Determining the Microwave Radiations Exposure Level Needed for Weed Control Using a Stationary and Running Belt Microwave Radiations Applicator System[1]

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Abstract

There is a demand for nonchemical weed control strategies, with microwave radiations one possible option. Accurately measuring a weed's exposure level to microwave radiations is a challenge when there is a gap between when electricity is applied to the magnetron and actual production of microwave radiations. This gap causes an error in the calculation of actual energy needed for weed management. Any misinterpretation over-estimates the required energy load, adversely affecting the perceived value of the technology. Studies were conducted to eliminate the existing lag period. A running belt prototype was built for this purpose using two magnetrons producing 900 watt each installed on a treadmill with a power supply. There was significant improvement in the precision for calculations of total energy required for weed control. These anatomically diverse weeds showed more uniform thermal injuries and greater control using the running belt prototype system than a stationary unit. The LD_{50} for broadleaf weeds treated with microwave radiations using the running belt system ranged from 31.2 joules·cm^{-2} for common ragweed (*Ambrosia artemisiifolia* L.) to 36.8 joules·cm^{-2} for pitted morningglory (*Ipomoea lacunosa* L.). In comparison, treatment of weeds with microwave radiations using the stationary mode system resulted in a range of LD_{50} values of 64.5 joules·cm^{-2} for common ragweed to 155.1 joules·cm^{-2} for white clover *(Trifolium repens* L.). Similarly, the LD_{50} values for grasses treated with microwave radiations using the running belt system ranged from 34.3 for dallisgrass *(Paspalum dilatatum* Poir.) to 69.5 joules·cm^{-2} for southern crabgrass *[Digitaria ciliaris* (Retz.) Koeler]); in comparison, the range in LD_{50} values for grasses treated with stationary system was 136.1 to 182 joules·cm^{-2}. The LD_{50} values for sedges treated with microwave radiations using the running belt system ranged from 29.2 joules·cm^{-2} for yellow nutsedge (*Cyperus esculentus* L.) to 78.1 joules·cm^{-2} for fragrant flatsedge (*Cyperus odoratus* L.); in comparison, the range in LD_{50} values for the stationary mode system was 119.4 joules·cm^{-2} for fragrant flatsedge to 145.9 joules·cm^{-2} for yellow nutsedge.

Index words: Nonchemical control, weed control, efficacy, prototype, weed management.

Significance to the Horticulture Industry

Microwave radiations are a potential means of nonchemical weed control. Information is needed on the dose required for effective control. A running belt system was developed to more uniformly distribute the microwave energy to all plant tissues, allowing for improved calculations of energy required compared to stationary units, where hot and cold zones probably result from uneven distribution. The running belt system bypassed the lag period during generation of microwave radiations application. Results are thus closer to actual field conditions where a microwave applicator will move continuously over a weed population.

Introduction

Weed management has always been a challenge in agriculture. Weeds compete with crops for water and nutrients, resulting in yield loss and quality reduction. However, chemical weed control requires widespread spraying, which can inefficiently apply herbicides but also potentially cause adverse effects on the environment (Knee et al. 2010, He 2004, Fernandez-Perez, 2007) decrease biological diversity (Ros et al. 2006), cause changes in the weed community (Schooler et al. 2010, Potts et al. 2010), and can result in resistance of weeds to herbicides (Cirujeda and Taberner 2010, Marshall et al. 2010)

Problems with herbicides, including underground and surface water contamination and pesticide residues in food, have raised public concerns and led to a change in the use pattern for certain herbicides. These problems have challenged weed scientists to consider alternatives and integrated systems of weed management to reduce herbicide inputs and impacts. Moreover, few new herbicide modes of action have been discovered, so new approaches for non-chemical weed management are needed. One of the positive aspects of nonchemical weed control is a potential reduction in the environmental impact. Weed control using microwave radiations is a thermal method. Thermal control methods can be divided in two groups according to their mode of action (a) the direct heating methods using flame, infrared, hot water, steaming, or hot air and (b) indirect heating methods, which includes electrocution, microwaves, laser radiation and ultraviolet radiation.

One potential alternative is the use of microwave radiation, a particular form of indirect thermal weed control. Microwave-based weed control methods work via a systematic increase of temperature due to dielectric heating, reaching biological limits that eradicate or suppress unwanted weeds, insects, and soil borne plant pathogens (Fujiwara et al. 1983, Diprose et al. 1984, Barker and Craker 1991). This dielectric heating has been exploited to kill weeds and weed seed (Davis et al. 1971, Barker & Craker 1991, Sartorato et al. 2006) and insects (Nelson 1996). Several related studies indicate plant

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developmental stage at the time of treatment is an important factor for weed control (Parish, 1989, Parish 1990, Casini et al. 1993, Ascard 1994, Ascard 1998, Daar 1994, Hansson & Ascard 2002). Energy cost evaluations indicated that increased efficiency is required for methods using microwave radiations to compete with other thermal methods of weed control. Microwave efficiency could be increased by a flux configuration that minimizes soil penetration and maximizes absorption by plants, which, in turn, depends on plant growth form (Sartorato et al. 2006).

