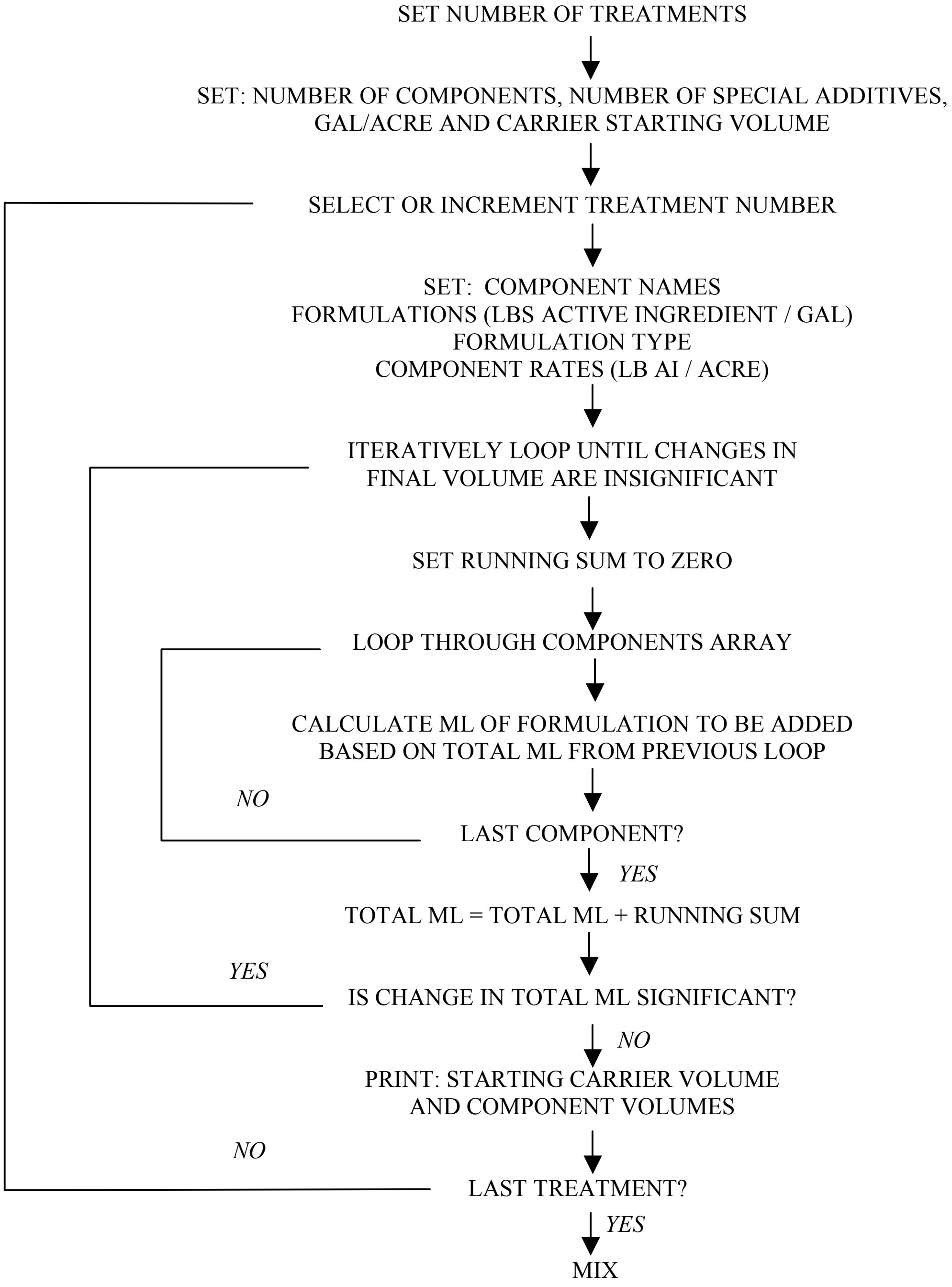

Figure 2. Flow chart of basic mixing program configured in Basic. This program uses ml as measurement criteria because volumetric measurement devices in the research arena are typically metric, however other factors are based on lb, gal, and acres that are not converted to metric equivalents.

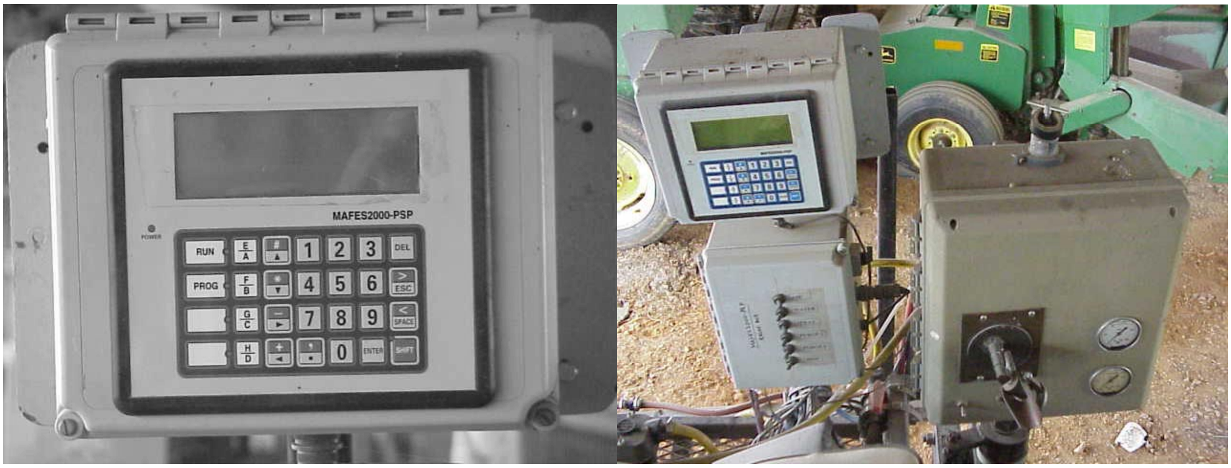

Figure 3. Computer console (left) and associated equipment (right) mounted on spray tractor.