There is a lag period in between electricity applied to a system and actual microwave radiations produced. Magnetrons consist of a cathode filament surrounded by a specifically designed cavity to produce a desired frequency of microwave radiations. This cavity is surrounded by two permanent or electromagnetic magnets. Its cathode filament is heated by using lower voltage with high amperage. This process takes time, causing a lag period between applying electricity and microwave radiations produced. This lag period depends upon factors like the initial temperature of the magnetron. In a stationary unit, it is hard to detect the magnitude of the existing gap properly. Negligence of these lag period results in an overestimation of the energy requirement and causing misinterpretations in any cost benefit analyses. To eliminate that lag period, a running belt system was built and used to produce a more realistic quantification of microwave radiations required for weed control as compared to stationary units. The hypothesis was this running belt microwave radiations applicator will allow elimination of the lag period and thus will give a more precise quantification of the energy required for weed control as well as provide a better simulation of field microwave applications.

Materials and Methods

These experiments were conducted at the Hampton Road Agricultural Research and Extension Center (HRAREC), Virginia Beach, VA. To eliminate the gap between electric power supplied to magnetrons and actual microwave radiations produced, a running belt prototype was built. A non-motorized treadmill, model number WLTL23180 (Weslo, Logan, Utah) was used as a base. An 115V, geared motor with torque 44 N.mm, manufactured by Dayton (Model no. 2Z797D, Niles, IL), was used to drive the treadmill belt system at a desired speed. A potentiometer (Levitop, Model No. 1LS1I1) was used to control the rotations per minute (RPM) of the geared motor. Total exposure time of a weed to microwave radiations was controlled by regulating speed of the geared motor. A rectangular tunnel was made of cardboard with dimensions 120 cm (47 in) in length, width 15 cm (6 in) , and 25 cm (10 in) in height. This cardboard tunnel was insulated inside with aluminum tape to avoid unwanted leakage of microwave radiations during operations (Fig.1). The geared motor was stopped when weed were treated in stationary mode and weeds were place underneath the waveguide in the cardboard tunnel. Total weed exposure time to microwave radiation in the stationary mode was controlled by switching on and off the magnetron power supply. In the running belt mode, the speed of the running belt controlled the total microwave radiations exposure to weeds. Microwaves could pass through the nylon belt and wooden frame of the treadmill so a tray filled with water was placed underneath the running belt to absorb the residual energy. This technique also protected the applicator from exposure to floor reflected microwave radiations, thus making the working environment much safer.

Two magnetrons (LG Electronics, Model No. 2M246, Seoul, South Korea) of output power of 900 watt each extracted from operational microwave ovens were fitted in the middle of the tunnel using suspension wire and a support frame made of PVC pipe. These two magnetrons were properly wired with corresponding capacitors (Model No. CH2100954C8N), diodes and high voltage transformer (Samsung, Model No.CBJ72, Seoul, South Korea) as per specifications provided by the manufacturer. These parts were also extracted from the same operational microwave oven mentioned above. Magnetrons were tested using the International IEC-705 standard (United States Government 2012). They were approximately 65% efficient in converting electric energy into microwave energy. Rest energy (35%) is converted into heat that may damage magnetrons so two fans attached to a tripod were used to cool the magnetrons during weed treatment. There were four aluminum doors, two at the inlet and two at the exit, that were installed in such a way that only one door opened as a container-grown weed moved through during microwave radiations treatment. This design increased the safety level for the operator.

Power supply and operation monitor. A simple power supply, including a magnetic-shunt transformer, a high voltage capacitor and rectifier, was used for each individual magnetron (LG Electronics, Model No. 2M246). Such a power supply allowed the operation from a standard 110 volt, 60 Hz supply. One three-phase 220 volt, 60 Hz power supply was used for the running belt prototype with two magnetrons. The three-phase power supply was actually an advantage, allowing one to turn on the individual magnetrons sequentially. The power supplies of adjacent magnetrons were connected to different phases of the three-phase supply so that electric load distributed evenly. In this way, the operation of the magnetrons is unsynchronized. When using a large number of magnetrons and corresponding power supplies, component failures are not unexpected. Unfortunately, in the parallel operation of several magnetrons, the failure of a single microwave source may go unnoticed, compromising the result of the experiment. An efficient and reliable monitor of the operation of each individual magnetron was therefore required. Sometimes a magnetron does not produce microwaves efficiently, even though all connections are intact, due to a voltage drop or a damaged cathode filament. Amperage load of each magnetron was monitored on a regular basis after each treatment to make sure the unit was running properly. The circuit diagram of the magnetron power supply and corresponding operation monitor is shown in Fig. 2. There were a total of two power supplies and two monitor circuits with two indicator light bulbs, one for each of the two magnetrons. A microwave-radiation leakage detector (CEM, Model no.

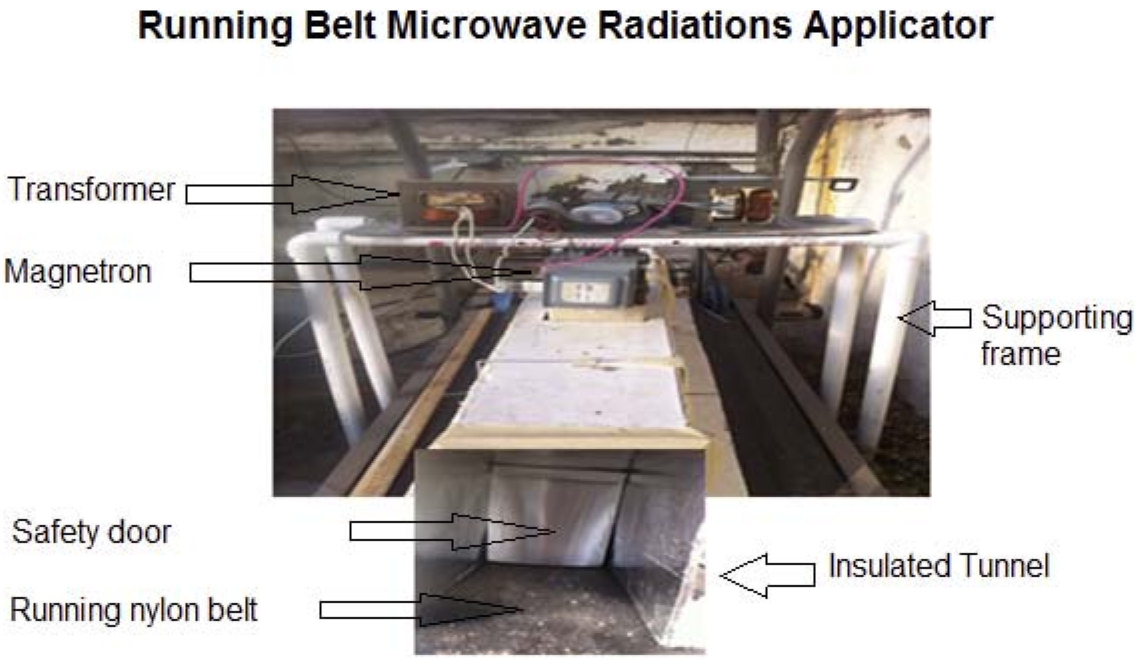

Fig. 1. Overview of the running belt microwave radiations applicator used for the weed control trials.

DT-2G, Matthews, NC) with a sensitivity range of 0 to 9.99 $mW \cdot cm^{-2}$ and warning value set at 5.0 $mW\ cm^{-2}$ was used to find any microwave radiations leakage during operations as well as to determine safe distances for human operators.

To test the assumption that the running belt microwave energy delivery system was more realistic, control of the following broadleaf, grass and sedge weed species was determined. Southern crabgrass *[Digitaria ciliaris* (Retz.) Koeler], dallisgrass *(Paspalum dilatatum* Poir.), fragrant flatsedge (*Cyperus odoratus* L.), common ragweed (*Ambrosia artemisiifolia* L.), white clover *(Trifolium repens* L.), pitted morningglory (*Ipomoea lacunosa* L.), and yellow nutsedge (*Cyperus esculentus* L.) were used in these studies. These weeds were selected based on their anatomical diversity. The assumption was that a wider leaf will intercept more microwave radiations energy. Plant canopy area was different for the species tested. The angle of inclination of microwave radiations on the canopy will be different for upright versus prostrate weeds. All weeds were grown from seeds in a flat containing a peat-based growing medium in a greenhouse for 3 to 4 weeks then transplanted to 10 by 10 cm (4 in by 4 in) pots. They were irrigated daily and fertilized with Osmocote (14-14-14, Everris, P.O. Box 40 4190 CA, Geldermalsen, The Netherlands), a polymer-coated fertilizer. A randomized complete block design with nine treatments and four replications were used in this study. Each weed species was treated using the running belt prototype system with the following doses of microwave radiations: 0, 54, 72, 90, 108, 128, 144, 162, and 180 joules per centimeter^2. Similar treatments were repeated using a stationary unit without a running belt. In general, a magnetron needs a critical temperature to produce microwave radiations optimally. Magnetrons were preheated for one minute before treatment started to ensure proper operation. The greenhouse temperature was approximately 32 C (90 F) at the time of treatment. These microwave radiations-treated weeds were evaluated visually at weekly intervals and then shoot fresh weight was recorded. Each study was repeated twice to confirm the results. Collected data were subjected to dose response analysis using statistical software (ARM 8, Gylling Data Management, Inc., Brookings, SD). Dose response algorithms, provided by Dr. J. J. Hubert, University of Guelph, were used to calculate LD_{50} values for each weed species under the two different modes of microwave radiations application. There was a significant three-way interaction among weed species, microwave radiations dose, and mode of application for percent injury and shoot fresh weight. Graphs for injuries at one week after treatment and shoot weight (% of untreated) were built using statistical software (JMP 10, SAS, Cary, NC).

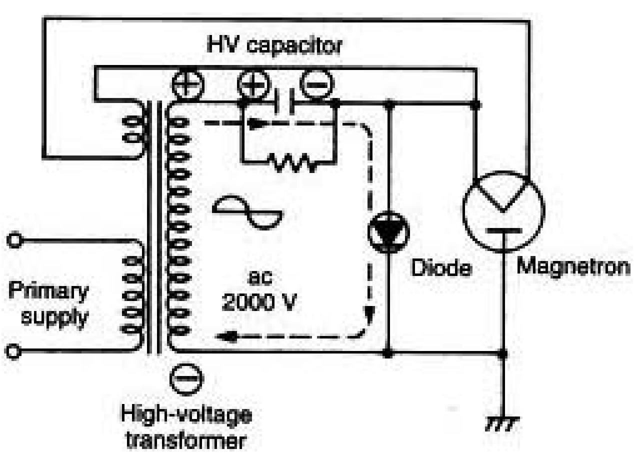

Fig. 2. A figure of electric circuit diagram of microwave radiations applicator used for the weed control trials.

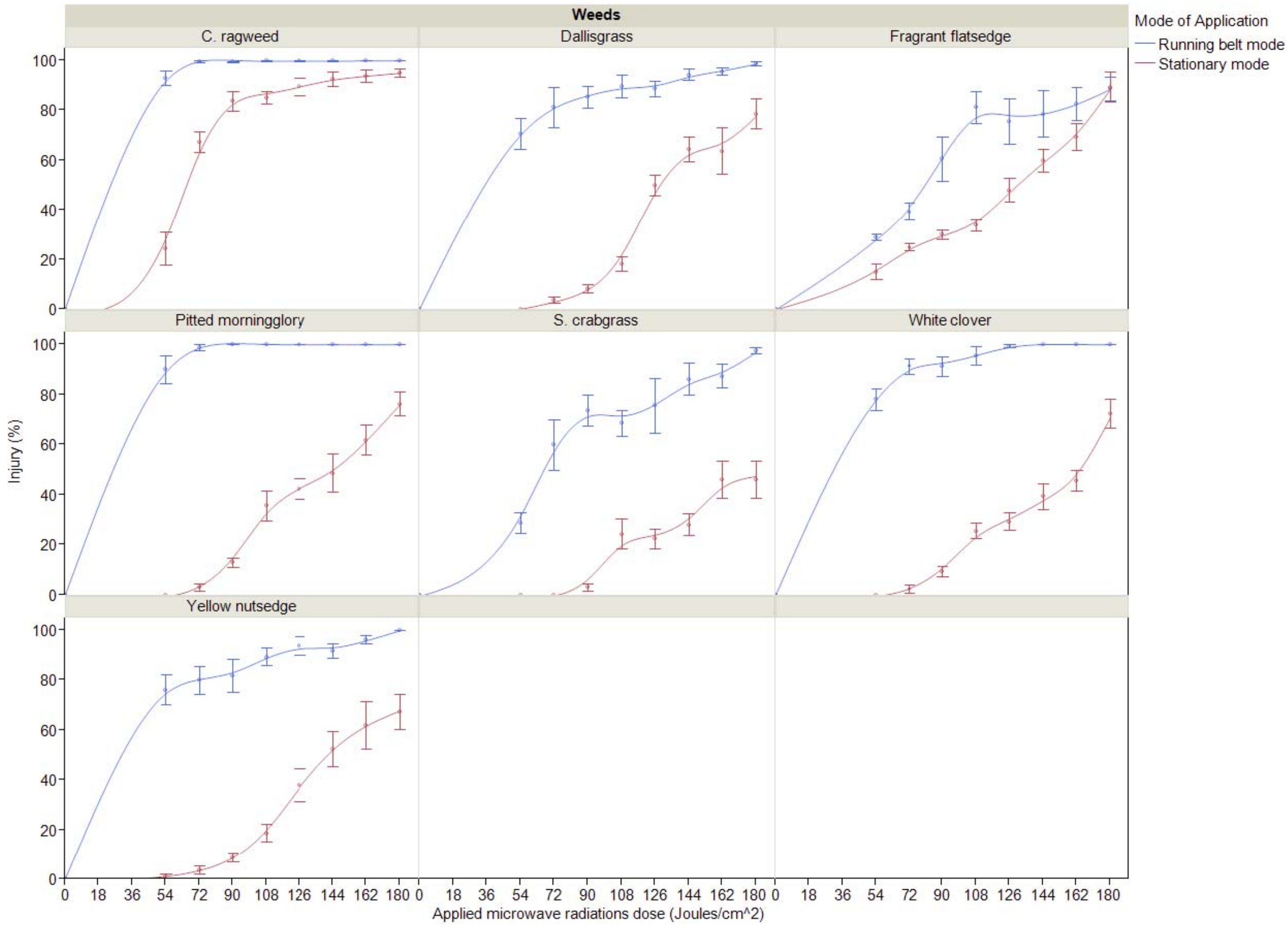

Fig. 3. Percent injury 1 week after treatment caused by microwave radiations applied with the running belt (blue line) and the stationary (red line) systems.

Results and Discussion

Grasses. Southern crabgrass did not show any injuries 1 week after treatment (WAT) when exposed to 54 and 72 J/·cm^{-2} in the stationary mode (Fig. 3). There was no significant shoot weight reduction in southern crabgrass at these microwave radiations doses in the stationary mode (Fig. 4). However, microwave radiations at 54 J·cm^{-2} caused 29% injury, with 60% injury seen at 72 J·cm^{-2} to southern crabgrass using the running belt system. Overall injuries to southern crabgrass by microwave radiations in the running belt system were higher in comparison to the stationary mode with each respective dose. Even the highest dose of microwave radiations (180 J·cm^{-2}) in the stationary mode did not control southern crabgrass (46% injury) while the same dose in the running belt system caused 98% injury. Dose response analysis determined the LD_{50} for southern crabgrass was 69.5 J·cm^{-2} for the running belt mode in comparison to 189 J·cm^{-2} when microwave radiations were applied in the stationary mode (Table 1). A similar pattern was noticed in fresh shoot weight of southern crabgrass, where that dose caused a 93% reduction in the running belt mode in comparison to a 46% reduction with the stationary system.

No injury was seen in dallisgrass 1 WAT when it exposed to 54 J·cm^{-2} of microwave radiation energy in the stationary mode (Fig. 3). Visual injuries to dallisgrass started at 72 J·cm^{-2} levels of microwave radiations. Maximum injury was 79% at 180 J·cm^{-2} with the stationary system. However, microwave radiations at 54 J·cm^{-2} caused 71% injury to dallisgrass using the running belt mode. Dallisgrass showed greater injury caused by microwave radiations in the running belt system in comparison to the stationary mode at each respective dose. Even the highest dose of microwave radiations (180 J·cm^{-2}) in the stationary mode did not completely control dallisgrass (79% injury) in comparison to the running belt mode where essentially complete control was seen at that dose 1 WAT. Dose response analysis showed the LD_{50} for dallisgrass was 34.3 J·cm^{-2} in the running belt mode in comparison to 136.1 J·cm^{-2} when microwave radiations were applied in stationary mode (Table 1). A similar pattern was noticed for the shoot fresh weight reduction of dallisgrass where 180 J·cm^{-2} dose in the running belt mode caused a 100% reduction while the same dose in stationary mode caused a 65% reduction compared to untreated plants. (Fig. 4). All weed species showed higher physical injuries caused by microwave radiations in the running belt system in comparison to the stationary mode for each respective dose.

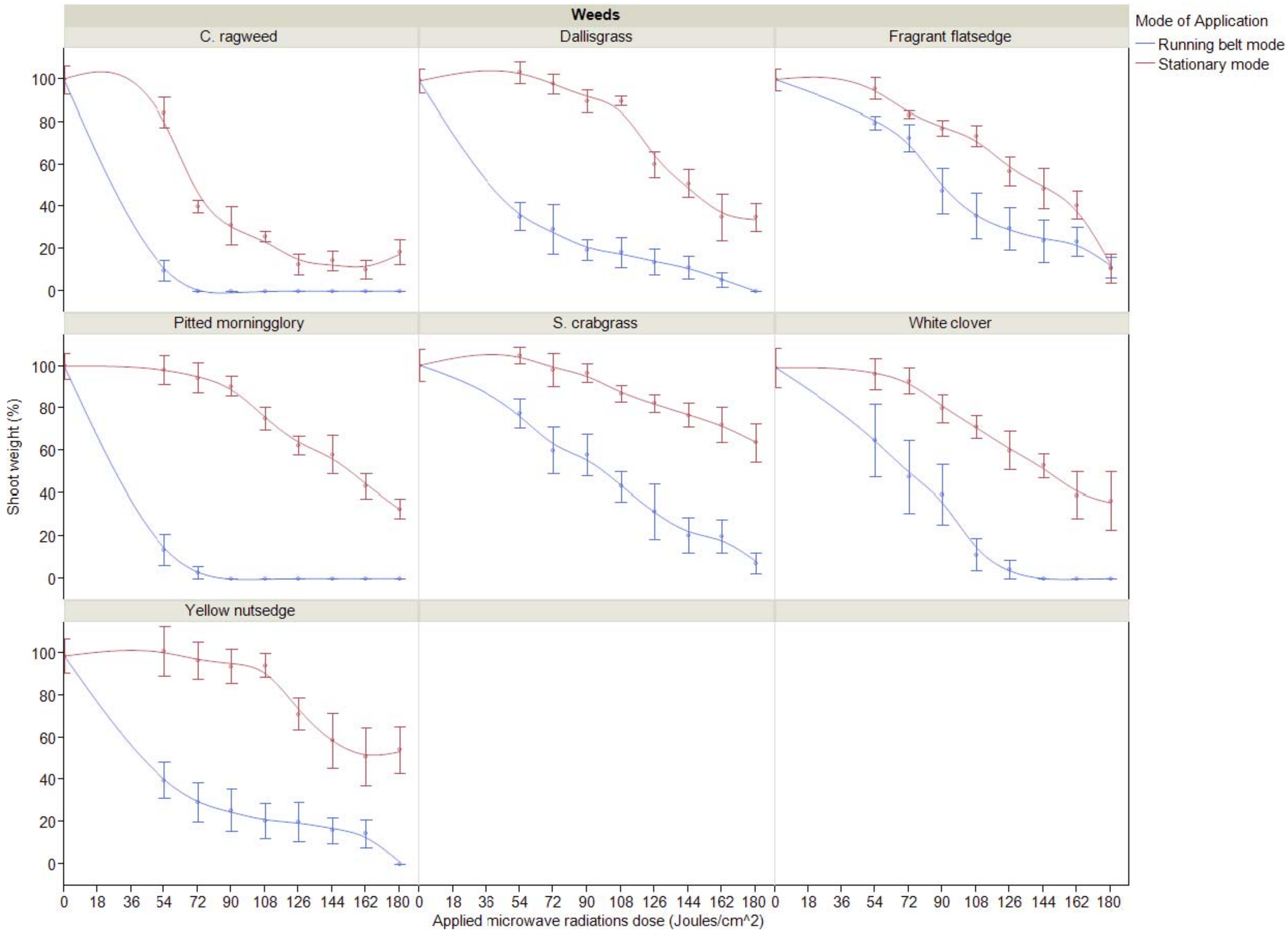

Fig. 4. Percent shoot fresh weight 4 weeks after treatment caused by microwave radiations applied with the running belt (blue line) and the stationary (red line) systems.

Sedges. Unlike southern crabgrass and dallisgrass, fragrant flatsedge was injured from both the stationary (15%) as well as the running belt mode (29%) when exposed to the lowest dose of microwave radiation energy (54 J·cm^{-2}) at 1WAT (Fig. 3). Fragrant flatsedge was injured more by microwave radiations in the running belt system in comparison to the stationary mode with each respective dose, similar to that seen with the two grass species. The highest dose of microwave radiations (180 J·cm^{-2}) provided similar fragrant flatsedge control (89%) irrespective of the application mode. Dose response analysis showed the LD_{50} for fragrant flatsedge was 78.1

Table 1. Dose response analysis of microwave radiations applied to different weed species using a stationary (STM) and a running belt (RBM) systems in greenhouse trials.

Weed	Mode	Logit Equation	LD_{50} J/cm^2	95% Confidence Limit Min	Max
Pitted morningglory	STM	Z = -19.7283 + 4.0012 X	138.4	136.3	140.6
Pitted morningglory	RBM	Z = -21.1432 + 5.8651 X	36.8	32.8	39.8
White clover	STM	Z = -20.3501 + 4.0345 X	155.1	152.4	158.1
White clover	RBM	Z = -10.0375 + 2.8343 X	34.5	30.3	38.1
Common ragweed	STM	Z = -13.8151 + 3.3151 X	64.5	62.6	66.4
Common ragweed	RBM	Z = -16.8028 + 4.8839 X	31.2	26.3	35.1
Fragrant flatsedge	STM	Z = -12.3981 + 2.5922 X	119.4	116.9	122.1
Fragrant flatsedge	RBM	Z = -10.5893 + 2.4302 X	78.1	75.7	80.2
Yellow nutsedge	STM	Z = -Z = -22.1804 + 4.4514 X	145.9	143.8	148.1
Yellow nutsedge	RBM	Z = -5.4714 + 1.6214 X	29.2	24.3	33.6
Dallisgrass	STM	Z = -25.0934 + 5.1071 X	136.1	134.4	137.8
Dallisgrass	RBM	Z = -6.6493 + 1.8809 X	34.3	30.2	38.0
Southern crabgrass	STM	Z = -15.9159 + 3.0583 X	182.0	176.3	189.0
Southern crabgrass	RBM	Z = -10.3655 + 2.4438 X	69.5	67.1	71.8

J·cm^{-2} for the running belt mode in comparison to 119.4 J·cm^{-2} when microwave radiations were applied in the stationary mode (Table 1). Shoot fresh weight of fragrant flatsedge was 11% of the nontreated plants irrespective of application mode at the highest dose (Fig. 4).

Yellow nutsedge did not show significant injury at 54 J·cm^{-2} and only 4% injury at 72 J·cm^{-2} when it exposed to microwave radiation energy in the stationary mode (Fig. 3). The maximum injury was 68% at the highest level of microwave radiations (180 J·cm^{-2}) in the stationary mode. However, 54 J/cm^2 of microwave radiations applied in the running belt mode caused 76% injury to yellow nutsedge. Yellow nutsedge showed higher physical injuries caused by microwave radiations with the running belt system in comparison to the stationary mode with each respective dose. The highest dose of microwave radiations (180 J·cm^{-2}) in the stationary mode only caused 68% injury to yellow nutsedge, while to the running belt mode gave complete control at 1 WAT. Dose response analysis showed the LD_{50} for yellow nutsedge was 29.2 J·cm^{-2} for the running belt mode in comparison to 145.9 J·cm^{-2} when microwave radiations were applied in the stationary mode (Table 1). A similar pattern was noticed in fresh shoot weight reduction of yellow nutsedge where the 180 J·cm^{-2} dose in the running belt mode caused a 100% reduction while the same dose in the stationary mode caused a 46% reduction compared to nontreated plants (Fig. 4).

Broadleaf weeds. White clover was not injured when exposed to 54 J·cm^{-2} and 72 J·cm^{-2} of microwave radiation energy in the stationary mode (Fig. 3). Maximum injury observed from the stationary mode in white clover was 73% when exposed to 180 J·cm^{-2}. In contrast, microwave radiations caused 78% injury at 54 J·cm^{-2} to white clover in the running belt mode. White clover was completely controlled at 144 J·cm^{-2} or greater doses of microwave radiations in the running belt system. Dose response analysis showed the LD_{50} for white clover was 34.5 J·cm^{-2} in the running belt mode in comparison to 155.1 J/·cm^{-2} when microwave radiations was applied in the stationary mode (Table 1). A similar pattern was noticed in fresh shoot weight reduction of white clover where the 144 J/cm^2 dose in the running belt mode caused a 100% reduction while the same dose in stationary mode caused a 63% reduction compared to untreated plants (Fig. 4).

Pitted morningglory did not show any significant injury at 54 and 72 J·cm^{-2} dose of microwave radiations in the stationary mode with an injury maximum of 76% at 180 J·cm^{-2} (Fig. 3). Whereas pitted morningglory was injured 90% at 54 J·cm^{-2} and totally controlled at 90 J·cm^{-2} or more in the running belt mode. Dose response analysis showed the LD_{50} for pitted morningglory was 36.8 J·cm^{-2} for the running belt mode in comparison to 138.4 J·cm^{-2} when microwave radiations were applied in the stationary mode (Table 1). A similar pattern was noticed in fresh shoot weight of pitted morningglory, where dose caused a 100% reduction at 90 J·cm^{-2} or more in the running belt mode in comparison to a 67% reduction with the stationary system (Fig. 4).

Common ragweed showed 24% injury at the 54 J·cm^{-2} dose of microwave radiations in the stationary mode with an injury maximum of 95% at 180 J·cm^{-2} (Fig. 3). However, common ragweed was injured 93% at 54 J·cm^{-2} and totally controlled at 72 J·cm^{-2} or more in the running belt mode. Dose response analysis showed the LD_{50} for common ragweed was 31.2 J·cm^{-2} in the running belt mode in comparison to 64.5 J·cm^{-2} when microwave radiations were applied in the stationary mode (Table 1). A similar pattern was noticed in shoot fresh weight reduction of common ragweed where in the running belt mode at 72 J·cm^{-2} gave complete control while 40% reduction was seen with the stationary mode (STM) compared to untreated plants (Fig. 4). Only 81% shoot weight reduction was noticed at 180 J·cm^{-2} in the stationary mode.

There are several possible for the observed differences in injury caused by microwave radiations for the stationary mode compared to the running belt system mode. One reason is the lag period between electricity applied to magnetrons and actual microwave radiations produced, which depends upon factors like the type of cathode filament and the magnetron temperature. Size of this gap error is hard to determine as it depend upon many factors, such as the initial temperature of the magnetron. Colder magnetrons, in general, can cause a larger gap error as compared to a warm magnetron. Ambient temperature was also a vital factor determining how temperatures rose during operation. Even the fans used to dissipate heat generated by the magnetrons could contribute to gap error.

Second, there may be non-uniform distribution of microwave radiations in the stationary mode. A magnetron antenna produces and distributes microwave radiation in all directions. One portion of the microwave energy will move directly toward the target weeds while other portions of microwave radiations would move towards the closed end of the waveguide and reflected back towards the target weeds. Almost half of the microwave energy produced in the stationary mode may bounce from the side walls of the waveguide and reach the target weeds at varying angles. This could cause uneven delivery of microwave energy to the weed canopy in the stationary mode. However, in the running belt mode, distribution was likely to be more uniform. This should result in more uniform absorption of microwave energy for the running belt system compared to the stationary one. Lower microwave radiations exposure in the stationary mode generally did not produce significant injury within one week of application, with very few lesions on plant leaves but none on stems. However, even the lowest dose applied with the running belt system for 3 seconds caused injury to weed seedlings. These results show that for the first few seconds, magnetrons were not producing sufficient microwave radiations to cause injury to plant tissues. This initial delay in microwave production might be causing lower injury to weeds in the stationary mode but this delay was eliminated in the running belt mode as the magnetrons were running continuously. This gap in microwave radiations produced is very crucial in the total energy calculation. Most researchers used custom-built stationary units of a microwave applicator in their trials. Most of researcher either did not take into consideration this gap in microwave energy production when using a stationary unit for their respective experiments or chose not to include it in their calculations. However, not counting this gap results in an overestimation of the total energy requirement for weed control. Mattsson (1993) reviewed the possibility of using microwaves for weed control. He concluded that microwave power was unlikely to be used for field weed control due to high energy consumption and high microwave power. Similarly, Sartorato et al. (2006) reported microwave irradiation controlled weed species effectively, but the energy requirements for satisfactory weed control were very high, ranging from 1,000 to 3,400 kg diesel fuel per hectare.

There is always non-uniformity in microwave energy distribution due to the antenna and waveguide, uneven distribution of the electric field, waveguide design and interferences during microwave energy transfer (Xiaofeng 2002). Non-uniformity can be a result of the interactions between electromagnetic waves and plant species. A uniform field in an empty applicator might be non-uniform after the introduction of the weeds. For example, attenuation can lead to non-uniform field distribution inside the material. Energy distribution pattern of microwaves are fairly non-uniform due to the design used. That is why most microwave ovens have either a rotating plate or other mechanism to avoid non-uniform heating. Similarly, using the running belt system more uniformly distributed the microwave energy in all plant tissues compared to the stationary unit, where hot and cold zones probably resulted from the uneven distribution. The running belt system actually bypass this lag period during microwave radiation application. Results are thus closer to actual field conditions where the microwave applicator would move continuously over the weed population. The energy dose applied by weed control machinery is mainly regulated by the driving speed (Ascard 1995, Hansson 2002). A combination of driving speed and treatment width of equipment determines the treatment time. The driving speed is usually quite low to achieve sufficient thermal weed control and reduce weed regrowth. However, a slow speed results in increased treatment time and costs, making the system less likely to be utilized by farmers due to economics. Experiments conducted using a stationary microwave unit includes a lag period error in energy calculations caused by the gap between electricity applied and actual radiation produced.

It is easy to eliminate this gap error just by using a running belt microwave system, where the system is operated only after the magnetrons are producing microwave radiations and are continuously running. Vela’zquez-Martı’ and Gracia-Lo’ pez (2004) also researched a microwave radiations applicator design and found a prototype based on overlapping magnetrons appears to be more efficient than waveguide prototype, because it allows lethal temperatures to be reached in a shorter time.

Existing magnetrons are designed for specific heating requirements of home appliances or a specific industry. Design of the microwave waveguide needs to be further investigated by engineers to meet the needs of the agriculture sector for weed management. This may lead to totally redesigned microwave generator magnetrons and waveguides, specifically designed to meet the needs of agriculture. The prototype used in this investigation was different than designs used by other researchers for similar kinds of research. Comparison of different designs of microwave radiations applicators for their efficacy in agriculture is needed.

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